Nigerian Journal of Soil Science

Journal Homepage: www.soilsjournalnigeria.com

Detailed Pedological Characterization of Dalori Soils, University of Maiduguri Farmland, Sudan Savanna, Nigeria

***I. B. Buji, A. A. Turajo and I. Z. Talha**

Department of Soil Science, Faculty of Agriculture, University of Maiduguri, Borno State
*Corresponding Author: ibrahimbuji84@gmail.com

DOI: 10.67042/njss.2026.d0mrov1a

Abstract

This study was conducted in 2023 at the University of Maiduguri farmland, Dalori, Konduga Local Government Area, Borno State, Northeastern Nigeria (latitudes 11°46.758′–11°47.116′ N; longitudes 13°12.744′–13°13.188′ E) to characterize the soils of the area. Morphological and physico-chemical properties of twenty-seven (27) soil samples were analyzed from identified genetic horizons of six (6) pedons within one (1) soil mapping unit (DL), which was subdivided into three phases (DL I, DL II, DL III). The soils were very deep, well-drained, with textures ranging from sandy loam to sandy clay loam, and sub-angular blocky structure in most phases. Soil color varied from dark brown to dull orange, with clear horizon differentiation between the Ap and B horizons. Bulk density was low (0.87–1.25 g/cm^3), increasing irregularly with depth, while total porosity decreased down the profile. Soil reaction ranged from strongly acidic to moderately alkaline (pH 5.43–8.25). Exchangeable bases were low to high (Ca^{2+}: 1.20–5.40, Mg^{2+}: 0.80–4.00, K^+: 0.01–0.74, Na^+: 0.04–0.44 cmol/kg), occurring in the order $Mg^{2+} > Ca^{2+} > Na^+ > K^+$, indicating moderate nutrient status. Base saturation was high (77.53–94.72%). Organic carbon (2.00–6.20 g/kg), total nitrogen (0.70–1.70 g/kg), and available phosphorus (7.35–17.15 mg/kg) were generally low to medium. Electrical conductivity was low (0.04–0.55 dS/m), classifying the soils as non-saline. Generally, fertility status was constrained by low organic matter, nitrogen, and phosphorus. Soil productivity could be improved through incorporation of crop residues and farmyard manure, reduced tillage, contour ridging, and application of recommended fertilizer rates for sustainable crop production.

Keywords: Soil characterization, Soil fertility, Soil morphology, Physico-chemical properties and Sudan Savanna

1.0 Introduction

Land is one of the most vital natural resources, and maintaining its health is essential to meeting the growing demand for fuel, food, fiber, and fodder (Fadlalla and Elsheikh, 2016). In agricultural sustainability, land users can benefit greatly from the integration of soil characterization and soil mapping (Sharu *et al*., 2013). Cropland use planning requires informed decisions about the environment and land resources. Since land suitability directly depends on soil properties, soil information is a crucial component of the planning process (Coleman and Galbraith, 2000).

Soil characterization provides an understanding of the physical, chemical, mineralogical, and microbiological properties of soils (Ogunkunle, 2005). According to Lekwa *et al*. (2004), soil characterization supplies the fundamental data needed to develop reliable soil classification schemes and to evaluate soil fertility, thereby addressing specific soil-related challenges within an ecosystem.

Soil morphology refers to the observable characteristics of soils within different horizons, as well as descriptions of the type and arrangement of these horizons (Marbut, 2000). Morphology plays a key role in describing and classifying soils, with field observation of soil profiles forming the starting point of such studies. Soil physico-chemical properties; including fertility, erosion susceptibility, and moisture content, are influenced by human-induced land use changes (Abad *et al*., 2014). Such changes may lead to soil compaction, reduced soil volume, and ultimately lower environmental quality and productivity (Abad *et al*., 2014). Therefore, this study was conducted to characterize the soils of Dalori, University of Maiduguri Farmland, located in the Sudan Savanna region of Nigeria.

2.0 Materials and Methods

2.1 The Study Area

The study was conducted in 2023 at the University of Maiduguri Farmland, located along Dalori in Konduga Local Government Area, Borno State, northeastern Nigeria (Fig. 1). The area lies between latitude 11°46.758′ to 11°47.11668′ N and longitude 13°13.18878′ to 13°12.74448′ E. It covers approximately 168 hectares (ha) within the University of Maiduguri farmland.

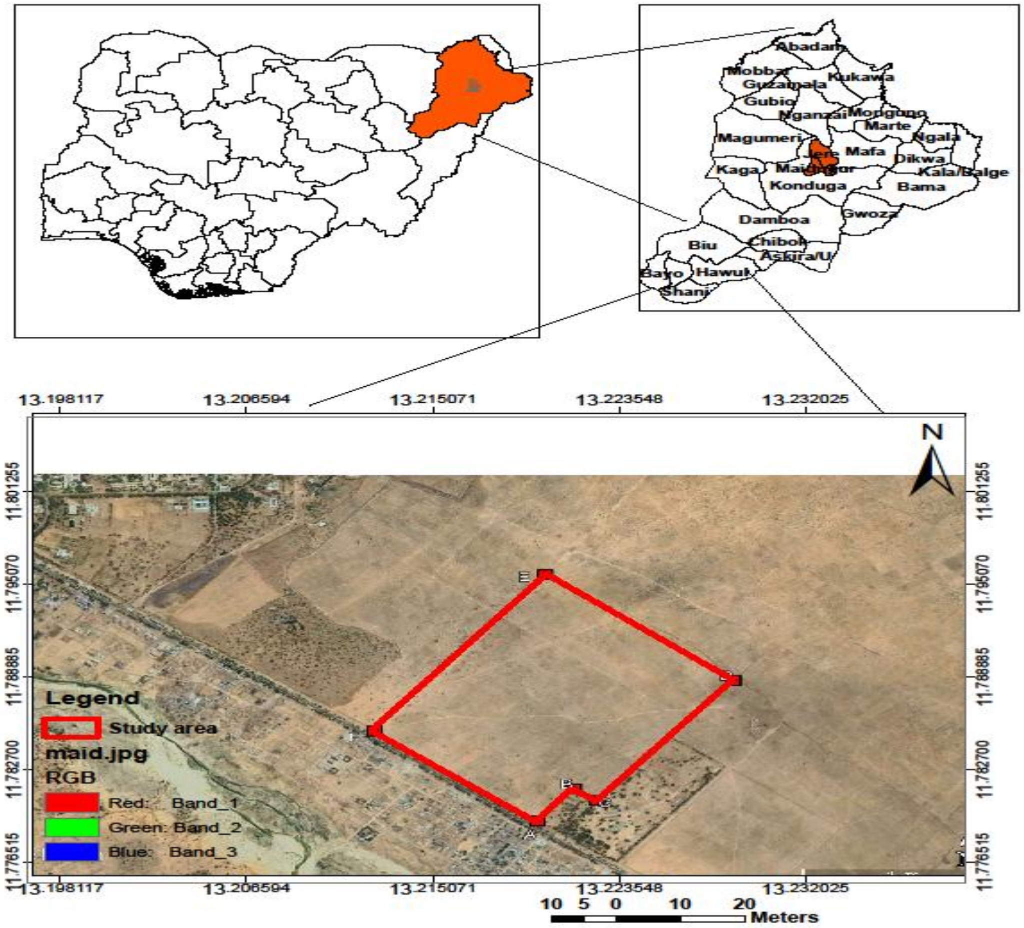

Fig. 1: Map of the Study Area

2.2 Climate and characteristics of the area

According to Ojanuga (2006), the climate of the area is dry sub-humid with a unimodal rainfall pattern. The mean annual temperature is about 32 °C, while the average annual rainfall is 660 mm, usually lasting no more than four months (June to September) (NIMET, 2023). The region, which falls within the Sudan Savanna agro-ecological zone, experiences a sharp increase in humidity during the wet season, followed by a sudden drop at its end. Relative humidity can reach 100% at night in August, but drop to 20% or less during the hottest part of the day in the harmattan period (World Bank, 2023).

The soils are predominantly Aeolian sands deposited by wind drift from the Sahel (FAO and ICRISAT, 2019). The elevation of the study area ranges from 325 to 333 meters above mean sea level, with topography varying from flat to gently undulating. Agriculture is the primary economic activity in the Sudan Savanna (Onwualu, 2009). The Dalori land is mainly cultivated with short-duration, drought-tolerant crops such as groundnut (Arachis hypogaea), cowpea (Vigna unguiculata), sorghum (Sorghum bicolor), and millet (Pennisetum glaucum).

The natural vegetation, which once consisted of shrubs, scattered trees, and patches of woodland, is rapidly disappearing due to climate change and over-exploitation. This has resulted in increased desertification and land degradation (Waziri *et al*., 2009).

2.3 Soil Survey

A reconnaissance survey was first conducted along specific traverses across the study area. A Polaris Navigator GPS was used to establish strategic points along the farm boundaries. A semi-detailed soil survey was carried out at a scale of 1:25,000. Along each traverse, soils were examined and described through auger borings spaced at 100 m intervals (Fig. 2).

Soil boundaries were delineated based on observations of morphological characteristics, physiographic position, topography, and soil color. Different soil types were analyzed to determine the precise locations of their boundaries, while similar soils were grouped into one mapping unit. Within each identified soil mapping unit, two modal profile pits were excavated, each measuring 1.0 m wide, 1.5 m long, and 2.0 m deep. The second pit in each unit served as a duplicate.

Bulked soil samples were collected from each genetic horizon for laboratory analysis. Soil profiles were described in accordance with the guidelines of the Soil Survey Manual (Soil Survey Staff, 2006).

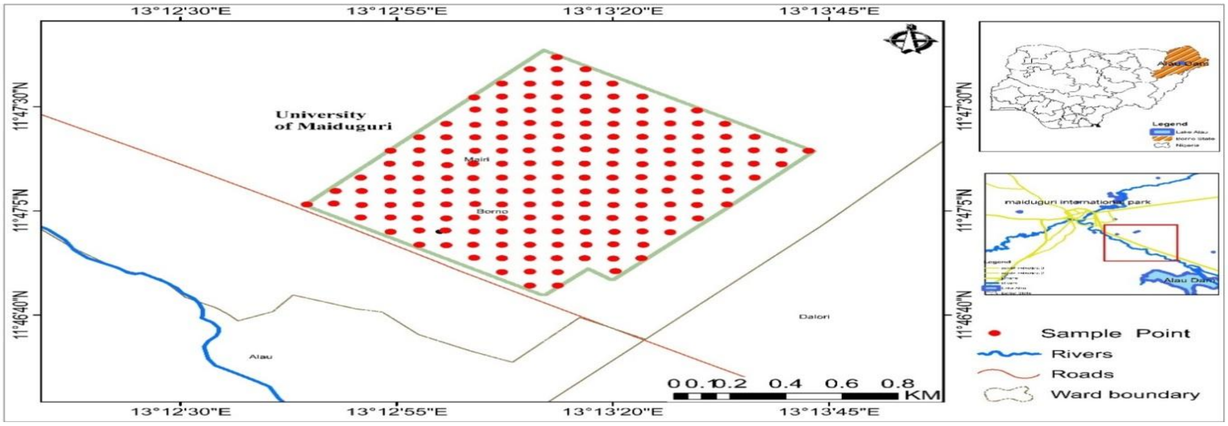

Fig. 2: Base Map of the Study Area

2.4 Laboratory Analysis

Soil samples collected from the various pedogenic horizons (layers) were air-dried, crushed with porcelain pestle and mortar and sieved to remove materials greater than 2 mm (gravel). The less than 2 mm material was used for physical and chemical analysis. The following parameters were determined using standard procedures:

2.4.1 Physical properties

Particle size analysis of the soil was determined as described by Bouyoucos hydrometer (Page *et al.*, 1982) using NaOH as the soil dispersing agent, and the textural classes were extrapolated using glass triangle. Bulk density was determined on the undisturbed core samples from each horizon using core samplers (Blake, 1965). Total porosity was derived from the relationship of particle density to bulk density using Vomocil (1965) formula TP = 1- (pb/ps) x 100.

2.4.2 Soil chemical analysis

The soil reaction (pH) was determined in the supernatant suspension of 1:2.5 soil-water suspensions using a glass electrode pH metre (Kacar, 1997). Buffer solutions of pH 4, 7 and 9 and Calcium Chloride solution 0.01M was used as reagents for the soil pH determination. The regular macro-Kjeldahl process was used to determine the Total Nitrogen (Bremner and Mulvaney, 1982). The Cation Exchange Capacity (CEC) was determined by saturating the samples with sodium acetate (NaOAc) 1.0 M, Ethanol (95 %), Ammonium acetate (NH_4OAc) 1.0M and standard solution of NaCl; exchangeable cations (Na, K, Ca and Mg) with ammonium acetate (NH_4OAc) 1.0M; electrical conductivity (EC) in 1:2.5 soil-water saturation and organic matter using Walkley-Black method as described by Durak *et al.* (2007). Available P was determined using Ammonium fluoride (0.03N NH_4F) to extract phosphorus from soil sample as described by Bray and Kurtz (1945).

3.0 RESULTS AND DISCUSSION

3.1 Extend and Distribution of Soil Unit

The study area was delineated into a single soil unit, designated as the Dalori Soil Unit (DL). This unit was further subdivided into three soil phases (Fig 3): Dalori Phase I (DL I: Pedons P1 and P2), Dalori Phase II (DL II: Pedons P3 and P4), and Dalori Phase III (DL III: Pedons P5 and P6). Soil phases DL I and DL II were located in the lower part of the study area, while DL III occurred in the upper part. The physiography of the site is a nearly level plain with a slope gradient of 0–2%. Groundwater was not encountered at any profile depth. In total, six (6) pedons were excavated and described. The morphological, physical, and chemical characteristics of the representative pedons are presented and discussed below. The soil map of the study area is shown in Figure 3.1.

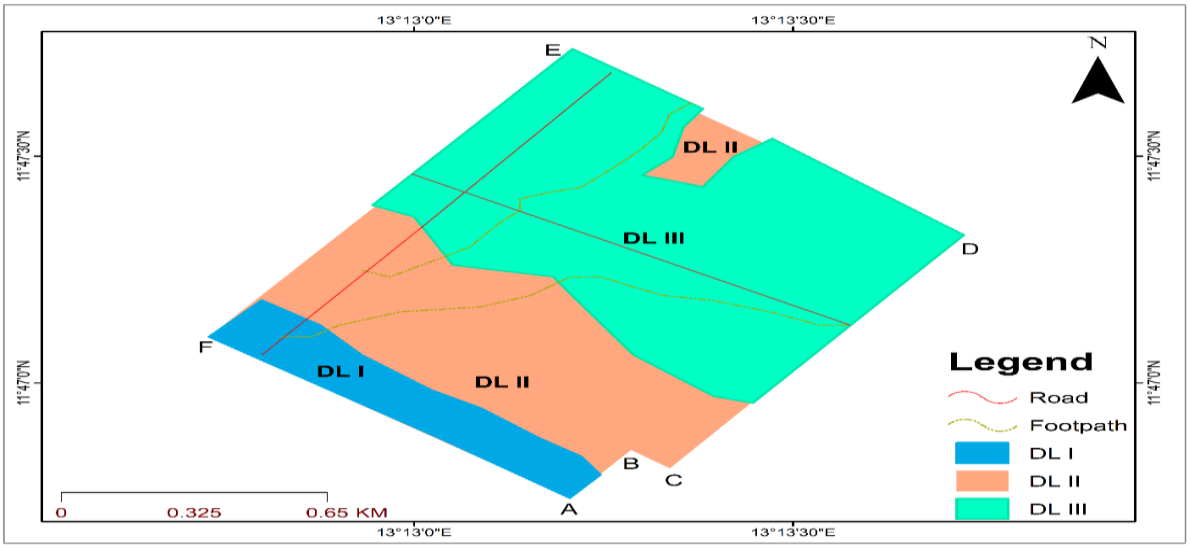

Fig 3: Study Area showing different Distribution of Soil Phases

3.2 Morphological Characteristics of the Soils

The findings of the morphological characteristics of the soils in the study area are presented in **Table 1**.

3.2.1 Soil depth

The Dalori soil phases were extremely deep, reaching depths of approximately 200 cm (Table 1). This depth is likely attributable to similarities among the phases in vegetation cover, climate, stage of soil development, and degree of pedogenesis. No restrictive layers were observed in either the surface or subsurface horizons. Such depth favors unrestricted root elongation and proliferation, thereby enhancing crop growth. These findings are consistent with those of Kowal and Kassam (1978), who provided a foundational description of soils in West African savanna zones, including the Sudan savanna. They emphasized that many savanna soils exhibit considerable depth, with well-developed horizons formed in the absence of restrictive layers such as ironstone or plinthite, and that soil depth is a key agronomic factor influencing root growth and crop development in these environments.

3.2.2 Soil color

The soil phase's surface horizons had different colors. The surface soil color for pedons P1 and P2 changes from brown (7.5YR4/4 moist) to brown (7.5YR4/6 moist) at soil phase DL I. Pedons 3 and 4 of soil phase DL II showed brown (7.5YR4/4 moist) to bright brown (7.5YR5/6 moist) surface colors, whereas pedons P5 and P6 of soil phase DL III showed brown (7.5YR4/3 moist) to dull brown (7.5YR5/4 moist) surface colors. The colors of the subsurface horizons varied from bright brown (7.5YR5/8 moist) to light yellow orange (7.5YR8/4 moist) at phase DL II pedons P3 and P4, from dull brown (7.5YR5/6 moist) to dull orange (7.5YR7/4 moist) for phase DL I pedons P1 and P2, and from dull brown (7.5YR5/4 moist) to dull orange (7.5YR7/4 moist) for phase DL III soils, as demonstrated in pedons P5 and P6. In every phase of the study area, the surface soils had low Chroma, while the subsurface soils were brightly colored (high Chroma).

The surface horizons of the soil phases showed different colors. In soil phase DL I (Pedons P1 and P2), surface colors ranged from brown (7.5YR 4/4, moist) to brown (7.5YR 4/6, moist). In soil phase DL II (Pedons P3 and P4), surface colors varied from brown (7.5YR 4/4, moist) to bright brown (7.5YR 5/6, moist). Soil phase DL III (Pedons P5 and P6) showed surface colors ranging from brown (7.5YR 4/3, moist) to dull brown (7.5YR 5/4, moist).

The subsurface horizons also varied in color. In DL II pedons (P3 and P4), colors ranged from bright brown (7.5YR 5/8, moist) to light yellow-orange (7.5YR 8/4, moist). In DL I pedons (P1 and P2), colors ranged from dull brown (7.5YR 5/6, moist) to dull orange (7.5YR 7/4, moist), while in DL III pedons (P5 and P6), subsurface colors ranged from dull brown (7.5YR 5/4, moist) to dull orange (7.5YR 7/4, moist).

Across all phases, the surface soils exhibited relatively low chroma, while the subsurface soils showed brighter colors (high chroma). The dominance of brown colors in surface soils may be attributed to the presence of organic matter. This finding agrees with Nuhu (1983), who reported that brownish colors in surface horizons are due to organic matter, the main coloring agent in surface soils. Similarly, Alemayehu *et al*. (2014) observed that surface soils tend to be darker owing to higher organic matter content.

The dull to light orange colors in subsurface soils may be linked to drainage conditions, as vibrant subsurface colors are often indicative of adequate drainage (Amusan, 1991). The variation of soil color with depth supports Brady and Weil's (1999) assertion that horizon differentiation accounts for color changes down the profile. According to Ahn (1970), the decline in organic matter content with depth also contributes to this color variation. Buji *et al*. (2021) further reported that soils at the University of Maiduguri Teaching and Research Farm (UMTRF) showed similar surface and subsurface color changes with depth due to reduced organic matter content.

Generally, the darker surface soils are associated with higher organic matter inputs, while the brighter subsurface horizons reflect reduced organic matter. These color differences have little direct effect on plant growth but provide valuable information about soil properties and pedogenesis.

The addition of organic matter tends to make the soil at the upper horizon darker, while the decrease in organic matter makes the soil at the lower horizon brighter. This demonstrates that, the color of the studied area has no effect on plant growth. According to (Kohnke, 1968), soil colour has no direct effect on plant growth but rather exert an indirect influence through its effects on soil temperature and moisture.

Table 1: Morphological Properties of Soil at the Study Area

Soil Phase	Pedon	HD	Soil depth (cm)	Color Dry	Color Moist	Texture	Structure	Consistency Wet	Consistency Moist	Consistency Dry	Horizon Boundary	Other Features
DL I	P1	Ap	0-35	Hue 7.5YR 5/6	4/4	SL	2,m Sbk	Sl St	Fr	SH	Ds	No mottled,
		B1	35-83	Hue 7.5YR 6/4	5/6	SL	2,m Sbk	Sl St	Fr	SH	Ds	No root, water
		B2	83-133	Hue 7.5YR 7/4	6/6	LS	2,m Bk	Sl St	Fr	H	Ds	table not
		B3	133-200+	Hue 7.5YR 8/4	7/4	LS	1,m-c Cr	N St	Vfr	H	---	encountered.
	P2	Ap	0-55	Hue 7.5YR 5/4	4/6	SL	2,m Sbk	Sl St	Fr	SH	Ds	No mottled,
		AB	55-90	Hue 7.5YR 5/8	5/6	SL	2,m Sbk	Sl St	Fr	SH	Gs	V. few fibrous
		B1	90-125	Hue 7.5YR 6/6	6/4	SL	2,m Sbk	Sl St	Fr	SH	Cs	root,
		B2	125-160	Hue 7.5YR 7/4	7/6	SL	2,m Bk	Sl St	Vfr	SH	Cs	No water table.
		B3	160-200+	Hue 7.5YR 8/4	8/4	SL	1,m Cr	N St	Vfr	SH	---	No stones.
DL II	P3	Ap	0-42	Hue 7.5YR 5/4	4/4	SL	2,m Sbk	Sl St	Fr	SH	Cw	No mottled,
		AB	42-80	Hue 7.5YR 5/8	5/6	SCL	2,m Sbk	Sl St	Fr	SH	Gs	V. few fibrous
		B1	80-126	Hue 7.5YR 6/6	5/8	SL	2,f Sbk	St	F	S	Cs	root,
		B2	126-161	Hue 7.5YR 8/4	6/6	SL	2,f Abk	St	F	S	Cs	No water no
		B3	161-200+	Hue 7.5YR 8/6	7/6	SL	2,f Abk	V St	F	S	---	stones.
	P4	Ap	0-53	Hue 7.5YR 5/4	4/4	SCL	2,m Sbk	Sl St	Fr	SH	Ds	No mottled,
		BA	53-88	Hue 7.5YR 6/4	5/4	SCL	2,m Sbk	Sl St	Fr	SH	Gs	Few fibrous root,
		Bt1	88-135	Hue 7.5YR 7/4	6/4	SCL	2,m Sbk	St	F	S	Cs	no stones no water
		Bt2	135-170	Hue 7.5YR 8/4	7/4	SCL	2,f Sbk	V St	F	S	Cs	encountered.
		Bt3	170-200+	Hue 7.5YR 8/6	8/4	SCL	2,f Abk	V St	F	S	---	
DLIII	P5	Ap	0-30	Hue 7.5YR 5/4	4/3	SCL	2,m Sbk	Sl St	Fr	SH	Ds	No mottled,
		Bt1	30-75	Hue 7.5YR 6/3	4/4	SCL	2,f-m Sbk	St	F	SH	Gs	No roots, no water
		Bt2	75-138	Hue 7.5YR 7/3	6/4	SCL	3,f Sbk	V St	F	S	Cs	table, moderate
		Bt3	138-200+	Hue 7.5YR 8/4	7/3	SL	3,vf Sbk	V St	F	S	---	cementation
	P6	Ap	0-24	Hue 7.5YR 5/4	4/4	SL	2,m Sbk	Sl St	Fr	SH	Ds	No mottled, no
		Bt1	24-55	Hue 7.5YR 6/4	5/4	SCL	2,m Sbk	Sl St	F	SH	Gs	root, simple
		Bt2	55-137	Hue 7.5YR 7/3	6/4	SCL	2,f Sbk	St	F	S	Cs	stones.
		Bt3	137-200+	Hue 7.5YR 8/4	7/4	L	3,f Bk	V St	F	S	---	

HD = Horizon Designation, **Color:** 4/3, 4/4, 4/6 = brown. 5/4 = dull brown. 5/6, 5/8 = bright brown. 6/6, 6/8 = orange. 6/4, 7/4, 7/6 = dull orange. 8/4, 8/6 = light yellow orange. **Texture**: SL = sandy loam, LS = loamy sand, SCL = sandy clay loam, **Structure:** 1 = weak, 2 = moderate, 3 = strong, m = medium, c = coarse, f = fine, sbk = sub angular blocky, b = blocky, cr = granular. **Consistence:** Sl St = slightly sticky, S = sticky, V St = very sticky, N St = non sticky, Fr = friable, V Fr = very friable, F = firm, V F = very firm, SH = slightly hard, H = hard, S = soft. **Boundary:** Gs = gradual smooth, Cs = clear smooth, Ds = diffuse smooth, Cw = clear wavy.

3.2.3 Soil texture

All pedons in the study area had surface horizons with textures ranging from sandy loam to sandy clay loam across the different phases, while the subsurface horizons were predominantly sandy loam, sandy clay loam, or loamy sand, except in DL III, where pedon P6 showed loamy soil. The type of parent material, stage of soil development, and degree of weathering likely contributed to the slightly coarser soils in phase DL I compared to phases DL II and DL III. Brady and Weil (2010) linked soil texture to both the rate and type of weathering processes, as well as to the parent materials from which the soils were derived. Similarly, Fitz-Patrick (1986) emphasized that a soil's textural class depends on weathering in relation to parent material, which is further influenced by climate over time.

The observed changes in texture, from sandy loam at the surface to sandy clay loam or loamy sand at the subsurface, suggest active illuviation processes. Generally, the soils of the study area were predominantly sandy loam. This finding agrees with Buji *et al*. (2021), who reported that the soil texture of University of Maiduguri Teaching and Research Farm (UMTRF) have high sand content followed by silt while clay has the lowest percentage which gives a textural class of sandy loam.

3.2.4 Soil structure

In all pedons, the surface horizons of phases DL I, DL II, and DL III exhibited moderately developed sub angular blocky structures. Subsurface horizons varied in grade: phase DL I soils showed sub angular blocky to granular structures, phase DL II soils had moderate sub angular to angular blocky structures, while phase DL III soils exhibited strong to moderate sub angular blocky structures.

The weak structures in DL I soils were likely due to tillage practices and continuous cultivation. In most pedons, structure grade increased with depth, presumably because of higher clay content. Angular blocky structures are commonly associated with subsurface B horizons (Singer and Munns, 1999), indicating increased pedogenic development (Yaro, 2005). However, the sub angular blocky to blocky structures of the study soils suggest moderate compaction, which may restrict root growth and thus make them only marginally suitable for crops such as groundnut and millet.

3.2.5 Soil consistence

In the surface horizons of all phases (DL I, DL II, and DL III), soils were typically very friable when moist, slightly hard when dry, and slightly sticky when wet. In DL I subsurface horizons, soils ranged from friable to very firm (moist), slightly hard to hard (dry), and slightly sticky to non-sticky (wet). In DL II, subsurface soils were friable to firm (moist) and slightly sticky to very sticky (wet). In DL III, subsurface soils were firm (moist), slightly hard to soft (dry), and slightly sticky to very sticky (wet). Comparably, the upper soils were harder and stickier than the lower ones.

Soil consistence generally increased with depth, with little variation across phases. Consistence shifted from hard to soft between surface and subsurface layers, likely due to reduced organic matter content. This agrees with Russell (1968), who reported that decreases in organic matter and moisture-holding capacity with depth influence soil consistence. The higher clay content in the upper part of the landscape also contributed to increased hardness and stickiness (Raji, 1995). Similar findings were reported by Maniyunda (1999), Hussaini (2011), and Buji *et al*. (2021).

3.2.6 Horizon boundary

Surface horizons of all phases generally had diffuse smooth boundaries, except DL II (pedon P3), which showed a clear wavy boundary. Subsurface horizons mostly had gradual to clear smooth boundaries, except DL II (pedon P1), which showed a diffuse smooth boundary.

Biological activity of soil flora and fauna may have contributed to clearer separations between horizons in most pedons. The wavy boundaries in DL II soils on the lower portion of the landscape may be due to irregular deposition of eroded materials. Horizon differentiation between Ap and B horizons was also pronounced, probably due to mineralization from the humification of organic matter in the Ap horizon

3.2.7 Other features

Most profile pits showed few fibrous roots in the surface horizons, with root size and quantity decreasing with depth. Other features varied slightly across the study area. Compared to subsurface horizons, surface horizons contained significantly larger and more abundant roots. Ahn (1970) noted that such features are often interrelated.

3.3 Physical Properties of Soil

3.3.1 Particle Size Distribution (PSD)

The soils of the Dalori phases have PSD of sand content ranging from 56.90 to 76.70% (mean: 64-68%) in surface horizons and 49.40 to 86.20% (mean: 52.70-77.70%) in subsurface horizons. Clay content ranged from 10.80 to 22.80% at the surface and increased to as much as 22.80-26.20% in some subsurface horizons (Table 2). The soils texture were predominantly sandy loam to sandy clay loam. The dominance of sand indicates coarse-textured soils typical of Sudan savanna environments developed from quartz-rich granitic parent materials (Wilson, 2010; Esu and Akpan, 2010). Vertically, clay content increased with depth, this trend reflects clay illuviation and argillic horizon development, a characteristic pedogenic process in tropical soils (Schaetzl and Anderson, 2005).

3.3.2 Water Holding Capacity (WHC)

Water holding capacity ranged from 26.79 to 36.08% (mean: 28.35-35.15%) in surface horizons and 26.38 to 53.96% (mean: 29.87-43.16%) in subsurface horizons. Phase DL I recorded the lowest mean surface WHC (28.35%), while DL II and DL III had higher means (35.15% and 34.22%, respectively). The relatively higher WHC in DL III corresponds with its higher clay fraction and finer texture, since clay and microporosity enhance water retention (Lal and Shukla, 2004). With depth, WHC showed variable trends. In DL I (P1), WHC decreased from 29.92% (0-35 cm) to 26.38% (83-133 cm) before slightly increasing again. In DL III (P6), WHC increased markedly to 53.96% at 137-200 cm, corresponding with finer texture. This confirms that WHC trends are strongly controlled by clay distribution (Gang *et al.*, 2007).

3.3.3 Bulk Density (BD)

Bulk density ranged from 1.06 to 1.25 g cm^{-3} in surface soils and 0.87 to 1.24 g cm^{-3} in subsurface horizons, with mean values generally between 1.04 and 1.17 g cm^{-3}. These values fall below the critical limit of 1.6 g cm^{-3} for root restriction (Brady and Weil, 2016), indicating favorable physical conditions for crop growth. Bulk density generally increased with depth. For instance, in DL I (P1), BD increased from 1.16 g cm^{-3} (0-35 cm) to 1.24 g cm^{-3} (133-200 cm). This increase is attributed to compaction from overburden pressure and reduced organic matter in subsoil (Islam and Weil, 2000). Similar depth-related increases have been reported in northern Nigerian savanna soils (Sharu *et al.*, 2013).

3.3.4 Total Porosity (TP)

Total porosity ranged from 52.83 to 60.00% in surface soils and 34.57 to 50.56% in subsurface soils. Higher porosity in surface horizons corresponds with lower bulk density and higher organic matter content (Lal and Shukla, 2004). In DL I, TP declined from 56.23% (surface) to 53.21% (deep subsoil). The decrease in some pedons may be linked to clay illuviation and structural densification (Sharu *et al.*, 2013).

Table 2: Physical Properties of Soil at the Study Area

Soil Phase	Pedons	HD	Soil Depth (cm)	Particle Size Analysis				WHC %	BD g/cm^3	TP %
				Sand	Silt	Clay	TC			
				g/cm^3						
DL I	P1	Ap	0-35	69.20	15.00	15.80	Sandy Loam	29.92	1.16	56.23
		Bt1	35-83	74.20	12.50	13.30	Sandy Loam	28.94	1.18	55.47
		Bt2	83-133	81.70	5.00	13.30	Loamy Sand	26.38	1.12	57.74
		Bt3	133-200+	86.20	3.00	10.80	Loamy Sand	27.84	1.24	53.21
	P2	Ap	0-55	76.70	9.50	13.80	Sandy Loam	26.79	1.25	52.83
		Bt1	55-90	76.70	12.50	10.80	Sandy Loam	26.94	1.21	54.34
		Bt2	90-125	69.20	20.00	10.80	Sandy Loam	33.17	1.14	56.98
		Bt3	125-160	74.20	15.00	10.80	Sandy Loam	33.37	1.10	58.49
		Bt4	160-200+	71.70	17.50	10.80	Sandy Loam	30.15	1.22	53.96
DL II	P3	Ap	0-42	69.20	15.00	15.80	Sandy Loam	34.22	1.07	59.62
		AB	42-80	68.50	11.20	20.30	Sandy Clay Loam	36.35	1.05	60.38
		Bt1	80-126	71.00	11.20	17.80	Sandy Loam	29.72	1.10	58.49
		Bt2	126-161	73.50	8.70	17.80	Sandy Loam	31.37	1.18	55.47
		Bt3	161-200+	66.00	16.20	17.80	Sandy Loam	35.34	1.10	58.49
	P4	Ap	0-53	63.50	13.70	22.80	Sandy Clay Loam	36.08	1.06	60.00
		BA	53-88	66.00	11.20	22.80	Sandy Clay Loam	36.62	1.04	60.75
		Bt1	88-135	61.00	18.70	20.30	Sandy Clay Loam	35.28	1.11	58.11
		Bt2	135-170	68.50	11.20	20.30	Sandy Clay Loam	34.64	1.04	60.75
		Bt3	170-200+	56.00	23.70	20.30	Sandy Clay Loam	33.98	1.08	59.25
DL III	P5	Ap	0-30	61.00	16.20	22.80	Sandy Clay Loam	33.51	1.11	58.11
		Bt1	30-75	56.00	21.20	22.80	Sandy Clay Loam	40.13	0.87	67.16
		Bt2	75-138	51.00	26.20	22.80	Sandy Clay Loam	38.63	0.89	66.42
		Bt3	138-200+	54.40	26.20	19.40	Sandy Loam	37.16	0.98	63.02
	P6	Ap	0-24	56.90	23.70	19.40	Sandy Loam	34.94	1.11	58.11
		Bt1	24-55	54.40	23.70	21.90	Sandy Clay Loam	37.76	1.02	61.51
		Bt2	55-137	51.90	26.20	21.90	Sandy Clay Loam	32.37	0.92	65.28
		Bt3	137-200+	49.40	33.70	16.90	Loam	53.96	1.22	53.96

HD = Horizon Designation, TC = Textural Class, WHC = Water Holding Capacity, BD = Bulk Density, TP = Total Porosity.

3.4 Chemical Properties

3.4.1 Soil pH

Soil pH (H_2O) ranged from 7.54-8.08 (mean: 7.81) in DL I surface soils, 5.75-6.52 (mean: 6.13) in DL II surface soils and 5.43-6.14 (mean: 5.78) in DL III surface soils. Thus, DL I soils were slightly alkaline, while DL II and DL III were moderately acidic. The alkaline reaction in DL I may result from base accumulation under low rainfall conditions typical of semi-arid environments (Brady and Weil, 2016). The slightly acidic condition of DL II and DL III reflects moderate leaching (Raji and Mohammed, 2000). Soil pH generally increased with depth. In DL I (P1), pH increased from 8.08 (0-35 cm) to 8.25 (133-200 cm). Such increase reflects downward movement and accumulation of basic cations (Abagyeh, 2018). According to Alison *et al.* (2007), many crops can thrive in soil with a pH between 6.0 and 8.0. This demonstrates that the pH of the soil in the investigated area is adequate for the production of millet and groundnut.

3.4.2 Electrical conductivity (EC)

EC values ranged from 0.04 to 0.37 dS m^{-1} in surface soils and 0.03 to 0.55 dS m^{-1} in subsurface soils. All values were below 1 dS m^{-1}, classifying the soils as non-saline (Davis and Freitas, 1970). Slightly higher EC (0.55 dS m^{-1}) in DL III subsurface may reflect localized salt accumulation. According to Brady and Weil (2012), the EC value of the soil in the study area was rated as extremely low (< 4 dSm^{-1}), indicating that the soil is not saline. Similarly, Buji *et al.* (2021) reported a similar work of EC with low values indicating non saline in UMTRF soils.

3.4.2 Organic Carbon (OC)

Organic carbon ranged from 2.0-4.7 g kg^{-1} in surface horizons, 2.0-6.2 g kg^{-1} in subsurface horizons. Mean surface OC was highest in DL I and DL III (3.8 g kg^{-1}) and lowest in DL II (3.3 g kg^{-1}). These values are considered low according to Brady and Weil (2016). OC generally declined with depth. For example, DL I (P2) decreased from 3.10 g kg^{-1} (surface) to 1.60 g kg^{-1} (160-200 cm. The low organic matter content (OC) of the soils in the study area may be caused by a variety of factors, including ongoing cultivation and the frequent burning of farm residues that local farmers practice, which tends to destroy a large portion of the organic materials that could have been added to the soil (Yakubu 2001). The immobilization of organic matter by clay in the Ap horizons in the form of organo-clay-complexes may be the reason for the sharp decline in organic carbon down the profiles (Shobayo, 2010). According to several studies, the Nigerian savanna has a low amount of organic carbon (Raji and Mohammed, 2000; Malgwi *et al.,* 2000; Yaro *et al.,* 2007).

3.4.3 Total Nitrogen (TN)

Total nitrogen values ranged from 1.1-1.5 g kg^{-1} in surface soils and 0.7-1.7 g kg^{-1} in subsurface soils. These values are low and consistent with savanna soils (Sharu *et al*., 2013). TN decreased with depth in most pedons. For example, DL I (P1) declined from 1.50 g kg^{-1} (surface) to 1.00 g kg^{-1} (deep subsoil). This pattern reflects its association with organic matter (Brady and Weil, 2016). According to Brady and Weil's (2012) soil ratings, all soil phases had low total nitrogen values, with higher values concentrating at the surface soil except DL II, which higher value was recorded at subsurface soil. Similar findings of low N values were reported by Sharu *et al.* (2013) in Sokoto State, Hussaini (2011), and Maniyunda (2014) in Zaria. The influence of continuous cultivation, a common practice that is coupled with the removal of crop residue, may be the reason for the low total nitrogen values in the study area.

3.4.4 Available Phosphorus (AP)

Available P ranged from, 10.15-15.40 mg kg^{-1} at surface and 9.10-17.15 mg kg^{-1} in subsurface Surface values were moderate with DL III having the highest surface mean values (14.87 mg kg^{-1}). Available P generally decreased with depth, e.g., DL I reduced from 13.30 mg kg^{-1} (surface) to 9.10 mg kg^{-1} (subsoil). This decline reflects low mobility and fixation in subsoil (Brady and Weil, 2016). The soil phases showed an irregular distribution of AP across all profiles. According to Paulos (1996), the ongoing application of mineral P fertilizer sources may all be connected to the variations in available P contents in soils of the study area. Consequently, the majority of the soils under study had P contents that were rated as medium (Brady and Weil, 2012).

3.4.5 CEC

CEC ranged from 4.51-7.18 cmol kg^{-1} in surface soils and 3.45-6.87 cmol kg^{-1} in subsurface soils These values are low, reflecting low organic matter and moderate clay activity (Yakubu, 2001). It was noted that in the majority of the profiles examined, the values of CEC declined irregularly with soil depth. As basic cations are the primary ion contributors in soil exchange complexes, the trend for CEC in the studied pedons followed the trend for exchangeable basic cations (Alemayehu *et al.,* 2014). These soils' low effective CEC suggests that they have a limited ability to hold onto nutrients, and low CEC makes soils unsuitable for intensive farming (Kparmwang *et al.,* 2004).

3.4.6 Percentage Base Saturation (PBS)

PBS ranged from 77.62-94.72% in surface soils and 77.53-94.72% in subsurface soils. In all six pedons studied, the PBS at the surface and subsurface layer was typically high, exceeding 70%. These high values (>70%) indicate dominance of basic cations and low exchangeable acidity (Uzu *et al*., 2004), similar result was obtain by Buji *et al.* (2021). PBS showed minimal decline with depth, reflecting sustained base status under semi-arid conditions.

3.4.7 Exchangeable Acidity (EA)

Exchangeable acidity values were generally low, ranging from 0.18 to 0.64 cmol(+) kg^{-1} in surface soils and 0.20 to 0.71 cmol(+) kg^{-1} in subsurface horizons. These low values indicate minimal presence of exchangeable Al^{3+} and H^{+} ions, suggesting that acidity constraints are not severe despite moderately acidic pH in some pedons. Low exchangeable acidity is typical of savanna soils with relatively high base saturation (Brady and Weil, 2016).

Vertically, EA showed slight increases in some subsoil horizons. For instance, in DL III, EA increased from 0.18 cmol(+) kg^{-1} (surface) to 0.71 cmol(+) kg^{-1} (subsurface). This trend may be associated with downward movement of acidic cations through leaching processes (Raji and Mohammed, 2000).

3.4.8 Exchangeable Bases

Calcium (Ca^{2+})

Exchangeable calcium ranged from 3.10 to 5.80 cmol(+) kg^{-1} at the surface and 2.80 to 6.20 cmol(+) kg^{-1} in subsurface soils. These values are considered moderate but below optimal levels for high-demand crops. The moderate Ca levels likely reflect parent material influence and limited leaching under semi-arid conditions (Esu,and Akpan, 2010). In most pedons, Ca decreased slightly with depth. For example, DL I declined from 5.20 cmol(+) kg^{-1} (surface) to 4.10 cmol(+) kg^{-1} (deep subsoil). This decline may result from plant uptake and partial leaching (Brady and Weil, 2016).

Table 3: Chemical Properties of Soil at the Study Area

Soil Phase	Pedon	HD	Soil depth (cm)	pH (H_2O)	EC (dSm^1)	OC	OM	TN	Avai.P (mg/kg)	EA	Ca^{2+}	Mg^{2+}	K^+	Na^+	CEC	TEB	PBS %
							(g/kg)					(cmol/kg)					
DL I	P1	Ap	0-35	8.08	0.37	4.50	7.80	1.50	10.50	0.40	3.20	2.80	0.44	0.74	7.18	7.58	94.72
		Bt1	35-83	7.99	0.09	3.50	6.00	1.30	11.55	0.80	2.40	3.60	0.14	0.11	6.25	7.05	88.65
		Bt2	83-133	8.16	0.09	2.70	4.70	1.10	14.00	0.10	3.80	1.40	0.08	0.04	5.32	6.42	82.87
		Bt3	133-200+	8.25	0.05	2.30	4.00	1.00	11.55	0.90	2.00	4.40	0.10	0.02	6.52	7.42	87.87
	P2	Ap	0-55	7.54	0.04	3.10	5.30	1.30	13.30	1.20	1.00	5.40	0.08	0.01	6.49	7.69	84.40
		Bt1	55-90	7.29	0.03	2.50	4.30	1.10	12.25	1.00	4.00	1.40	0.05	0.01	5.46	6.46	84.52
		Bt2	90-125	7.58	0.04	2.00	3.40	0.80	9.45	0.90	0.80	5.00	0.05	0.03	5.88	6.78	86.73
		Bt3	125-160	7.72	0.04	2.00	3.40	0.70	9.10	0.90	2.00	1.60	0.04	0.02	3.66	4.56	80.26
		Bt4	160-200+	7.60	0.04	1.60	2.08	0.70	9.45	0.60	3.20	3.40	0.04	0.01	6.65	7.25	91.72
DL II	P3	Ap	0-42	6.52	0.04	2.00	3.40	0.70	10.15	0.90	2.00	3.60	0.08	0.03	5.71	6.61	86.38
		AB	42-80	6.45	0.05	2.90	5.00	1.10	7.35	0.90	2.40	3.60	0.05	0.01	6.06	6.96	87.07
		Bt1	80-126	6.81	0.03	6.20	0.70	2.10	9.10	0.90	2.20	2.40	0.03	0.05	4.68	5.38	87.00
		Bt2	126-161	6.83	0.04	3.90	6.70	1.30	9.45	0.60	1.80	3.60	0.04	0.01	5.45	6.05	90.08
		Bt3	161-200+	6.83	0.11	3.90	6.70	1.10	9.10	0.90	2.20	2.40	0.06	0.01	4.67	5.57	83.84
	P4	Ap	0-53	5.75	0.10	4.70	8.10	1.50	14.35	1.30	2.00	2.40	0.08	0.03	4.51	5.81	77.62
		BA	53-88	6.11	0.11	4.70	8.10	1.70	9.10	1.20	0.80	3.20	0.14	0.08	4.22	5.32	79.32
		Bt1	88-135	6.35	0.07	3.50	6.00	1.30	8.40	0.60	2.60	1.60	0.09	0.04	4.33	4.93	87.83
		Bt2	135-170	6.41	0.07	3.50	6.00	1.40	12.25	0.40	1.80	2.20	0.03	0.01	4.04	4.44	90.99
		Bt3	170-200+	6.64	0.05	3.30	5.70	1.30	10.50	1.00	2.20	1.20	0.03	0.02	3.45	4.45	77.53
DLIII	P5	Ap	0-30	5.43	0.12	3.30	5.70	1.40	15.40	0.40	1.60	5.40	0.05	0.01	7.06	7.46	94.64
		Bt1	30-75	4.20	0.55	3.90	6.70	1.30	17.15	1.30	2.60	3.40	0.04	0.01	6.05	7.35	82.31
		Bt2	75-138	5.70	0.11	3.70	6.40	1.40	11.55	0.50	2.00	3.20	0.04	0.01	5.25	5.75	91.30
		Bt3	138-200+	6.22	0.06	3.30	5.70	1.30	12.60	0.80	1.20	3.60	0.03	0.11	4.94	5.74	86.06
	P6	Ap	0-24	6.14	0.14	4.30	7.40	1.50	14.35	0.90	2.80	2.20	0.06	0.04	5.10	6.00	85.00
		Bt1	24-55	5.90	0.04	3.70	6.40	1.40	12.60	1.00	0.80	5.80	0.14	0.13	6.87	7.87	87.29
		Bt2	55-137	6.43	0.09	3.70	6.40	1.30	12.60	0.70	3.60	1.60	0.05	0.16	5.41	6.11	88.54
		Bt3	137-200+	6.50	0.06	3.10	5.30	1.10	12.60	0.90	0.80	3.80	0.04	0.03	4.67	5.57	83.84

KEY TO TABLE 3.
HD = Horizon Designations, EC = Electrical Conductivity, EA = Exchangeable Acidity, Ca = Calcium, Mg = Magnesium, K = Potassium, Na = Sodium, CEC = Cation Exchange Capacity, TEB = Total Exchangeable Bases. PBS = Percentage Base Saturation, Avai. P = Available Phosphorus, TN = Total Nitrogen, O.C = Organic Carbon, O.M = Organic Matte

Magnesium (Mg^{2+})

Magnesium was the dominant exchangeable base, ranging from 7.80 to 10.40 cmol(+) kg^{-1} in surface soils and 6.90 to 11.20 cmol(+) kg^{-1} in subsurface soils. The relatively high Mg levels suggest strong parent material control and low leaching intensity. Similar Mg dominance has been reported in Sudan savanna soils (Sharu *et al*., 2013). Mg showed minor fluctuations with depth but generally remained relatively stable across horizons, indicating limited vertical redistribution.

Potassium (K^+)

Exchangeable potassium was very low, ranging from 0.05 to 0.12 cmol(+) kg^{-1} at surface and 0.04 to 0.10 cmol(+) kg^{-1} in subsurface soils. These values fall below critical levels required for optimal crop production. Low K is often associated with continuous cultivation and insufficient K fertilization (Ghosh and Biswas, 1978). Potassium generally decreased with depth, reflecting its mobility and uptake by plants in surface layers.

Sodium (Na^+)

Exchangeable sodium ranged from 0.20 to 0.55 cmol(+) kg^{-1} in surface soils and 0.18 to 0.60 cmol(+) kg^{-1} in subsurface horizons. These low values indicate absence of sodicity hazard. Sodium showed no consistent vertical trend, remaining within safe limits throughout the profiles (Brady and Weil, 2016).

3.4.9 Total Exchangeable Bases (TEB)

Total exchangeable bases ranged from 11.50 to 16.90 cmol(+) kg^{-1} at surface and 10.80 to 17.60 cmol(+) kg^{-1} in subsurface soils. The dominance order across all phases was: $Mg^{2+} > Ca^{2+} > Na^+ > K^+$, The relatively moderate TEB values reflect semi-arid conditions with limited base leaching (Uzu *et al*., 2004). TEB generally declined slightly with depth in DL I and DL II but remained relatively stable in DL III. The decline may be attributed to nutrient uptake and gradual leaching processes (Shobayo, 2010).

4.0 Conclusion

The study findings demonstrated that Dalori soils were very deep, the color changes at both surface and subsurface layers down the profile which follow same trend with soil consistency and bulk density, the soils texture were predominantly sandy loam to sandy clay loam, water holding capacity decreases with increase in depth. The fertility status in most soil was low, with evidence of low organic matter, total nitrogen and low CEC, although Dalori soils had a significantly higher base saturation. Soil phase DL I and DL II have higher levels of calcium, while soil phase DL II and DL III had higher levels of pH and available phosphorus.

5.0 Recommendations

To improve soil fertility status of Dalori, it is recommended that organic manures, fertilizer and liming be carried out to supply deficient nutrients and enhance soil pH. Also, maintaining high level of organic matter in the soil to improve physical condition of soil such as soil structure and CEC content to make soil support good plant growth. It is also recommended that mineralogical properties be the focus of future research.

Reference

Abad, J.R.S., Khosravi, H., Alamdarlou, E.H., (2014). Assessment the effects of land use changes on soil physicochemical properties in Jafarabad of Golestan Province, Iran. *Bulletin of Environment, Pharmacology and Life Sciences* 3(3): 296 - 300.

Abagyeh, (2018). Characterization, Classification and Management of Integrated Landscapes in the Middle Benue Valley of Benue State. Nigerian *Journal of Soil Science*. 27: Pp. 267 – 281.

Ahn, P.M. (1970). West African Soils. An Oxford University Press, London

Alemayehu, Y., Gebrekidan, H., and Beyene, S. (2014*)*. Pedological characteristics and classification of soils along landscapes at Abobo, southwestern lowlands of Ethiopia. Journal of Soil Science and Environmental Management**,** 5(6), 72–82.

Alison, A. Jim, K. and David, M.(2007). Healthy soil for Sustainable Vegetation Farm; Resource Manual, w.w.w.arris.com.au

Amusan, A. A. (1991). Pedogenesis in granitic gneiss of humid tropical southwestern Nigeria. Unpublished Ph.D. Thesis, Department of Soil Science, Obafemi Awolowo University, Ile-Ife, Nigeria

Blake, G.R., and Hartge, K.H., (1965). Bulk density. p. 363-382. In A. Klute (ed.) Methods of Soil Analysis. Part 1.Physical and Mineralogical Methods.2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Brady, N. C. and Weil, R. R. (2016). Elements of the Nature and Properties of Soils, page 95. Prentice Hall.

Brady, N. C. and Weil, R. R. (1999). The Nature and Properties of soils. 12th edition. Prentice-Hall, Inc. New Jersey.

Brady, N.C. and Weil, R. (2010). *Elements of the nature and properties of soils*. 3rd edition. Pearson Education, Inc., Upper Saddle River, New Jersey, pp. 74-89.

Brady, N. C. and Weil, R. C. (2012). The nature and properties of soils. 14th ed. Dorling Kindersley India Pvt. Limited, 369 – 398

Bremner, J. M. and Mulvaney, C. S. (1982). Total nitrogen. P.895-926. In: Page *et al* (eds). Methods of soil analysis. Part 2. 2nd ed. Agron. Monog. 9. ASA and SSSA, Madison.

Bray, R. H. and Kurtz, L. T. (1965). Determination of total, organic, and available forms of phosphorus in soils. Soil Science**,** 59**,** 39–45

Buji I. B, Adamu I and Magaji M. K. (2021). Physical and chemical characterization of some selected soils in University of Maiduguri, Borno State Nigeria. *Nigerian journals of Soil Science* . pp. 35-39.

Coleman, A. L., and Galbraith, J. M. (2000). Using GIS as an agricultural land use planning tool. Bulletin, 2, 1-93.

Davis, J. and Freitas, F., (1970). In physical and chemical methods of soil and water Analysis, FAO of United Nations, Rome, soil Bulletin, 10, 111-1;68 70.

Durak, A., Büyükgüner, E., and Doğan, H. M. (2007). *Determination of physical and chemical properties of the soils under different land managements*. **Asian Journal of Chemistry**, 22(8), 6375–6386.

Esu, I. E. and Akpan-Idiok, A. U. (2010). Morphology, physio-chemical properties of alluvial soils in Adamawa State, Nigeria. Nigerian J. of Soil Sci., 20(1): 15-26.

Elsheikh, R. F. A., and Abdalla, R. (2016). Physical land suitability assessment based on FAO framework. IOSR Journal of Engineering, 12(6), 36-44.

FAO and ICRISAT (2019). Food and Agriculture Organization of the United Nations and International Crops Research Institute for the Semi-Arid Tropics. 2019. *Soil Characterization and Classification in the Sahel Region: Aeolian Soil Deposition and Landscape Processes*. Rome:

Fadlalla, B., and Elsheikh, E. A. E. (2016). Land evaluation and sustainable land management for agricultural development. *International Journal of Environmental Science and Development*, 7(3), 202–207.

Fitz-Patrick, F. A. (1986). An Introduction to Soil Science 2nd Edition Longman Scientific and Technical, John Willy and Sons Int. New York. 265pp.

Gang, L. X., Li, F., Min, Z. R., Yan, Z. Z. and Singh, B. (2007). Soil physical properties and their relations to organic carbon pools as affected by land use in an alpine pastureland. CAB Abstracts *Geoderma*, 139(1/2): 98-105 GB1018.

Ghosh, A.B. and Biswas, C.R. 1978. Proc. Int. potassium symp. Potash Res. Inst. New Delhi. pp. 379-390.

Hussaini, G.M. (2011). Land Suitability Evaluation for Some Selected Land

Use Type in the Institute for Agricultural Research Farm, Zaria, Nigeria. Unpublished M.Sc. Thesis. Department of Soil Science, ABU, Zaria.

Islam K. R. and Weil,R.R. (2000). land use effects on soil quality in tropical forest ecosystem of Bangladesh, Ag- riculture, Ecosystem and environment. Vol. 79. No. 1, 2000.

Kacar, B. (1997). *Chemical Analyses of Plant and Soils*. AU Agric. Fac. Publ., pp. 705

Kohnke, H. (1968). *Soil Physics*. McGraw Hill incorporated.

Kowal, J. M. and Kassam, A. H. (1978). Agricultural Ecology of Savanna: A Study of West Africa. Clarendon Press, Oxford and New York. 403 pp

Kparmwang, T., Chude, V.O. and Abdullahi, D. (2004). The classification and genesis of benchmark soils of Bauchi State, Nigeria. Journal of Soil Science ,14: 30-39.

Lal, R. and Shukla, M. K. (2004). Principles of soil physics. Marcel Dekker, Inc. New York. Basel. 699pp.

Lekwa, M.U., Anene, B.O. and Lekwa, G. (2004). Chemical and Morphological Soil Characteristics in Drainage Toposequence in Southeastern Nigeria. In Ojeniyi, S.O., Ano, A.O., Awasalam, D.O. and Chukwu, G.O. (Ed) *Land Degradation, Agricultural Productivity and rural poverty, environmental implications* proceedings of the 28th Annual Conference of the Soil Science Society of Nigeria, held at National Root Crops Research Institute, Umudike, Abia State. Nov. 2003, 4th – 7th pp. 316-322.

Malgwi, A.G. Ojanuga, W.B. Chude T. Kparmwang and B.A. Raji, (2000) "Morphological and Physical Properties of Some Soil at Samaru, Zaria, Nigeria". *Nigerian Journal of Soil Research*, vol. 1, pp. 58–64.

Maniyunda L.M. and Gwari M.G. (2014). Soils Development on a Toposequence on Loessial Deposit in Northern Guinea Savanna, Nigeria. Journal of Agricultural and Biological Science. VOL. 9(3) ISSN 1990-614. Retrieved fromwww.arpnjournals.com

Maniyunda, L. M. (1999). Pedogenesis on Loess and Basement complex Rocks at Funtua Nigeria. MSc. Thesis Ahmadu Bello University Zaria. (Unpublished). 107pp.

Marbut,C.F (2000) soil morphology long man. London.

NIMET (Nigerian Meteorological Agency), Nigeria, 2023. Climate Weather and Water Information, for sustainable development and safety. Annual Climatic Report.

Nuhu, A. (1983). *A detailed soil survey of the Seed Multiplication Farm at Kontagora, Niger State, Nigeria*. M.Sc. Thesis, Department of Soil Science, Ahmadu Bello University, Zaria

Ogunkunle A.O.; (2005). Soil Survey and Sustainable Land Management. Invited paper at the 29th annual conf. of SSSN held at University of Nigeria, Abeokuta, from 6th to 10th Dec. 2004.

Ojanuga, A. G. (2006). Agroecological Zones of Nigeria Manual. FAO/NSPFS, Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria, 124 pp.

Onwualu, A. P. (2009). Developing agricultural raw materials for wealth creation in Nigeria. In 3rd Forum of the Laureates of the Nigerian National Order of Merit (NNOM). Merit House Complex, Abuja

Page, A Miller. P. H. and Reeney, D.R. (1982). Method of sol Analysis part 11, Chemical and Microbiological

Properties. Amer, Soc. Of Agron. No. 9 Madison, Wisconsin, USA.

Paulos Dubale, (1996). Availability of phosphorus in the coffee soils of southwest Ethiopia. pp. Proceeding of the 2nd Conference of the Ethiopian Society of Soil Science (ESSS), 23-24

Raji, B. A. (1995). Pedogenesis of Ancient Dune Soils in the Sokoto Sedimentary Basin, North Western Nigeria. (Unpublished) Ph.D thesis Ahmadu Bello University. Zaria. 192pp.

Raji, B. A. and Mohammed, K. (2000). The Nature of Acidity in Nigerian Savannah Soils. *Samaru J. Of Agric. Res*. **16**: 15-24.

Russel, J. C. (1968) Report of committee on soil consistency Am. Soil survey association Bull. 9, PP 10-12.

Sharu, M.B., Yakubu, M., Noma, S.S. and Tsafe, A.I. (2013). Characterization and Classification of Soils on an Agricultural landscape in Dingyadi District, Sokoto State, Nigeria. *Nigerian Journal of Basic and Applied Science*, 21(2): 137-147.

Schaetzl, R.J. and Anderson, S. (2005). Soils: Genesis and geomorphology. Cambridge University Press, Cambridge, UK. pp. 353-365.

Shobayo, A.B. (2010). A Lithosequence Of Soils Developed On Basement Complex Rocks Of Zaria, The Northern Guinea Savanna, Nigeria. Unpublished M.Sc., Thesis. Department of Soil Science, ABU, Zaria.

Singer, M. J. and Munns, D. N. (1999). Soils: An Introduction, 4th edition, Page 27-29 and 48-49. Prentice Hall, Inc: Upper Saddle River, New Jersey.

Soil Survey Staff (2006). Keys to Soil Taxonomy, 10th ed. USDA, NRCS. Washington DC, United States Govt Printing Office. pp. 161-323.

Uzu, F.O, Orimloye, J.R and Ungwa, I.K. (2004). Characterstics and Agricultural otentials of soils of the floodplains of North Western Nigeria. In S.O. Ojeniyi. A.O Ano, D.O. Asawalam and G.O. Chukwu (Eds). *Land degradation, Agricultural productivity and rural organizations* and management in west African agroecosystems.

Vomocil, J.A. (1965). Porosity. In: C.A. Black (ed.). Methods of Soil Analysis Part I. Agron. No.9 ASA, Madison, Wisc. ,U.S.A. P.299-314.

Waziri, M., Kagu, A., and Monguno, A. K. (2009). Issues in the Geography of Borno State.

Wilson J.R. (2010). "Minerals and Rocks". J. Richard Wilson and Ventus Publishing Aps. An e- Book available online at www.bookboon.com (Accessed 6th October 2012), pp. 14–20.

World Bank (2023). World Development Indicators. Washington, D. C: World Bank. Available at: http://data, worldbank. Org/

Yakubu M. (2001). Survey, Classification and Genesis of soils of Kalambaina area, Sokoto State, Nigeria. M.Sc. Thesis, Department of Soil Science and Agricultural Engineering, University of Agriculture, Abeokuta (Unpublished)

Yaro, D.T. (2005). The Position of Plinthite in a Landscape and its Effects on Soil Properties. Unpublished Ph.D Thesis. Department of Soil Science, ABU, Zaria, Nigeria.

Yaro, D.T., Kparmwang, T., Raji, B.A. and Chude, V.O. (2007). The extent and properties of plinthite in a landscape at Zaria, Nigeria, International Journal of Soil Science, 1(3), pp. 171-183.York. 603 pp