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Morphological and Physical Characterization of Semi-Arid Soil of Dutse, Jigawa State, North Western Nigeria

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ABSTRACT
Soil characterization is fundamental for understanding soil genesis, classification, agricultural potential, and sustainable land management. This study characterized the morphological and physical properties of selected soils in the semi-arid environment of Dutse, Jigawa State, Nigeria. A semi-detailed soil survey was conducted at a scale of 1:50,000. Three representative pedons (FUD-P1, FUD-P2, and FUD-P3) was described following the USDA Soil Survey Manual. The coordinates of the pedons were recorded using a Global Positioning System (GPS), while Locus Map version 4.29 (Asamm Software) was used to delineate the study area. The soils colour varied from yellowish brown (10YR7/4) to reddish brown (7.5YR5/3) in both topsoil and subsoil of all the pedons. Soil texture varied from loamy sand to sandy loam, with sand content ranging from 70.0 to 82.0%.with highest value in FUD-PI. Bulk density values ranged from 1.19-1.68 Mg m^{-3}. Water-holding capacity ranged from 40 to 60% in both topsoil and subsoil while total porosity varied from 35.20 to 55.26%. Gravimetric moisture content increased with depth, particularly in FUD-P3, indicating its higher clay content and lower bulk density. Significant differences ($p \leq 0.05$) were observed in sand content and bulk density among the pedons, whereas differences in porosity and moisture content were not significant ($p > 0.05$). The silt: clay ratio exceeded 0.15 in all pedons, indicating weak soil profile development and signifying that the soils are at an early stage of Pedogenesis. There is need for appropriate soil management for sustainable use of the land.

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INTRODUCTION

Soil is one of the most valuable natural resources because it supports food production, maintains habitant functions, conserves biodiversity, and sustains human livelihoods (Bamikola et al.,2020). It provides a suitable environment for plant growth, stores and supplies water and nutrients regulates, and supports many biological processes that are essential for healthy habitant (Umeugokwe et al., 2022). However, soil properties differ from one place to another since they are influenced by several interacting soil-forming factors, such as climate, parent material, topography, living organisms, and time (Babalola et al., 2021). Physical characterization of soils is equally important because properties such as texture, bulk density, porosity, and water retention directly affect soil productivity. Soil texture controls nutrient retention, infiltration, and water storage, while bulk density and porosity influence root growth and soil aeration (Babalola et al., 2019; Delgado & Gómez, 2024). Morphological characterization provides valuable information for identifying soil horizons, assessing soil development, and supporting soil classification according to international systems such as USDA Soil Taxonomy and the World Reference Base for Soil Resources (WRB). Soil classification depends largely on diagnostic morphological and physical properties that reflect soil-forming processes and environmental conditions.

Soil characterization involves the systematic description and evaluation of soil, how they function and can be used in determining soil properties (Conklin, 2013). Field observations of soil morphology, such as horizon sequence, soil depth, colour, structure, consistence, and drainage, provide valuable information about soil development and the processes responsible for soil formation (Soil Survey Staff, 2014). Understanding these properties is therefore essential for soil classification, land evaluation, and the development of appropriate soil management practices. Semi-arid regions are usually experienced low and low rainfall, high temperatures, and prolonged dry seasons. These conditions often reduce soil organic matter, increase erosion, and weaken soil structure, leading to lower agricultural productivity (Adegbite et al., 2019). Physical characterization of soils is equally important because properties such as texture, bulk density, porosity, and water retention directly affect soil productivity. Soil texture controls nutrient retention, infiltration, and water storage, while bulk density and porosity influence root growth and soil aeration. The soils of Jigawa State have developed from diverse parent materials including aeolian sand deposits, sedimentary formations, and alluvial materials. Variation in parent material and landscape position has produced differences in soil depth, texture, drainage, and structural development.

Several studies have characterized soils in the semi-arid regions of Africa and reported that parent material, climate and landscape position strongly influence soil morphology and physical properties. Dinssa and Elias (2021) found that soils in western Ethiopia varied in texture, bulk density and profile development according to topographic position, morphological and physical properties while Yeboah et al.

(2022) reported that land use significantly affected soil physical properties in the Guinea Savanna of northern Ghana. Similarly, Patrick et al. (2024) observed considerable variation in soil characteristics along a toposequence in Sokoto State, Nigeria, demonstrating the importance of detailed soil characterization for land evaluation and crop production.

In Jigawa State, Santuraki et al. (2025) showed that the influences of selected soil properties within the Federal University Dutse landscape. Girei et al. (2026) and Gambo et al. (2025) characterized soils along a toposequence around Dutse and reported that the soils were generally weakly developed and dominated by sandy textures. Similarly, Sharu et al. (2025) reported similar characteristics for Zagga soils in north-western Nigeria. Yet, these studies mainly focused on soil characterization and classification, toposequence variability or fertility assessment, while comprehensive evaluation of both morphological and physical properties of semi-arid soils in Dutse remains limited. Soil classification depends largely on diagnostic morphological and physical properties that reflect soil-forming processes and environmental conditions. Although several studies have investigated on soil properties in Dutse, but lack of up to date data is still limited. Such information also provides a reliable information in the study area for soil classification and contributes to sustainable use of land resources. So, this study aimed to characterize the morphological and physical properties of in semi-arid soils in Dutse, Jigawa State, Nigeria to provide new soil data for soil resource assessment and improved land use planning.

MATERIALS AND METHODS

The study was carried out in Dutse local government area of Jigawa state at Federal University Dutse (Figure 1). Dutse lies within latitudes 11°41′48″N- 11043’08’’N and longitudes 9°21′49″E- 9023’’27’’E of the Greenwich Meridian, with an altitude of approximately 440 m above sea level. The area is part of the Sudan Savanna ecological zone and has a tropical semi-arid climate. The research area was delineated into three units namely Zoological Garden (FUD-P1), Soil Science Research Farm (FUD-P2) and Faculty of Agricultural Farm (FUD-P3).

The study area was characterized by prolong dry season from October to May and short raining season from June to September. With the highest peak of raining from August to September with the mean annual rainfall of 650-800 mm. The temperature was hot up to 45 ^{o}C in the month of April and May while drop to 15 ^{o}C in December and January. The average low temperature during these dry months is approximately 25°C. The geology of the study area consists of alternating shale and limestone with sandy mudstones, siltstones and sandstones. The geomorphology of the study area are generally gently undulating to almost flat. The soils except those found along the swampy areas are generally well drained. The vegetation found is drought-resistant grasses, shrubs, and scattered trees like Acacia species, Desert Date (Aduwa), and Baobab tree (Kuka).

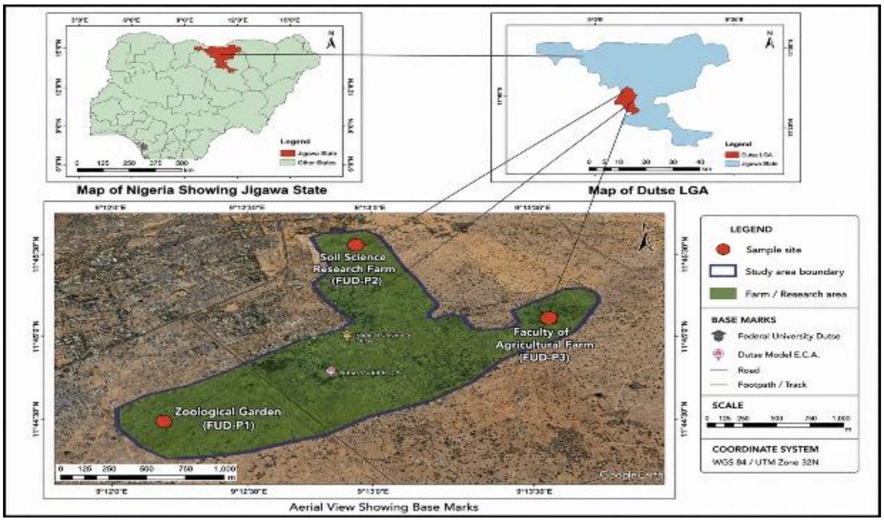

Figure 1: Map of Nigeria Showing the Study Area

Most farmers depend on rain fed during the raining season (May to September), growing crops such as millet (pennisetum glaucum), sorghum (sorghum bicolor), maize (zea mays), cowpea (vigna unguiculata), groundnut (Arachis hypogaea) and rice (oryza sativa). During the dry season irrigation farming is practiced using surface and ground water to produce vegetables such as onion, tomato, pepper and leafy vegetables as well as wheat and rice. Farmers also grow cash crops including sesame (sesamum sabdariffa) which provide an important source of income.

Field Survey

A semi detailed survey was employed at a scale of 1:50 000 which enabled delineation of the boundary and enable to create a map through using locus and global position system to take the coordinates of the location and geographical information system software (GIS 10.8) was used to create a map of the area. Identification of the soil profile location and soil pits digging were done, In each identified unit, three representative soil pedons (1.5m width × 1.5m length × 2m depth) were excavated and described in situ, following the guidelines for field soil description (Soil Survey Staff, 2014). The morphological description was observed using Munsell Colour Chart to compare with the soil in each horizon. Soil structure was described in order of grade, size and type, consistence was described at dry and moist moisture conditions in terms of sticky and plasticity while horizons boundary are described based on thickness and topography. Mottling, roots, activities of microorganism, depth to water table and out rock crop were all determined and recorded in soil profile sheet. However, undisturbed soil samples were taken by core sampler to measure the soil bulk density and soil samples from each horizon identified were taken for laboratory analysis.

Laboratory Analysis

For the determination of physical properties of the soil, the following laboratory standard were followed: The particles size distributed was determined by the Bouyoucos hydrometer method (Gee & Or, 2002). Sand silt and clay were obtained after dispersing the soil with sodium hexametaphosphate (NaPO3) using 5% calgon.The texture of the soil was determined by applying the particles size distribution to the Marshal's textural triangle to determine the textural class of the soils. The soil bulk density was determined from the undisturbed soil samples in the field using core samplers (Blake & Hartge, 1986). 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 (mgm-3). 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_β = Bulk density (Mg m⁻³)

ρ_p = Particle density (Mg m⁻³)

Gravimetric moisture content was obtained using gravimetric method, the soil sample after weight was putting in oven dry at certain temperature of 105ºC around 48 hours. Silt: clay ratio was express as: percentage of silt/ percentage of clay.

Statistical Analysis

Data obtained from field and laboratory was subjected Descriptive statistic; calculate the mean, standard deviation, and coefficient of variation for each horizon across the soil profiles. Analysis of variance (ANOVA) was performed to determine significant difference among each location and means of separation was carried out using appropriate post hoc test at 5% level of probability. All statistical analyses were conducted using statistical software Minitab version 19 Pennsylvania USA.

RESULTS AND DISCUSSION

Soil Depth and Colour

The morphological characteristics of the studied pedons are presented in Table 1. The soils showed well developed horizon sequences consisting predominantly of Ap, Bw, and C horizons, indicating moderate pedogenic development. Pedons FUD-P1 and FUD-P3 contained five genetic horizons (Ap Bw_1 Bw_2 Bw_3 C), whereas FUD-P2 comprised four horizons (Ap Bw_1 Bw_2 C). The occurrence of cambic (Bw) horizons without evidence of argillic or kandic horizon development implied that the soils are weakly developed, a characteristic commonly associated with young soils formed under semi-arid conditions where weathering intensity is relatively low (Knezebik et al., 2025; Badia & moral, 2015).FUD-P3 and P1 are very deep with soil depth (0-185cm) to (0->114cm), FUD-P2 is moderately deep with soil depth (0-85cm), and the lowest value in FUD-P2 was result of water presence below the last horizon. FUD-P1 and P3 are better drained compare to FUD-P2 (Table 1). The availability of water to plant roots and nutrients supply depends on the rooting depths of soil. . The soil colour of FUD-P1 varied from very pale brown (10YR 7/4, dry) to strong brown (7.5YR 5/5, moist) and brownish yellow to (10YR6/6, dry) to reddish yellow (7.5YR6/6, moist) at subsoil. In FUD-P2, the colour ranged from very pale brown (10YR 7/3, dry) at the topsoil to brown (7.5YR 5/4, moist). In the subsoil, it changed to light grey (10YR 7/2–10YR 7/1). The observed light grey colour in the subsoil indicates presence of water below the last horizons (Table 1). In FUD-P3 the colour varied from very pale brown (10YR 7/3, dry) colour, to very pale brown (10YR 7/4, moist). The subsoil colour varied from light brown (7.5YR 6/4, dry) to yellowish brown (10YR 5/4) and light yellowish brown (10YR 6/4) under moist conditions. These yellowish-brown indicate well-drained conditions. The differences in color change between the pedons could be attributed to difference in organic matter content and drainage conditions. Also these colour variations are mostly affected by landscape position, groundwater movement, and the oxidation and reduction of iron during soil formation. This was in agreement with studies on similar soil in different part of Nigeria reported by (Atofarati et al., 2012; Gambo et al., 2025; Sharu et al., 2025).

Soil Structure, Consistency and Boundaries

The structure of all pedons in the surface soil were weak with granular structure and varying to strong, medium sub angular blocky at subsurface (Table 1). Granular structure in the surface is usually linked to cultivation, biological activity, and the incorporation of organic residues, whereas the predominance of sub angular blocky structure in the Bw horizons indicates soil aggregation resulting from pedogenic processes. Such structural development improves root growth, soil porosity, and water movement through the profile (Brady & Weil, 2017).However, structure is generally weak in all pedons, which reflects low clay content and early soil development. The consistency ranged from non-sticky non plasticity at FUD-P1and P3, friable and very friable but slightly sticky at last horizon in FUD-P3 while FUD-P2 are moderately sticky and friable throughout the profiles. Friable soils are easy to cultivate and allow roots to grow easily, but they also tend to have weak stability and low cohesion. No mottles were observed in any of the pedons except FUD-P2 which had few mottles at subsurface where FUD-P2 and P3 indicating that the soils are well drained and have not experienced prolonged periods of seasonal waterlogging. The absence of Redoximorphic features suggests that oxidation processes dominate throughout the profiles, which is consistent with the well-drained landscape positions occupied by the study area. The boundaries between horizons range from clear to diffuse and from smooth to wavy. Soil boundaries show how quickly one layer changes into another and help explain how soil has formed. Such boundary are characteristics of soils that have undergone continuous in situ weathering (Yudina & Kuzyakov, 2023).

Soil Texture and Sand Content

Physical properties of the study area is given in Table 2. The texture of the soil is characterized by sandy loam to loamy sand. The sand content of the soils ranged from 66-82% sand with the mean values of 70.0-77.60% respectively. This is signifying that all the pedons have high sand content but higher in FUD-P1.The nature of parent material played a vital role where mostly the soils developed from sand deposit parent material which is common in Sudan savannah region (Lal. 2020; Yeboah et al., 2022). Sandy soils usually drain quickly, hold fewer nutrients and have weak structural stability (Brandy & Weil, 2017). Statistically, FUD-P3 is significantly difference at ($p \leq 0.05$) compare FU-P1 and P2.These lower sand in FUD-P3 may suggest clay movement into the profile particularly at subsurface through a process of illuviation (Dinssa & Elias, 2021). The CV for sand ranged from 3.36- 5.39% indicating low variability, showing that sand distribution was relatively uniform within each pedon.

Bulk Density, Porosity and Moisture Content

The bulk density values ranged from 1.19-1.68Mgcm^{-3}with mean values of 1.37-1.57 Mgcm^{-3} with coefficient of variability (CV) values ranged from 4.88-9.28% respectively (Table 2). The CV values indicate moderate uniformity within pedons. he bulk density values varied generally between the pedon, in FUD-P1the values increase with the increasing depth, FUD-P2 had irregular patterns with depth. The bulk density values also increased in depth 2 (4-40cm) and decreased with depth 3, 4 and 5 in FUD-P3. These differences is as a result of high clay content and low sand content found in FUD-P3 compare to FUD-P1 and P2. FUD-P3 is significantly lower among the pedons at ($p \leq 0.05$), FUD-P3 is likely associated to higher clay content and improved porosity. Porosity values ranged from 35.20%-55.26% with CV values ranged from 10.97-16.50% indicating moderate to high. Porosity varies slightly among pedons but shows no significant difference. FUD-P3 has the highest porosity, consistent with its lower bulk density and higher clay content. Soil porosity is generally inversely related to bulk density (Plaster, 2014, Harsh and Kumar, 2022). The trend supports better structural condition in FUD-P3. Moisture content ranged from 14.24-40.74% respectively. The slightly higher moisture may be linked to greater clay content and lower bulk density. All data studied revealed that the silt: clay ratio are more than 0.15in all the study sites which indicates that the soils are not developed still at immature stage. The weathering intensity signify less weathering due to Pedogenesis process and aeolian parent material which formed at surface and subsurface soil (Sharu et al., 2022; Ojetade et al., 2022; Ikpe, 2021).

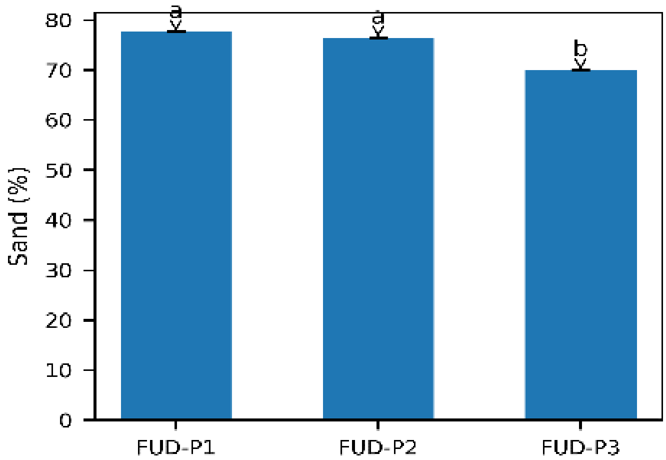

Figure 2: Mean Sand Content of Dutse Soil. Means with the Same Letters are Significantly not Difference at (P< 0.05) by Using Tukey Test

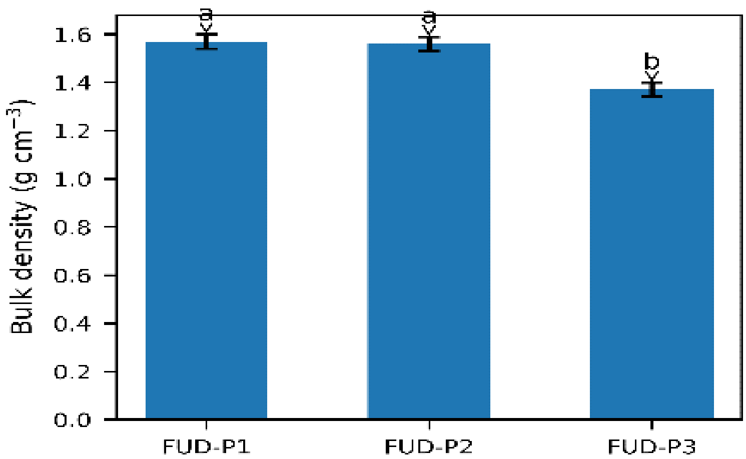

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Figure 3: Mean Bulk Density of Dutse Soil. Means with the Same Letters are Significantly not Difference at (P< 0.05) by Using Tukey Test

Table 1: Morphological Characteristics of the Soil Profile

Pedon	Horizon Depth (cm)	Horizon Designation	Colour Dry	moist	Structure	Textural Class	Consistence	Boundary	Mottles	Inclusions
FUD-P1	0-12	Ap	10YR 7/4	7.5YR 5/5	3wfg	LS	nsnp, 2vfs	cs	n	grm, 2mf
	12-44	Bw^{1}	10YR 6/6	7.5YR5/8	3wfsbk	LS	nsnp, 2fs	ds	n	grm, 2ff
	44-78	Bw^{2}	7.5R 6/6	7.5YR 5/8	3wfsbk	SL	nsnp, 2fs	ds	n	2fm
	78-114	Bw^{3}	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	Bw^{1}	10YR7/2	7.5YR5/3	3wmsbk	LS	Ss,2 fs	gw	n	grm, 2cm
	28-52	Bw^{2}	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	3sfg	SL	nsnp, 2ls	aw	n	grm, 2cf
	5-30	Bw^{1}	7.5YR6/3	10YR5/4	3mmsbk	SL	nnnp, 2vfh	gw	n	grm, 2ff
	30-66	Bw^{2}	7.5yr6/3	10YR5/3	3mmsbk	SL	nsnp, 2fh	gw	n	grm, 2ff
	66-119	Bw^{3}	7.5YR6/3	10YR6/3	3mmsbk	SL	2fs	gw	n	grm, 2ff
	119-185	C	10YR7/3	10YR6/4	3mmsbk	SL	ss, 2fh	gw	n	cc,2mm

Table2: Physical Characteristics of the Soil Profile

Pedon	Horizon Depth (cm)	Horizon Designation	Sand %	Silt %	Clay %	Textual class	Bulk density Mg/cm^{-3}	Particle density Mg/cm^{-}	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

Pedon	Horizon Depth (cm)	Horizon Designation	Sand %	Silt %	Clay %	Textual class	Bulk density Mg/cm^{-3}	Particle density Mg/cm^{-}	WHC %	Porosity %	Moisture content (%)	Silt: Clay Ratio
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
	5-30	Bw1	70	16	14	SL	1.54	2.40	52	35.83	24.95	1.1
	30-66	Bw2	68	14	18	SL	1.35	2.66	56	49.24	30.91	0.7
	66-119	Bw3	66	16	18	SL	1.35	2.50	40	46.0	29.75	0.8
	119-185	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

CONCLUSION

The morphological and physical characterization of the studied soils showed variation among the three pedons. The soils were predominantly deep to very deep, well drained, and characterized by sandy loam to loamy sand textures. Surface horizons displayed weak granular structure, while subsurface horizons showed weak to moderate sub angular blocky structure, signifying limited pedogenic development. FUD-P3 showed better physical conditions, including lower bulk density, higher porosity, and greater moisture retention, high silt: clay ratios observed across all pedons indicate that the soils are young and weakly weathered. Proper soil management practices, including organic matter incorporation, conservation tillage, and balanced fertilizer application, are recommended to improve soil quality, enhance productivity, and promote sustainable agricultural production in the study area.

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