



PEDOLOGICAL CHARACTERIZATION AND CLASSIFICATION OF SOILS ON AN AGRICULTURAL LANDSCAPE FORMED ON BASEMENT COMPLEX TERRAIN IN MINNA, NIGER STATE, NIGERIA

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ABSTRACT

Morphological, physical, chemical, and mineralogical properties of soils of Pkaidina, Legbe, and Pyinko were studied with the view of classifying them taxonomically and providing useful information that could aid in better management. Three profile pits were dug within the study area and described according to the Schoeneberger guideline for soil description. The soils had deep profiles (>100cm) with generally sandy loam texture and imperfect drainage. Physical properties of the soils indicate sand fraction to be dominant, ranging from 620 to 840g kg⁻¹, with a relatively moderate bulk density and high porosity. The soils had a favourable pH (H₂O) ranging from 5.08 to 6.75, high base status ranging from 67.89 to 87.06%, but low to medium fertility status, with mixed mineralogy of Quartz, Orthoclase, Muscovite, Albite, and Anorthite. The soils were classified as Coarse-loamy, Mixed, Semi-active, strongly acid Oxyaquic Haplustalfs (Haplic Luvisols (Loamic)) for pedon PKA; Sandy over Coarse-loamy, Mixed, Active, Slightly acid Arenic Haplustalfs (Haplic Luvisols (Loamic)) for pedon LGB; and Coarse-loamy, Mixed, Active, Moderately acid Typic Epiaquepts (Eutric Gleyic Cambisols (Loamic, Colluvic)) for pedon PYK.

Keywords: Basement, Complex, Characterization, Classification, and Morphological properties

INTRODUCTION

There is an emerging trend of environmental degradation and decline in agricultural productivity, which necessitates an increased demand for information on soils as a means to sustain and improve food production (Sharu *et al.*, 2013). Due to advances in agricultural development in the country and increasing demand for experimental data, several studies have been carried out on soil characterization. Soil information generated by systematic identification, grouping, and delineation of different soils in a locality, coupled with climatic, ecological, and socio-economic factors, is required when sound interpretations for land use potentials are made (Solange *et al.*, 2016). Ogunkunle (2004) reported that pedological characterization provides the information for our understanding of the morphological, physical, chemical, mineralogical, and biological properties of the soils we depend on to grow crops, sustain our ecological vegetation, as well as support homes and society structures. This will provide the building block for understanding soil potentials and limits to certain crop production in a particular area (Onyekanne *et al.*, 2012).

According to Fasina *et al.* (2015), the suitability of soils for the production of specific crops due to climatic and site-specific parameters can be provided via soil characterization. Differences in soil properties along non-uniform agricultural landscapes are the reason for varying land uses and crop outputs across localities and regions. Field investigations through soil survey help to characterize soils in a given area, generate data on soil basic properties, which will facilitate the assessment of the agricultural potentials, limitations, and possible management options for the soils. Soil classification, on the other hand, helps to organize our knowledge, facilitates the transfer of experience and technology from one place to another, and helps to compare soil properties.

Apart from the increasing demand for land due to expansive population growth, another major problem militating agricultural development in the country is limited information on soil and land characteristics by local farmers (Ahukaemere *et al.*, 2016), as soils within a geographical land unit are mostly treated under similar management practices. Minna, a region in the middle belt of Nigeria, has a considerable distribution of temperature and rainfall that favours a significant amount of cereals and tuber production. Minna forms part of the Chanchaga Local Government area in Niger State and is the administrative capital of the state. The soils of Minna and its environs are developed mainly from weathered basement complex rocks of granite, migmatites, gneisses, and schists (Ojanuga, 2006). Like other regions in the country, Minna soils are also characterized by declining productivity caused by intensive farming, incompatible land use, inappropriate fertilizer use, and poor soil conservation practices. Hence, the study aims at characterizing and classifying the soils on an agricultural landscape in Minna by determining their morphological, physical, chemical, and mineralogical attributes, as well as generating soil information required for better management practices.

MATERIALS AND METHODS

The Study Area

The study was carried out in Pkaidina (PKA), Legbe (LGB), and Pyinko (PYK), which are suburbs within Minna. The area is situated 2.9 km Southwest of the Minna Airport runway, Maikunkele, Minna, Niger State. The area, as identified in Fig. 1, lies between latitude 09° 36' 56.66" N and 9° 34' 46.58" N, and longitude 06° 24' 5.19" E and 6° 26' 51.38" E on altitudes ranging from 260 m to 329 m above mean sea level. The area is intensively cultivated with an array of crops such as maize, millet, guinea corn, rice, groundnut, cowpea, yam, and cassava. The length of the growing period is approximately 150 to 180 days. The soils of the area are developed on Basement complex rocks made up of granites, migmatites, gneiss, and schists (Ojanuga, 2006). The present study locations at Pkaidina, Legbe, and Pyinko are underlain by granodiorite, granite, and mica granite respectively. The physiography of the area consists of gently to strongly undulating high plains, with "Inselbergs of weathered granites" and low residual hills rising conspicuously above the plains. The dominant slope is < 5 % on the undulating plains to > 12 % in the hilly areas.

The climate of Minna is characterized by moderate to high rainfall, averaging 1284 mm per annum, and a mean annual temperature of about 28 °C; followed by a distinct dry season of 5 months, usually from November to March (Adeboye *et al.*, 2013). The temperature is constantly high in the months of March to June with a mean maximum of 34 °C (Ojanuga, 2006). Relative humidity varies between 50 % and 70 %. Mean daily maximum and minimum temperatures are 33.6 °C and 22.3 °C respectively (NOAA, 2023). Minna lies within the Southern Guinea savanna vegetation belt of Nigeria.

Field Study

Through reconnaissance field survey, using transect walks, auger observations, and description, the representative study sites were established. Three representative profile pits were dug, one each at Pkaidina (09° 34' 55.81" N, 06° 24' 32.88" E); Legbe (09° 35' 47.47" N, 06° 24' 27.94" E); and Pyinko (09° 36' 41.76" N, 06° 26' 14.07" E) at elevations of 299 m, 297 m, and 251 m respectively above mean sea level. The coordinates of the profile sites were obtained by a Garmin eTrex H GPS meter. The sample pits were characterized according to guidelines outlined in the Field Book for Describing and Sampling Soils (Schoeneberger *et al.*, 2012). Genetic

horizons were identified on the basis of observed differences in some morphological characteristics such as colour, texture, structure, depth of horizon, and inclusions. Bulk soil samples were obtained from each genetic horizon and preserved in labelled polythene bags for onward delivery to the laboratory for analysis.

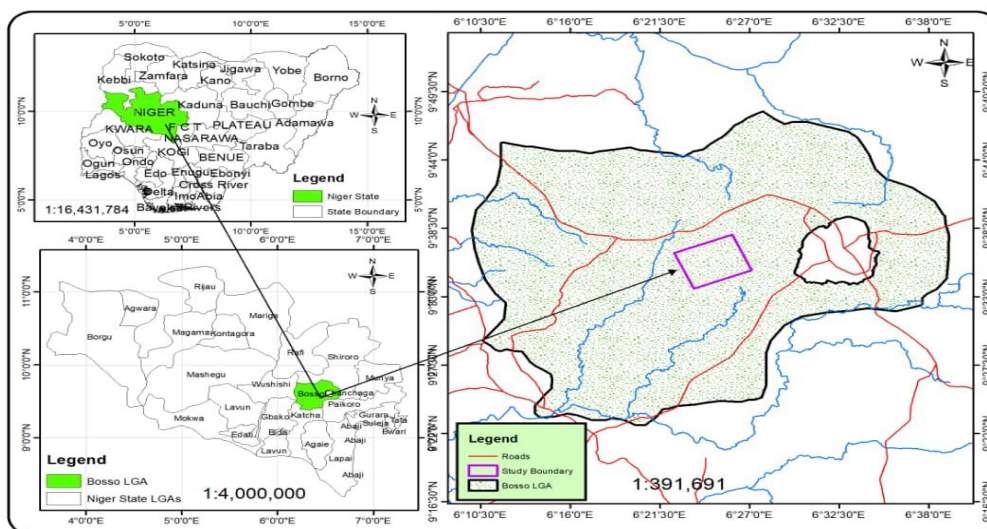


Figure 1: Map of Nigeria showing the location of the Study area

Laboratory Analysis

The samples were air-dried, gently crushed using a wooden mortar and pestle, and then sieved through a 2 mm mesh. Particle size analysis was determined by the Bouyoucous hydrometer method (Gee and Bauder, 1986). Bulk density was determined by the undisturbed soil core method (Blake and Harte, 1986). Total porosity was calculated from particle density and bulk density using the relationship: $P = 100(1 - B_d/P_d)$, where P =porosity, B_d =Bulk density, and P_d = particle density, assuming P_d to be 2.65 Mg m^{-3} for mineral soils (Danielson and Sutherland, 1986). Soil pH in H_2O and CaCl_2 were determined using glass electrode pH meter. Organic carbon content was determined by the wet dichromate method (Nelson and Sommers, 1982). Total N was obtained by the Macro-Kjedahl method (Bremnar and Mulvaney, 1982). Available P was determined by Bray-1 method (Bray and Kurtz, 1945). Exchangeable bases (Ca, Mg, Na, K) were determined using the 1N NH_4OAc (pH 7) extractant method, after which Ca and Mg were determined using an atomic absorption spectrometer, while Na and K were obtained by Flame Photometer. Exchangeable acidity was determined by the 1N KCl method. CEC was determined by the neutral 1N NH_4OAc displacement method, while the percentage base saturation of the soils was calculated using the summation of all exchangeable bases, divided by CEC and multiplied by 100. Cation Exchange Capacity of clay (CEC_{clay}) was calculated using the formula outlined by Landon, 1991: $\text{CEC}_{\text{clay}} = (\text{CEC}_{\text{soil}}/\% \text{Clay}) \times 100$.

The Mineralogical analysis was carried out at the Geological Survey Agency in Kaduna. Three samples from each of the sample profiles were subjected to bulk powder XRD analysis. The samples were subjected to various size-reduction processes in order to meet a 150micron particle size fraction. One to two grams of the powdered sample was compacted using a glass slide to obtain an even surface area. The samples were then placed on the XRD multi-sample holder's chamber for analysis. The samples were scanned with a RIGAKU Miniflex X-ray diffractometer

using Cu anode ($\lambda_{Cu\ K\alpha}$) radiation at 30kv and 15mA. Identification of minerals was based on the location and intensity of peaks on the 2θ scale (2° - 145°) at a measurement speed of 0.01 to $100^\circ/\text{min}$. The results of the analysis were automatically saved using the Studio Smart Lab II software.

Statistical Analysis

Pearson's correlation coefficient analysis was carried out to evaluate the relationship between soil physical and chemical properties by using Microsoft Excel 2016 Analysis ToolPak.

RESULTS AND DISCUSSION

Morphological and Physical Properties of the Soils

The morphological and physical characteristics of the three profiles representing soils of Pkaidina (PKA), Legbe (LGB), and Pyinko (PYK) are presented in Table 1 and Table 2 respectively. The soils were generally deep ($> 100\text{cm}$), imperfectly drained, with colour variation of grayish brown and light grayish yellowish brown on topsoils, overlying pale brown, light grayish brown, brownish yellow, and light yellowish brown at subsoils. Textural class of the soils varies from loamy sand to sandy loam in Pedon LGB; however, sandy loam texture was consistent within horizons of Pedon PKA and Pedon PYK. This suggests minimal vertical translocation of soil materials such as clay and silt across sub-profiles.

The soils had moderate to strong angular blocky structure, with hard and firm consistence generally within sub-horizons. This could limit water movement and root penetration within the sub-horizons of the soils. According to Peverill *et al.* (1999), soil consistency could serve as an index for the measure of soil permeability and root penetration; loose and soft consistence implies easy water movement, while harder and rigid consistence could imply less water movement and poorer root penetration. The presence of Fe-Mn concretions within sub-horizons suggests alternating periods of saturation and aeration may have led to redoximorphic conditions in which Fe and Mn oxides have reduced in conditions of soil saturation, followed by oxidation and precipitation under conditions of soil aeration. Visible presence of ant tunneling activities within the solum of Pedon LGB and Pedon PYK indicates faunal-pedoturbation is also an active process in the soils. The gradual broken boundary featured in sub-horizons of the soils suggests gradual disruption in pedogenic processes from one sub-horizon to the next.

The results of the soil physical properties (Table 2) show that sand particles were the dominant fractions in the soils, generally ranging from 620 to 840g kg^{-1} . The dominance of sand may be attributed to the type of parent materials (granodiorite, granite, and mica granite) from which the soils were developed. Sand fractions are made of quartz minerals, which are dominant components of granite and granodiorites (Lawal *et al.*, 2012; Aki *et al.*, 2016). The sand fractions generally decreased with profile depth, while the clay fractions alternately increased with soil depth. The soils of the three pedons were also observed to contain an appreciable amount of clay content within sub-horizons despite the sandy loam texture that characterized the sub-layers. This indicates the pedogenic process of eluviation-illuviation to be active in the soils, hence the coding of "Bt" in sub-horizons. Clay contents in the soils were, on average 100 and 187g kg^{-1} (PKA), 80 and 160g kg^{-1} (LGB), and 80 and 110g kg^{-1} (PYK) on surface and sub-surface horizons respectively. The silt/clay ratio ranged from 0.60 to 1.40 (for PKA), 1.00 to 1.11 (for LGB), and 1.00 to 2.75 (for PYK), suggesting that the soils are genetically young in terms of weathering and development. According to Said *et al.* (2021), silt to clay ratio above 0.12 indicates soils of less weathered and younger parent materials.



Table 1. Morphological properties of the Soils

Horizon	Depth	Colour	Mottling	Texture	Structure	Consistence	Boundary	Other inclusions
Pedon PKA: Coarse-loamy, Mixed, Semi-active, Strongly acid Oxyaquic Haplustalfs (Haplic Luvisols (Loamic))								
Ap	0-27	10YR5/2 (GB)	-	SL	1fm gr	fi	cw	3f rt, 1f pore distribution, 1fm gravel
Bt1	27-60	10YR6/3 (PB)	10YR6/4 (LYB)	SL	2fmc ab	fi	gb	2fm gravel, pan layer of clay & coarse grains, 1fm Mn nodules
Bt2	60-85	10YR6/2 (LGB)	5YR5/6 (YR)	SL	3fm ab	fi	gb	1fm gravel, pan layer, 1fm Fe concretions, 1m Mn nodules
BC	85-128	7.5YR6/3 (PB)	5YR5/6 (YR)	SL	2fm ab	fi	-	2fm gravel, 1m Fe concretions, 1m Mn nodules
Pedon LGB: Sandy over Coarse-loamy, Mixed, Active, Slightly acid Arenic Haplustalfs (Haplic Luvisols (Loamic))								
Ap	0-26	10YR6/4 (LYB)	-	LS	1fm gr	l	aw	3f rt, 1fm gravels, ant tunneling activities
Bt	26-52	10YR6/6 (BY)	-	SL	2mc ab	fi	gi	1fm rt, 1fm gravels, 1f concretions, 1fm pore distr., ant tunneling
Btc	52-102	10YR7/4 (VPB)	5YR 5/8 (YR)	SL	2mc ab	fi	gb	2mc gravels, gravel line, 3mc Fe concretions
BC	102-174	10YR7/3 (VPB)	5YR 5/8 (YR)	SL	3mc ab	fi	-	1mc gravels
Pedon PYK: Coarse-loamy, Mixed, Active, Moderately acid Typic Epiaquepts (Eutric Gleyic Cambisols (Loamic, Colluvic))								
Ap	0-27	10YR5/2 (GB)	-	SL	1f gr	fr	aw	3f rt
B1	27-68	10YR6/2 (LGB)	5YR5/6 (YR)	SL	2fm ab	fi	cb	2fm rt, 1m gravels
B2	68-99	10YR6/4 (LYB)	5YR5/6 (YR)	SL	2fm ab	fi	gb	1fm rt, 1m Fe-Mn concretions, ant tunneling activities
Btg	99-143	10YR7/2 (LG)	7.5YR 6/6 (YR)	SL	3mc ab	fi	gb	1fm rt, 3mc gravels
BC	143-177	10YR7/3 (VPB)	10YR 5/2 (GB)	SL	2fm ab	fi	-	1mrt

(-) = property not determined

Colour: GB=grayish brown; PB=pale brown; VPB=very pale brown; LYB=light yellowish brown; LGB=light grayish brown; BY=brownish yellow; YR= yellowish red

Texture: SL=sandy loam; LS=loamy sand

Structure: 1=weak; 2=moderate; 3=strong; f=fine; m=medium; c=coarse; gr=granular; ab=angular blocky: Consistency: h=hard; vh= very hard; fi=firm; vfi=very firm; vfr=very friable

Other Features: 1=few; 2=common; 3=many; f=fine; m=medium; c=coarse; rt=roots: Boundary: cw=clear wavy; gb=gradual broken; aw=abrupt wavy; gi=gradual irregular

Table 2. Physical properties of the soils

Horizon	Depth (cm)	Gravel (%)	Sand (g kg ⁻¹)	Silt (g kg ⁻¹)	Clay (g kg ⁻¹)	Textural Class	Silt/Clay ratio	Bulk density (Mg/m ³)	Total Porosity (%)
Pedon PKA: Coarse-loamy, Mixed, Semi-active, Strongly acid Oxyaquic Haplustalfs (Haplic Luvisols (Loamic))									
Ap	0-27	4.08	760	140	100	SL	1.40	1.28	51.70
Bt1	27-60	10.05	720	120	160	SL	0.75	1.43	46.04
Bt2	60-85	6.08	680	120	200	SL	0.60	*	*
BC	85-128	11.05	660	140	200	SL	0.70	*	*
Mean		7.82	705	130	165	-	0.86	1.38	48.87
Pedon LGB: Sandy over Coarse-loamy, Mixed, Active, Slightly acid Arenic Haplustalfs (Haplic Luvisols (Loamic))									
Ap	0-26	2.00	840	80	80	LS	1.00	1.45	45.28
Bt	26-52	4.06	760	120	120	SL	1.00	1.42	46.42
Btc	52-102	10.22	620	200	180	SL	1.11	1.46	44.91
BC	102-174	6.04	620	200	180	SL	1.11	1.64	38.11
Mean		5.58	710	150	140	-	1.06	1.49	43.68
Pedon PYK: Coarse-loamy, Mixed, Active, Moderately acid Typic Epiaquepts (Eutric Gleyic Cambisols (Loamic, Colluvic))									
Ap	0-27	-	700	220	80	SL	2.75	1.57	40.75
B1	27-68	2.01	700	200	100	SL	2.00	1.04	60.75
B2	68-99	-	780	120	100	SL	1.20	1.27	52.08
Btg	99-143	12.77	720	140	140	SL	1.00	1.54	41.89
BC	143-177	-	740	160	100	SL	1.60	*	*
Mean		7.39	728	168	104	-	1.71	1.36	48.87

The silt/clay ratios of Pedon PKA and Pedon LGB were relatively higher in topsoil than in subsoil, indicating that the subsoils are more weathered than the topsoils. Nwaloka *et al.* (2019) reported similar results on the soils of Minna. The bulk density values ranged from 1.28 Mg/m³ to 1.57 Mg/m³ for surface soils, and are considered favourable for plant growth since they fall within the range of 1.00-1.60 Mg/m³ for mineral soils (Akapan-Idiok *et al.*, 2012). The bulk density values of the soils also indicate that soils have fairly adequate pore spaces, as corroborated by moderate to high total porosity, which ranged from 38.11 to 60.75 %.

Chemical and Mineralogical Properties of the Soils

Results of the chemical and mineralogical properties of the soils are presented in Table 3 and 4 respectively. The mean pH (H₂O) values of the soils were 5.26, 6.28, and 5.80 for PKA, LGB, and PYK respectively; and are considered ideal for most crops (Brady and Weil, 2002). Soil pH was observed to be irregular with increasing soil depth in Pedon PKA and Pedon LGB, but increased steadily in PYK. Generally, pH measured in CaCl₂ was lower than the corresponding pH in H₂O by 0.2 to 2.4 units. This indicates that the soils possess net negative charges, enabling them to retain basic cations (Aki *et al.*, 2016). The organic carbon values of the soils were generally low (< 10 g kg⁻¹) as compared with the ratings of Chude *et al.* (2011) and Esu (1991). However, Pedon PKA recorded high carbon value of 13.34 g kg⁻¹ in surface horizon which could be adequate for crop yield. Correspondingly, available P in the soils of PKA were also high with values ranging from 29.67 mg kg⁻¹ to 118.68 mg kg⁻¹ across the horizons. High available P values in the soils may be due to the application of compost manure in the area during seasons of cultivation. Total N values ranged from 0.25 to 0.59 g kg⁻¹ (mean 0.45 g kg⁻¹) in Pedon PKA, 0.20 to 0.28 g kg⁻¹ (mean 0.26 g kg⁻¹) in Pedon LGB, and 0.03 to 0.34 g kg⁻¹ (mean 0.45 g kg⁻¹) in Pedon PYK. These N values are considered high according to Esu's (1991) ratings. Similar results of high N values for soils of Minna were reported by Tsado *et al.* (2014). The total N of the soils of PKA and PYK was observed to increase irregularly with depth, which suggests leaching losses of materials or the influence of continuous cultivation, resulting in massive plant root uptake of N within topsoils.





Table 3. Chemical properties of the soils

Horizon	Depth	pH (H ₂ O)	pH (CaCl ₂)	OC (g kg ⁻¹)	TN	AP (mg kg ⁻¹)	Ca	Mg	K	Na (cmol/kg)	EA	CEC	CEC _{clay}	BS (%)	ESP (%)
Pedon PKA: Coarse-loamy, Mixed, Semi-active, Strongly acid Oxyaquic Haplustalfs (Haplic Luvisols (Loamic))															
Ap	0-27	5.44	5.15	13.34	0.39	29.67	2.80	0.76	0.21	0.10	0.40	5.70	57.00	67.89	1.75
Bt1	27-60	5.08	4.92	1.20	0.25	39.97	3.00	0.81	0.21	0.10	0.40	5.20	32.50	79.23	1.92
Bt2	60-85	5.37	4.82	4.79	0.56	118.68	3.80	1.03	0.25	0.12	0.40	6.80	34.00	76.47	1.76
BC	85-128	5.15	4.83	5.81	0.59	35.50	3.80	1.10	0.23	0.11	0.40	6.50	32.50	80.62	1.69
Mean		5.26	4.93	6.29	0.45	55.94	3.35	0.93	0.23	0.11	0.40	6.05	39.00	76.05	1.78
Pedon LGB: Sandy over Coarse-loamy, Mixed, Active, Slightly acid Arenic Haplustalfs (Haplic Luvisols (Loamic))															
Ap	0-26	6.60	4.31	0.34	0.28	3.77	2.60	0.70	0.17	0.06	0.20	5.00	62.50	70.60	1.20
Bt	26-52	6.75	4.37	0.17	0.28	2.23	3.80	1.14	0.17	0.07	0.20	6.60	55.00	78.48	1.06
Btc	52-102	6.19	4.75	0.34	0.20	1.89	4.44	1.20	0.18	0.10	0.40	6.80	37.78	87.06	1.47
BC	102-174	5.58	4.91	4.62	0.28	2.06	5.20	1.40	0.18	0.16	0.40	8.60	47.78	80.70	1.86
Mean		6.28	4.59	1.37	0.26	2.49	4.01	1.11	0.18	0.10	0.30	6.75	50.77	79.21	1.40
Pedon PYK: Coarse-loamy, Mixed, Active, Moderately acid Typic Epiaquepts (Eutric Gleyic Cambisols (Loamic, Colluvic))															
Ap	0-27	5.10	4.19	2.28	0.03	2.40	3.40	0.90	0.21	0.09	0.40	6.70	83.75	68.66	1.34
B1	27-68	5.64	4.48	3.61	0.34	1.89	3.50	0.95	0.19	0.06	0.60	5.80	58.00	81.03	1.03
B2	68-99	5.95	4.87	0.95	0.20	1.89	3.20	0.96	0.15	0.06	0.40	5.60	56.00	78.04	1.07
Btg	99-143	5.98	4.90	0.38	0.11	1.54	2.40	0.72	0.17	0.09	0.40	4.90	35.00	68.98	1.83
BC	143-177	6.32	4.80	0.19	0.22	2.06	3.00	0.81	0.24	0.18	0.40	5.70	57.00	74.21	3.16
Mean		5.80	4.65	1.48	0.18	1.96	3.10	0.87	0.19	0.20	0.44	5.74	57.95	74.18	1.69

Table 4. Mineralogical properties of the soils

Pedon	Horizon	Depth (cm)	Quartz (%) (SiO ₂)	Orthoclase (%) (Al ₂ O ₃ .K ₂ O.6SiO ₂)	Muscovite (%) (K Al ₂ (Si ₃ Al) O ₁₀ (OH, F) ₂)	Albite (%) (Na Al Si ₃ O ₈)	Anorthite (%) Ca Al ₂ (Si O ₄) ₂	Montmorillonite (%) ((Ca, Na) _{0.3} Al ₂ (Si, Al) ₄)	Illite (%) (2K ₂ O.3MgO. Al ₂ O ₃₋₂₄)
PKA	Ap	0-27	60.0	21.0	14.0	6.0	-	-	-
	Bt1	27-60	63.0	-	17.0	16.0	-	1.6	2.0
	BC	85-128	47.0	20.0	11.0	9.0	13.0	-	-
LGB	Ap	0-26	68.0	21.0	0.6	10.0	-	-	-
	Bt	26-52	55.0	24.0	2.8	18.0	-	-	-
	BC	102-174	54.0	25.0	6.0	15.0	-	-	-
PYK	Ap	0-27	76.0	2.0	3.0	18.7	-	-	-
	Bt	99-143	63.0	20.0	2.8	13.0	1.0	-	-
	BC	143-177	59.0	4.0	27.0	-	10.0	-	-

The concentration of exchangeable bases in the soils were rated low to medium ($2.40 - 5.20 \text{ cmol kg}^{-1}$) for Ca, medium ($0.70 - 1.40 \text{ cmol kg}^{-1}$) for Mg, and medium ($0.15 - 0.25 \text{ cmol kg}^{-1}$) for K. These values represent moderate levels of plant nutrients in the soils. The Na levels in the soils were useful in forecasting soil sodicity, which is a more important parameter than the absolute levels of exchangeable Na for plant nutrition (Said *et al.*, 2021). The exchangeable sodium percentage (ESP) of the soils ranged from 1.03 to 3.16 %, and are below 15 %, which is indicative of a non-sodic soil (Brady and Weil, 2002). According to Said *et al.* (2021), soils with ESP less than 6 % are safe from sodicity, not liable to problems of soil dispersion, and are suitable for crop production.

Cation exchange capacity (CEC) values (4.90 to $8.60 \text{ cmol kg}^{-1}$) were generally low to medium, with mean values of $6.05 \text{ cmol kg}^{-1}$ (Pedon PKA), $6.75 \text{ cmol kg}^{-1}$ (Pedon LGB), and $5.75 \text{ cmol kg}^{-1}$ (Pedon PYK). The CEC values may be attributed to low clay content and low amount of organic matter that was consistent in most horizons. In contrast, the CEC_{clay} ranged from 32.50 to $57.00 \text{ cmol kg}^{-1}$ (Pedon PKA), 37.78 to $62.50 \text{ cmol kg}^{-1}$ (Pedon LGB), and 35.00 to $83.75 \text{ cmol kg}^{-1}$ (Pedon PYK). According to Kebeney *et al.* (2015), CEC_{clay} is an essential indicator of weathering development and the dominant clay mineral type of a soil. CEC_{clay} values observed in the soils reflect a mixed clay mineralogy comprising smectite, illite, chlorite, or hydroxy-interlayered clay minerals (Boul *et al.*, 2011; Soil Survey Staff, 2022). Percentage base saturation (PBS) generally ranged from 67.89 to 87.62 %, reflecting the dominance of basic cations in the exchange complex (Aki *et al.*, 2016). Similar observations have been made in the past for soils of Minna by several authors (Nwaloka *et al.*, 2019). The high base status values (> 50 %) indicate that the soils are generally fertile (FAO, 1999).

X-ray diffraction analysis of the soils reveals quartz, muscovite, orthoclase, albite, and anorthite in that order, are the dominant crystalline minerals present in the soils (Figure 2). Quartz accounted for 76.0 to 47.0 %, muscovite accounted for 27.0 to 0.6 %, orthoclase accounted for 25.0 to 2.0%, Albite accounted for 18.7 to 6.0 % and anorthite accounted for only 13.0 to 1.0 %. Other minerals present in trace amounts are Montmorillonite (1.6 %) and illite (2.0 %). The composition of quartz minerals in the soils confirms that considerable weathering has occurred, but not to an advanced degree due to the presence of significant amounts of weatherable minerals like feldspars such as orthoclase, albite, and anorthite. According to Aki *et al.* (2016), soils with quartz mineral composition greater than 80 % with less percentage of weatherable feldspars (less than 10 %) are at advanced stage of weathering.

Correlation Analysis of Selected Soil Properties

The correlation matrix in Table 5 shows that sand content had high negative correlations with silt, clay, *exch. Mg*, and CEC; and significant negative correlations with *exch. Ca* and PBS. Clay content had significant positive correlations *exch. Ca*, *exch. Mg* and PBS; and positive correlations with Organic C, total N, avail. P, *exch. K*, *exch. Na*, *exch. acidity* and CEC. Organic carbon content also correlated positively with total N, avail P, *exch. Ca*, *exch. Mg*, *exch. K*, *exch. Na*, *exch. acidity* and CEC. Similarly, avail P showed a significant positive relationship with total N, and positive relationships with *exch. Ca* and *exch. Mg*. CEC showed highly positive correlations with *exch. Ca* and *exch. Mg*; and positive relationships with silt, CEC, organic C, total N, avail. P, *exch. K*, *exch. Na* and *exch. acidity*. Also, significant positive relationships existed with PBS, *exch. Ca* and *exch. Mg*. The positive correlations with clay content, CEC, *exch. Ca*,



exch. Mg and PBS may be due to the colloidal nature of clay particles, which have a high surface area that is able to hold and exchange most plant nutrients in the soil.

Soils with higher clay content tend to have higher CEC which enable them to retain exchangeable bases. The results from the study show that an increase in sand content promotes low concentration of exch. bases (especially Ca and Mg), low CEC, and low PBS. Sandy soils have low clay content, hence will have less negative charges, which can hold exch. bases; this makes sandy soils more prone to leaching of basic nutrients (Collin *et al.*, 2018). Also, an increase in organic C, total N, exch. Ca and exch. Mg, increases avail P. This indicates that avail P is dependent on organic C and total N contents of the soil. Further increase in exch. Ca and Mg will not promote phosphorus fixation in the soils.

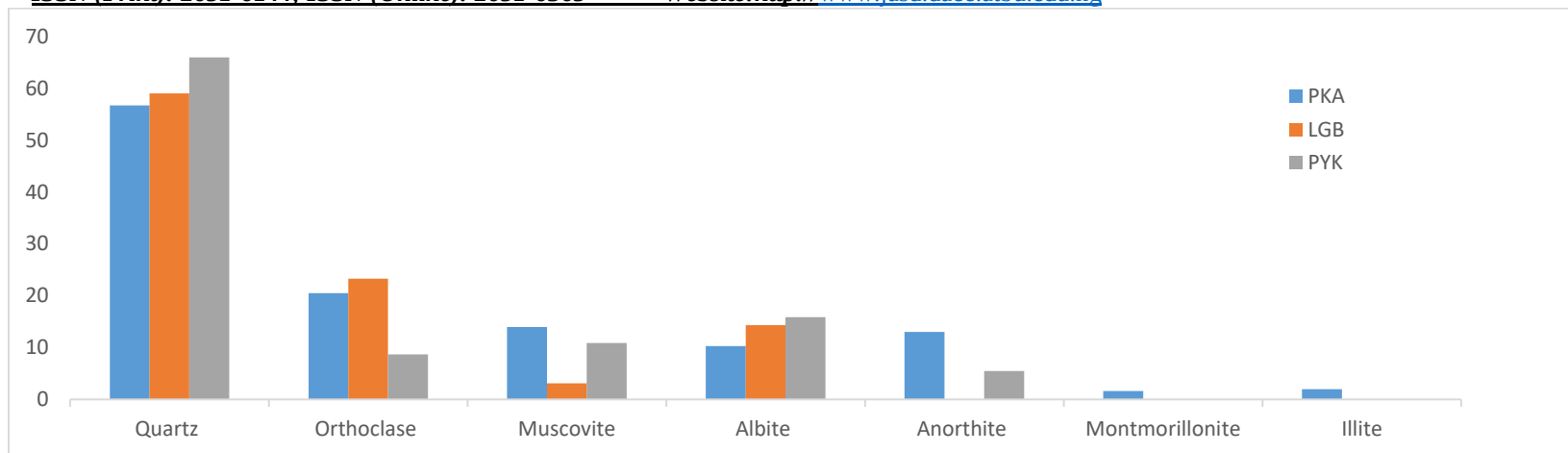


Figure 2: Percentage abundance of minerals in each Pedon

Table 5. Correlation matrix of the studied soils

	Sand	Silt (g kg ⁻¹)	Clay	pH(H ₂ O)	OC (g kg ⁻¹)	TN (g kg ⁻¹)	Ap (mg/kg)	Ca	Mg	K (cmol/kg)	Na	EA	CEC	BS (%)
Sand	1													
Silt	-0.698**	1												
Clay	-0.742**	0.038	1											
pH (H ₂ O)	0.456	-0.313	-0.344	1										
OC	-0.120	0.068	0.104	-0.519	1									
TN	-0.161	-0.336	0.540	-0.260	0.537	1								
Ap	-0.175	-0.326	0.550	-0.459	0.359	0.690*	1							
Ca	-0.602*	0.525	0.582*	-0.144	0.052	0.212	0.052	1						
Mg	-0.718**	0.436	0.593*	-0.042	0.007	0.229	0.019	0.977**	1					
K	-0.285	0.079	0.323	-0.510	0.364	0.510	0.667*	0.009	-0.082	1				
Na	-0.474	0.289	0.391	-0.166	0.133	0.127	0.183	0.357	0.277	0.588*	1			
EA	-0.496	0.604*	0.127	-0.576	0.274	0.072	0.072	0.122	0.057	0.258	0.137	1		
CEC	-0.715**	0.547	0.486	-0.192	0.185	0.181	0.102	0.942**	0.907**	0.119	0.456	0.058	1	
BS	-0.587*	0.250	0.585*	0.031	-0.239	0.265	0.012	0.710**	0.732**	-0.088	0.076	0.238	0.442	1

**correlation is significant at 0.01 level, *correlation is significant at 0.05 level

OC=organic carbon, TN=total nitrogen, Ap=available P, EA=exchangeable acidity, CEC=cation exchange capacity, BS=base saturation



Taxonomic Classification of the Soils

On the basis of morphological, physico-chemical, and mineralogical properties, the soils were classified up to family level under the USDA soil taxonomy (Soil Survey Staff, 2022), and to the second level of World Reference Base for soil resources (IUSS Working Group WRB, 2022). The soils of PKA and LGB meet the requirement for placement in the soil order – Alfisols, since they have argillic horizons with high base saturations (>50% by 1N NH₄OAc); formed in an ustic moisture regime, with no further associable feature, they fit into Haplustalfs at the Greatgroup level. Saturation in layers within 100 cm depth for 30 or more days, qualify Pedon PKA as Arenic Haplustalfs at the Sub-group level; while Pedon LGB qualifies as Arenic Haplustalfs due to the presence of loamy sand within 50 cm soil depth. Soils of PYK exhibit minimal profile development, occasioned by little accumulation of illuvial clay within its B1 and B2 layers, with experience of aquic conditions and intermittent saturation at some periods in the year; thus, it qualifies as Typic Epiaquepts at the Subgroup level.

At the family level, Pedon PKD exhibited a mixed mineralogy, with a semi-active cation-exchange class and a strongly acid reaction; the soils qualify as Coarse-loamy, Mixed, Semi-active, strongly acid Oxyaquic Haplustalfs. While Pedon LGB are classified as Sandy over Coarse-loamy, Mixed, Active, Slightly acid Arenic Haplustalfs. Soils of PYK exhibited mixed mineralogy, with an active cation-exchange activity class and a moderately acid reaction, qualifying as Coarse-loamy, Mixed, Active, Moderately acid Typic Epiaquepts. Under the WRB classification, Pedon PKA and Pedon LGB are classified as Haplic Luvisols (Loamic), while Pedon PYK are Eutric Gleyic Cambisols (Loamic, Colluvic).

CONCLUSION AND RECOMMENDATIONS

Characterization of the soils Pkaidina, Legbe, and Pyinko reveals that the soils have favourable pH, high base status, but low to medium fertility status. However, from the correlation analysis results, farm management practices that could improve the concentration of organic carbon in the soils may also improve the concentrations of total N, available P, Ca, Mg, and CEC status in the soils, especially in soils of LGB and PYK. Therefore, adequate applications of non-acid mineral fertilizers, incorporation of organic materials into the soil during tillage, and conservation tillage could generally improve the quality and productive potential of the soils. Also, the silt/clay ratio and CEC_{clay} reveal that the soils still possess a relatively high to moderate weathering potential. The soils have mixed mineralogy of Quartz, Orthoclase, Muscovite, Albite, and Anorthite under the same geologic and climatic conditions, and are therefore, undergoing almost similar rate of weathering.

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