



PEDOLOGICAL STUDY OF HILLY SOILS DEVELOPED ON BASEMENT COMPLEX TERRAIN IN MINNA, NIGER STATE, NIGERIA

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ABSTRACT

A pedological characterization of hilly soils developed on basement complex terrain was carried in Minna, Niger State, Nigeria. The site was delineated into three physiographic units (positions) and designated as summit, shoulder and foot slope. Two modal profile pits were excavated in each unit to permissible depths, giving a total of six (6) profiles. The soil samples were analysed in the laboratory following standard analytical procedures. Particle size analysis showed dominance of sand over other mineral fractions irrespective of the physiographic units. Silt was next to sand in dominance and clay particle was the least in particle size. Bulk density increased with increasing soil depth in all the physiographic positions while porosity decreased down the profiles. Soil reaction (pH) ranged from moderately acid to slightly acidic in all the terrains. Organic carbon, total nitrogen and available P decreased with the increased in soil depth in all the landforms. Calcium and Magnesium were moderate while Potassium rated high in the sampled soils. The mean Na in the sampled soils rated low to moderate. Cation Exchange Capacity (CEC) in the soils rated moderate while percentage base saturation (BS) rated high. The soils are non-sodic and the electrical conductivity (EC) values are low. The soils of summit and shoulder were classified as Typic Paleustalfs while the footslope soils were classified as Typic Paleudalfs. The soils were classified as Plinthosols when correlated with WRB for soil resource.

Keywords: basement complex, characterization, classification, hilly area, pedological study.

INTRODUCTION

Soil varies tremendously in physical and chemical properties in vertical and horizontal directions. Whichever form variability in soil takes, a major contributory factor could either be intrinsic (soil forming factor) or extrinsic (majorly soil management practices) or combination of the two (Khalil *et al.*, 2015). Among the intrinsic factors, topography has controlling effect in spatial distribution in soil properties (Babalola *et al.*, 2007). Soils on hilly areas are mostly shallow, gravelly or stony, thereby limiting their use by farmers. In many parts of the world today, hilly areas are increasingly being cultivated (Lal *et al.*, 2014). Hillslopes are classified into summit, shoulder, backslope, footslope and toeslope (Berh *et al.*, 2018). Adequate knowledge on soil formation on hilly areas and on different landscape positions is of great importance in pedological studies. Basement complex, is one of the three major petro-lithological components that make up the geology of Nigeria (Obaje, 2009). The Basement Complex is present in about half the total surface area of Nigeria. Therefore, the objectives of



this research were to characterize and classify the soils developed from Hilly Area on Basement complex terrain in Bosso Local Government Area, Niger State, Nigeria.

MATERIALS AND METHODS

Description of the study area

The study was carried out in a suburb of Minna, Niger State of Nigeria on latitude $09^{\circ}69'49''\text{N}$ and longitude $006^{\circ}46'42''\text{E}$. It is located in the hilly terrain of Maikunkele in Bosso local Government Area. The elevation is about 372 m above the sea level which no trend has established by previous research of this hilly area on the basis of pedological studies. Minna experiences two different type of seasons; dry and rainy (wet) seasons. The climate is sub-humid with mean annual rainfall of 1284 mm. Temperatures rarely fall below 22°C , while wet season temperature averages about 28°C . The peaks are 38°C (February – March) and 34°C (November – December) (Ojanuga, 2006).

The total land area of Niger State is estimated to be 7,211, 614.681 ha out of which about 1,078,994.813 ha comprises hilly areas. This means that a relatively large part of the resources of Niger state including basement complex and sedimentary areas are unexploited. The soils of the study area are derived from basement complex rocks. The soils ranged from shallow to very deep soils consisting mainly of granitic rocks (Okoli, 2015). Lawal *et al.*, (2012a) observed quartz to be prominent mineral constituents of the soils around Minna.

Field Studies

Satellite imagery and topographic map information were integrated to prepare the base map for the study (Figure 1). With the aid of satellite imagery of the study site and computer software, Sulfer II (Golden Software Inc., 2012), contour map of the study site was plotted to facilitate ground-truthing and subsequent interpretation of results (Fig.2). Two modal profile pits were excavated in the summit, shoulder and footslope to permissible depths giving a total of six (6) profiles. Soil samples were collected and taken to the laboratory for the characterization, following the procedures described by (FAO, 2014).

Sample Preparation and Laboratory Analysis

The soil samples collected from the soil profiles were air-dried, gently crushed using porcelain pestle and mortar and passed through a 2 mm sieve to obtain fine earth separates, while subsamples were further passed through 0.5 mm sieve for total nitrogen and organic carbon determinations. The particle size distribution was determined by the hydrometer method as described by Gee and Or (2002). Bulk density (B-d) was determined by clod method (Grossman and Reinsch, 2002). Porosity was calculated as function of the total volume not occupied by soil solids from bulk density. Soil pH was determined in water solution at a 1:1 soil/water or solution ratios (Thomas, 1996). The organic carbon was determined by the Walkley-Black dichromate wet oxidation method as described by Nelson and Sommers (1982).

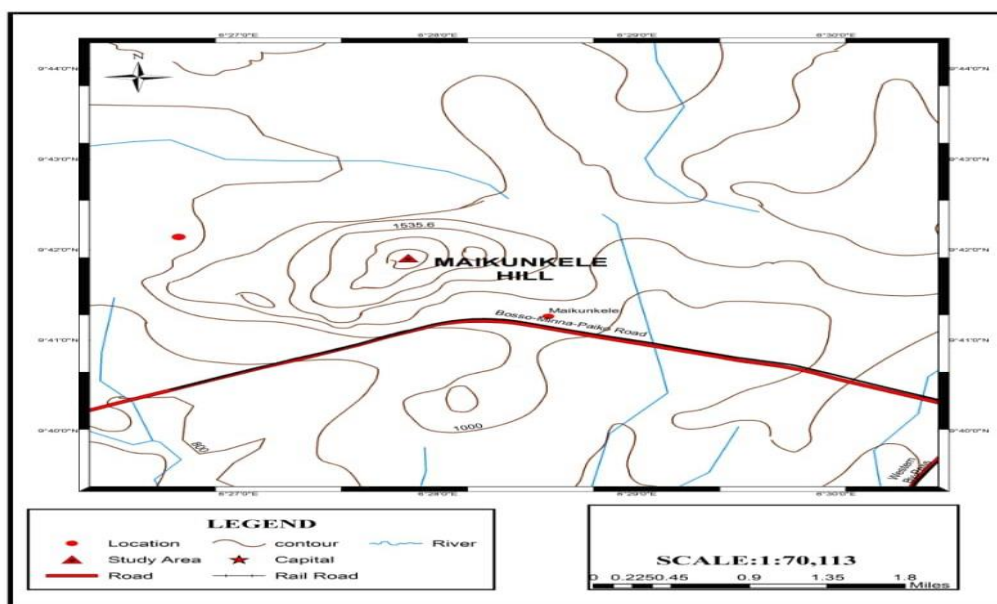


Figure 1: The study site as extracted from topographical map of Zungeru Sheet 163

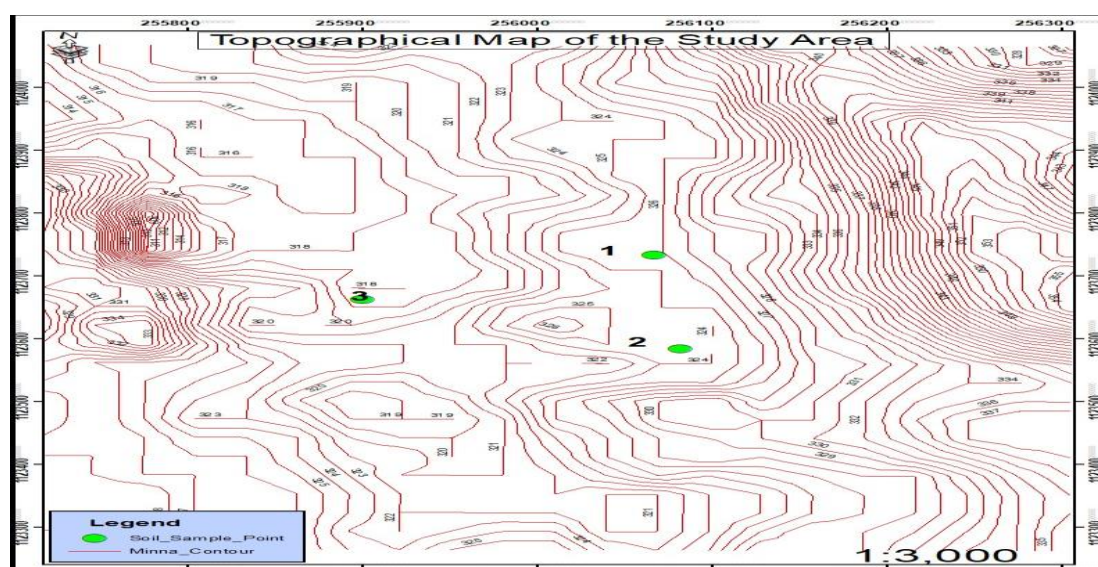


Figure 2: Topographical map of the study site.

Total nitrogen (TN) content, of the soils was determined using the Micro-Kjeldahl Technique as described by Bremner and Mulvaney (1982). Available phosphorus was determined following Bray II method (Olsen and Sommer, 1982). Exchangeable bases such as calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) were extracted using NH_4OAc saturation method (IITA, 1979). Calcium and magnesium in extract were determined using Atomic Absorption Spectrophotometer (AAS) (FAO, 2006). Potassium and sodium were determined using a Flame Emission Photometer. Total exchange acidity ($\text{H} + \text{Al}^{3+}$) was determined by titration of the extract with standard NaOH solution (Thomas, 1982). The cation exchange capacity (CEC) was determined by the neutral (pH 7.0) NH_4OAc saturation method (Rhoades, 1982). The base saturation percentage was determined by summation of exchangeable of all base forming cations, divided by cation exchange capacity and multiplied

by 100. The exchangeable sodium percentage was calculated as the proportion of the CEC (NH_4OAc) occupied by sodium cations. Electrical conductivity was determined at a 1: 2.5 soil/water ratio using a wheat stone bridge at 25 °C (Udo *et al.*, 2009).

Taxonomic Classification

Laboratory analytical (physical and chemical) data were used to classify the soils according to the USDA Soil Taxonomy System (Soil Survey Staff, 2014) up to the subgroup level and correlated with World Reference Base for Soil Resources Classification Method (IUSS WRB Soil Working Group, 2014).

RESULTS AND DISCUSSION

The study revealed that the study site is found on high elevation as shown on Digital Elevation Model (DEM) (Figure 3). The physical properties of the studied soils are presented in (Table 1). Sand contents decreased with increase in soil depth in summit and shoulder, but had irregular distribution with depth at the foot slope. The decrease in sand with depth of soil profile is in an agreement with the report of Okoli (2015) in Southern Guinea Savanna of Nigeria where sand content was found to decrease with increased in soil depth.

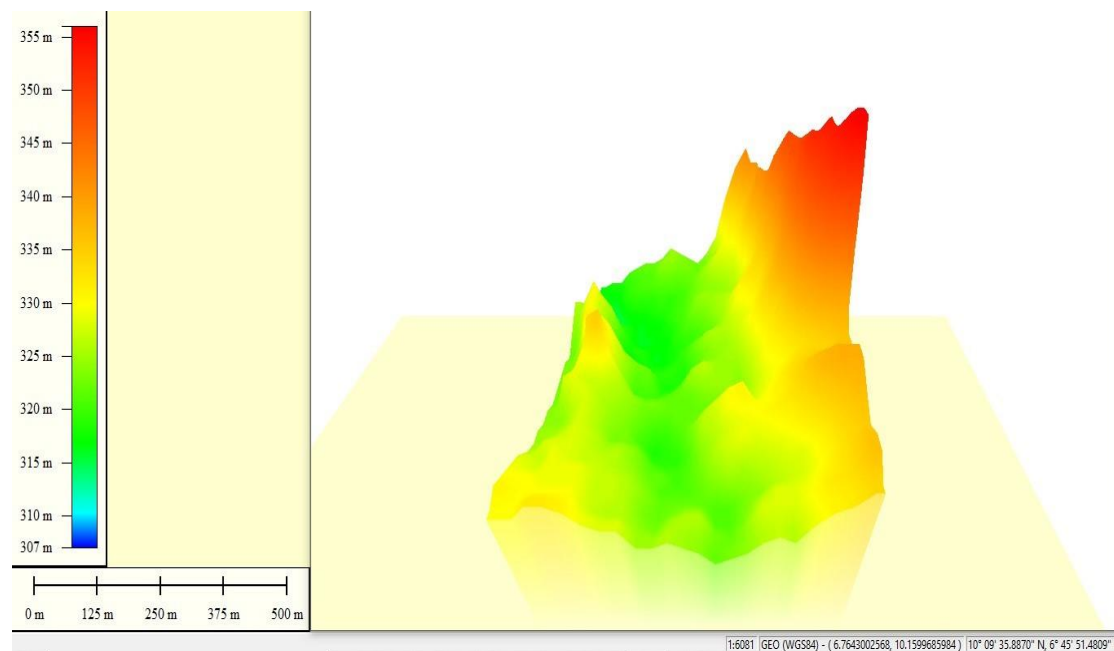


Figure 3: Digital elevation model (DEM) of the study site.



Table 1: Physical properties of the soil

Horizon	Soil depth (cm)	Gravel (%)	Sand	Silt → gkg ← 1	Clay	*Textural class	Bulk density Mg/m ³	Porosity (%)
Soils on summit			Latitude 09°69'49"N		Longitude 006°46'42"E		Elevation 372m	
Ap	0-39	47.77	794	126	80	Vgr SL	1.55	41.51
BA	39-102	58.87	744	176	80	Vgr SL	1.62	38.87
Soils on shoulder			Latitude 09°69'45"N		Longitude 06°46'43"E		Elevation 356m	
Ap	0-30	28.23	804	126	70	Vgr LS	1.37	50.57
B1	30-95	49.97	644	246	110	Vgr SL	-	-
Bt2	95-165	23.86	744	06	250	Mg SCL	1.56	41.51
Soils on footslope			Latitude 09°69'41"N		Longitude 06°46'43"E		Elevation 340 m	
Ap	0-25	34.75	654	246	100	Mg SL	1.44	45.66
Bg1	25-82	37.33	714	196	90	Vgr SL	1.33	49.88
Bg2	82-123	24.49	784	146	70	Mg LS	1.46	44.91
Bg3	123-195	32.00	734	176	90	Mg SL	1.48	44.15

*Texture: Vsg very slightly gravelly, Sg = slightly gravelly, Mg = moderately gravelly, Vgr = very gravelly, Exg = extremely gravelly, SL = sandy loam, LS = loamy sand, SCL = sandy clay loam.

The decreased sand contents with increasing soil depth could be as a result of erosive action, thereby blowing and washing away of finer particles (silt and clay) away from the soil surface. Silt content was highest on Ap horizon of the footslope. The implication for soils with high silt content lies in their ability to absorb and hold water, thereby creating an extended period of soil water retention for plant use (Beyene, 2011). The relatively higher clay content recorded on the subsoil horizons than the surface horizon could be as a result of migration of finer particles from the surface soil to subsoil horizons. Bulk density increased with increasing soil depth in all the terrains. According to London (1991), bulk density values greater than 1.75 Mg/m³ for sandy soils or 1.63 Mg/m³ for silty and clayey soils are known to have negative impact on root penetration. There was a decrease in porosity down the profiles and the values are less than 50 %. Brady and Weil (2007), stated that an ideal medium textured and well granulated surface soil in good condition for plant growth should have approximately 50 % of its volume as pore space. The chemical properties of the studied soils are shown in Table 2. Soil reaction (pH) ranged from moderately acid to slightly acidic in all the landforms. Organic matter (OM) decreased with the increased in soil depth. This is similar to the findings of Yakubu (2009) and Okoli (2015). The decrease of organic matter content in soil depth could be as a result of accumulation of plants and animal debris at the surface of the soil and less of it at the subsoils. Total nitrogen (TN) decreased within the soil depth. Getanah *et al.* (2007), reported that decrease in total nitrogen is due to continuous cultivation throughout the year. There was decrease in available phosphorous in all the profiles, except where available P picked in B3 horizon of foot slope. Tabi *et al.* (2012), noted that high available P content could be as a result of optimum pH medium. Calcium rated medium on the investigated soils. The distribution of Mg in the profiles did not show any pattern of distribution. According to Ande (2011), opined that irregular distribution of nutrient indicates the origin of geogenetic.



Potassium rated high in the studied soils. The high K recorded may be due to the presence of K bearing soil parent materials which in weathering releases K into the soil. The mean Na in the sampled soils rated low to moderate. The low to moderate sodium content in the study site suggests that Na cannot predispose treat to crop growth. The value of exchangeable acidity is irregular with increasing soil depth. Cation exchange capacity (CEC) in the soils rated moderate. The percentage base saturation (BS) rated high to very high in the soils. According to FAO (2014), base saturation is said to be low in a soil sample when the average value is less than 50 %. The value of ESP obtained in the soils was less than 15% which is considered to be the critical value according to Brady and Weil (2007). The soils are non-sodic, implying that the surface soils will not have severe crusting and will not be prone to severe gully erosion. The electrical conductivity (EC) rated low as the values are lower than 4 ds/m^{-1} .

Soil Classification

The soils were classified according to the criteria of USDA Soil Taxonomy (Soil Survey Staff, 2014) and correlated with World Reference Base (WRB). The soils have base saturations $> 50 \%$ (by $1 \text{ M NH}_4\text{OAc}$) in subsoils which qualified them as Alfisols at the Soil Order Level. Based on soil moisture regime, the soils possessed Ustic moisture regime, therefore the soils of the summit and shoulder fit into Ustalfs at the Suborder soil. Footslope soils fit into Udalfs at the Suborder Level, because of its physiographic position and the proximity to the perennial stream, thereby causing it to have udic moisture conditions as experienced by the occurrence of mottles in the subsoils. The soils of the summit, shoulder and footslope have well developed and clear B horizons, which placed the summit and shoulder soils under Great Group as Paleustalfs while the soils of the footslope was placed into Paleudalfs. At the Subgroup level, summit and shoulder soils fit into Typic Paleustalfs while the footslope soils fit into Typic Paleudalfs. Therefore, when correlated with WRB for soil resources the soils were classified as Plinthosols.

CONCLUSION AND RECOMMENDATIONS

The soils vary in physical and chemical properties as a result of the nature of the parent materials and the landforms. Sand particles predominated over other mineral particles. Due to sandy nature of the soils, organic fertilizers applications are recommended to improve the soil fertility and to conserve soil moisture for maximum crop yields. Minimum tillage operations are also recommended to improve the soil tilth as a result of the nature of the terrains. Bulk density and porosity increased with increasing soil depth in all the profiles investigated. Soil reaction (pH) which rated moderately acid to slightly acid, mean that acid forming fertilizers should be avoided or minimized. Organic matter, total nitrogen and available P decreased with the increased in soil depth in all the investigated soils. Potassium rated high in the sampled soils, suggesting that the soils may not require K applications. Percentage base saturation (BS) rated high, meaning that currently the soils may not have fertility problems.



Table 2: Chemical properties of Minna hilly area soils

Horizon	Soil depth (cm)	pH (H ₂ O) 2:5	pH CaCl ₂ 2:5	OM (g kg ⁻¹)	TN	P (mg kg ⁻¹)	Ca	Mg	K	Na	EA	CEC	BS (%)	ESP (%)	EC (ds/m ⁻¹)
							←(cmol kg ⁻¹)			→					
Ap	0-39	Soils on summit		Latitude 09 ⁰ 69.488N		69.488N	Longitude 006 ⁰ 46.421E		46.421E		Elevation 372				
		6.50	5.82	1.54	0.41	3.08	4.72	2.08	0.63	0.23	0.20	14.6	52.39	1.57	0.073
BA	39-102	6.51	5.84	1.05	0.37	0.71	8.80	3.44	0.68	0.30	0.25	13.2	96.62	2.26	0.044
Ap	0-30	Soils on shoulder		Latitude 09 ⁰ 69.450N		69.450N	Longitude 006 ⁰ 46.430E		46.430E		Elevation 356 m				
		6.20	5.71	8.51	0.25	8.65	9.20	1.84	1.62	0.21	0.18	18.0	71.18	1.16	0.176
B1	30-95	6.35	5.74	2.84	0.11	0.86	5.28	2.72	1.12	0.24	0.14	16.7	55.75	1.43	0.063
Bt2	95-165	6.62	5.74	1.38	0.17	2.48	4.16	2.40	0.92	0.28	0.51	15.7	49.20	1.76	0.030
Ap	0-25	Soils on footslope		Latitude 09 ⁰ 69. 407N		69. 407N	Longitude 006 ⁰ 46.430E		46.430E		Elevation 340 m				
		6.50	5.68	3.97	0.34	3.08	7.12	1.76	0.87	0.24	0.24	9.87	97.15	2.43	0.331
Bg1	25-82	6.54	5.72	2.03	0.21	2.14	8.72	3.44	0.69	0.29	0.08	15.7	83.32	1.84	0.047
Bg2	82-123	6.52	5.89	0.24	0.19	1.81	4.80	2.80	0.57	0.29	0.15	6.76	98.26	4.27	0.031
B3	123-195	6.50	5.82	7.22	0.36	18.91	8.80	4.56	0.55	0.44	0.30	11.0	97.95	3.72	0.060



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