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CHARACTERIZATION OF SANDSTONE SOIL: A CASE STUDY OF SANDSTONE DERIVEDSOILS IN MISAU BAUCHI STATE, NIGERIA

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ABSTRACT

The interaction of parent material, climate, topography, biological activity, and time controls soil development on sandstone. This study was embarked upon to evaluate the characteristics of soils derived from sandstone with respect to agricultural production in Misau, Bauchi State, Nigeria. Field work was accomplished by auger drillings and soil profile examination. Standard laboratory methods were used to analyze physico-chemical properties of the soil. Soils of the study area are generally deep and have predominantly sandy loam textures. Mean particle size distribution for soils of this area is 78, 12,and 10% for sand, silt and clay fractions respectively. Soil dispersion ratios are high (> 0.80) and reflect the susceptibility of these soils to erosion.The pH range of soils is moderate to strongly acidic.Soil pH buffer capacity in soils of the study area was also very low (< 350 mg $CaCO_3$ (kg soil)$^{-1}$pH^{-1}).Soil organic matter and nitrogen are very low, being less than 2 and 0.05% respectively. Also available phosphorus content was low, with values measuring below 7 mg/kg. Cation soil content occurs in the order of magnitude: Ca > Mg> K > Na. Mean base saturation was 53% whereas exchangeable acidity constituted 47% of the effective cation exchange capacity. Low values of exchangeable cations were also observed and this further underscore the low fertility of these soils.

Keywords: Organic matter, nitrogen, available phosphorus, CEC

Introduction

Sandstone-derived soils, covering approximately 18% of Nigeria's land surface, are prevalent across various ecological zones, forming sandy to sandy loam soils often classified as acid sands (Ogunwale *et al.*, 1975). The unique characteristics of these soils stem from the mineralogy and structure of their parent sandstone material, the prevailing climate, topography, and the influence of biological and anthropogenic processes (Lawley, 2009). Sandstone is a clastic sedimentary rock composed predominantly of sand-sized mineral grains, primarily quartz and feldspar, cemented by secondary minerals such as silica, calcite, or iron oxides (Bonewitz, 2012). The depositional environments of sandstone are diverse, including fluvial, deltaic, aeolian, shoreline, and deep marine settings, each imparting distinct textural and mineralogical signatures to the resulting rock (Hartel *et al.*, 2007). The color of sandstone varies widely (tan, brown, yellow, red, grey, pink, white, or black)depending on the cementing agents and mineral impurities present (Bonewitz, 2012).

The development of soils on sandstone is governed by the interplay of parent material, climate, topography, biological activity, and time (Lawley, 2009)). Key pedogenic processes in these soils include downward movement of clay particles, often resulting in the formation of argillic (clay-enriched) horizons in subsoils, leaching, formation of secondary clay minerals, redistribution of soil

material along slopes and in valley bottoms, contributing to soil profile variability.

The land use of Misau area of Bauchi state is primarily agrarian although not much has been done to study the soils of the area. Although similar studies had been carried out by Ogunwale *et al.* (1975) in selected ecological zones of Nigeria. Consequently, this study was embarked upon to examine characteristics of soils derived from sandstone in an agrarian area of Misau, Bauchi state, Nigeria.

Materials and Methods

Field Studies and Laboratory Analysis

A random sampling approach was employed for the study. Soil observation was made by auger drilling to a depth of 90cm and examining soil profiles. Four soil profiles were described, and soil samples collected from genetic horizons using the soil survey manual. Soil samples were air-dried in the laboratory, crushed with porcelain pestle and mortar and sieved to remove material greater than 2mm (gravel and other coarse fragments).

The particle size distribution was determined by the hydrometer method as described by Hossain *et al.* (2021). Soil pH was determined in 0.01M $CaCl_2$ solution at a 1:2.5 soil/solution ratio as described by Kissel and Sonon (2014). Exchangeable bases (Ca, Mg, K and Na) were determined using NH_4OAc saturation method as described by Hendershot *et al.*, (2008). Organic matter was determined by the Walkley-Black dichromate wet oxidation method as described by FAO (2021a) whereas nitrogen was determined by the Kjeldahl method. (FAO, 2021b). The Bray-1 extraction procedure was used to determine available phosphorus(FAO, 2021c).

Results and Discussion

The Environment of the Study Area

Misau is in the northern guinea savanna vegetation zone of Nigeria, although a significant fraction of the original vegetation has been destroyed for farming purposes (Saleh, 2000). Soil of the study area is derived from sandstone parent materials (Federal Department of Agricultural Land Resources. 1990). Elevation data at 30-meter resolution obtained from the Shuttle Radar Topography Mission (SRTM) was used to produce an elevation model of the study area with the aid of the System for Automated Geo-scientific Analysis (SAGA) software.

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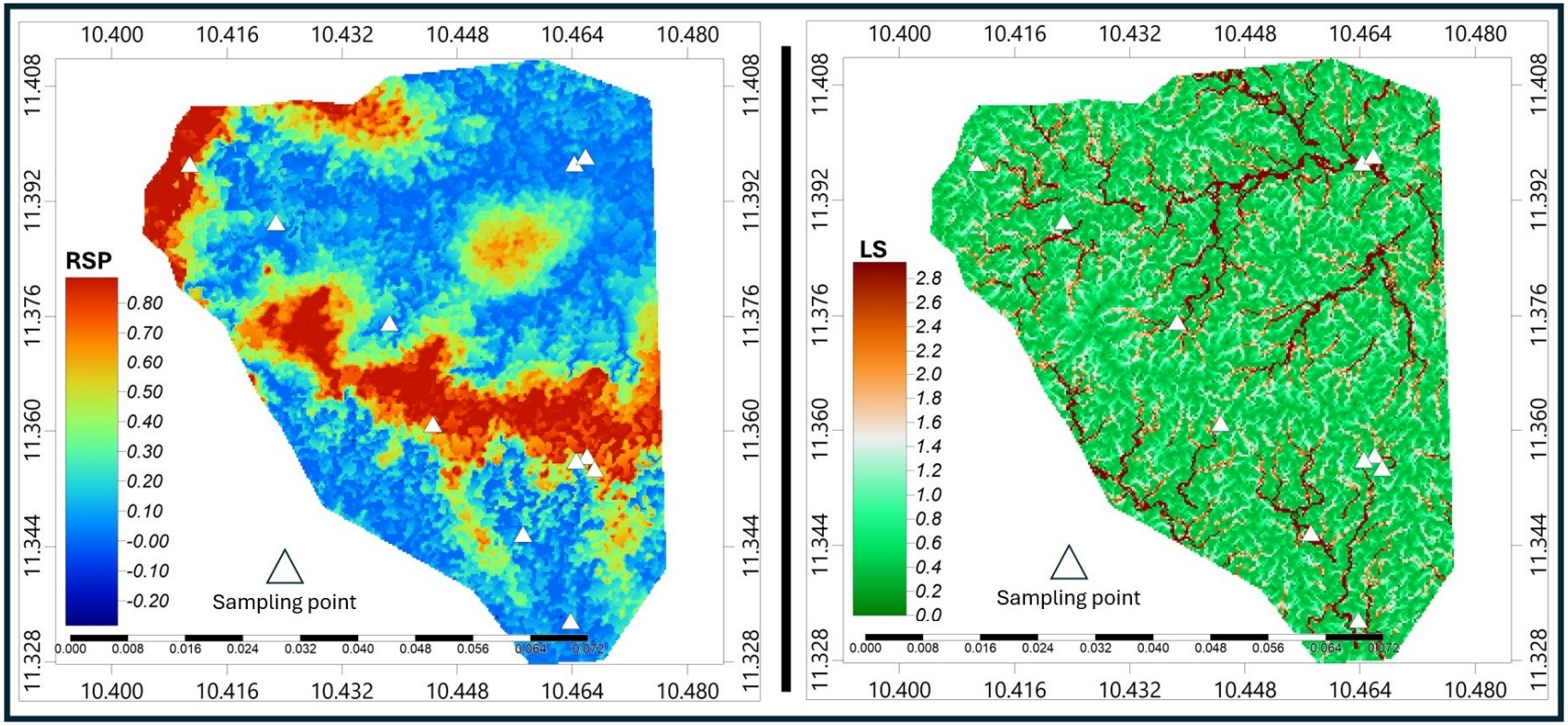


Figure 1: Relative slope position and topographic factor (LS) of the Misau area

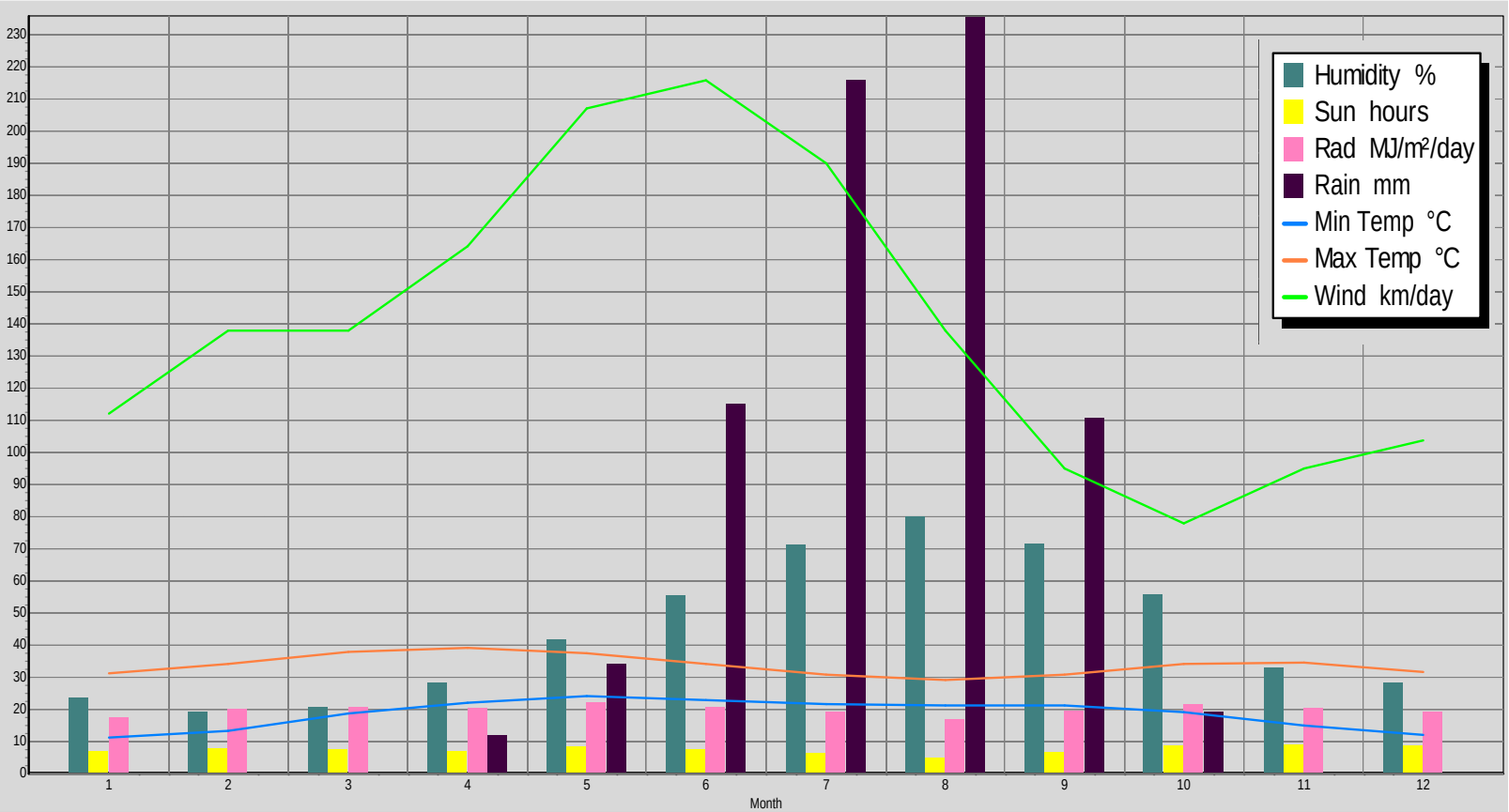


Figure 2: Climatic characteristics of Misau area (Grieser, J. 2006)

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(1) (2) (3) (4)

Figure 3: Soil profiles (1 to 4) examined in the study area

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The topographic features of the research area are shown in Figure 1. The terrain is gently undulating to undulating plains with some lateritic/iron pan exposures (Figure 1). The influence of topography on soil erosion in the study area is low as indicated by the low topographic factors (LS <3.0). However, sheet and rill erosion dominates the entire terrain with some gullies cutting through the landscape. Total annual rainfall over the area is 743 mm. Rainfall begins in the month of April, peaks in August and terminates in October (Grieser, 2006). Detail climatic description of the study area is presented in Figure 2.

Physical Characteristics

Physical characteristics of soils of the Misau area presented in Tables 1 to 2. Soils are deep to very deep and are well drained (Figure 3). The occurrence of deep soils could be related to the relatively gentle to flat terrain. For instance, Owonubi and Mustapha (2024) reported shallow soils on summit to back slope and deep soils on foot slope positions on a sandstone landscape.

Soils of this unit are dominated by sandy loam textures in both surface and subsurface soils. These result from the soils' high sand and low clay levels (Figure 4). These findings are consistent with those of Nkwopara (2018), Ahukaemere *et al.* (2021) and Owonubi and Mustapha (2024). The coarse textures of theses soils are most likely influenced by thepredominantly sand-sized mineral grains composition of the parent material (Bonewitz, 2012).

The dispersion ratios of these soils are greater than 0.8. Consequently, these soils aggregate poorly due to their high dispersion ratios (DR). The very low amounts of clay present in the soils mean that micro aggregate indices (CDR), albeit low, do not have influence of aggregate stability. Antisari *et al.* (2023) noted that sandstone parent materials result in the formation of soils with weak soil structure. The coarse texture, weak structure, and low organic matter of sandstone-derived soils have been noted to make them highly susceptible to both water and wind erosion, particularly on sloping terrain or where vegetation cover is sparse (Ahukaemere *et al.*, 2021). Soil consistencies in the study area range from soft to hard and from loose to friable, with non-sticky and non-plastic surface soils, and non-sticky to slightly sticky and non-plastic to slightly plastic subsurface soils. These consistencies would be suitable for zero and minimum tillage practices to aid in conservation of these soils (Bezboruah *et al.*, 2024).

Table 1: Soil physical characteristics in selected soil profiles

	Location			Depth	Clay	Silt	Sand	Textural class	DR	CDR
P	N	E	Horizon	(cm)	(%)					
1	11.3751	10.4382	A	0-30	12	18	70	sandy loam	0.84	0.20
			B	30-130	10	12	78	sandy loam	0.82	0.23
			C	130-230	3	18	69	sandy loam	1.14	0.71
2	11.3451	10.4568	A	0-35	12	18	70	sandy loam	0.84	0.20
			B	35-175	10	18	72	sandy loam	0.86	0.23
			C	175-300	12	18	70	sandy loam	0.84	0.20

3	11.3329	10.4632	A	0-50	12	18	70	sandy loam	0.84	0.20
			B	50-150	10	12	78	sandy loam	0.82	0.23
			C	150-300	12	18	70	sandy loam	0.84	0.20
4	11.3974	10.4646	A	0-100	10	18	72	sandy loam	0.86	0.23
			B	100-160	12	18	70	sandy loam	0.80	0.20
			C	160-250	20	18	62	sandy clay loam	0.74	0.12

DR = Dispersion ratio, CDR = Clay dispersion ratio, P = profile, N = latitude, E = longitude

Table 2: Soil physical characteristics at auger sampling points

Location		Depth	Clay	Silt	Sand	Textural class	DR	CDR
N	E	(cm)	(%)					
11.3974	10.4646	0-30	10	12	78	sandy loam	0.82	0.23
		30-60	12	16	72	sandy loam	0.82	0.20
		60-90	10	18	72	sandy loam	0.86	0.23
11.3748	10.4386	0-30	10	12	78	sandy loam	0.82	0.23
		30-60	10	18	72	sandy loam	0.86	0.23
		60-90	10	12	78	sandy loam	0.82	0.23
11.3751	10.4382	0-15	10	12	78	sandy loam	0.82	0.23
		30-60	10	12	78	sandy loam	0.82	0.23
		60-90	10	14	76	sandy loam	0.84	0.23
11.3451	10.4568	0-15	10	14	76	sandy loam	0.84	0.23
		30-60	10	12	78	sandy loam	0.82	0.23
		60-90	10	12	78	sandy loam	0.82	0.23
11.3329	10.4632	0-20	10	14	76	sandy loam	0.84	0.23
		20-60	12	18	70	sandy loam	0.84	0.20
		60-100	10	18	72	sandy loam	0.86	0.23
11.3974	10.4646	0-30	12	18	70	sandy loam	0.84	0.20
		60-90	10	18	72	sandy loam	0.86	0.23
11.3751	10.4382	0-30	10	12	78	sandy loam	0.82	0.23
		30-50	10	12	78	sandy loam	0.82	0.23

DR = Dispersion ratio, CDR = Clay dispersion ratio, N = latitude, E = longitude

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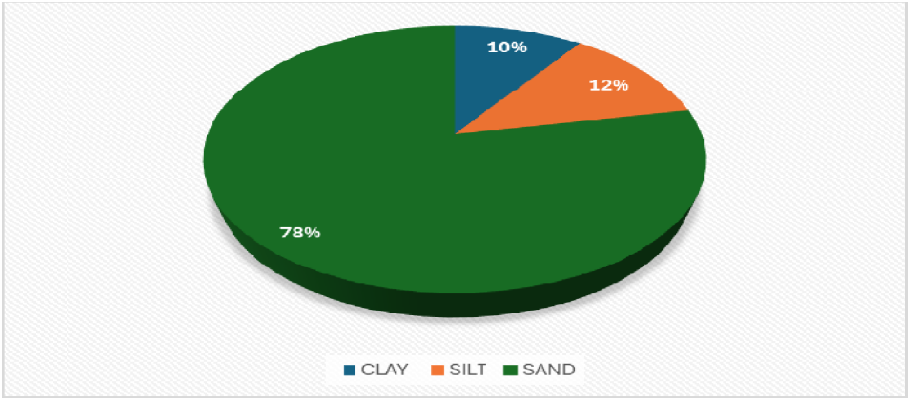


Figure 4: Mean particle size distribution over the study area

Chemical Characteristics

Organic matter

Soil chemical data are presented in Table 3 and 4. Organic matter content in soils of the study area is low being less than two percent. Low organic matter content was also observed by Nkwopara (2018) under humid tropical conditions. Medium to low organic matter contents were observed by Owonubi and Mustapha (2024) on a sandstone landscape in the southern guinea savanna of Nigeria. These levels in organic matter content were attributed to the prevailing warm climatic conditions and the coarse texture of the soils. Also, Antisari *et al.* (2023) reported for a temperate climate that soil organic matter stocks were higher at elevations above 1000 m than at or below 1000 m, and vegetation did not appear to impact soil organic matter levels. This was noted to indicate that climate likely has a stronger effect on soil organic matter content than vegetation does. Furthermore, Nkwopara (2018) reported that organic matter had positive significant relationship with clay content under humid topical climate.

Nitrogen

Very low nitrogen contents were observed in the soils of the study area. Similar observations were made by Owonubi and Mustapha (2024), Edet and Aki (2024) and Eyong and Akpa (2019) for sandstone derived soils and for various land use types and hill slope terrain conditions. Low nitrogen contents observed in the study area may not be unrelated to its inherently low soil organic matter content. Owonubi (2024) reported that organic matter distribution is likely to influence soil nitrogen content under tropical Nigerian conditions.

Table 3: Soil chemical characteristics at auger sampling points

Location		Depth	pH	pHBC	Soil reaction	OM	N	P
N	E	(cm)				(%)		(mg/kg)
11.3974	10.4646	0-30	5.8	293	Moderately acid	0.82	0.03	4
		30-60	5.4	323	strongly acid	0.54	0.02	2

		60-90	5.2	245	strongly acid	0.69	0.02	3
11.3748	10.4386	0-30	5.1	245	strongly acid	0.82	0.03	5
		30-60	4.9	261	Very strongly acid	0.80	0.03	5
		60-90	5.2	274	strongly acid	0.62	0.02	3
11.3751	10.4382	0-15	5.2	279	strongly acid	0.65	0.02	3
		30-60	5.8	291	Moderately acid	0.59	0.02	3
		60-90	5.7	335	Moderately acid	0.53	0.02	3
11.3451	10.4568	0-15	6.0	268	Moderately acid	0.83	0.03	4
		30-60	5.6	228	Moderately acid	0.76	0.03	3
		60-90	5.7	201	Moderately acid	0.62	0.02	3
11.3329	10.4632	0-20	5.4	250	strongly acid	0.86	0.03	5
		20-60	5.0	253	Very strongly acid	0.90	0.03	6
		60-100	5.3	299	strongly acid	0.85	0.03	5
11.3974	10.4646	0-30	4.5	203	Very strongly acid	0.60	0.02	3
		30-60	4.2	202	Extremely acid	0.61	0.02	3
		60-90	4.4	205	Extremely acid	0.76	0.02	4
11.3751	10.4382	0-30	4.2	201	Extremely acid	0.62	0.02	3
		30-50	5.2	264	strongly acid	0.79	0.03	4

pHBC: pH Buffer Capacity (mg CaCO3 (kg soil)$^{-1}$pH^{-1}), N = latitude, E = longitude

Table 4: Soil chemical characteristics in selected soil profiles

P	N	E	Depth (cm)	pH	pHBC	Soil reaction	OM (%)	N	P (mg/kg)
1	11.3751	10.4382	0-30	5.0	218	Very strongly acid	0.83	0.03	5
			30-130	5.4	311	strongly acid	0.84	0.03	5
			130-230	5.8	300	Moderately acid	0.60	0.02	3
2	11.3451	10.4568	0-35	4.2	152	Extremely acid	0.66	0.02	3
			35-175	5.7	271	Moderately acid	0.48	0.02	2
			175-300	6.0	347	Moderately acid	0.76	0.02	4
3	11.3329	10.4632	0-50	5.7	203	Moderately acid	0.62	0.02	3
			50-150	5.0	230	Very strongly acid	0.52	0.02	2
			150-300	5.7	351	Moderately acid	0.78	0.03	4
4	11.3974	10.4646	0-100	4.5	201	Very strongly acid	0.61	0.02	3
			100-160	5.5	353	strongly acid	0.65	0.02	3
			160-250	5.2	290	strongly acid	1.48	0.05	7

pHBC: pH Buffer Capacity (mg CaCO3 (kg soil)$^{-1}$pH^{-1}), N = latitude, E = longitude

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Phosphorus

The available phosphorus content of the study area was low, with values measuring below 7 mg/kg. Similarly, Eyong and Akpa (2019) observed low values of available phosphorus for forest and rubber plantation land use types and attributed the low values to fixation phosphorus under acidic soil conditions. Low available phosphorus contents were also reported by Owonubi (2024) and Edet and Aki (2024) for sandstone derived soils in humid tropical conditions. Edet and Aki (2024) attributed these low values of available phosphorus to continuous cultivation, bush burning, high rate of mineralization and crop residue removal without incorporating back to soils. In contrast, Eyong and Akpa (2019) observed high levels of available phosphorus contents in sandstone derived soils under arable cropping conditions. These high levels were attributed to anthropogenic influences involving fertilizer applications.

Cation Exchange Processes

Cation exchange characteristics are presented in Table 5 and 6.Cation distribution in these soils occur in the order Ca>Mg>K>Na (Figure 5). Soils contents of these cations were low. Cation exchange processes in these soils were also very low with cation exchange capacity falling below 5 cmol/kg. Similar trends for sandstone derived soils have been observed by Owonubi and Mustapha (2024), Nkwopara (2018), and Eyong and Akpa (2019).

The low cation exchange capacities observed in these soils may not be unrelated to the predominance of low activity sand-sized mineral grains. Sandstone has been noted to be composed predominantly of sand-sized mineral grains, primarily quartz and feldspar, cemented by secondary minerals such as silica, calcite, or iron oxides (Bonewitz, 2012). Medium base saturation (45–50%) were observed in these soils although higher base saturation was reported by Eyong and Akpa (2019) for sandstone derived soil under arable cropping conditions.

Table 5: Soil cation exchange characteristics at auger sampling points

Location		Depth	Ca	Mg	K	Na	EA	ECEC	CEC	BS
N	E	(cm)	(cmol/kg)							(%)
11.3974	10.4646	0-30	1.24	0.40	0.13	0.01	1.55	3.33	3.82	47
		30-60	1.25	0.41	0.13	0.01	1.56	3.36	3.86	47
		60-90	1.24	0.41	0.13	0.01	1.55	3.34	3.80	47
		0-30	1.24	0.40	0.13	0.01	1.55	3.33	3.84	46
		30-60	1.24	0.40	0.13	0.01	1.55	3.33	3.78	47
		60-90	1.24	0.40	0.13	0.01	1.55	3.33	3.81	47
11.3751	10.4382	0-15	1.24	0.40	0.12	0.01	1.55	3.32	3.83	46
		30-60	1.24	0.40	0.13	0.01	1.55	3.33	3.84	46
		60-90	1.25	0.41	0.13	0.01	1.55	3.35	3.85	47
11.3451	10.4568	0-15	1.25	0.40	0.13	0.01	1.55	3.34	3.84	47
		30-60	1.24	0.39	0.13	0.01	1.55	3.32	3.81	46
		60-90	1.24	0.40	0.13	0.01	1.55	3.33	3.83	46
11.3329	10.4632	0-20	1.25	0.41	0.13	0.01	1.55	3.35	3.85	47

		20-60	1.28	0.49	0.14	0.01	1.56	3.48	3.97	48
		60-100	1.24	0.40	0.13	0.01	1.55	3.33	3.83	46
11.3974	10.4646	0-30	1.23	0.39	0.13	0.01	1.55	3.31	3.80	46
		30-60	1.33	0.49	0.14	0.01	1.56	3.53	3.93	50
		60-90	1.32	0.48	0.14	0.01	1.56	3.51	3.92	50
11.3751	10.4382	0-30	1.24	0.47	0.13	0.01	1.55	3.40	3.90	47
		30-50	1.24	0.40	0.13	0.01	1.55	3.33	3.89	46

N = latitude, E = longitude

Table 6: Soil exchange characteristics in selected soil profiles

P	N	E	Depth (cm)	Ca	Mg	K	Na	EA	ECEC	CEC	BS (%)
				(cmol/kg)							
1	11.3751	10.4382	0-30	1.3	0.48	0.13	0.01	1.56	3.48	3.97	48
			30-130	1.25	0.40	0.13	0.01	1.55	3.34	3.83	47
			130-230	1.28	0.47	0.13	0.01	1.57	3.46	3.96	48
2	11.3451	10.4568	0-35	1.32	0.48	0.14	0.01	1.56	3.51	3.91	50
			35-175	1.25	0.41	0.13	0.08	1.55	3.42	3.85	49
			175-300	1.33	0.48	0.14	0.01	1.56	3.52	3.92	50
3	11.3329	10.4632	0-50	1.34	0.49	0.14	0.01	1.56	3.54	3.90	51
			50-150	1.24	0.43	0.13	0.01	1.55	3.36	3.85	47
			150-300	1.34	0.48	0.14	0.01	1.56	3.53	3.93	50
4	11.3974	10.4646	0-100	1.24	0.40	0.13	0.01	1.55	3.33	3.82	47
			100-160	1.31	0.45	0.13	0.01	1.56	3.46	3.95	48
			160-250	2.03	0.55	0.23	0.01	1.60	4.42	4.92	57

N = latitude, E = longitude

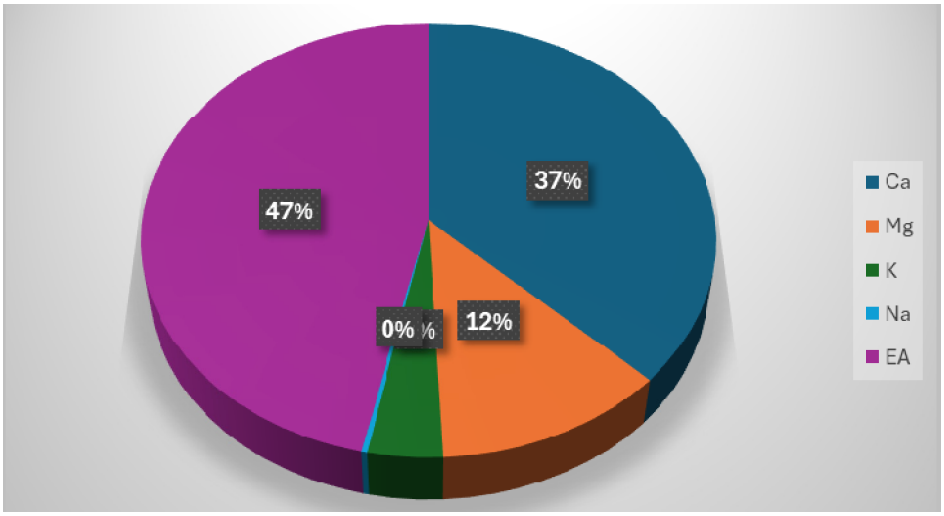


Figure 5: Mean distribution of cations in the study area

Soil reaction

The pH range of surface soils is moderately to strongly acidic. This is most likely related to the medium base saturation (45–50%) and low content of organic matter (<2%) observed in these soils. Similar trends were observed in studies of sandstone derived soils (Eyong and Akpa, 2019; Afu *et al.*, 2022; Owonubi and Mustapha, 2024; Edet and Aki; 2024). However exchangeable acidity values were very low with a mean of 1.55 cmol/kg.

This may imply low contribution of exchangeable acidity to total acidity in these soils. Furthermore, Owusu *et al.,* (2024) noted that the relevance of soil pH for investigating the negative effects of soil acidity should be based on the relationship between pH and exchangeable acidity. Owusu *et al.,* (2024) also found that soil pH predicts exchangeable acidity when pH is above 5.0, but for soils with pH below 5.0, including exchangeable bases, cation exchange capacity to clay ratio, and soil depth enhances accuracy. Soil pH buffer capacity in soils of the study area was very low (< 350 mg $CaCO_3$ $(kg\ soil)^{-1}pH^{-1}$). Similar trends were observed by Owonubi and Chiwendu (2022). The observed low pH buffer capacities could be because of the coarse texture, and low organic matter content of the soils (Brady and Weil, 2017).

Conclusion

Sandstone derived soils of this study area are deep but have very high dispersion ratios with sandy loam textures making them vulnerable to soil erosion. Soil reaction was moderate to strongly acidic. However low concentrations of nitrogen, phosphorus and exchangeable cations were observed. Whereas these attributes are likely to affect soil fertility, the situation is further compounded by low organic matter and cation exchange capacity.

The following practices will help to improve soil fertility in the study area: conservation tillage practices such as no-till, minimum, mulch till, or strip till would aid in soil conservation in this area. Crop rotation and or mixed cropping involving legumes; agroforestry involving leguminous shrubs and trees; application of organic manures and enriched biochar will help to boost soil fertility and productivity. In the short-term application of inorganic fertilizers containing N, P and K would be complementary.

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