ADAN J. Agric. 2025, 6: 160-172

ISSN 2736-0385
DOI:10.36108/adanja/5202.60.0151

Characterisation and classification of soils in the dry sub-humid area of Maiduguri, Borno state, Nigeria

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Abstract

This study examines the characteristics and classification of soils in a dry, sub-humid area of Borno, North-Eastern Nigeria. The objective was to provide detailed soil information for improving land use, research, and agricultural productivity. It involved soil sampling from eight pedons representing upland, midland, and lowland areas. We examined soil samples for their morphological, physical, and chemical characteristics. The soils were classified using the taxonomic and the world reference base systems. Pedon 8 has a very high organic carbon content, exceeding 2.0%, in both its surface and subsurface horizons. Pedon 1 shows high organic carbon only in the surface Ap horizon, while all other pedons are rated low on both surfaces and suboptimal for sustainable productivity. Nitrogen values for crop production were adequate in the surface and subsurface of pedons 7 and 8, ranging from 0.2 to 0.5%. The Ap horizons of Pedons 1, 4, 6, and 8 have medium levels of available phosphorus, which can support crops with some inputs. In contrast, other pedons exhibit low phosphorus levels (5 to 10 mg/kg), indicating a likely deficiency. The pH values (6.20 to 6.81) are neutral to slightly acidic in all soils studied. Cation exchange capacity (15.15 to 34.22 cmol/kg) and base saturation of over 97% in the Ap surface horizons are often high, indicative of nutrients present. The nutrient availability decreases with depth in organic carbon, total nitrogen, and available phosphorus diminish in the subsurface horizons. Pedons 1 - 8 are Typic Haplustept (USDA soil taxonomy) while correlating with the Eutric Cambisols of the WRB system for soil resources. Thus, it needs specialised moisture and nutrient management. These findings will inform future land management and farming practices for optimised soil use in the region.

Key words: *Inceptisols, Soil Morphology characteristics, Soil Texture and Structure, Soil Chemical Properties*

Introduction

Soil characterization is a building block for understanding the soil properties and their distribution over an area necessary for a soil management plan, rehabilitation of degraded lands, and sustainable land uses (Abera *et al.*, 2016). It identifies and assesses soil potential and limitations for a specific type of use necessary for agricultural sustainability. Agricultural land use is discriminatory as different crops have varied needs in terms of nutritional content and physical quality, so a soil type acceptable for one crop may not be suitable for another (Adeyolanu *et al.*, 2017). Maniyunda and Gwari (2014) argue that a lack of information on soil characteristics and the potential of land for specific agricultural uses can lead to misuse, mismanagement, and degradation. Soil characterization and classification are now the primary sources of information for precision agriculture, land use planning, and management (Seifu *et al.,* 2022).

Agricultural experimentation has been essential in all areas of the economy to increase productivity, and there is a need for quality information on soils for precise experiments geared towards maximizing production. The soil characteristics are crucial in determining whether the agricultural output required is feasible. Thus, describing the distinctive morphological, physical, and chemical characteristics of the soils becomes essential for improved and sustainable productivity.

The land and soils of the Maiduguri University research and demonstration farm have long been used for research and small-scale farming without determining the land's potential. Year after year, irrational land use by staff and students for research purposes has occurred with no objectives seeking maximum yield from each land use; this will only result in the gradual, irreversible deterioration of the land and soil. Consequently, characterization and classification become the only solutions to instituting rational land use, which is to use each land or soil in a way that best suits its characteristics and to program its management for minimal deterioration. Identifying the most suitable areas for crop growth will enhance research output and productivity in the long run. The research output, with proper characterization and classification, will benefit the farming community in addition to the teaching and learning that has taken place.

Therefore, the broad objective is to characterize and classify the upland, midland, and lowland areas of the University of Maiduguri Research and Demonstration Farm to improve experimental results, while the specific objectives are to determine the I. Soil morphological, II. Soil physical, and III. Soil chemical characteristics of the sampling units.

Materials and Methods

Description of the study site

The study site has a total area of about 56,553 square meters (m2) (5.6553 ha), and its latitude and longitude are N 110 83.33' and E 130 15.00', respectively. The region experiences a hot desert climate (Köppen climate classification BWh). The mean annual temperatures often reach 40°C (104°F) during the peak dry season (March to May), and very low humidity levels, especially during the dry season, record annual means of 10-20%. The rainfall is low and irregular, with a mean annual value of about 600 mm, mostly falling during the wet season (June to September) (NIMET, 2021). Maiduguri, situated in the Chad Basin, a sedimentary basin with a geological formation of the Miocene to Pleistocene age, is the primary rock unit in the area. It consists of sandstones, shales, and clays. The Chad Basin is an inland intra-cratonic basin belonging to the African Phanerozoic sedimentary basin, with its origin related to the dynamic process of plate divergence (Oladele et al., 2018). The site's soils are generally sandy loam, with low fertility and high susceptibility to erosion. On the study site, mango, cashew, and citrus trees, as well as onions, tomatoes, and cabbage, grow alongside weed grasses such as buffelgrass, fountain grass, incense grass, and half-moon grass, which grow during the rainy season.

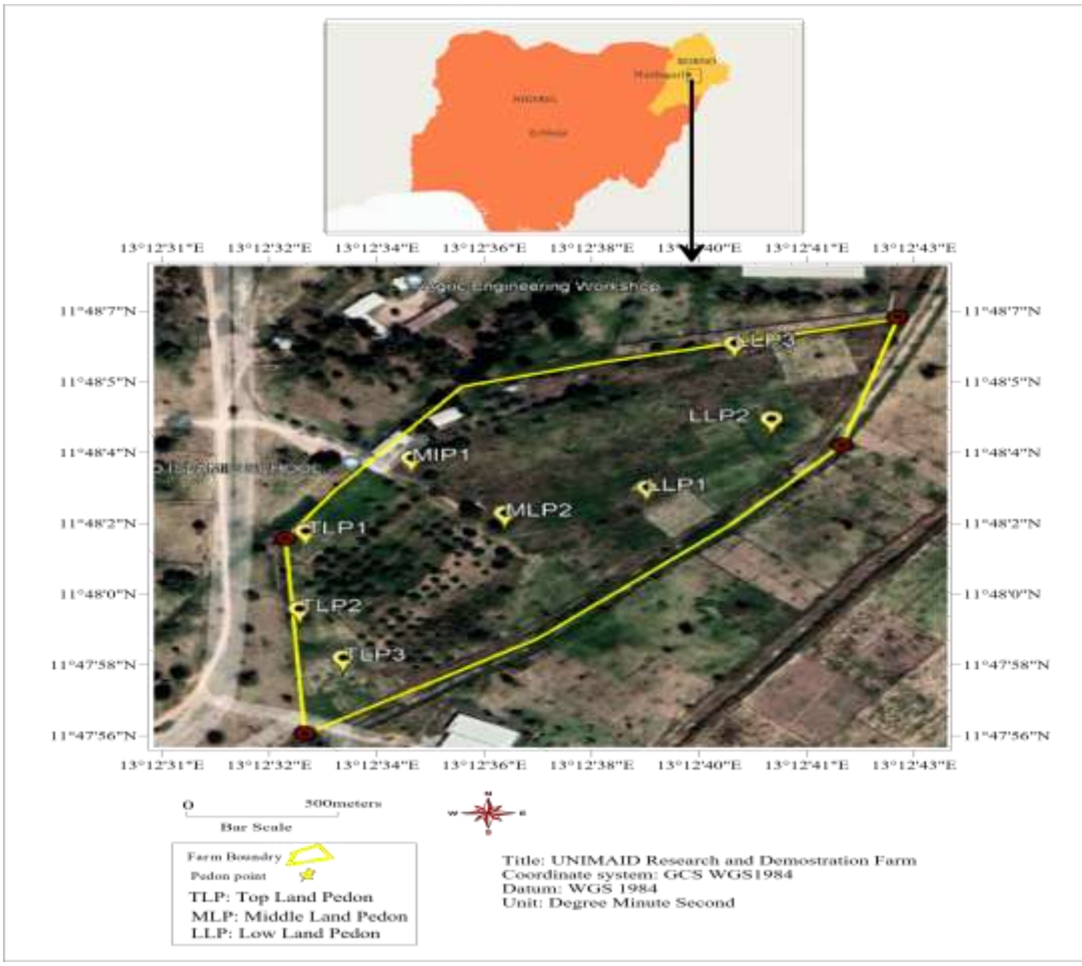

Figure 1: Location Map of the Study Site and Sampling Soil Unit

Field study, sampling and profile description

The study site (farm) was initially subjected to a reconnaissance survey to determine the primary characteristics of the terrain in terms of the kind of soil, vegetation, and other biophysical aspects. Following a free survey along the topographical axis, soil boundaries were detected using soil colour, textural differentiation, soil structure, and physiographic position. We dug eight (8) profile pits at the research site and named them Pedon 1, Top Land Pedon 1 (TP1), Pedon 2, Top Land Pedon 2 (TP2), Pedon 3, Top Land Pedon 3 (TP3), Pedon 4, Mid Land Pedon 1 (MP1), Pedon 5, Mid Land Pedon 2 (MP2), Pedon 6, Low Land Pedon 1 (LP1), Pedon 7, Low Land Pedon 2 (LP2), and Pedon 8, Low Land Pedon 3 (LP3) to represent the entire study site. We then took three (3) samples from each horizon for laboratory analysis. The profile mini pit has dimensions of 1 m in width, 1 m in length, and 2 m in depth for characterisation purposes. Profile description follows the (Jahn et al., guidelines for soil description [FAO, Rome (2006)].

Sample preparation and laboratory analysis of physical and chemical characteristics

Ninety-eight (96) soil samples were collected from eight profile pits and then taken to the laboratory. They were spread out to air dry and then crushed until they could pass through a 2 mm sieve to achieve fine soil separation. The physical and chemical characteristics of the soil samples were analysed and interpreted. The distribution of particle sizes was analysed using the hydrometer method (Gee and Bauder, 2002). The undisturbed core samples were dried in an oven at 105°C until they reached a constant weight to calculate the bulk density. The bulk density (Db) is determined by dividing the oven-dry mass of the soil sample (M) by its volume (V). Soil pH was measured in a 1:2:5 soil-water ratio using a glass electrode pH meter. The soil organic carbon content was determined by Nelson and Sommers (1996). Total Nitrogen was determined by Bremner (1996). The soil phosphorus levels were examined using Sims' (2009) method. While Ca and Mg were determined using the Atomic Absorption Spectrometer (AAS) at the fitting wavelengths, Na and K were determined using the flame photometer. Exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, Na^+) were determined by repeated extraction procedure with neutral 1M NH_4OAc (pH 7) solution. The cation exchange capacity was calculated by summing up the exchangeable bases and exchangeable acidity (H + Al). Percentage base saturation was calculated using the following formula: % BS= (A/B) x 100 Where: A = $NH_4\ OA_C$ (pH 7.0) Extractable Bases (Ca + Mg + Na + K) (cmol (+) kg^{-1}), B = CEC (cmol (+) kg^{-1}).

Results and Discussion

Soil morphology

The distinctive morphological characteristics of the pedons under study are in detail in Table 1. All eight soil profiles within the study area exhibited exceptional depth, surpassing 200 meters. Furthermore, the study site's elevation was consistently 300 meters above sea level across all the pedons. The terrain was nearly flat, with a maximum slope of 2%, and each of the analysed soil profiles possessed excellent drainage.

The soil colour (dry) in all the surface AP horizons of the Inceptisols (Pedon 1–8) was light brown on the surface (7.5 YR 6/3) to darker brown (7.5 YR 5/3) in the subsurface soils. Pedon 4 was yellowish brown (10YR 5/4), indicating varying amounts of organic matter or moisture content. Pedon 2 at the surface horizon (7.5 YR 5/4) and Pedon 7 (7.5 YR 5/3) are darker in colour, which is due to higher organic matter content. The colour values range from 7.5YR 5/3 to 7.5YR 8/6, with a transition from browns to lighter brown/yellowish colours as depth increases. Darker browns (7.5YR 5/3) colouration at B subsurface horizons, signifying more organic material. The lighter colours (7.5YR 7/8) at the deep surface had a lower organic matter content and different mineral compositions. Pedon 7 subsurface Bw horizon (7.5YR 6/8) shows an intense yellowish colour, meaning there might be oxidation or well-drained conditions. The variations in iron oxide forms, parent material types, organic matter concentrations, and drainage conditions are responsible for colour variations between soil pedons and within a pedon (Schaetzl and Thompson 2015; Talha et al. 2022). According to the soil profiles, there is a mixture of loam and sandy loam textures. The silt/clay ratios and clay content increase with depth, indicating that the soil is relatively developed with clay accumulation. Due to the weak to moderate development of soil horizons, with some evidence of clay accumulation, they have a wide range of textures, pH, and nutrient levels (Tables 2 and 3).

Table 1: Soil morphological characteristics

Horizon	Depth (cm)	Colour	Structure	Consistency (dry)	Other features	Horizon boundary
Pedon 1 (TLP 1)						
Ap	0-32	7.5YR 6/3	SBK	H	None	D,W
AB	32-61	7.5YR 5/3	ABK	SH	Root Net/W	D,W
Bw1	61-119	7.5YR 5/4	PL	S	Root Net/W	D,W
Bw2	119-200	7.5YR 4/2	PL	S	None	D,W
Pedon 2 (TLP 2)						
Ap	0-40	7.5YR 5/4	BK	H	None	D,W
AB	40-134	7.5YR 6/3	SBK	SH	None	D,W
Bw1	134-155	7.5YR 7/6	PL	SH	None	D,W
Bw2	155-200	7.5YR 7/8	GR	S	None	D,W
Pedon 3 (TLP 3)						
Ap	0-50	7.5YR 6/4	ABK	H	None	D,W
Bw	50-88	7.5YR 6/3	PL	S	None	D,W
Bt	88-131	7.5YR 7/6	PL	S	None	D,W
C	131-200	7.5YR 7/8	GR	S	None	D,W
Pedon 4 (MPL 1)						
Ap	0-34	10YR 5/4	SBK	H	None	D,W
B	34-111	7.5YR 6/3	PL	SH	None	D,W
Bw1	111-138	7.5YR 8/2	BK	S	None	D,W
Bw2	138-200	7.5YR 7/2	GR	S	None	D,W
Pedon 5 (MPL 2)						
Ap	0-34	7.5YR 6/4	BK	H	None	D,W
B	34-75	7.5YR 7/4	PL	SH	None	D,W
Bw	75-123	10YR 6/6	PL	S	None	D,W
Bw1	123-167	7.5YR 7/4	PL	S	None	D,W
Bw2	167-200	7.5YR 8/2	SBK	S	None	D,W
Pedon 6 (LLP 1)						
Ap	0-30	7.5YR 5/3	SBK	S	None	D,W
Bw1	30-60	7.5YR 6/3	SBK	S	None	D,W
Bw2	60-119	7.5YR 6/4	BK	S	Root Net/W	D,W
Bw3	119-200	7.5YR 8/6	BK	S	None	D,W
Pedon 7 (LLP 2)						
Ap	0-65	7.5YR 5/3	SBK	H	None	D,W
B	65-160	7.5YR 6/8	BK	SH	None	D,W
Bw2	160-200	7.5YR 7/8	BK	H	None	D,W
Pedon 8 (LLP 3)						
Ap	0-70	7.5YR 6/3	SBK	S	None	D,W
Bw	70-110	7.5YR 6/4	BK	S	None	D,W
Bw1	110-140	7.5YR 6/3	GR	S	None	D,W
Bw2	140-200	7.5YR 7/6	BK	S	None	D,W

STRUCTURE: SBK=Sub-angular blocky, BK=Blocky, PL=Platy, GR= Granular. CONSISTENCY: H=Hard, SH=slightly hard, S=Soft. HORIZON BOUNDARY: D= Diffuse, I= Wavy.

Soil depth, structure, consistency and horizon boundaries

Thicker Ap surface horizons (Pedons 7 and 8) indicate better surface soil development or organic matter accumulation. These characteristics are a function of land use and environmental conditions. The structures of Inceptisols (pedons 1–8) in the surface Ap soils were weak. Pedons 2 and 5 were blocky in structure. The angular blocky structure in Pedon 3 indicates slightly poorer soil stability than subangular blocky structures. The soil structures in the subsurface B and C soil horizons vary from blocky to subangular blocky in Pedons 6, 7, and 8, suggesting a medium water movement. In Pedons 1 to 5, with a Platy soil structure, many B horizons can restrict water movement. Subsurface C horizon of pedons 2, 3, and 4, there was granular soil structure, indicating loose soil, well aerated with good drainage. In the surface pedons of 1 to 5 and 7, soil consistency was hard, implying that the surface horizons may hinder crop growth by affecting water infiltration during dry seasons. The soil profiles 6 and 8 exhibit soft consistency. This narrative may be beneficial for root growth and water infiltration. In the subsurface horizons of pedons 1, 3, 6, and 8, the consistency was dominantly soft, which means better root growth and water movement. The slightly hard and hard consistency in Pedons 2, 4, and 7 at the subsurface B horizons had shown reduced water infiltration. The surface soils exhibit more sub-angular structures due to a mix of biological activity and the accumulated organic matter content, improved aeration, and water infiltration. In contrast, subsurface soils display blocky structures caused by pedoturbation and clay content (Weaver and Bligh, 2016; Brady and Weil, 2017). The structures is due to foot activities at the surface horizons, while overburden pressure is at the subsurface horizons (Rowell, 2014). The diffused and wavy boundary between horizons in all pedons suggests a gradual transition between the surface and the subsurface horizons, i.e., a slow change in soil characteristics between horizons and a more uniform soil profile. The depth of the soil determines the amount of water and plant nutrients available to the roots. Distinctive morphological features often manifest in the horizon boundaries of soil samples, particularly at depths where the surface and subsurface meet. These soil features point to the early phases of soil development. The gradual transition makes the boundaries between horizons not well-defined, and the diffuse and wavy boundaries confirm the soils are still developing (Bockheim, 2024).

Soil physical characteristics

The physical characteristics of the soils are presented in Table 2

Soil particle size distribution

All soils examined and classified as Ineptisols (pedons 1-8) in the Ap horizon have a predominantly sandy loam or loam texture, except pedon 3, which is silty loam that changes to loam at the Bw horizon, meaning more water retention. The sandy loam is generally favourable for crop growth due to easy root penetration; soil profile 3 (silt loam) (USDA, 2019). The variation in texture with depth indicates changes in soil properties and potentially affects water infiltration, nutrient availability, and root growth. The subsurface Bw soil horizons are often loam or sandy loam in texture, with moderate moisture retention. Soil profile 3 has a loam, whereas Pedon 5 and 8 have sandy loams in the subsurface or transitional horizons. The subsurface B horizons are loams, except for Pedons 5, 6, and 8, where the texture is a sandy loam zone of clay illuviation or accumulation. The predominant loam or sandy clay loams in the subsurface horizons suggest moderate to high sand content. Profiles examined (3, 5, and 8) are sandy clay loams capable of retaining moisture.

Table 2: Physical characteristics of soil in University of Maiduguri demonstration farm

Horizon	Depth (cm)	Sand (%)	Silt (%	Clay (%)	Silt/clay ratio	Textural class	Bulk Density (mg/m3)
Pedon 1 (TLP 1)							
Ap	0-32	62	23	15	1.5	Sandy loam	1.33
AB	32-61	55	28	18	1.6	Sandy loam	1.32
Bw1	61-119	45	38	18	2.1	Loam	1.12
Bw2	119-200	45	35	20	1.8	Loam	1.23
Pedon 2 (TLP 2)							
Ap	0-40	50	35	15	2.3	Loam	1.33
AB	40-134	47	35	18	1.9	Loam	1.27
Bw1	134-155	45	38	18	2.1	Loam	1.25
Bw2	155-200	57	23	20	1.2	Sandy clay loam	1.33
Pedon 3 (TLP 3)							
Ap	0-50	32	52	16	3.3	Silt loam	1.20
Bw	50-88	52	30	18	1.7	Loam	1.23
Bt	88-131	57	25	18	1.4	Loam	1.19
C	131-200	55	25	20	1.3	Sandy clay loam	1.16
Pedon 4 (MPL 1)							
Ap	0-34	55	27	18	1.5	Sandy loam	1.32
B	34-111	47	38	15	2.5	Loam	1.35
Bw1	111-138	40	45	15	3.0	Loam	1.20
Bw2	138-200	57	25	18	1.4	Loam	1.21
Pedon 5 (MPL 2)							
Ap	0-34	65	17	18	0.9	Sandy loam	1.39
B	34-75	62	20	18	1.1	Sandy loam	1.35
Bw	75-123	60	27	13	2.1	Sandy loam	1.32
Bw1	123-167	57	30	13	2.3	Sandy loam	1.30
Bw2	167-200	42	43	15	2.9	Loam	1.29
Pedon 6 (LLP 1)							
Ap	0-30	57	25	18	1.4	Sandy Loam	1.33
Bw1	30-60	47	35	18	1.9	Loam	1.22
Bw2	60-119	42	35	23	1.5	Loam	1.13
Bw3	119-200	32	48	20	2.4	Loam	1.26
		44.60	35.63	19.77			
Pedon 7 (LLP 2)							
Ap	0-65	57	25	18	1.4	Sandy loam	1.33
B	65-160	45	33	22	1.5	Loam	1.27
Bw2	160-200	44	38	18	2.1	Loam	1.25
		49	32	19	1.7	Loam	
Pedon 8 (LLP 3)							
Ap	0-70	55	25	20	1.3	Sandy clay loam	1.20
Bw	70-110	57	20	18	1.1	Sandy Loam	1.23
Bw1	110-140	60	22	18	1.2	Sandy Loam	1.19
Bw2	140-200	52	30	18	1.7	Loam	1.16

Pedon 1, Top Land Pedon 1 (TP1), Pedon 2, Top Land Pedon 2 (TP2), Pedon 3, Top Land Pedon 3 (TP3), Pedon 4, Mid Land Pedon 1 (MP1), Pedon 5, Mid Land Pedon 2 (MP2), Pedon 6, Low Land Pedon 1 (LP1), Pedon 7, Low Land Pedon 2 (LP2), and Pedon 8, Low Land Pedon 3 (LP3).

Silt/clay ratio

The silt clay ratio ranged from 0.9 to 3.3 at the surface Ap horizons of all the pedons, while there was a range of 1.1 to 3.0 at the subsurface B horizons. There was no consistent decrease or increase in clay/silt ratio with soil types and depth in all the pedons except for pedons 2 and 3. As the silt/clay ratio reduces with increasing depth, confirming more subsurface weathering and a higher ratio on the surface AP horizons of profiles 3 and 4 affirms higher silt content with improved water retention and nutrient availability. The lower ratios in Pedon 5 show sand dominance with less moisture retention but good drainage. The silt/clay ratios in the subsurface Bw horizons range from 1.1 to 2.5, indicating variation in the balance between water retention and permeability. The higher ratios on the subsurface of profile 4 indicate better nutrient-holding capacity, whereas the lower ratios in profile 5 suggest faster drainage. In the subsurface horizons B (ranging from 1.2 to 3.0), the silt/clay ratios confirm higher clay content, while in the subsurface horizons (ranging from 1.2 to 2.9). A lower ratio, such as 1.2 in soil profile 2, implies faster drainage. The variation in silt-clay ratio suggests differences in soil formation processes and weathering patterns among pedons. The Ap surface horizons with sandy loam textures and the clay-rich B horizons found in most pedons result in a highly adaptable soil profile suitable for various crops. Certain areas have high clay content, which needs effective drainage management.

Bulk density

The bulk densities of Ap soil horizons for surface and subsurface range between 1.20 and 1.39 mg/m³ across pedons (Table 3). High bulk densities at the surface horizons suggest a high risk of managing the physical properties (> 1.30 g/cm³). Conversely, the lower bulk density moderate bulk density (1.10–1.30 g/cm³) in Pedon 3 suggests an ideal range, offering the potential for enhanced crop growth. Bulk densities at the Bw horizon range between 1.22 and 1.35 mg/m³ and are rated moderate, supporting good crop growth under controlled conditions. A bulk density of 1.12 mg/m³ is considered low to moderate, especially for a subsurface horizon. The ideal range for plant growth is between 1.1 and 1.4 mg/m³, considering the texture is loam (Table 2). Bulk density values in the B horizons are similar, ranging from 1.16 to 1.33 mg/m³, implying a consistent soil structure and homogeneous texture or management history.

Soil chemical characteristics
Soil reaction (pH)

On both the surface and subsurface horizons, the pH values of all the analyzed soils were less than seven and over six. The pH of the surface horizons ranges from 6.3 to 6.8, while at the subsurface horizons, it ranges from 6.2 to 6.8 (Table 3). Based on Brady's Brady and Weil (2017) findings, it is essential to maintain a soil pH score between 6 and 7 to ensure optimal agronomic crop production. Thus, at the surface horizons, the soil pH is favourable for most crops; at the subsurface B horizons, it suggests a minimal change in soil acidity with depth, indicating good soil chemistry for root development throughout the profile.

Soil organic carbon and Total nitrogen

Regardless of location and soil type, soil organic carbon values generally decrease with depth in all pedons. At the surface Ap horizons, the organic carbon content is higher, ranging from 0.70 to 1.48 g/kg in most pedons, with a notably higher value in Pedon 8 (6.43 g/kg), and this is typical for surface soils, which receive organic inputs from plant residues and other organic matter. At the subsurface soils with B and C horizon notations, organic carbon content declines with depth across all pedons, with values as low as 0.31 g/kg in the Bw horizons and slightly higher ranging from 0.43 to 0.70 g/kg. This decrease reflects less organic matter content as you move away from the surface down the profile, affecting nutrient availability and microbial activity. Based on the Hazelton and Murphy (2016) rating system for all the soils under study, the soil's organic carbon content ranged from low, which indicates very poor structural condition and very low structural stability, to extremely high (associated with undisturbed deposits). Researchers Dinssa and Elias (2021) and Talha et al. (2022) have demonstrated that decomposable organic material concentrates more on the surface than the subsurface horizons. The reason behind this is the increasing accumulation of litter on the surface.

The nitrogen levels are from extremely low 0.03 to a high 0.32 (g/kg) in the surface horizons (Esu, 1991). In the surface horizons, the total nitrogen levels vary from very low to medium (0.01 to 0.25 g/kg). In Pedon 7 and 8 (0.32 g/kg), higher total nitrogen values were observed on the surface horizons, correlating with organic matter distribution. The subsurface B horizons decline in total nitrogen with values mostly <0.15 g/kg. Improvements in soil organic carbon content can increase total nitrogen, positively impacting plant growth and ecosystem health. The low N contents in the soils resulted from low-activity clays and inadequate organic carbon (Brady and Weil, 2017).

The carbon-nitrogen ratios in the surface Ap horizons (2.2 in Pedon 7 to 30 in Pedon 2) show a significant difference, indicating variations in organic matter decomposition. Lower ratios imply faster decomposition and nutrient cycling, while higher values imply slower breakdown of organic matter. Carbon-nitrogen ratios in the subsurface soil horizons typically decrease with depth due to reduced organic inputs or more stable organic matter.

Available phosphorus

Readily available phosphorus is consistently more abundant on the surface than in deeper horizons. Every value at the investigated soils' subsurface horizons was less than 10 mg/kg, and phosphorus is highest in the Ap surface horizons (Pedon 6 and 8 (10.85 and 11.20 mg/kg), which is beneficial for early root development and plant growth. At the subsurface available phosphorus values drop drastically except for some localized high values in Pedon 1 and 5 in B horizons. The low phosphorus levels in the subsurface soils suggest that phosphorus availability is largely restricted to the surface horizons, which may necessitate surface-applied P fertilizers for deep-rooted crops. The amount of available phosphorus was declining in all the soil pedons with increased depth. In such cases, soil enrichment and quality improvement are essential for optimal plant growth. According to the FAO (2006) standard rating, all soil samples collected at the study site are deficient (< 10 mg/kg), except for pedons 6 and 8 at the surface horizons. The low phosphate potential of the source rock may have contributed to the observed low phosphate levels, similar to the reports of Talha et al. (2022). Dinssa and Elias (2021) affirm that the low intrinsic phosphorus levels resulted from the decline in soil organic matter content and the clay mineralogy of all the studied pedons. Also, this study sheds light on the fact that the deposition sites in the study area harbour abundant levels of other crucial nutrients apart from phosphorus (Table 4).

Exchangeable cations

In Table 4, the calcium concentration varied from 6.60 cmol/kg in Pedon 8 to 11.80 cmol/kg in Pedon 7. Higher calcium levels indicate excellent soil structure and nutrient availability. Metson (1961) and Esu (1991) rated the research site's exchangeable calcium as moderate to high on both the surface and subsurface. Calcium is often the dominant cation (ranging from 6.60 cmol/kg in Pedon 8 to 11.80 cmol/kg in Pedon 7). The calcium values suggest good soil structure and nutrient availability while the magnesium values are moderate, (ranging from 3.60 cmol/kg in Pedon 6 to 22.20 cmol/kg in Pedon 1), contributing to plant metabolic processes. The magnesium levels were ranked next to Ca on the exchange site. On the surface horizons, magnesium values varied from 3.60 cmol/kg in Pedon 6 to 22.20 cmol/kg in Pedon 1 aiding plant metabolic processes. Sodium levels are consistently low, ranging from 0.06 to 0.10 cmol/kg, while potassium levels range from 0.06 to 0.50 cmol/kg, with moderate levels in most surface Ap horizons, presenting no issues. Calcium and magnesium dominate in the B subsurface horizons, with decreasing levels of depth, especially magnesium. The sodium and potassium levels remain low in the subsurface soils, similar to the surface horizon. Research indicates that calcium and magnesium availability are highest at pH values between 5 and 9 (Hazelton and Murphy, 2016).

Cation Exchange Capacity (CEC) and Percent Base Saturation

The CEC in surface Ap horizons ranges from 15.15 cmol/kg in Pedon 5 to 34.22 cmol/kg in Pedon 7, indicating a good ability to hold and exchange nutrients. The CEC had a medium rating at the surface and a medium-to-high rating at the subsurface, with good nutrient retention and buffering capacity (FAO 2006). The soil organic carbon offers sites for cation exchange and hence becomes pivotal in determining levels of CEC. There is often a positive correlation between organic carbon and CEC values. CEC values vary across different soil horizons, with surface Ap horizons generally having higher values than B horizons. The percentage of base saturation values ranges from 93.34 to 99.50, with most values above 97, indicating high base saturation across all soil samples studied (Table 3). All the soil units studied had a high base saturation percentage, with values greater than 80%.

Soil classification based on soil taxonomy and WRB

According to the Keys to Soil Taxonomy (2022), Inceptisols (Pedons 1–8) are a soil order characterised by a young landscape with limited profile development. There were cambic diagnostic horizons with no argillic or nitric horizons forming in a young landscape. In this case, the soils are usually young, unconsolidated parent materials with limited weathering. Based on the morphological, physical, and chemical characteristics following the USDA Soil Taxonomy. The soil order for all the soils was Inceptisol due to a cambic horizon limiting profile development and with limitation in clay illuviation. The suborder is Ustept, based on a ustic moisture regime and a thermic temperature regime. The Haplustept belongs to a great group characterised by the presence of a cambic horizon and limited development of the soil profile. The subgroup is Typic Haplustept based on the absence of additional distinguishing characteristics.

Table 3: Chemical characteristics of soil in University of Maiduguri demonstration farm

Horizon	Depth (cm)	pH (H_2O)	OC (g/kg)	C:N	TN (g/kg)	AP (mg/kg)	Exchangeble Bases (cmol (+)/kg)				CEC	BS
							Ca^{2+}	Mg^{2+}	Na^{+}	k^{+}		
Pedon 1 (TLP 1)												
Ap	0-32	6.77	1.48	14.8	0.10	8.05	11.00	22.20	0.07	0.37	33.64	98.03
AB	32-61	6.80	0.55	7.86	0.07	5.25	8.20	17.80	0.08	0.40	26.48	98.51
Bw1	61-119	6.79	0.49	12.25	0.04	9.45	9.30	13.75	0.07	0.40	23.52	98.25
Bw2	119-200	6.81	0.41	4.10	0.10	4.82	9.20	7.80	0.07	0.41	17.48	98.31
Mean		6.79	0.73	9.75	0.08	6.89	9.43	15.39	0.07	0.40	25.28	
Pedon 2 (TLP 2)												
Ap	0-40	6.80	0.90	30.00	0.03	7.70	10.60	9.60	0.07	0.06	20.63	98.55
AB	40-134	6.71	0.62	10.33	0.06	8.05	10.00	9.80	0.07	0.19	20.16	99.50
Bw1	134-155	6.62	0.62	5.64	0.11	1.05	7.80	6.20	0.06	0.19	14.65	97.27
Bw2	155-200	6.46	0.43	3.07	0.14	2.10	9.00	2.70	0.07	0.23	12.30	97.56
		6.65	0.64	12.26	0.09	4.73						
Pedon 3 (TLP 3)												
Ap	0-50	6.64	0.70	6.36	0.11	3.15	8.00	9.40	0.06	0.32	17.88	99.44
Bw	50-88	6.59	0.41	2.28	0.15	1.75	10.80	11.80	0.07	0.28	23.25	98.71
Bt	88-131	6.55	0.70	7.00	0.10	2.10	10.40	6.80	0.10	0.23	17.83	98.32
C	131-200	6.51	0.60	4.62	0.06	8.40	9.00	1.00	0.08	0.20	10.35	99.04
		6.57	0.60	5.07	0.11	3.85						
Pedon 4 (MPL 1)												
Ap	0-34	6.40	0.78	11.67	0.06	8.40	11.00	14.40	0.07	0.37	25.84	98.82
B	34-111	6.50	0.68	6.8	0.01	0.35	12.00	6.80	0.08	0.29	19.17	98.97
Bw1	111-138	6.40	0.68	9.71	0.07	3.85	12.60	3.80	0.08	0.20	16.68	97.28
Bw2	138-200	6.50	0.70	5.57	0.14	5.60	10.00	0.40	0.07	0.27	10.74	98.48
		6.45	0.71	10.14	0.07	4.55	11.40	6.35	0.08	0.28	18.11	
Pedon 5 (MPL 2)												
Ap	0-34	6.30	0.82	8.2	0.10	4.90	8.80	6.00	0.08	0.27	15.15	99.34
B	34-75	6.50	0.31	5.17	0.06	5.25	7.20	4.80	0.07	0.29	12.36	97.63
Bw	75-123	6.50	0.70	11.67	0.06	9.45	10.20	3.20	0.09	0.28	13.77	97.18
Bw1	123-167	6.50	0.60	0.75	0.08	8.75	8.20	2.20	0.07	0.37	10.84	98.19
Bw2	167-200	6.40	0.74	6.72	0.11	8.05	10.60	0.20	0.07	0.35	11.22	93.34
		6.44	0.63	6.50	0.08	7.28	9.00	3.28	0.08	0.31	12.67	
Pedon 6 (LLP 1)												
Ap	0-30	6.33	0.84	6.31	0.13	10.85	11.20	3.60	0.08	0.50	16.58	97.89
Bw1	30-60	6.40	0.70	3.33	0.21	1.05	11.40	3.80	0.07	0.49	15.76	98.13
Bw2	60-119	6.38	0.70	4.12	0.17	6.30	12.40	4.40	0.09	0.36	15.05	98.81
Bw3	119-200	6.32	0.72	3.50	0.24	3.85	10.20	2.20	0.09	0.41	13.90	98.69
		6.36	0.77	4.32	0.19	5.51	11.30	3.50	0.08	0.44	15.32	
Pedon 7 (LLP 2)												
Ap	0-65	6.31	0.86	2.20	0.32	3.50	11.80	22.00	0.10	0.32	34.22	98.99
B	65-160	6.20	0.55	2.69	0.25	1.75	15.20	4.00	0.08	0.35	19.63	99.13
Bw2	160-200	6.41	0.72	4.80	0.15	1.05	12.20	2.20	0.07	0.31	14.78	94.87
		6.31	0.71	3.23	0.24	2.10	13.07	9.40	0.08	0.33	22.88	
Pedon 8 (LLP 3)												
Ap	0-70	6.43	6.43	3.36	0.32	11.20	6.60	0.08	0.42	19.30	26.40	97.03
Bw	70-110	6.17	6.17	1.47	0.25	0.70	4.20	0.10	0.44	17.94	22.68	98.97
Bw1	110-140	6.39	6.39	2.97	0.31	1.40	2.60	0.08	0.41	16.69	19.78	97.66
Bw2	140-200	6.37	6.37	3.41	0.27	2.10	1.20	0.09	0.38	13.07	14.74	97.29
		6.34	6.34	2.80	0.29	3.85	3.65	0.09	0.41	16.75	20.90	

Their formation may originate from parent materials of alluvial or colluvial deposits. It could also involve loess or residual materials. Moreover, deposits of sand, silt, and clay lithified into sedimentary rocks, such as shale or sandstone, can greatly enhance its formation. According to the World Reference Base (WRB) for Soil Resources, the corresponding classification for Typic Haplustept in USDA Soil Taxonomy is: The correlating WRB (2022) soil resource, the Reference Soil Group is Cambisol (Pedon 1–8). The Cambisol RSG correlating with the Typic Haplustept soils have a cambic horizon, a key diagnostic feature of Cambisols. Further classified as Eutric in the subgroup category due to the typical neutral to slightly alkaline pH and do not exhibit strong acidity or alkalinity.

Conclusion and Recommendations

The results conclude that the characterization and classification of soils in a dry, sub humid area revealed distinct variations in morphological, physical, and chemical characteristics across the farm areas. Higher organic carbon levels in the surface horizons improve soil nutrient retention, as evidenced by increased cation exchange capacity and base saturation. However, there is a need for improvement in organic matter content to enhance soil fertility. The variation in the distribution of essential nutrients also highlights the need for site-specific soil management practices to improve soil productivity and sustainability. The soil classification will support informed decisions on land use planning and management. At the same time, characterisation will also guide experimental research and maximise the yield potential.

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