Nigerian Journal of Soil Science

Journal homepage:www.soilsjournalnigeria.com

Characterization and Classification of The Soils of Bukuru-Jos, North Central Nigeria

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ARTICLE INFO

Article history:
Received March 28, *2018*
Received in revised form July 30, 2019
Accepted August 2, 2019
Available online November 10, 2019

Keywords:
Characterization,
Classification,
Soils,
Bukuru,
Typic
isothermic
Kandic
ustalfs,
Lixisols

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https://doi.org/10.36265/njss.2020.290210

ISSN-1597-4488 cpublishingrealtime.

ABSTRACT

Twelve profile pits were sunk, four in each of the three locations of Bukuru, the study area. Proper soil profile description was done and recorded to obtain field characterization data after which thirty-six soil samples were collected from all the genetic horizons for soil characterization. Bukuru soils showed higher sand fraction (71%) than silt (12%) and clay (17%) at the topsoil but showed increased clay content at the subsoil. While Gyel and Fwarti locations soils were sandy loam, Rabi location soil was sandy clay loam. Soil pH, Organic carbon (Org. C), Total Nitrogen (Total N), and Available phosphorus (Avail. P) were 6.2, 6.3 gkg-1, 1.9 gkg-1 and 4.82 mgkg-1respectively and were graded low. Exchangeable bases were dominated by Ca2+ and Mg2+. Sodium (Na+), Potassium (K+), Calcium (Ca) and Magnesium (Mg) were 0.24 cmolkg-1, 0.06 cmolkg-1, 15.7 cmolkg-1 and 2.60 cmolkg-1 respectively. While Na+ and K+ were graded low, Ca2+ and Mg2+ were graded high. Cation Exchange Capacity (CEC) was 18.82 cmolkg-1, and was graded high. All the soil samples analysed showed high percentage base saturation (PBS), above 90%. The low values of Org. C, Total N, Na and K and the characteristic sandiness of Bukuru soils in the surface horizon indicated the low fertility status of Bukuru soils. Bukuru soils were classified using the Keys to Soil taxonomy of the USDA as "Typic isothermic kandic ustalfs". This was correlated to "Lixisols" in the World Reference Base (WRB) of FAO at a higher level and "Rhodic/Chromic" as a principal qualifier. .

1.0. Introduction

The inherent ability of soils to supply nutrients for crop growth and maintenance of soil physical conditions to optimize crop yields is the most important component of soil fertility that virtually determines the productivity of agricultural systems. Thus, a good knowledge of the soil resources of any given territory is indispensable for planning its agricultural development. The coupling of soil characterization, soil classification, and soil mapping provides a powerful resource for the benefit of mankind especially in the area of food security and environmental sustainability (Sharu *et al*. 2013). Soil characterization and classification is the main information source for precision agriculture, land use planning, and management. Soil characterization provides the information for our understanding of the physical, chemical, mineralogical and microbiological properties of the soils we depend on to grow crops, sustain forests and grasslands as well as support homes and society structures (Ogunkunle, 2005). Soil classification can be defined as the systematic arrangement of soils into groups or categories based on their characteristics. Soil taxonomy (classification) provides a hierarchical grouping of natural soil bodies. The system is based on soil properties that can be objectively observed or measured rather than on presumed mechanisms of soil formation (Akamigbo, 2010). It helps to organize our knowledge, facilitates the transfer of experience and technology from one place to another and helps to compare soil properties (Sharu *et al*. 2013). Its unique international nomenclature gives a definitive connotation of the major characteristics of the soils in question (Brady and Weil, 2010).

According to Lawal *et al.* (2013), the surface horizon of all the pedons of soils of southern guinea savannah was mottle-free, an indication of good surface drainage. However, strong brown (7.5YR4/6) mottles were common at the subsurface of which changed to red (2.5YR4/8) at a lower horizon. The surface soil was weak and crumb-structured. Absence of cracks on the surfaces of the pedons probably inferred that the soils have nonexpanding clay minerals e.g. kaolinite in them. Stones of quartz origin and gravels made of iron (Fe) and manganese (Mn) concretions were common in surface horizon whereas plinthites cemented with clay dominated the subsurface of which contributed to its poor subsurface drainage. Sand dominated the mineral fraction in all the landscape positions of the soils which may be partly attributed to parent material rich in quartz mineral, an essential component in granite and partly to geological processes involving sorting of soil materials by biological activities (Wilson, 2010). Bukuru, the study area lies within the southern Guinea savannah belt.

Bukuru soils were described as lateritic soils. They consist of sandy-clay loam to sandy soils in other places. The brown soils are gritty and sandy whereas the reddish soils are denser and rich in clay occurring as residual mineral deposits on the low lying basement rock (Oleije, 2001). The texture of the soil is mainly fine to medium grained and in exceptional cases, coarse and in places where weathering has taken place, moderately deep to deep well-drained soils, gravely surfaces over sandy loam to sandy clay loam and sometimes gravely subsoil (FADLR 1990). This was further reported by (Hassan *et al.* 2015), who reported that the typical soils of the Bukuru series consist of well-drained, light brown to dark brown gravelly sandy loam over yellowish red (5YR 5/6) to gravelly sandy clay loam subsoil. The occurrence of soft and hardened iron oxide nodules and manganiferous concretions indicates that plinthization is an active soil-forming process in the soils. Definite clay bulges (Bt horizons) also occur in the soil profiles indicating that argillic or kandic horizons abound in the soils

2.0. Materials and Methods

The study area (Bukuru town) lays between longitudes 8° 50′ E and 9° 00′E and latitudes 9°45′N and 9°50′N (Figure 1). It was formerly dominated by mining activities in areas such as Maiadiko, Gold and Base settlements, and many others. It has an average elevation of about 1,150 meters above mean sea level and the highest peak some 20 km eastwards from Jos-Shere hill, rising to 1777 meters above mean sea level. The Jos-Bukuru Younger Granite Ring Complex is part of generalized ring complexes of the Younger Granite suite. According to Edun and Davou (2013), the mode of emplacement of the Younger Granite complexes is not related to or associated with any orogenic event or activity. The lack of sediments associated with the volcanic rock of the younger granite complex, which erupted to a land surface undergoing erosion (non-deposition), is an indirect evidence to show that the Granites were associated with epirogenic upliftment. As a result of weathering activity, the rocks of the study area have undergone immense laterization resulting in the formation of laterites in areas that were formerly covered by rocks.

The mean annual temperature is about 220C but the mean monthly varies between 19.40C and 290C in the hottest month. It has a cool climatic condition due to its high altitude. Between November and February, the average mean daily temperature is 180C, while it is warm between March and April before the onset of the rains. The rainy season which is between May and October has its peak in August. Weather Travel (2012) reported that the soil temperature regime is inferred to be isothermal and about 1,400 millimeters (55 inches) of rainfall annually, the precipitation arising from both conventional and orographic sources owing to the location of the city on the Jos Plateau.

According to Gwom (1992), the people of Jos South (Bukuru inclusive) were predominantly farmers and hunters, but with the coming of mining activities and the location of mining camps in many areas within the local government, the early occupation of the inhabitants has been overtaken by these mining activities. Common food crops grown in the area include irish potato (Solamum tuberum), sweet-potato (Ipomea batatas), maize (Zea-mays), millet (Sorghum bicolor), cabbage (Brassica spp) tomato (Lycopersicum esculentum) and many other varieties of vegetables. On the three locations of the study area, major crops grown were sweet-potato (Ipomea batatas), maize (Zea-mays), cabbage (Brassica spp) and tomato (Lycopersicum esculentum).

2.1. Field characterization

The study adopted the experimental design and was conducted in three locations of the Bukuru area namely, Gyel, Rabi and Fwarti (Figure 2). Twelve profile pits were cited, three of which were cited at the mined sites and one at an unmined sites (control) in each location of the study area. The GPS position of the profile pits are presented in Table 1. The dimension of each profile pit was 200 cm x 150 cm x 200 cm depth, except where hard rock or water table was encountered before 200 cm (Plate 1). Before soil samples were taken, proper description of the soil profiles was done according to FAO (2006) manual and recorded for field characterization data (macro morphological studies.

Thirty-six (36) soil samples were collected from all of Ap, B, Bt and C horizons of the profile pits. The samples were air-dried, gently crushed using a wooden mortar and pestle and then sieved through a 2mm mesh. The sieved samples were stored for physicochemical analysis which included particle size analysis, bulk density determination (core samplers were used to collect 36 soil samples for bulk density determination), soil porosity, pH, organic C, total N, available P, exchangeable acidity (H+ and Al3+), exchangeable bases (Na+, K+, Ca+, Mg+), cation exchange capacity (CEC) and Percentage Base Saturation. The particle size was determined using the hydrometer method according to the procedure of Gee and Or (2002) using sodium hexa-meta phosphate and deionized water as dispersants.

Thirty core samples were taken from all the Ap, B, Bt and C horizons. The samples were saturated with water, weighed, oven-dried at 1050C for 24 hours and weighed again to obtain the oven-dry weight. The bulk density was calculated as follows (Gee and Or, 2002).

Soil Bulk Density = ….Equation 1

Total porosity was determined by calculation as described by Landon (1991) and expressed mathematically as:

(f) = 1- ꝉb/Pd X 100% ………………………Equation 2,

where:

Particle density (Pd) is taken as 2.65, (f) = total porosity and ꝉb = Bulk density

Soil pH was determined using distilled water in 0.1N KCl solution, using a soil: liquid ratio 1. 2.5. The pH was read

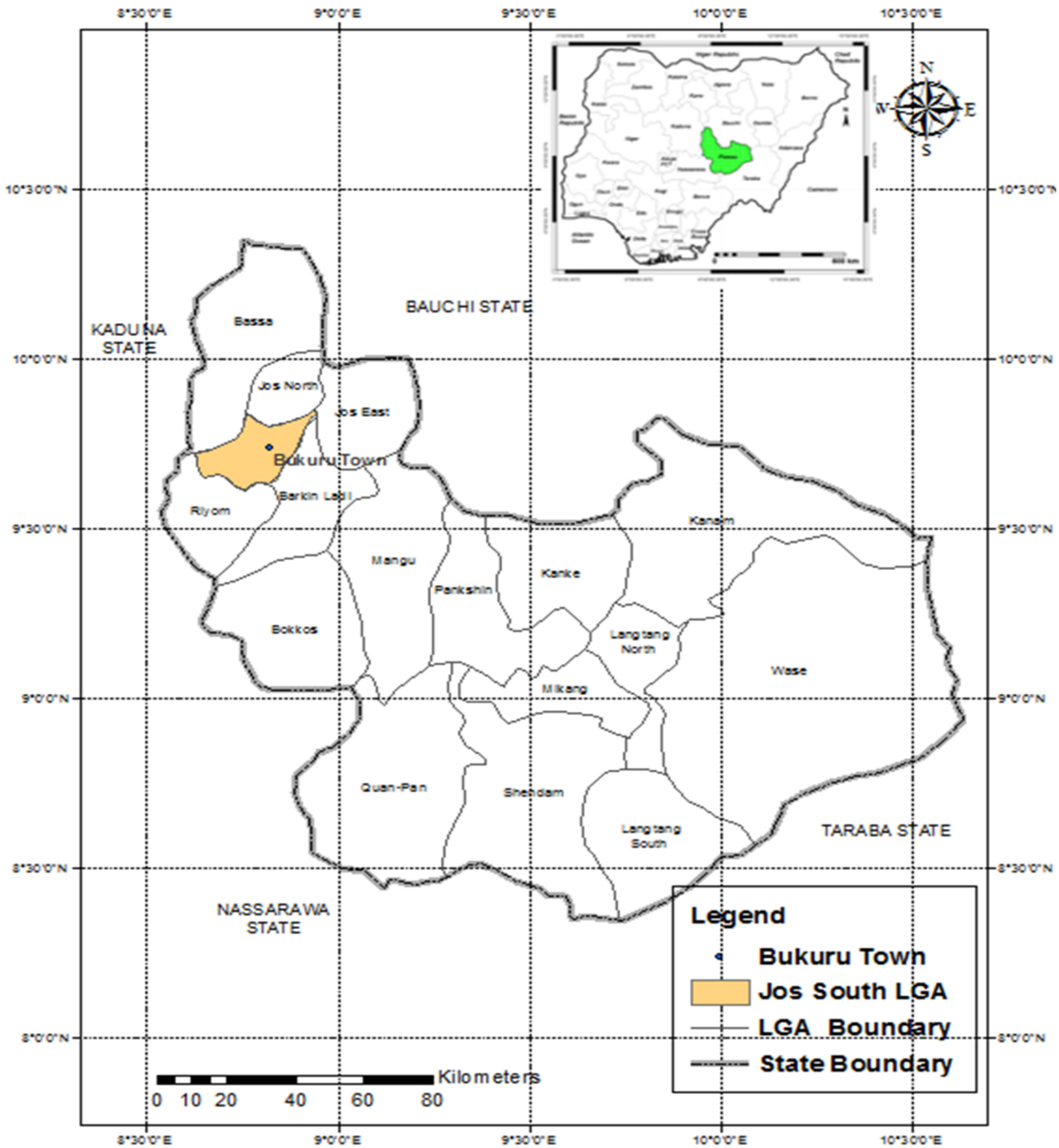

Figure 1: Plateau Sttate Showing Jos LGA and Bakuru Town
Source: Adaspted from Plateau State Ministry of Land Survey and Town Planning

***Table 1:** GPS positioning of the profile pits sunk in Bukuru study area*

	Unit	Pedon 1	Pedon 2	Pedon 3	Control
Location					
GYEL	Latitude	9. 7 35	9.784	9.786	9.788
	Longitude	8.620	8.859	8.859	8.855
	Altitude	14.16	14.57	15.06	15.21
	Accuracy	2.5m	3.3m	9.1m	2.2m
FWARTI	Latitude	9.08	9.806	9.806	9.03
	Longitude	8.873	8.877	8.878	8.877
	Altitude	3.28	13.33	13.23	13.03
	Accuracy	1m	2.4m	2.1m	2.2m
RABI	Latitude	9.783	9.784	9.784	9.777
	Longitude	8.883	8.884	8.835	8,889
	Altitude	12.44	12.33	12.36	12.21
	Accuracy	7m	1.2m	1m	1m

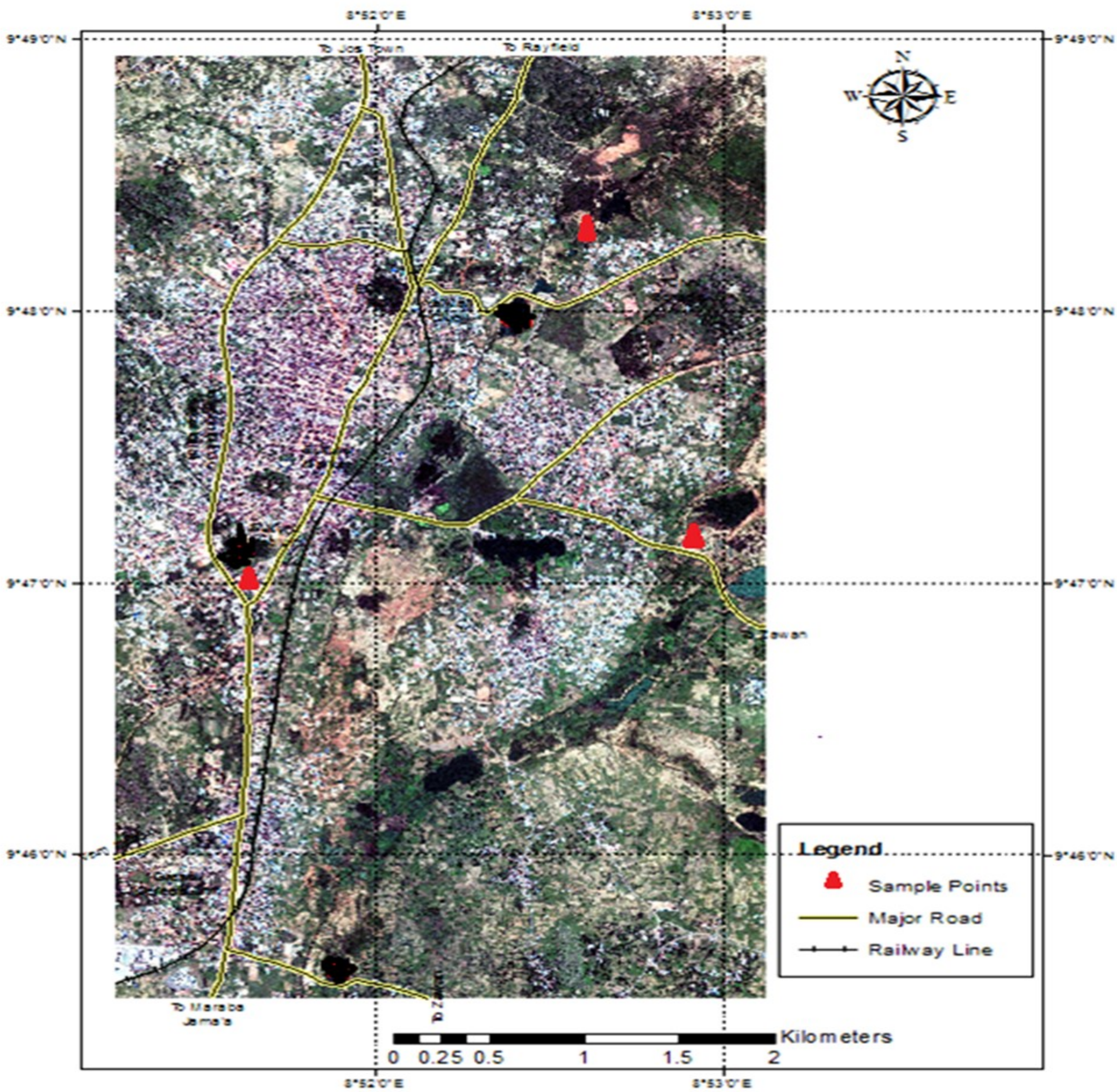

Figure 2: Bukuru Town showing samples collection points
Source: Adapted from Google imagery (2014). Scale 1:100,000

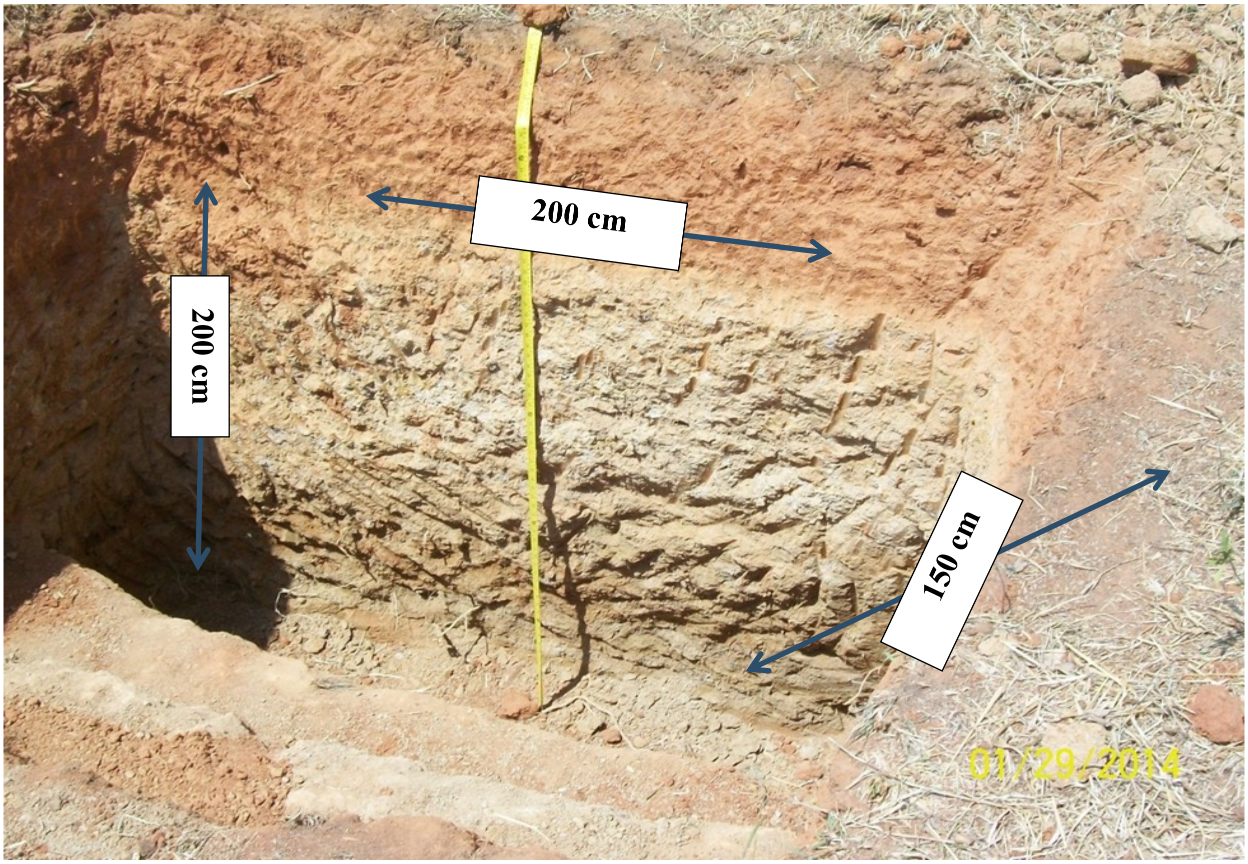

Plate 1: Profile pits sunk at Bukuru study area showing pedogenic horizons for macromorphological studies (field characterization) and soil sampling for physicochemical and heavy metals analyses

off after stirring for 30 minutes, using a glass electrode pH meter (Thomas, 1996). The organic carbon content of the soils was determined by the modified Walkley-Black method as described by Nelson and Sommers (1996). Oxidizable matter in the soil is oxidized by 1 N K2Cr2O7 solution. The reaction is assisted by the heat generated when two volumes of H2SO4 are mixed with one volume of the dichromate. The remaining dichromate is titrated with ferrous sulphate. The titre is inversely related to the amount of C present in the soil sample. Total nitrogen was determined by the Macro-Kjeldahl digestion and distillation procedures using concentrated H2SO4 and a copper sulphates catalyst mixture. Ammonium in the digest was displaced with 45% NaOH solution and distilled into 4% boric acid, and then determined by titration with 0.05 N HCL (Bremner, 1996). Available Phosphorus (P) was extracted with Bray 1 solution as described by Page et al. (1982). Exchangeable Acidity (H+ and AL3+) was determined by the titration method using 1N KCl extract (Mclean 1982).

Exchangeable bases (Na+, K+, Ca2+, Mg2+) in the soil were determined using the ammonium acetate extract from the CEC determination. Sodium (Na+) and Potassium (K+) were extracted with 1N neutral ammonium acetate (NH4OAC) and determined by flame photometric method (Thomas, 1982). Exchangeable calcium (Ca2+) and Magnesium (Mg2 were determined by complexometric method, using ethylene diamine tetra-acetic acid (EDTA) (Thomas, 1982). Cation Exchange Capacity (CEC) was determined titrimetrically, using ammonium acetate (NH4OAC), (Bremmer, 1996).

PBS (%) = X ..Equation 3.

The percentage base saturation (PBS) of the soils was calculated by dividing the value of the total exchangeable bases (Ca, Mg, K, and Na) by the CEC and multiplying the quotient by 100 as follows:

3.0. Results and Discussion

The morphological characteristics of Bukuru soils are presented in Tables, 2 (Gyel location), 2 (Rabi location), and 3 (Fwarti location). At Gyel location (Table 1) results for pedon 1 showed that the texture of the Ap and B horizons were sandy clay loam, while that of the C horizon was sandy loam. Ap horizon had a firm, moderate coarse granular structure, the B horizon was firm, moderate fine subangular blocky while the C horizon had loose, single grain and structureless. The Ap and C horizon colors were bright brown (7.5YR5/8), however, the B color was bright reddish-brown (7.5YR5/6). The boundary between Ap and B and the one between B and C were clear and smooth. Other features observed in the Ap horizon were macropores, hydrocarbons (old plastic, rubber) and well-drained soil conditions. In the B horizon, artifacts (rags and broken clay pots), few fibrous roots, cutans, and mottles were observed, while evidence of biological origin and yellow mottles were observed in the C horizon.

Results for pedon 2, (Table 1) revealed the texture of the Ap, B and C horizons were sandy loam. However, the C horizon was also gravelly. The Ap color was yellowish-brown (10YR5/6), while the B and C colors were bright brown (7.5YR5/8). The Ap horizon had a firm, moderate coarse subangular blocky structure, the B and C horizons were friable and structureless. The boundary between Ap and B and the one between B and C were clear and abrupt.

Other features observed in the Ap horizon were macropores, hydrocarbons (old plastic, rubber), artifacts (pieces of clay pot), and many fibrous roots. In the B horizon, concretion, evidence of biological origin and a few fine roots were observed while poor drainage conditions

Table 2: Morphological Characteristics of Gyel Soils

Pendon	Horizon	Depth (cm)	Colour	Mottles	Textural class	Structure	Consistency	Other features	Boundary
1	Ap	0-10	$7.5YR^{5}/_{8}$		SCL	2cgrn	fm	mp, hc	cs
	Bt	10-60	$5YR^{5}/_{6}$		SCL	2fsbk	fm	mp, 2fr, ct	cs
	C	60-200	$7.5YR^{5}/_{8}$	$7.5YR^{8}/_{8}$	SL	0sg	lo	bo	-
2	Ap	0-20	$10YR^{5}/_{8}$		SL	2sbk	fm	mp, 2fr, ct	ca
	B	20-60	$7.5YR^{5}/_{8}$		SL	0sg	frb	1fr, bo	ca
	C	60-200	$7.5YR^{5}/_{8}$	$2.5YR^{6}/_{8}$	SL	0sg	frb	-	-
3	Ap	0-15	$10YR^{4}/_{6}$		SL	3csbk	fm	mp, bo, 2fr	cs
	Bt	15-80	$10YR^{6}/_{8}$		SCL	1fsbk	frb	mp, bo	cs
	C	80-200	$10YR^{5}/_{8}$	$2.5YR^{6}/_{8}$ $7.5YR^{8}/_{8}$	SL	0sg	frb	mp	-
4 (control)	Ap	0-30	$10YR^{5}/_{8}$		SL	2cgrn	frb	mp, 2fr, hc, bo	ca
	Bt	30-113	$7.5YR^{7}/_{6}$		SL	2fsbk	fm	1fr	ca
	R	113-150	$7.5YR^{8}/_{6}$		S	3mcsbk	fm	-	-

Structure: 0=structureless, 1=weak, 2=moderate, 3=strong, sg=single grain, cgrn= Coarse granular, csbk = coarse subangular blocky, fsbk= fine, subangular blocky, m=massive;. **Consistence:** lo=loose, frb=friable, vfr=very friable, fm=firm, efm=extremely firm;. **Roots**: 1=few 2=moderate, 3=many, fr= fine roots, co=coarse, mp = many pores, fp=few pores, hc=hydrocarbons, bo=biological origin evidence; **Boundary**: A= abrupt, C=clear, G=gradual, **S**=smooth, W=wavy, **GV**=gravels

Note: symbols or codes according to FAO, 2006

and red mottles (2.5YR6/8) were observed in the C horizon.

The morphological characteristics of pedon 3 (Table 1) showed that the texture of the Ap and C horizons were sandy loam, while the Bt horizon was sandy clay loam. The Ap color was brown (10YR4/6), the Bt color was bright yellowish-brown (10YR6/8) while C horizon color was yellowish-brown (7.5YR5/8). The Ap horizon had a strong coarse subangular blocky structure, the Bt was weak with fine subangular blocky structure while the C horizon had a friable, structureless single grain structure. The boundaries between Ap and B horizons and the one between B and C horizons were clear and smooth. Other features observed in the Ap horizon were macropores, evidence of biological origins, concretions, artifacts (torn sack), and few fibrous roots. In the B horizon, macropores and evidence of biological origin were observed, while poor drainage conditions and red and yellow mottles were observed in the C horizons.

For pedon 4 (Table 1), results showed that the Ap and Bt horizons were sandy loam, while the R horizon was the rock. The Ap color was dark grayish brown (10YR5/3), the Bt color was orange (7.5YR7/6) while the R horizon color was light orange (7.5YR8/6). The Ap horizon had weak coarse granular structure, the Bt had a moderate fine subangular blocky structure, while the C horizon had coarse extremely firm and massive structure but can be chipped with a hammer. The boundary between Ap and B and the one between Bt and R horizons were clear and abrupt. Other features observed in the Ap horizon were macropores, hydrocarbons (polythene bags), artifacts (broken pots and bottles), evidence of biological origins (earthworms and dead insects) and many fibrous roots. In the Bt horizon features observed were very fibrous roots and iron oxide hardpan. No other features were observed in the R horizon except the massive coarse granitic rock. It was also noticed that the Ap horizon of the Control was thicker (30 cm) than the AP horizons of the three profiles at the mined site (Disturbed area)

The morphological characteristic of Rabi soils, Bukuru are presented in Table 3 and are described as follows. For pedon 1 (Table 2), the texture of the Ap horizon was sandy loam, the Bt1 horizon texture was loamy sand, while the texture of the Bt2 horizon was sand. The Ap horizon was also thick (30 cm) and having a bright reddish-brown color (5YR5/6). The Bt1 horizon color was orange (7.5YR6/8), while that of the Bt2 horizon was bright brown (7.5YR5/6). The Ap horizon had a friable coarse granular structure while the Bt1 and Bt2 horizons were loose, structureless and single grain. The boundaries between Ap and Bt1 and between Bt1 and Bt2 horizons were clear and abrupt. Other features observed in the Ap horizon were macropores, evidence of biological origins (earthworms), undecomposed and partially decomposed organic matter and many fibrous roots in the Ap horizons. In the Bt1 horizons, few fibrous roots, macropores, evidence of biological horizons (earthworms) and a very large taproot were observed.

The morphological characteristics of pedon 2, Rabi location (Table 2), showed that the texture of the Ap horizon was sandy loam, while that of Bt1 and Bt2 horizons were sandy clay loam. The Ap horizon color was bright reddish-brown (5YR5/8), the Bt1 horizon color was light brownish brown-gray (5YR7/2) while the Bt2 horizon had bright yellowish-brown (10YR6/6) color. The Ap horizon had a weak, coarse granular structure with friable consistency. However, the Bt1 horizon had a strong extremely firm fine subangular blocky structure, while the Bt2 horizon had weak and friable fine subangular blocky structure. The boundaries between the Ap and Bt1 horizons and the one between Bt1 and Bt2 were clear and abrupt. Other features observed in the Ap horizon were macropores, undecomposed and partially decomposed plant materials, evidence of biological origin (black ants) and few fibrous roots. In the Bt1 very few fibrous roots, evidence of biological origin (black ants), macropores, and very large taproots were observed. In the Bt2 horizon, features observed were few tap roots, evidence of biological origin

Table 3: Morphological Characteristics of Rabi Soils

Pendon	Horizon	Depth (cm)	Colour	Mottles	Textural class	Structure	Consistency	Other features	Boundary
1	Ap	0-10	7.5YR$^5/_8$		SCL	2cgrn	fm	mp, hc	cs
	Bt	10-60	5YR$^5/_6$		SCL	2fsbk	fm	mp, 2fr, ct	cs
	C	60-200	7.5YR$^5/_8$		SL	0sg	lo	bo	-
2	Ap	0-20	10YR$^5/_8$		SL	2sbk	fm	mp, 2fr, ct	ca
	B	20-60	7.5YR$^5/_8$		SL	0sg	frb	1fr, bo	ca
	C	60-200	7.5YR$^5/_8$	2.5YR$^6/_8$ 7.5YR$^8/_8$	SL	0sg	frb	-	-
3	Ap	0-15	10YR$^4/_6$		SL	3csbk	fm	mp, bo, 2fr	cs
	Bt	15-80	10YR$^6/_8$	2.5YR$^6/_8$ 7.5YR$^8/_8$	SCL	1fsbk	frb	mp, bo	cs
	C	80-200	10YR$^5/_8$	2.5YR$^6/_8$ 7.5YR$^6/_8$	SL	0sg	frb	mp	-
4 (control)	Ap	0-30	10YR$^5/_8$		SL	2cgrn	frb	mp, 2fr, hc, bo	ca
	Bt	30-113	7.5YR$^7/_6$		SL	2fsbk	fm	1fr	ca
	R	113-150	7.5YR$^8/_6$		S	3mcsbk	fm	-	-

Structure: 0=structureless, 1=weak, 2=moderate, 3=strong, sg=single grain, cgrn= Coarse granular, csbk = coarse subangular blocky, fsbk= fine, subangular blocky, m=massive;. **Consistence:** lo=loose, frb=friable, vfr=very friable, fm=firm, efm=extremely firm;. **Roots**: 1=few 2=moderate, 3=many, fr= fine roots, co=coarse, mp = many pores, fp=few pores, hc=hydrocarbons, bo=biological origin evidence; **Boundary**: A= abrupt, C=clear, G=gradual, **S**=smooth, W=wavy, **GV**=gravels

Note: symbols or codes according to FAO, 2006

(earthworms), poor drainage conditions, red (2.5YR6/8) and yellow (7.5YR8/8) mottles.

Results of morphological characteristics of pedon 3 Rabi location, (Table 2) revealed that the texture of the Ap, Bt1 and Bt2 horizons were sandy clay loam. The Ap color was dull brown (7.5YR5/4), Bt1 color was bright yellowish gray (5YR7/2) while the color of the Bt2 horizon was Bright brown (7.5YR8/8). The Ap horizon had moderate, coarse granular structure, with friable consistency. Bt1 horizon had an extremely firm, strong fine subangular blocky structure while the Bt2 horizon had fine subangular structure with friable consistency. The boundary between the Ap and Bt1 horizons and the one between Bt1 and Bt2 horizons were clear and abrupt. Other features observed in the Ap horizon were macropores, undecomposed and partially decomposed plant materials, evidence of biological origin (termites), many fibrous roots, well-drained soil conditions and artifacts (broken bottles). In the Bt1 few fibrous roots, macropores, concretions, evidence of biological origins and small gravels, red (2.5YR6/8) and yellow (7.5YR8/8) mottles were observed. No other features were observed in the Bt2 horizon.

Morphological characteristics of pedon 4 Rabi location, (Table 2), showed the texture of the Ap horizon was sandy loam, while that of Bt1 and Bt2 horizons were sandy clay loam. The Ap Munsell color was dull yellowish-brown (10YR5/4). The Bt1 horizon color was bright yellowish-brown (10YR7/6), while the Bt2 horizon color was Bright Brown (2.5YR5/8). The Ap horizon had a moderate coarse granular structure with a firm consistency. The Bt1 and Bt2 horizons had fine subangular blocky structure, however, they differ inconsistency. While the Bt1 horizon had firm consistency, Bt2 had friable consistency. Ap horizon of pedon 4 was thicker than the Ap horizons of pedons 1, 2 and 3. The boundaries between the Ap and Bt1 horizons and the one between Bt1 and Bt2 horizons were clear, abrupt and smooth. Other features observed in the Ap horizon of pedon 4 were macropores, hydrocarbons (charcoals and rubbers), evidence of biological origins (termites), many fibrous roots and well-drained soil conditions. In the Bt1 horizon, features observed were very few fibrous roots, evidence of biological origin, well-drained soil conditions and gravelly. In the Bt2 horizon observed features were evidence of biological origin (ants) and well-drained soil conditions.

The morphological properties of pedon 1 of Fwarti location (Table 3), revealed that the texture of the Ap and C horizons were sandy loam, while the Bt horizon was sandy clay loam. The Ap color was orange (7.5YR6/8), the Bt horizon color was yellowish-orange (7.5YR7/8) while the C horizon color was red (2.5YR6/8). The Ap horizon had loose structureless single grain, the Bt horizon had moderate and friable coarse granular structure, while the C horizon had a strong and firm coarse subangular blocky structure. The boundary between the Ap and the Bt horizons was clear and abrupt, while the boundary between the Bt and C horizons was diffuse and wavy. Other features observed in the Ap horizon were macropores and many fine roots. In the Bt horizon, the observed features were few fibrous roots, macropores, red mottles (2.5YR6/8), while observed features in the C horizon were very few fibrous roots, gray ((10YR5/3) and dark yellow (10YR5/4) mottles and small gravels.

For pedon 2 Fwarti location (Table 3), the texture of the Ap and C horizons were sandy loam, while that of B horizon was sandy clay loam. Munsel color for the Ap horizon was Yellowish Brown (10YR5/8), that of the Bt horizon was Bright yellowish-brown (10YR6/8), while the C horizon color was bright yellowish-orange (10YR6/3). Although Ap and C horizons had the same texture, they differ in structure and consistency. While the Ap horizon was loose, structureless and single grain, the C horizon had a strong coarse subangular blocky structure. The B horizon had weak and granular structure. The boundary between Ap and B horizons was diffuse and wavy while the one between Bt and C horizons was clear and abrupt. Other features observed in the Ap horizon were macropores, many fibrous roots, evidence of biological origins (termites) and well-drained soil conditions. In the Bt horizon, there were few fibrous roots, macropores, small gravels and red mottles (2.5YR6/8). Other features observed in the C horizon were few fibrous roots, evidence of biological origins (termites), gray (10YR5/3) and red (2.5YR6/8) mottles.

Morphological properties of pedon 3 Fwarti location, Bukuru (Table 3) indicated that the texture of the Ap and Bt2 horizons were sandy loam, while that of Bt1 was sandy clay loam. The Ap Munsel color was Bright Brown (7.5YR5/8), Bt1 was orange (7.5YR6/8) in color, while the Bt2 Munsel color was red (2.5YR5/8). The Ap horizon had loose, weak coarse granular structure, the Bt1 had a moderately fine granular structure having a friable consistency, while the Bt2 horizon had a strong coarse subangular blocky structure with a firm consistency. The boundaries between the Ap and Bt1 were clear and wavy, while the boundary between Bt1 and Bt2 horizons was diffuse and wavy. Features observed in the Ap horizon were macropores, evidence of biological origins (ants and termites), many fibrous roots and well-drained soil conditions and partially decomposed plant materials. In the Bt1 horizon features observed were few fibrous roots, evidence of biological origin (termites) and small stony gravels, while other features observed in the Bt2 horizon were very few fibrous roots and small stony gravels.

Results of morphological characteristics of pedon 4, Fwarti location (Table 3), showed the texture of the Ap and the Bt2 horizons were sandy loam, while the Bt1 horizon texture was loamy sand. The Ap and the Bt1 Munsel color were both bright yellowish-brown (10YR6/6), while the Bt2 Munsel color was Red (2.5YR6/8). The Ap and Bt1 horizons both had coarse granular structure, however, Ap horizon consistency was firm while the Bt1 horizon had friable consistency. The Bt2 horizon structure was subangular blocky having friable consistency. The Ap horizon depth was 25 cm, therefore, thicker than the Ap horizons of pedons 1, 2 and 3. Other features observed in the Ap horizon were macropores, hydrocarbons (used polythene bags), evidence of biological origins (termites ants and dead insects), many fibrous roots and partially decomposed plant materials. In the Bt1 horizon, features observed were very few fibrous roots, evidence of biological origin (termites), and small stony gravels. Observed features in the Bt2 horizon were embedded small black gravels (manganese's concretions) with no roots present. The boundary between the Ap and Bt1 was clear and wavy while the boundary between Bt1 and Bt2 was diffuse and wavy.

The Ap Horizons for the three locations of the study area were generally thin for all the pedons except for Gyel, pedon 4 and Rabi pedon 1 and 4 which was 0-30 cm, (Tables 1 and 2). Kpamrwang et al. (1998) reported that thin Ap horizons may be due to cultivation which is usually on the flat, resulting in minimal deep mixing of the topsoil which is prone to sheet erosion. Hassan et al (2015) also reported that the thin Ap horizons in Jos Plateau soils are attributed to the high clay content of the soils, which complexes humus and thus reduces its ability to move downwards in the profiles. The thick horizons were observed mostly in pedon 4 of three locations of the study area. Bukuru area is a heavily mined area spanning several years, and pedons 2, 3 and 4 were cited close to actively

Table 4: Morphological Characteristics of Fwarti Soils, Bukuru

Pendon	Horizon	Depth (cm)	Colour	Mottles	Textural class	Structure	Consistency	Other features	Boundary
1	Ap	0-20	$7.5YR^{6}/_{8}$		SL	0sg	lo	mp, 3fr	ca
	Bt	20-950	$7.5YR^{7}/_{8}$	$2.5YR^{5}/_{8}$	SCL	2fgm	fbr	mp, 2fr	dw
	C	95-200	$2.5YR^{6}/_{8}$	$10YR^{5}/_{3}$ $10YR^{5}/_{4}$	SL	3csbk	fm	1fr, grv	-
2	Ap	0-18	$10YR^{5}/_{8}$		SL	0sg	lo	mp, fr, bo	dw
	B	18-110	$10YR^{6}/_{8}$	$2.5YR^{5}/_{8}$	SCL	1gm	frb	mp, 2fr, grv	ca
	C	110-200	$10YR/_{3}$	$2.5YR^{5}/_{8}$ $10YR^{5}/_{3}$	SL	3csbk	fm	2fr, bo	-
3	Ap	0-14	$7.5YR^{5}/_{8}$		SL	1cgm	lo	mp, 3fr, bo	Cw
	Bt	14-93	$7.5YR^{6}/_{8}$		SCL	2fgm	frb	2fr, bo, grv	dw
	C	93-200	$2.5YR^{6}/_{8}$		SL	2csbk	fm	-	-
4 (control)	Ap	0-20	$10YR^{6}/_{6}$		SL	3csbk	fm	mp, 3fr, bo, hc	cw
	Bt	20-70	$7.5YR^{7}/_{6}$		LS	2csbk	frb	1fr, bo, grv	dw
	R	70-200	$2.5YR^{6}/_{8}$		S	2fsbk	frb	nr, grv	-

Structure: 0=structureless, 1=weak, 2=moderate, 3=strong, sg=single grain, cgrn= Coarse granular, csbk = coarse subangular blocky, fsbk= fine, subangular blocky, m=massive;. **Consistence:** lo=loose, frb=friable, vfr=very friable, fm=firm, efm=extremely firm;. **Roots**: 1=few 2=moderate, 3=many, fr= fine roots, co=coarse, mp = many pores, fp=few pores, hc=hydrocarbons, bo=biological origin evidence; **Boundary**: A= abrupt, C=clear, G=gradual, **S**=smooth, W=wavy, **GV**=gravels

Note: symbols or codes according to FAO, 2006 mined areas. Thus the thin Ap horizons for pedons cited near those areas could be as a result of the negative impacts of the tin mining activities in those areas.

The Ap horizons of Bukuru were quite distinct from the B Horizons, and are marked by clear boundaries due to the melanization of organic matter in the Ap Horizons (Plate 2). The surface horizon consists of well-drained, light brown to dark brown gravelly sandy loam over yellowish red (5YR 5/6) to gravelly sandy clay loam subsoil (Plate 3). Fanning and Fanning, (1989) reported that oxidation-reduction of goethite coupled with leaching was suggested to give hues 5YR to 2.5YR in some of the soils of Bukuru. This report was also confirmed by Hassan et al. (2015), who further reported that hematite could cause the reddish color in the subsoils of Bukuru, Jos. The darker color of the Ap Horizons was probably due to melanization from humified organic matter, while the bright colors of some of the pedons were probably due to drainage conditions (Brady and Weil, 2010).

The physical, properties of Bukuru soils are presented in Tables 4. Bukuru soils showed higher sand (71 %) and lower in silt (12 %) and clay (17 %) contents. The sand fraction was above 70%, giving the characteristic sandiness of Bukuru soils, which could be attributed to the nature of parent materials from which the soils were formed (Akamigbo and Asadu, 1983), and coupled with the aggressive tropical climate and land-use history of the study area. Similar observations were made by Asadu et al. (1997) and Onweramadu, (2008). Soils with high sand content and low clay content have high leaching potentials. For instance, for irrigation purposes, loamy and clay textures are classed as high moisture-holding capacity, while loamy sands and sands have low moisture-holding capacity. The sandiness of Bukuru soils, therefore, suggests leaching of nutrients, thus reducing the productivity. One striking feature of the sand fraction is the decrease in-depth, but with an abrupt increase in the third horizon. This observation conforms with the reports of Hassan et al. (2015). The increase in clay content in the Bt horizons in all the pedons sunk except for Gyel pedon 2 and Rabi pedon 1, therefore, confirms the field evidence of clay translocation (cutans) from the surface horizons into the Bt horizons of the pedons, (Tables 1, 2 and 3), strongly suggesting that the Bt horizons of Bukuru are argillic/Kandic horizons. Bukuru the study area

The bulk density of the surface horizons of the three locations of Bukuru ranged from 1.46 mgcm-3 to 1.54 mgcm-3 with a mean of 1.49 mgcm-3 (Tables 4). They are within the limits for bulk density values for surface horizons, that is, >1mgcm-3, which was consistent with the previous report by Hassan et al. (2015). Plant performs best in bulk densities below 1.4 mgcm-3 and 1.6 mgcm-3 for clayey and sandy soils respectively (Donahue et al. 1990). Generally, the above bulk density values for Bukuru soils are low and indicate that the soils have high macroporosity and are thus well-aerated as well as non-compacted by farm machinery. Similar observations were made by (Esu, 2010). The bulk density increases with depth which corresponds with a decrease in porosity with depth. This is attributed to an increase in clay content in the sub-surface horizon. Similar results were also reported by Idoga et al. (2006) in the soils of Samaru area, Kaduna State, Nigeria and Hassan et al. (2015).

The chemical characteristics of Bukuru soils are presented in Table 5. Bukuru soils had a mean pH (H2O) value of 6.2 (Table 5), therefore the soils were slightly acidic based on the critical limits for interpreting fertility levels of analytical parameters for Nigerian soils (Chude et al. 2011). The low pH may have contributed to the low nutrient status of Bukuru soils. Oviasoge and Ndiokwere, (2008), reported that lower pH favors the availability, mobility, and redistribution of the metals lead (Pb) and Cadmium (Cd) due to solubility of their ions in the environment. The values of organic carbon content (Organic C) of

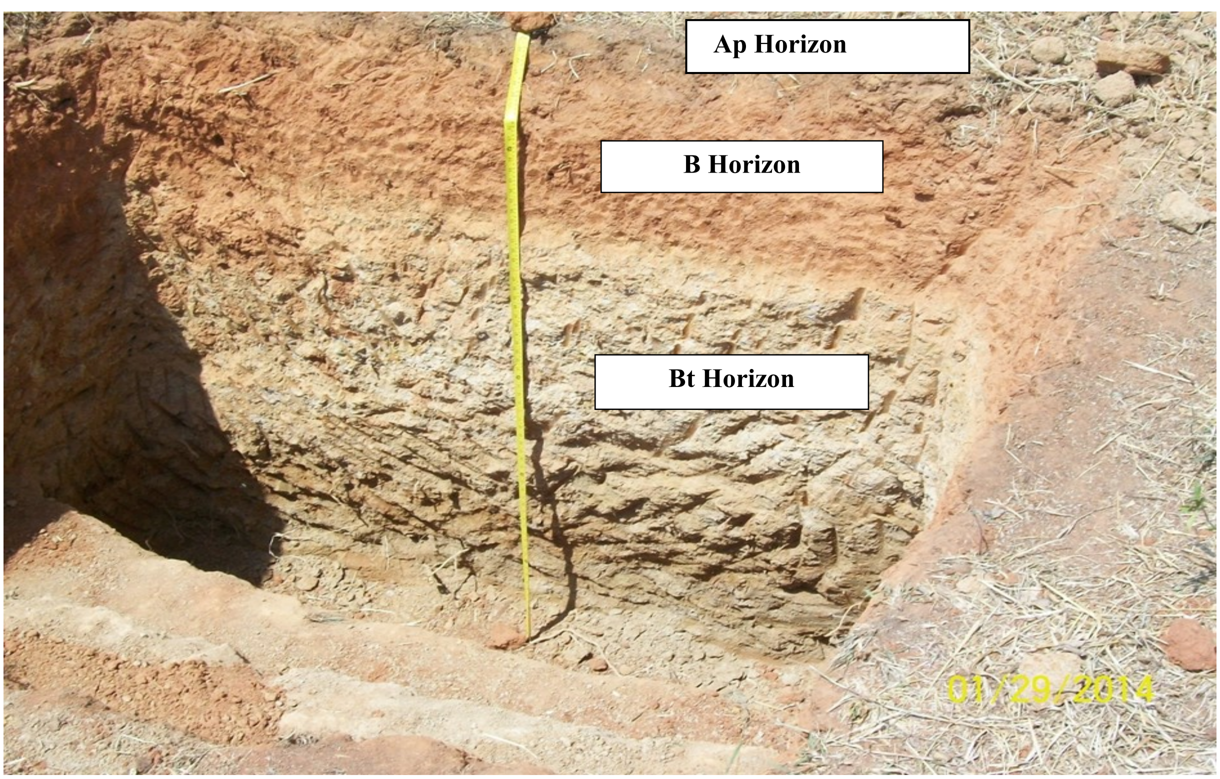

Plate 2: Soil profile at Rabi location, Bukuru showing different pedogenic horizons.

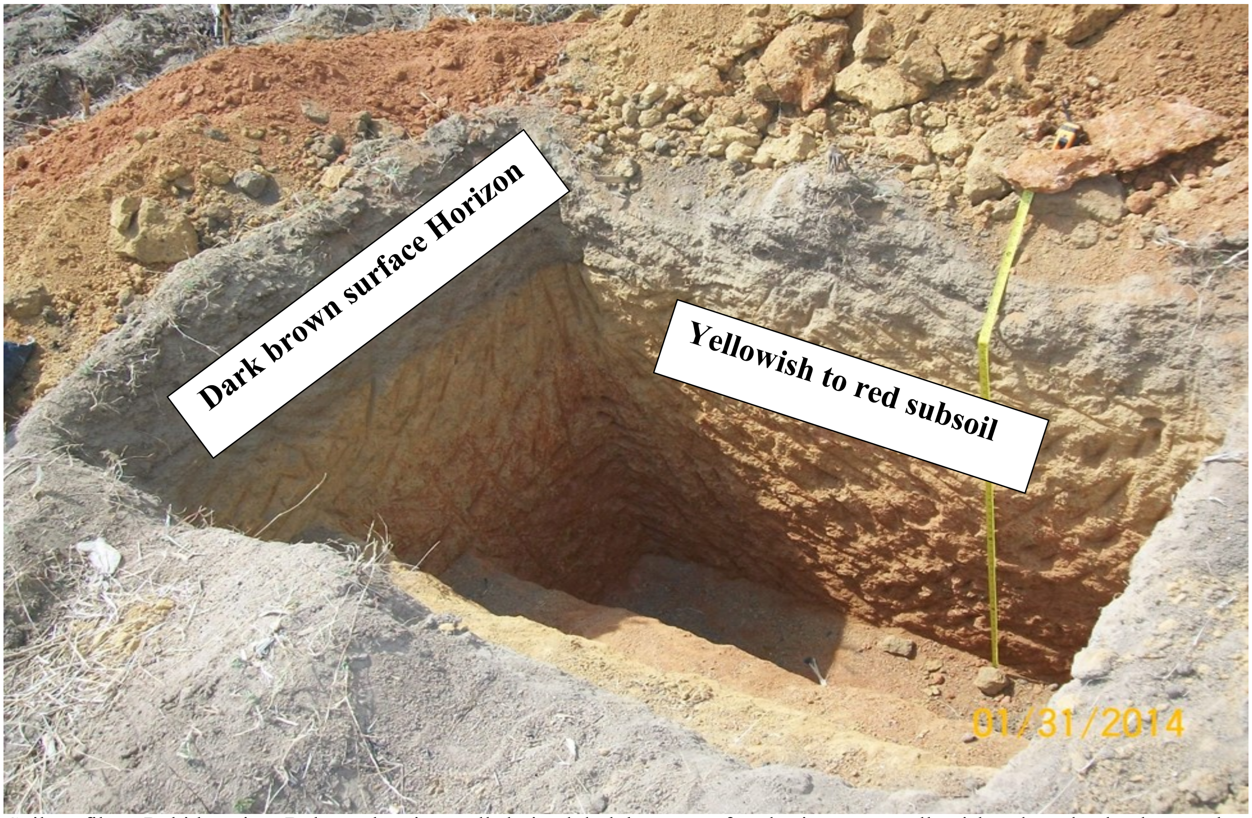

Plate 3: Soil profile at Rabi location, Bukuru showing well-drained dark brown surface horizon over yellowish red sandy clay loam subsoil

Table 5: Physical Properties of Bukuru Soils

Location	Clay (%)	Silt (%)	Fine Sand (%)	Coarse Sand (%)	Total Sand %	Bulk Density (gcm^{-3})	Total Porosity (%)	Texture Class
Gyel	15	10	35	39	74	1.54	41.8	SL
Rabi	18	14	37	31	68	1.47	44.8	SCL
Fwarti	17	12	36	35	71	1.46	45.1	SL
Grand mean	17	12	36	35	71	1.49	43.8	SL
LSD (P≤0.05)	ns	ns	ns	ns		ns	ns	

LSD=Least significant Difference of means, SL = Sandy Loam and SCL = Sandy Clay Loam Data represent mean and standard error of 4 replicates, N=36.

Bukuru soils ranged from 5.4 gkg-1 to 6.9 gkg-1. However, the mean value of organic carbon in the study area of Bukuru was 6.3 gkg-1 (Table 5) and was graded low (Esu, 1991). The low organic carbon content is attributed to the paucity of vegetation, low return of crop residues and mineralization of the Ap horizon which conforms with the findings of Yaro et al. (2006) and Hassan et al. (2015). This will lead to low fertility status of the soil and therefore low agricultural productivity. Total Nitrogen (N) in Bukuru soils ranged from 1.8 gkg-1 - 2 gkg-1. The mean value was 1.9 gkg-1. The mean values were very low typical of tropical soils (Landon, 1999). The mean value of available phosphorus (P) in soils of the three locations of the study area, ranged from 0.93 mgkg-1 to 7.46 mgkg-1, with an overall average mean of 4.8 mgkg-1 (Table 5). These values were below the critical limit of 10 mgkg-1 of P for interpreting fertility levels of analytical parameters for Nigerian soils (Esu, 1991). Available P in Bukuru soils was, therefore, graded low.

The exchangeable bases of Bukuru soils were dominated by Ca^{2+} and Mg^{2+} which had a mean value of 15.7 cmolkg-1 and 2.60 cmolkg-1 above the critical limits 5 cmolkg-1 and 1 cmol kg-1, therefore, graded as high for Nigerian soils (Table 1). However, Na^+ had 0.02 cmolkg-1, while K^+ had a mean value of 0.06 cmolkg-1, which were below the critical limits of 0.1 cmolkg-1 regarded as the lower limit for Na^+ and 0.15 cmolkg-1 for K^+ for fertile soils in Nigeria, (Table 1). This confirms previous studies by Olowolafe (1995) and Hassan et al. (2015), who reported similar results on the Jos plateau soils. The low exchangeable bases could be attributed to acidifying prop-

Table 6: The Chemical Properties of Bukuru Soils

			Fine	Coarse	Total	Bulk Density	Total	Texture Class				
		pH	**C**	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**CEC**	**AL**	**H**	**BS**	**P**
Location	**H_2O**	**KCL**	**gkg^{-1}**				**$cmolkg^{-1}$**				**%**	**$mgkg^{-1}$**
Gyel	7.1	6.3	6.9	0.20	0.13	17.50	2.78	21.34	0.00	1.15	95.77	7.5
Rabi	6.1	5.7	6.5	0.02	0.02	15.13	2.27	18.40	0.00	1.10	94.46	6.0
Fwarti	5.6	4.1	5.4	0.03	0.03	12.87	2.75	16.72	0.00	1.43	93.97	0.9
Grand Mean	**6.2**	**5.0**	**6.3**	**0.24**	**0.06**	**15.17**	**2.60**	**18.82**	**0.00**	**1.23**	**94.65**	**4.8**
LSD ($P \leq 0.05$)	0.62	0.73	0.5	0.01	0.10	2.48	ns	2.89	0.00	0.180	1.39	ns

LSD = Least significant Difference, C = Carbon, Ca= Calcium, Na= Sodium, K=Potassium, CEC=Cation exchange Capacity, Al=Aluminum H=Hydrogen, BS= Base Saturation, P=Phosphorus and ns = not significant

Data represent mean and standard error of 4 replicates, N=36.

erties of organic matter, aluminum and the leaching of exchangeable bases (Tisdale et al. 2004). The exchangeable acidity of Bukuru soils were dominated by H+, and generally low, with a mean value of 1.23 cmolkg-1, depicting the slightly acidic nature of the soils (Table 5). This confirms the results of previous studies by Akpan-Idiok et al. (2013)) and Hassan et al. (2015), who reported low exchangeable acidity, <1.6 cmolkg-1 on the Jos plateau. The value of KCl pH bears a strong correlation with Al3+ as. Al displaced by K+ on the exchange complex consumes OH+ and increases H+ (Amos Tau-Tua et al. 2014). This explains the dominance of the exchangeable acidity of Bukuru soils by H+.

All the soil samples analyzed had very high base saturation (>90 %), with a mean value of 94.65 % as shown in Table 5. These values were higher than the critical limit established for Nigerian soils (Esu, 1991) and also followed the same pattern established by (Isirimah, 2003). This indicates the presence of soluble forms of basic cations in soil solution and that applied fertilizers will be in an available form for crop uptake (Akpan-Idiok et al. 2013). Therefore, Percentage Base Saturation gives us another tool to use in predicting the soil's ability to provide adequate crop nutrients, and indicate needed changes in fertilizer or lime programs (Kissel et al. 2014). Percentage base saturation is used in soil characterization and taxonomy, for example, soils with an argillic or kandic horizon and a base saturation < 35% at 2 m depth or 75 cm below a fragipan is a ultisols, (Akamigbo, 2010; Brady Weil, 2010).

4.0. Conclusion

Based on the field characterization presented in Tables 1-3 and the physicochemical properties presented in Tables 4 and 5, the diagnostic criteria for the classification of Bukuru soils according to the USDA Soil Taxonomy, (Soil Survey Staff, 2010), include a "ustic soil moisture regime" due to a pronounced dry season (lasting 3-6 months) and an isothermic soil temperature regime (annual soil temperature is 150C or higher but lower than 220C), characteristics of the tropics (Akamigbo, 2010; Brady and Weil, 2010). Furthermore, Bukuru soils have well-developed horizons, characterized by the sub-surface accumulation of clay (argillic), dominated by kaolinite (low activity clay), oxides of Fe and Al, (Ogunwale, 1985; Hassan 2010) and high base saturation, >90 %, (Table 5), therefore, the subsurface is argillic/kandic. The surface horizons were "Ochric epipedon" because the horizons were generally light-colored, have low organic carbon content (6.3 gkg-1), may be hard and massive when dry, and includes horizon of organic matter but is too thin to meet the requirements for histic and filistic epipedon (Akamigbo, 2010). These characteristics qualify Bukuru soils as Alfisols (Order); Ustalfs (Suborder); Argilic/Kandic (Great Group); Typic,(Subgroup); having an Ochric epipedon, (Soil Survey Staff, 2010; Akagmigbo, 2010). Bukuru soils were therefore classified according to the Keys to Soil Taxonomy of the USDA as: "Typic Isothermic Kandic Ustalfs" having ochric epipedon.

From field characterization data and laboratory results presented in Tables 1-5, Bukuru soils have the following morphological and physicochemical characteristics:

Diagnostic argillic B horizon with evidence of translocation of clay from the surface to the B horizons starting from < 100 cm from the surface of the soils

The mean Cation Exchange Capacity (CEC), of the soils of the three locations of the study area, ranged from 16.72 to 21.34 cmolkg-1, with mean of 18.82 cmolkg-1

Percentage Base Saturation (PBS) of the soils of the three locations ranged from 93.77% to 95.77% and therefore, were greater than 50% Base saturation

The pH of Bukuru soils was slightly acidic, with a mean value of 6.2

According to World Soil Map Legend (WRB), 2014), Lixisols are soils with argillic B diagnostic horizons starting ≤100 cm from the soil surface; and with a CEC (by 1 M NH4OAc, pH 7) of < 24 cmolkg-1 clay in some part of the argic horizon within ≤50 cm below its upper limit, and base saturation (NH4OAC) >50% within 125 cm of the pedon, with hard material or a cemented or indurated layer starting ≤ 100 cm from the mineral soil surface. Therefore, Bukuru soils were correlated to "Lixisols" at a higher level, and "Rhodic/Chromic" as a principal qualifier.

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