PROFILE DISTRIBUTION AND PEDOGENIC PROPERTIES OF THE FORMS OF IRON AND MANGANESE, AND CLAY MINERALOGY OF SOME SOILS OVERLYING THE BASEMENT COMPLEX OF NORTH-EASTERN NIGERIA.

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ABSTRACT

Soil genesis and the distribution of forms of Fe and Mn, as well as clay minerals in the soils overlying Basement Complex in the tropics act as important fertility and pedogenetic indices. In this investigation, the distribution and pedogenic properties of the forms of Fe and Mn, and clay mineralogy in some soils overlying the Basement Complex of North-eastern Nigeria were examined. Guided by the contour and geologic maps, crestal positions were identified in the soils over porphyritic-granite, pegmatite and granite-gneiss in Kona, Bakin-Dutse and Garin-mallum, respectively. Three crests were identified in each of the three lithologies, resulting in nine soil profile pits and thirty-three soil samples. Standard laboratory procedures were used to analyze the soil samples for general soils properties, as well as the forms of Fe and Mn, and clay mineralogy. The soils were slightly acid to slightly alkaline with low organic matter content and CEC that is dominantly influenced by clay content. Dithionite Fe increased with soil depth in most of the soil profiles with values that accumulate in the Bt and Crt horizons and appear higher in the soils over granite-gneiss, while oxalate Fe and Mn were irregularly distributed in the studied soils. Higher values of crystalline Fe were obtained in the B and C horizons. The mineralogy of the clay fraction showed dominance of quartz and kaolinite over montmorillonite with trace amounts of rutile and gibbsite. The concentration of the forms of Fe and Mn, and clay mineralogy typify highly weathered tropical soils.

Keywords: pedogenesis, sesquioxides, clay mineralogy, Basement Complex

Highlights

- The soils have low soil organic matter and CEC that is largely influenced by clay amounts.
- Dithionite Fe and Mn increased with increasing soil depth, accumulating in the Bt and Crt horizons.
- Forms of Fe and Mn, and clay minerals are fertility and pedogenetic indices.
- Dominant clay minerals are quartz, kaolinite and microcline with traces of gibbsite.

INTRODUCTION

Soils in the northern guinea savannah of Nigeria are intensively cultivated, but still preferred by farmers as a result of the favourable solar radiation during growing season, reliable and well-distributed rainfall, as well as lower night temperatures that promote litter accumulation. Lithology has major influences on the overlying soils in an area and provides a starting material upon which other soil forming factors act to give rise to soil, and influences the nature and properties of soils (Esu, 2010, Asadu et al., 2012). Consequently, soils formed over a lithology have specific properties, support specific crops and result in a lithosequence of soils connecting the lithology(Usul and Dengiz, 2010; Maniyunda, 2012).

The northern guinea savannah of Nigeria is predominated by crystalline Precambrian Basement Complex rocks. The Basement Complex is an assemblage of migmatite-gneiss, schist, older granite and under-formed acid dykes (Obaje, 2009), and occupies near 50 % of the Nigerian surface area (Ogezi, 1977). The diverse soil types developed over thesecombinations of rocks support arable/food (yam, cassava, etc.) and tree crop (rubber, oil palm, timber) production in other regions of Nigeria (Eshett et al., 1990).

Soils in the Nigerian guinea savannah are slightly acid, less leached, coarse textured and are dominated by sandy loam or loam over gravelly clay loam (Esu and Ojanuga, 1985) with lower clay content in the surface soils (Lawal*et al*. 2013). Soils of the region are fragile (Salako, 2003), gravelly and shallow (Salako*et al*., 2002) with large proportion of sand and low organic matter content (Adewale and Odoh, 2017). The low organic matter in the surface soils of the Nigerian Savannahhas been attributed to the rapid rate of mineralization of organic matter, high degree of sheet erosion as well as the use of grasses in the region for roofing and grazing (Esu, 2010). The soils have been variously classified as Luvisols (Salako, 2003) and Lithisols **(**Ogungbile*et al*. 1999).Among other factors in the study environment, low crop yield has been attributed to soil fertility decline (Salami *et al*., 2011; Olaniyan, 2015).

Iron and manganese dominated minerals are collectively referred to as manganiferous minerals. The presence of Fe-Mn concretions in the subsurface soils of the northern guinea savannah of Nigeria have been observed by Babalola *et al*. (2019). They act as depositions of Fe and Mn (Sun et al., 2018) and are common products of pedogenesis (Tan et al., 2004). The forms of Fe and Mn are commonly present as amorphous, crystalline and organic complexes. Soil physical and chemical properties are influenced by the nature, amount and distribution of these oxides in soils (Schertmann and Taylor, 1989., Jelic*et al*., 2011) and have been used to make predictions of the degree and stage of soil genesis (Durn*et al*., 2001; Igwe*et al*., 2001; Osodeke*et al*., 2005; Kefas*et al*., 2020). The influence of the oxides and hydroxides of Fe and Mn on soil physical as well as chemical properties cannot be unattended in studies related to agricultural soils as the dominance of these oxides and their minerals influence the fertility status of the soils.

Agricultural production in the Nigerian northern guinea savannah is focused on crop and livestock production. Crop production in the area is with a focus on cereals like millet, sorghum, maize and wheat, as well as legumes like cowpea, groundnut and soybean (Ajeigbe*et al*., 2010; Foli, 2012). Though livestock is important in the farming system of the area (Smith *et al*., 1997), it is often integrated with crops (Foli, 2012) as both have reciprocal benefits. Importantly, farmers in the region combine organic and inorganic inputs as well as intercrop cereal-legume mixtures to consciously manage and improve soil fertility (Harris, 1998; Hoffmann and Gerling, 2001). Earlier, Raji*et al*. (2000), Igwe (2001), and Ibia (2002) emphasized the forms of sesquioxides in northwest Nigeria, flood plains of Niger, and southeast Nigeria, respectively. The soils of northern guinea savannah seem to have been studied however, only a few reports have been made of the mineralogy and forms of sesquioxides in relation to the genesis of soils overlying the Basement Complexes. The present study is therefore focused on the distribution and pedogenic properties of the forms of Fe and Mn, and clay mineralogy of some soils overlying the Basement Complex of North-eastern Nigeria.

MATERIALS AND METHODS

Location, geology and climate of the study area

The study was conducted in Taraba State (6^{o}30′, 9^{o}30′ N; 9^{o}00′, 12^{o}00′ E), north-eastern Nigeria.The selected study sites were in Kona (08^o 57´0´´ N and 011^o 21´0´´ E; 393 m), Garin-mallum (08^{o}51´0´´ N and 011^{o}18´0´ E; 268 m) and Bakin-Dutse (08^{o}50'14.6''N and 011^o 17 '43.0''E; 247 m). Undifferentiated Basement Complex rocks dominate the geology of the area. However, Precambrian granitic and migmatite gneisses with outcrops of the rocks occur at intervals. The study area is characterized by tropical climate with distinct wet (7 months) and dry (5 months) seasons and mean annual rainfall which ranges from 800 mm in the northern agricultural zone to over 2000 mm in the southern agricultural zone of the state. Precipitation is lowest in January with a peak in August (217 mm). Mean annual temperature varies from 28.4 in the coolest month of December to 37 ^{o}C in the hottest month of March (NIMET, 2009). Taraba state is characterized by guinea savannah, sub-sudan vegetation and a semi-temperate climate with luxuriant pasture and short trees in the Mambilla plateau area.

Field and laboratory study

Reconnaissance visits were carried out to the study sites and the underlying lithology was identified as porphyritic-granite in Kona, granite-gneiss in Garin-mallum and pegmatite in Bakin-Dutse with the aid of the geology map of Taraba State obtained from the Nigerian Geological Survey Agency. These geologic materials occupy a vast expanse with broad agricultural value. The contour maps of the selected areas weredeveloped in the ArcGIS environment and used for the identification of soils on the crest. Three soil profile pits were sited on three crests in each of Kona, Garin-mallum and Bakin-Dutse, respectively. Nine soil profile pits were dug and used for the study. The pedons were delineated and sampled bottom-top from pedogenic horizons. Standard cylindrical cores were used in the collection of soil samples meant for bulk density determination. Soil samples were air dried under laboratory conditions, grindedand passed through a 2 mm sieve. The fine earth fraction (< 2 mm) of the pedogenic horizons was used for the analyses of all parameters. However, samples from theendopedons of each soil profile were bulked, subsampled and used for clay mineralogy analysis. Particle size distribution was determined by the Bouyoucos hydrometer method, while soil pH was determined in H_2O by the ratio 1:2.5 (soil: water). Organic carbon was obtained by the Walkley-Black modified acid-dichromate method, while 1 *N* neutral NH_4OAc was used as extractant in the determination of cation exchange capacity. Dithionite and oxalate forms of iron and manganese were determined by the procedures of Mehra and Jackson (1960) as described by Soil Survey Staff (2014). The mineralogy of the clay fraction was determined by using an X-ray diffractometer with Ni-filtered Cu-Kα radiation at 40 kV, 30 mA and at a wavelength of 1.54 Å. The type clay minerals in the samples were identifiedon X-ray diffractograms (Soil Survey Staff, 2014).

RESULTS

General properties of the soils

The results of the general properties of the soils are presented in Table 1. The soils were dominantly sandy loam and loamy sand, and sandy clay loam in the Crt horizons of soils over granite-gneiss. The soils were dominated with sand fraction with values exceeding 700 g/kg in most horizons and coarse sand occurring in greater amounts than the fine sand fraction. Clay amount increased in the B horizons except in some sols over porphyritic-granite (BDCP2, BDCP3) and pegmatite (KCP2), where clay amount remained constant or decreased with soil depth. Bulk density values were within the range of 1.47-1.85 Mg/m^3 in all the studied soils with most values in the subsurface soils greater than those in the surface soils.

Soil pH (H_2O) values ranged from 5.4 to 7.5 in the entire soils with the least values occurring in most surface soils and the soils over pegmatite (KCP2 and KCP3). Organic carbon had a range of 0.041-1.726 g/kg in the entire soils with values higher in the surface soils, and particularly in the soils over pegmatite. However, comparatively lower values were obtained in KCP3. Cation exchange capacity had values with ranges of 7.2-19.6, 6.0-28.0 and 8.0-20.8 cmol/kg in the soils over porphyritic-granite, pegmatite and granite-gneiss, respectively.

Table1: General properties of the Soils

Horizon	Depth	Clay	Silt	fine sand	Coarse sand	Texture	Bulk density	pH	OC	CEC
Porphyritic granite										
BDCP1		…………	g/kg	…………….			Mg/m^3		g/kg	cmol/kg
Ap	0 – 20	100	90	390	420	LS	1.82	6.2	0.375	10
Btv	20 – 81	180	70	370	380	SL	1.53	5.8	0.375	16.8
Bt	81 – 128	140	70	370	420	SL	1.85	6.6	0.375	14
Ccv	128 – 178	120	70	300	510	SL	1.74	6.7	0.075	15.2
BDCP2										
Ap	0 – 35	80	130	410	380	SL	1.54	6.1	0.781	9.2
Btv	35 – 106	80	50	400	470	LS	1.85	6.9	0.164	10
CBtv	106 – 173	80	190	440	290	SL	1.84	7.1	0.164	7.2
BDCP3										
Ap	0 – 12	120	70	370	440	SL	1.47	6.9	1.013	16.4
CB	12 – 62	80	70	300	550	LS	1.59	6.5	0.263	19.6
C	62 – 126	80	50	350	520	LS	1.79	6.9	0.075	9.6
Pegmatite										
KCP1										
Ap	0 – 12	100	90	320	490	LS	1.61	6.6	1.439	10.8
AB	12 – 38	80	50	340	530	LS	1.66	6.3	0.37	9.2
Bt	38 – 63	220	290	410	80	SCL	1.66	6.3	0.37	12.4
CB	63 – 123	180	210	420	190	SL	1.79	6.4	0.247	8
Bt2	123 – 159	120	210	320	350	SL	1.52	7.3	0.123	8
Cvt	159 – 176	90	170	340	390	SL	1.72	7.2	0.041	6.4
KCP2										
Ap	0 – 20	100	50	320	540	LS	1.78	5.4	1.726	9.6
Bt1	20 – 62	80	110	440	370	LS	1.61	5.9	1.069	28
Bt2	62 – 126	80	90	630	200	LS	1.7	6.4	0.411	16
BC	126 – 168	80	70	300	550	LS	1.72	6.6	0.164	9.6
C	168 – 200	120	90	340	450	SL	1.58	6.6	0.123	6
KCP3										
Ap	0 – 46	80	30	270	620	LS	1.69	6.5	0.244	10
Bt	46 – 97	220	250	610	120	SCL	1.68	5.8	0.529	16.8
Cr	97 – 145	80	30	180	710	LS	1.74	6.3	0.081	15.2
Granite-gneiss										
MCP1										
Ap	0 – 12	100	70	430	400	LS	1.65	6.7	1.676	11.2
B	12 – 36	120	90	360	430	LS	1.64	6.4	0.479	14
Crt	36 – 100	220	70	320	390	SCL	1.66	6.6	0.439	20.8
MCP2										
Ap	0 – 12	100	70	330	500	LS	1.51	6.7	0.838	13.6
Bt	12 – 38	120	70	330	480	LS	1.73	6.7	0.798	8
Crt	38 – 110	220	90	530	160	SCL	1.82	6.5	0.082	17.6
MCP3										
A	0 – 30	80	70	360	490	LS	1.66	7.1	1.058	8.8

B	30 – 80	100	90	360	450	LS	1.69	7.5	0.326	12.4
C	80 – 155	100	70	360	470	LS	1.65	7.4	0.285	19.2

Higher values of CEC were obtained in the endopedons, particularly in regions of clay accumulation.

The forms of Fe and Mn and their derivatives as well as the mineralogy of the clay fraction of the soils are presented in Table 2. The distribution of the major forms is presented in Fig. 1a, b, c.

Table 2: Pedogenic distribution of forms of Fe and Mn, and Mineralogy of the clay fraction

Horizon	Depth	Fe_d	Fe_o	Cry. $Fe_{(d-o)}$	Fe_o/Fe_d	$CoFe_d$	Mn_d	Mn_o	Cry. $Mn_{(d-o)}$	Mn_o/Mn_d	$CoMn_d$	Mineralogy
	Cm	…………..mg/kg………………					………..mg/kg………….					
Porphyritic-granite												
BDCP1												
Ap	0 – 20	2063.6	773.6	1290	0.37	0.021	237.1	131.1	106	0.55	0.002	
Btv	20 – 81	2793.7	1206.2	1587.5	0.43	0.016	110.6	66	44.6	0.60	0.001	
Bt	81 – 128	2666.3	1384.7	1281.6	0.52	0.019	95.2	515	419.9	5.41	0.001	
Ccv	128 – 178	3047.7	1543.2	1504.5	0.51	0.025	131.4	70	61.4	0.53	0.001	GQ
BDCP2												
Ap	0 – 35	2266.5	1485.2	781.3	0.66	0.028	82.4	83.5	1.1	1.01	0.001	
Btv	35 – 106	3089.1	2312.7	776.4	0.75	0.039	131.1	62.7	68.4	0.48	0.002	
CBtv	106 – 173	2977.2	1981.4	995.8	0.67	0.037	52.1	29.0	23.1	0.56	0.001	MQ
BDCP3												
Ap	0 – 12	2473.1	1201.5	1271.6	0.49	0.021	151.7	6.0	145.7	0.04	0.001	
CB	12 – 62	2377.1	683.2	1693.9	0.29	0.030	56.1	22.1	34	0.39	0.001	
C	62 – 126	1421.6	481.3	940.3	0.34	0.018	402.1	231.8	170.3	0.58	0.005	MQC
Pegmatite												
KCP1												
Ap	0 – 12	2548.9	1051.4	1497.5	0.41	0.025	84.85	83.6	1.25	0.99	0.001	
AB	12 – 38	1936.2	966.1	970.1	0.50	0.024	46.15	43.0	3.15	0.93	0.001	
Bt	38 – 63	2942.2	904.4	2037.8	0.31	0.013	17.25	21.6	4.45	1.25	0.000	
CB	63 – 123	2090.9	1002.6	1088.3	0.48	0.012	35.45	21.7	13.75	0.61	0.000	
Bt2	123 – 159	2740.15	868.6	1871.55	0.32	0.023	315.8	40.9	274.9	0.13	0.003	
Cvt	159 – 176	3021.0	649.4	2371.6	0.21	0.034	25.5	34.8	9.3	1.36	0.000	K
KCP2												
Ap	0 – 20	3071.4	1316.7	1754.7	0.43	0.031	14.25	141.7	127.45	9.94	0.000	
Bt1	20 – 62	3199.05	1234.8	1964.25	0.39	0.040	98.05	76	22.05	0.78	0.001	
Bt2	62 – 126	2715.45	646.1	2069.35	0.24	0.034	51.45	31.1	20.35	0.60	0.001	
BC	126 – 168	2662.9	374.4	2288.5	0.14	0.033	25.1	11.4	13.7	0.45	0.000	
C	168 – 200	2633.1	894.1	1739.0	0.34	0.022	87.7	49	38.7	0.56	0.001	IQA
KCP3												
Ap	0 – 46	2548.0	1396.1	1151.9	0.55	0.032	15.4	97.4	82	6.32	0.000	

N/B: Q=quartz, I=illites,

Bt	46 – 97	1636.95	654.2	982.75	0.40	0.007	17.24	145.4	128.16	8.43	0.000	
Cr	97 – 145	2730.3	1007.5	1722.8	0.37	0.034	14.15	146.1	131.95	10.32	0.000	QM
Granite-gneiss												
MCP1												
Ap	0 – 12	3186.45	941.1	2245.35	0.30	0.032	232.6	86.4	146.2	0.37	0.002	
B	12 – 36	3323.9	1356.4	1967.5	0.41	0.028	322.7	94.4	228.3	0.29	0.003	
Crt	36 – 200	3269.15	1559.8	1709.35	0.48	0.015	145	51.3	93.7	0.35	0.001	QMiD
MCP2												
Ap	0 – 12	2192.3	682.2	1510.1	0.31	0.022	183.6	117.2	66.4	0.64	0.002	
Bt	12 – 38	2413.5	1225.6	1187.9	0.51	0.020	206.4	92.1	114.3	0.45	0.002	
Crt	38 – 200	2930.7	937	1993.7	0.32	0.013	171.8	93.5	78.3	0.54	0.001	IQK
MCP3												
A	0 – 30	2270.95	501	1769.95	0.22	0.028	231.9	84.6	147.3	0.36	0.003	
B	30 – 80	2762.85	910	2219.75	0.33	0.028	309.5	150.3	159.2	0.49	0.003	
C	80 – 155	3082.55	983.1	2099.45	0.32	0.031	242	92.1	149.9	0.38	0.002	OQ

K=Kaolinite, M=Montmorillonite, O=Orthoclase, D=Dolomite, A=Albite, C=Chrysotile, G=Gibbsite, M= Microcline, Fed and Mnd= dithionite Fe and Mn, Feo and Mno= oxalate Fe and Mn, Cry. Fe and Mn= Crystalline Fe and Mn, Fe_o/Fe_d and Mno/Mnd= Degree of activation of Fe and Mn, CoFed and CoMnd= comigration of Fe and Mn

Dithionite Fe (Fed) had a range of 1421.6-3089.1 mg/kg in the soils over porphyritic-granite with values that increased regularly with soil depth except in BCDCP3 where values decreased with soil depth, while dithionite Mn (Mnd) in the soils had a range of 52.1-402.1 mg/kg withirregularly distributed values. However,values appear higher in the plinthic and concretionary endopedons. Fe and Mn concretions are depositions of Fe and Mn (Sun et al., 2018), released from weatherable minerals and are indices of pedogenesis (Tan et al., 2004). In the soils developed over pegmatite, Fed was irregularly distributed with soil depth, and had a range of 1636.95-3199.05 mg/kg with higher values occurring in Cr and horizons of clay accumulation (Bt) except in BDCP3 where Fed decreased continuously with increasing soil

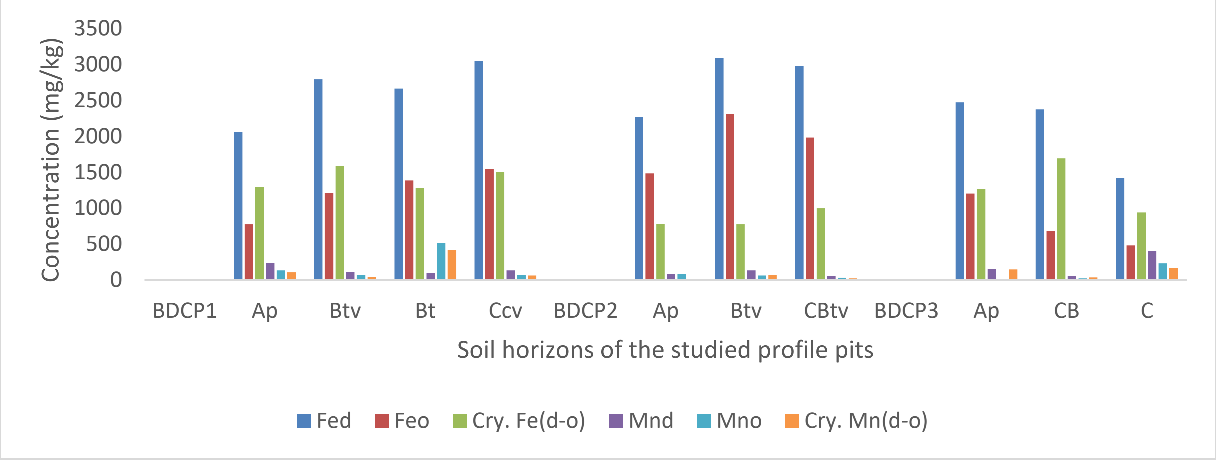

Fig. 1a: Soil profile distribution of the forms of Fe and Mn for Porphyritic-granite

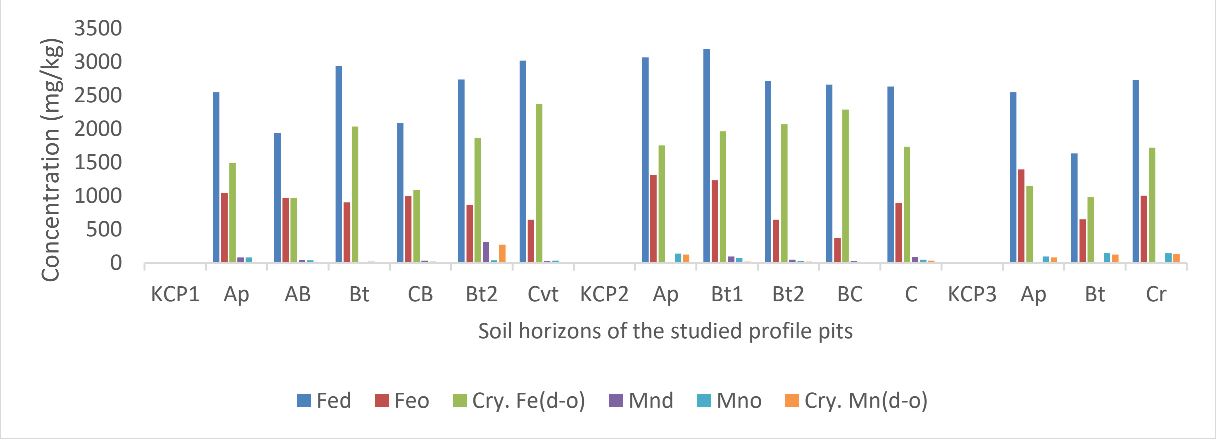

Fig. 1b: Soil profile distribution of the forms of Fe and Mn for pegmatite

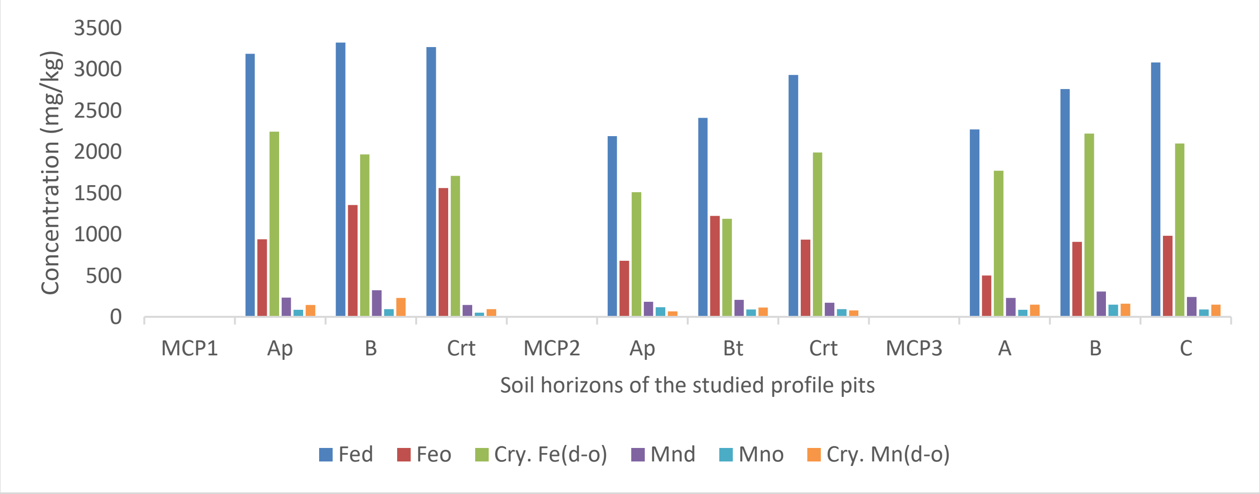

Fig. 1c: Soil profile distribution of the forms of Fe and Mn for granite-gneiss depth.

In the soils developed from pegmatite, 14.15-315.8 mg/kg was obtained for Mnd with the highest values in each pedon occurring in the Bt horizons.

Soils over granite-gneiss had range of 2192.3-3323.9 mg/kg for Fed with a regular increase in values in the endopedons. These values appear to be higher than those over other geological formations with a range of 145-322.7 mg/kg and comparatively higher values in the B horizons.

In all the studied soils, oxalate Fe was less than Fed with ranges of 481.3-2312.7, 374.4-1396.1, and 501-1559.8 mg/kg in the soils over porphyritic-granite, pegmatite and granite-gneiss, respectively. Though the values decreased irregularly with increasing soil depth in most of the profile pits, values in BDCP1, BDCP2, MCP1 and MCP3 appear to have increased withsoil depth. Oxalate Mn decreased with profile depth in most of the studiedsoils and increased irregularly in BDCP1, BDCP3, KCP3 and MCP3 with values ranging from 21.6 in KCP1 to 515 mg/kg in BDCP1.

There were clear indications of higher values of crystalline Fe in the B and C horizons of the studied soils, except in MCP1 where higher values were obtained in the Ap horizons.

Crystalline Fe had ranges of 776.4-1693.9, 970.1-2371.6 and 1510.1-2245.35 mg/kg in soils over porphyritic-granite, pegmatite and granite-gneiss, respectively. Values of crystalline Mnwere quite low compared to crystalline Fe with higher values occurring in the B and C horizons. Ranges of 1.1-419.9, 1.25-274.9 and 66.4-228.3 mg/kg, were obtained for crystalline Mn in soils over porphyritic-granite, pegmatite and granite-gneiss, respectively. However, KCP2 had higher values in the Ap horizons.

The bar charts in Figures 1a, b and c show the distribution of dithionite, oxalate and crystalline Fe and Mn. The charts indicate highest peaks for dithionite form for Fe and Mn in all soil horizons, while the concentrations of oxalate and crystalline forms alternate in amount. This trend was sustained for porphyritic-granite, pegmatite and granite-gneiss.

Active Fe ratio increased in the B and C horizons, especially in zones of clay accumulation (argillic horizons) for the studied soils. However, values of active Fe decreased with soil depth in BDCP3, KCP2 and KCP3. The values of active Fe were all less than 1.0. A similar trend in values were obtained for active Mn with values less than 1.0 except in some horizons in KCP1, KCP2 and MCP2 where values seem to be irregularly distributed with soil depth.

The values of co-migration of Fe were less than 0.040 in the studied soils and appeared irregularly distributed with soil depth. The values decreased in the B horizons of BDCP1, KCP1, KCP3, MCP1 and MCP3, while values increased continuously in other pedons. The co-migration of Mn presented very low ratios (<0.005) with most values being negligible.

Mineralogy of the clay fraction

The mineralogy of the clay fraction is presented in Table 2, while the X-ray diffractograms of the studied soils are presented in Figure 3. X-ray diffractograms of the clay fractions indicate that quartz,illite, kaoliniteand microcline were among the well distributed clay minerals, while quartz was dominant and represented in all the soils of the Basement Complex. Albite and montmorillonite were obtained in soils over pegmatite, while orthoclase and gibbsite were found in soils developed from granite-gneiss and porphyritic-granite, respectively.Dolomite and gibbsite were also detected in reasonable amounts in soils over granite-gneiss and porphyritic-granite.

Discussion

General properties of the soils

The predominance of sand, especially coarse sand over silt and clay indicates relative youthfulness. This may result in high hydraulic conductivity and loss of exchangeable bases to leaching, particularly in the surface soils. Similar soil textures have been reported by Eshett et al. (1990) in the Basement Complex soils of South-eastern Nigeria, while Aki et al. (2014) reported loamy sand and sandy loam in the surface soils developed from the Basement Complex of Akamkpa.They further attributed the decrease or constant clay amount with increasing soil depth to retarded downward movement of clay particles in suspension, caused by impeded drainage condition. Soil bulk density values will encourage the proliferation of roots in the surface and subsurface soils as values were less than 1.80 Mg/m^3 with the absence of hardpans in most pedons, except in BDCP3 (porphyritic-granite) where hardpan was observed at 126 cm and in MCP1 and MCP2 (granite-gneiss) where hardpans were observed at 100 and 110 cm, respectively. This may hinder root development.

Soil pH values indicate that most of the soils were slightly acid to slightly alkaline. Higher values of pH in the soils is due to the reduced precipitation in the study area which may have reduced the exposure of the soils to leaching. Lower values (4.3-5.3) were reported by Eshett et al. (1990) in the Basement Complex soils of south-east Nigeria. Soil organic carbon was low in the studied soils of the Basement Complex in the savannah region of Nigeria. The relatively high values of CEC obtained in regions of clay accumulation indicates that mineral colloids and not organic colloids are responsible for holding exchangeable cations in the soil exchange complex.

Forms of Fe and Mn

The highest mean values of Fed were obtained in MCP1 (granite-gneiss) and KCP2 (pegmatite), while MCP3 and MCP1 (granite-gneiss) recorded the highest Mnd. Increasing concentration of Fed and Mnd is synonymous with increasing weathering and soil age (Udo et al., 2009, Schwertmann, 1993). These pedons also had clear bulges at the B horizons indicating that weathered manganiferous minerals had been eluviated from the epipedons and illuviated in the B and C horizons over time; hence the pedons are the most developed. Higher values of Fed and Mnd in the endopedons is connected with more developed soils, since the movement of Fed occurs over time. The concentration of Fed increases with soil depth and age (Dolui and Bera, 2001).

Higher values of Fed and Mnd compared to Feo and Mno, respectively reflect relative dominance of crystalline over amorphous minerals in the Basement Complex soils (Dolui and Mondal, 2007). Values of oxalate Fe were less than 2000 mg/kg in the studied soils. When Feo is less than 2000 mg/kg, the values of Feo are regarded as low (Wilson et al., 2017) and may indicate the presence of allophane and imogolite in the soils. The low values may be due to high temperatures (Juo et al., 1974) which cause dehydration of Fe oxides leading to lower crystallinity (Sherman et al., 1964). Mnd and Mno had positive correlation with soil pH (r= 0.495) and bulk density (r= 0.378), respectively while Mno/Mnd negatively correlated with soil pH (r= -0.488). Non crystalline or amorphous forms of Fe and Mn are associated with soil organic matter (Osayande et al., 2013, Obi et al., 2009). The highest values of Mnd in each pedon occurred in the B horizons and indicate combined movement of Mnd with clay to the B horizons. Manganese containing minerals may have been weathered in the surface horizons and translocated alongside clay to the endopedons. This may have warranted the higher values of crystalline Fe and Mn in the B and C horizons. This process may be responsible for the occurrence of concretions in the C horizons of the studied soils. Higher values of crystalline Mn in the Ap horizon of KCP2 is due to the resistance or low exposure of related soil minerals to weathering agents which has slowed the process of weathering in the surface soils.Crystallinity increases at the expense of poorly crystalline forms with increased aging and it is facilitated by high temperatures and prolonged dry season (Seal et al., 2006).

Active Fe ratio was low in the studied soils as its values were < 0.18 (Wilson et al., 2017) or < 1 in the solum (Seal et al., 2006). Such low ratios indicate that free Fe oxides in the soils are at an advanced stage of crystallinity or aging (Mahaney et al., 1991). This has warranted most of the minerals to be eluviated in the company of clay to the endopedons.

When clay minerals weather in the soil surface as a result of their exposure to agents of weathering, they move in the company of clay, preferably fine clay to the endopedons in the process of eluviation-illuviation. This phenomenon was common in the entire soils as higher values of co-migrated Fe were obtained either in the B or C horizons, except in the soils over granite-gneiss (MCP1 and MCP2) where values rather decreased with increasing soil depth. This indicates relative youthfulness as the soils may not have been exposed sufficiently to the processes of pedogenesis. The co-migration of Mn (CoMnd) was however not obvious in the studied soils as very low values (<0.005) were obtained. In the soils over granite-gneiss, the ratios of CoMnd decreased with increasing depth, this affirms the trend of CoFed in the same soils. When CoFed decreases with soil depth, the implication is that Fe movement is partially independent of the movement of clay (Juo et al., 1974) and leads to the formation of distinct soil horizons when the ratio increases with soil depth (Dolui and Bera, 2001).CoFed had positive significant correlation with clay (r= 0.437) and CEC (0.368), while CoMnd correlated negatively with soil pH (r= -0.519).

Factor analysis of variable loadings for the soil properties

Eighteen (18) soil variables were compressed into 3 principal components (PC1, PC2, PC3) (Table 3). The most influential PC is PC1 and the least influential is PC3. The three PCs contributed 48.1 % of the total variation in soils overlying porphyritic-granite, pegmatite and granite-gneiss, respectively. 17.4 % of the total variation was accounted for by each of PC1 and PC2, while PC3 accounted for only 13.3 %. The three PCs had eigen values of >2.0 and had significant contributions to soil variability and were in turn adopted.

Table 3: Factor analysis

Variable	PC1	PC2	PC3
Clay	0.266427	0.169266	0.729528
Silt	0.397175	0.475660	0.484387
Fine sand	0.229727	0.281178	0.718136
Coarse sand	-0.287821	-0.456599	-0.811559
Bulk density	0.136676	-0.349662	0.130455
Ph	-0.706840	0.159792	-0.090599
Organic carbon	0.034407	-0.007433	-0.097297
Cation exchange capacity	-0.001010	0.028348	0.302659
Fed	-0.156558	0.165857	-0.021468
Feo	0.026976	-0.558994	0.190128
Cry. Fe	-0.220072	0.678335	-0.192738
Feo/Fed	0.140975	-0.692268	0.226947
CoFed	0.026662	-0.536288	0.442108
Mnd	-0.820625	-0.054426	0.181487
Mno	-0.081315	-0.599450	0.133553
Cry. Mn(d-o)	-0.361090	-0.409746	0.148111
Mno/Mnd	0.660461	-0.420321	-0.220969
CoMnd	0.693477	-0.345567	-0.225852
Porphyritic-granite	-0.164096	-0.603690	0.213775
Pegmatite	0.720066	0.424503	-0.384954
Granite-gneiss	-0.629742	0.151867	0.206597
R2X	17.4000	17.4000	13.3000
R2X(Cumulative)	17.4000	34.8000	48.1000

Eigenvalue	3.648000	3.652000	2.797000
%total variance	17.370000	17.390000	13.320000
Cum eigenvalue	3.648000	7.300000	10.100000

PC1 was influenced by soil pH, Mnd and CoMnd with loadings of -0.707, -0.821 and 0.692, respectively to the variation of the studied soils, and were negatively correlated with PC1 except CoMnd which was positively correlated. Crystalline Fe and Feo/Fed exerted their contributions to soil variation in PC2 with loadings of 0.678 and -0.692, respectively to soil variation. The least influential PC (PC3) was influenced by contributions from particle sizes of clay, fine sand and coarse sand with loadings of 0.729, 0.718 and -0.811, respectively to soil variation. The low loadings of the forms of Fe compared to Mn imply that soils over Basement Complex have a similar concentration of the forms of Fe.

Mineralogy of the clay fraction

The mineralogy of the clay fraction of soils developed over Basement Complex is presented in Table 2 and Figure 2. The dominance of the soils by quartz and kaolinite is typical of most tropical and highly weathered soils. Quartz is resistant to weathering (Tuncay et al., 2019), inert and chemically inactive, as a result, it dominates most tropical soils and contributes so little to chemical fertility as it has small surface area which is attributed to the Si-O broken bonds and Si-OH groups on particle edges. Its resistance has necessitated its dominance in the soils. The dominance of kaolinite over montmorillonite and other weatherable minerals with significant negative charges suggests advanced soil development, leaving kaolinite as the dominant crystalline mineral in the soils. Advanced weathering of the soils had resulted in gibbsite in some of the soils mainly from the transformation of primary minerals or neoformation from the recombination of Si in solutions. Kaolinite and quartz have low CEC and contribute so little to the activity and chemical fertility of soils. Tropical soils are dominated by kaolinite (Foth, 1990, Esu, 2010, Asadu et al., 2012). Gibbsite is favoured by high temperatures (Kampf and Curi, 2012) and high soil pH may facilitate its formation (SilvaNeto, 2008). Its presence as well as those of other Fe bearing minerals in most tropical soils has been linked to soil maturity (Ofem et al., 2020). In the present study, gibbsite was obtained in soils over porphyritic-granite.

Though scanty in most of the studied soils as a result of its very mobile nature, dolomite was obtained in the soils over granite-gneiss (MCP1). The solubility of dolomite in soils, rainfall and temperature regimes of the study area may have influenced its amount and lost as a result of dissolution and leaching (Ofem et al., 2020).

Montmorillonite is poorly distributed in the studied soils, and low compared to the wide distribution of kaolinite in the soils. Montmorillonite is a high activity and expanding clay mineral that imparts natural fertility on soils by virtue of its high CEC. The mineral may have been transformed to kaolinite during soil development under the influence of precipitation and leaching (Carroll and Hathaway, 1953). This transformative property may have informed the dominance of kaolinite over montmorillonite in the soils. In similar soils in southern Nigeria, Eshett et al. (1990) obtained kaolinite as the dominant phyllosilicate with smectite occurring in small amounts as well as goethite, mica, gibbsite, hematite and quartz, while Aki et al. (2014) reported quartz, microcline and kaolinite in the Basement Complex soils of Akamkpa.

Conclusion

This study examined some soil properties, forms of iron and manganese oxides as well as the clay mineralogy of soils overlying porphyritic-granite, pegmatite and granite-gneiss. Soils developed over Basement Complex are dominated by sand with bulk density values that encourage plant root proliferation. The soils are slightly acid to slightly alkaline with low organic matter content and CEC that is dominantly influenced by clay content. Dithionite Fe increased with soil depth in most of the soil profiles with values that accumulate in the Bt and Crt horizons and appear higher in the soils over granite-gneiss, while oxalate Fe and Mn were irregularly distributed in the studied soils. Higher values of crystalline Fe were obtained in the B and C horizons. The mineralogy of the clay fraction showed dominance of quartz and kaolinite and comparatively less microcline, illite, gibbsite and montmorillonite. The concentration of the forms of Fe and Mn, and clay mineralogy typify highly weathered tropical soils.

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REFERENCES

Adewale, B.D. and Odoh, N.C. (2017).Northern Guinea Savanna Edaphic Properties andNutrients Combination Impact on Maize Mycorrhizal Colonization and Biomass Yield.*Applied Tropical Agriculture,22 (1): 103-110*

Ajeigbe, H.A., B. B. Singh, et al. (2010). Improved cowpea-cereal cropping systems: cerealdouble cowpea system for northern Guinea savanna zone. IITA. Ibadan, IITA: 17.

Aki, E. E., Esu, I. E. and Akpan-Idiok, A. U. (2014). Pedological study of soils developed on Biotite-Hornblende-Gneiss in Akamkpa

Local Government Area of Cross River State, Nigeria. *Int Jour. of Agric. Res*, 9 (4): 187-199

Asadu, C. L. A., Nnaji, G. U and Ezeaku, P. I (2012). *Conceptual Issues in Pedology*. University of Nigeria Press Limited, University of Nigeria, Nsukka, 186 Pp.

Babalola, T.S., Fasina, A.S., Kadiri, W.O.J., Ibitoye-Ayeni, N.K. and Omonile, T. (2019).Variation of Soil Morphological Properties along a Lithosequence on Basement Complex Geology of Nigeria.*FULafia Journal of Science and Technology*, 5 (1): 55-65.

Carroll, D. and Hathaway, J. C. (1953). Clay Minerals in a Limestone Soil profile. *Second National Conference on clays and clay minerals*. Pp. 171-182

Dolui, A. K. and Bera, R. (2001). Relation between Fe forms and pedogenic processes in some Alfisols of Orissa, India. *Agrochim.* XLV: 161-170

Dolui, A. K. and Mondal, A. (2007). Influence of Different Forms of Iron and Aluminum on the Nature of Soil Acidity of Some Inceptisols, Alfisols, and Ultisols, *Comm in Soil Sci. and Plant Anal*, 38:1-2, 119-131

Durn, G., Slovenec, D. and Covic, M. (2001). Distribution of iron and manganese in Terra Rossa from Istria and its genetic implications. *GeologiaCroatica* 54(1):27-36.

Eshett, E. T.,Omueti, J. A.I.&Juo, A. S. R. (1990) Physicochemical, morphological, and clay mineralogica properties of soils overlying basement complex rocks in Ogoja, northern cross river state of Nigeria, Soil Science and Plant Nutrition, 36:2, 203-214, DOI: 10.1080/00380768.1990.10414985

Esu, I.E. (2010): Soil characterization, classification and survey. HEBN Publishers, Plc, Ibadan,Nigeria.73-99.

Esu, I.E. and Ojanuga, A.G. (1985). Morphological physical and chemical Characteristics of Alfisols in the Kaduna Area of Nigeria. *Samaru Journal of Agricultural Research*, 31: 39-49.

Foli, S. (2012).Farm characterisations in the southern and northern Guinea savannah zones of Nigeria: *Identification of niches for grain legume technologies*. MSc thesis. Plant Production Systems, Wageningen University, Pp. 67.

Foth, H. D. (1990). *Fundamentals of Soil Science*. 12th edition. John Willey and Sons, New

York.

Grunwald.ufl.edu/Nat_resources/organic_matter/organic.htm

Harris, F.M.A. (1998). Farm-level assessment of the nutrient balance in northern Nigeria.*Agriculture, Ecosystems and Environment*71(1-3): 201-214.

Hoffmann, I. andGerling, D. (2001).Farmers' management strategies to maintain soil fertilityin a remote area in northwest Nigeria.*Agriculture, Ecosystems and Environment*86(3): 263-275.

Ibia, T.O. (2002). Forms of Fe and Al in soil profiles of inland flood plains of South EasternNigeria.*Nig. J. Soil Res*. 3:72-77.

Igwe, C.A. (2001). Free oxide distribution in Niger flood plain soils in relation to their total and available phosphorus. Proceed. Soil Sci. Soc. Nig. pp. 196-201.

Jelic, M.Z., Milivojevic, J.Z., Trifunovic, S.R., Dalovic, I.G., Milosev, D.S. and Seremesic, S.I. (2011).Distribution and forms of iron in the Vertisols of Serbia.*J. Serbian Chem. Soc.* 76(5):781-794.

Juo, A. S. R., Moormann, F.R. and Maduakor, H.O. (1974). Forms and pedogenetic distribution of extractable iron and aluminum in selected soils of Nigeria. *Geoder*, 11: 167--179.

Kampf, N. and Curi, N (2012). Formação e evolução do solo (pedogênese). In: Ker JC, Curi N, Schaefer CEGR, Vidal-Torrado P, (eds.) Pedologia: fundamentos. Viçosa, MG: *SociedadeBrasileira de Ciência do Solo*. 207-302.

Kefas, P.K., Ali, S. Ofem, K.I. and Umeugokwe, C.P. (2020).Genesis and classification of soils along a Toposequence in the Teaching and research Farm of Taraba State University.*Global Journal of agricultural sciences* Vol.19,2020:33-43

Lawal, B.A., Ojanuga, A.G, Tsado, P.A. and Mohammed, A. (2013): Characterization, Classification and Agricultural Potentials of Soils on a Toposequence in Southern Guinea Savanna of Nigeria.*International Journal of Agricultural and Biosystems Engineering* 7(5).

Mahaney, W. C., Hancock, R. G. and Sanmugadas, K. (1991). Extractable Fe-Al and geochemistry of Late Pleistocene Paleosol in the Dalijia Shan, Western China. *Jour. of Southeast Asian Earth Sci*, 6: 75-82

Maniyunda L.M. (2012). Pedogenesis of a lithosequence in northern guinea savannah ofKaduna State, Nigeria.Ph.D thesis (unpublished), Ahmadu Bello University, Zaria. 219pp.

Mehra, O.P. and Jackson, M.L. (1960). Iron oxide removal from soils and clays by dithionite-citrate system buffered with sodium bicarbonate. *Clays Clay Minerals* 7:317-327.

NIMET(2009).Nigeria meteorological station, Yola international airport.

Obaje, N.G. (2009). *Geology and mineral resources of Nigeria.*Springer Dordrecht HeidelbergLondon New York. 219p.

Obi, J. C., Akinbola, G. E. and Anozie, H. F. (2009). Distribution of dithionite and oxalate-extractable iron oxides of a catena in the basement complex soils of Southwestern Nigeria. *Nig Jour of Soil Sci* 19:100-108

Ofem, K.I., C.L.A. Asadu, P.I. Ezeaku, J. Kingsley, M.O. Eyong, V. Katerina, T. Václav, N. Karel, D. Ondrej and P. Vít, (2020). Genesis and classification of soils over limestone formations in a Tropical Humid Region. Asian J. Sci. Res., 13: 228-243.

Ogezi, A.E.O. (1977). *Geochemistry and Geochronology of Basement Rocks fromNorthwesternNigeria.*Unpublished Ph.D. Thesis, University of Leeds.

Ogungbile, A.O., Tabo, R. and Duivenbooden, N.V. (1999).Multiscale characterization ofproduction systems to prioritize research and development in the Sudan Savanna Zone of Nigeria, International Crops Research Institute for the Semi-Arid Tropics.

Olaniyan, J.O. (2015). Maize: Panacea of hunger in Nigeria. *African Journal of PlantScience,* 9(3): 155-174.

Osayande, P. E., Oviasogie, P. O., Aisueni, N. O., Stephen, O., Irhemu, P. and Ekebafe, M. O. (2013). Assessment of Dithionite and Oxalate Extractable Iron and Aluminium Oxides in Soils Supporting Raphia palms (Raphia spp.) at NIFOR Main Station. *Nig Jour of soil sci*. 23 (2):1-10.

Osodeke, V. E., Nwotiti, I. L. and Nuga, B. O. (2005).Sesquioxides distribution along a toposequence in Umudike area of SoutheasternNigeria.*Electr. J. Environ. Agric. Food Chem.* 4(6):1117-1124.

Raji, B.A., Esu, E.I. and Chude, V.O. (2000). Status and profile distribution of free oxides in Haplustults and Quartzipsamments developed on ancient dunes in NW Nigeria. *Sam. J. Agric. Res.* 16:41-51.

Salako, F.K. (2003). Soil Physical Conditions in Nigerian Savannas and Biomass Production.Lecture given at the College on Soil Physics Trieste, 3-21 March 2003.

Salako, F.K., Tian, G. and Kang, B.T. (2002).Indices of root and canopy growth of leguminous cover crops in the savanna zone of Nigeria.*Tropical Grasslands* 36: 33-46.

Salami, B.T., Okogun, J.A. and Sanginga, N. (2011). Delineation of management zones by classification of soil physico-chemical properties in the Northern Savanna of Nigeria. *African Journal of Agricultural Research*, 6(6): 1572-1579. DOI: 10.5897/AJAR10.573

Schwertmann, U. (1993). Relations between iron oxide, soil colour, and soil formation. In: J. M. Bigham and E. J. Ciolkosz (editors). Soil colour. *Soil Sci. Soc. Am. Special Pub*. No. 31. Pp. 51-69

Schwertmann, U. and Taylor, R. M. (1989). *Iron oxides*. In Dixon J. B *et al*. (eds.). Minerals in Soil Environments. ASA, Madison, USA. Pp. 379-438

Seal, A., Bera, R., Bhattacharyya, P., Mukhopadhyay and Giri, R. (2006). Degree of Soil Development in some Alfisols of Subtropical India with special reference to the nature and distribution of iron and aluminum. *Int Jour of Agric Res*, 1: 305-311

Sherman, G.D., Matsusaka, Y., Ikawa, H. and Uehara, G. (1964). The role of amorphous fraction in the properties of tropical soils. *Agrochimica*, 7: 146--163.

SilvaNeto, L. F. (2008). Oxidos de ferro emlatossolostropicais e subtropicaisBrasileirosemplantiodireto. *RevistaBrasileira de Ciencias do solo,* 32(5): 1873-1881

Smith, J. W,Naazie, A. et al. (1997). Integrated crop-livestock systems in sub-Saharan Africa:An option or an imperative? *Outlook on Agriculture*26(4): 237-246.

Soil Survey Staff (2014). Kellogg soil survey laboratory methods manual. Soil Survey Investigations Report No. 42, Version 5.0. R. Burt and Soil Survey Staff (ed.). U.S. Department of Agriculture, Natural Resources Conservation Service.

Sun, Z. X., Jianga, Y.Y., Wang, Q. B., Owens, P. R. (2018). Fe-Mn nodules in a southern Indiana loess with a fragipan and their soil forming significance. Geoderma 313: 92–111. http://dx.doi.org/10.1016/j.geoderma.2017.10.025

Tan, W. F., Liu, F., Li, X. Y.(2004). Characteristics of band structure in iron-manganese nodules from yellow-brown soil in Wuhan. Quat. Sci. 24 (2), 198–203.

Tuncay, T., Dengiz, O., Bayramin, I., Kilic, S. and Baskan, O. (2019). Chemical weathering indices applied to soils developed on old lake sediments in a semi-arid region of Turkey. *Eurasian Jour of Soil Sci*, 8(1): 60-72

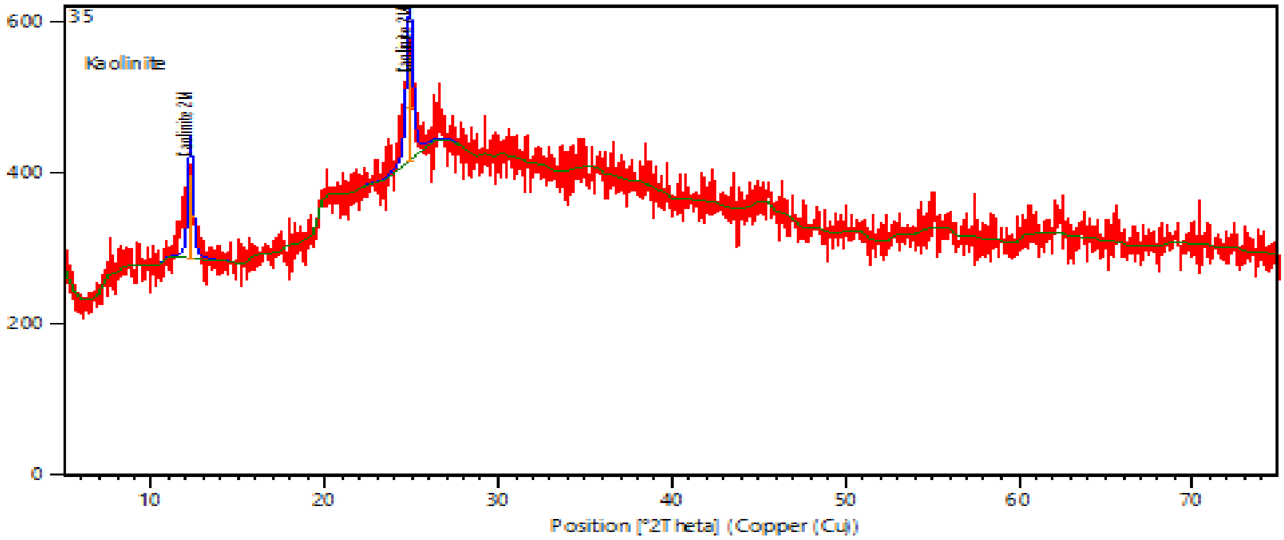
Udo, T. Ibia,T.O., Ogunwale, J.A., Ano, A.O. and Esu, I.E., (2009). Manual of soil, plant and water Analyses. Sibon books Ltd, Lagos, Nigeria.

Usul, M. and Dengiz, O. (2010).Pedological development on four different parent materials.*Anadolu Journal of Agricultural Sciences 25(S-2): 204-2011*

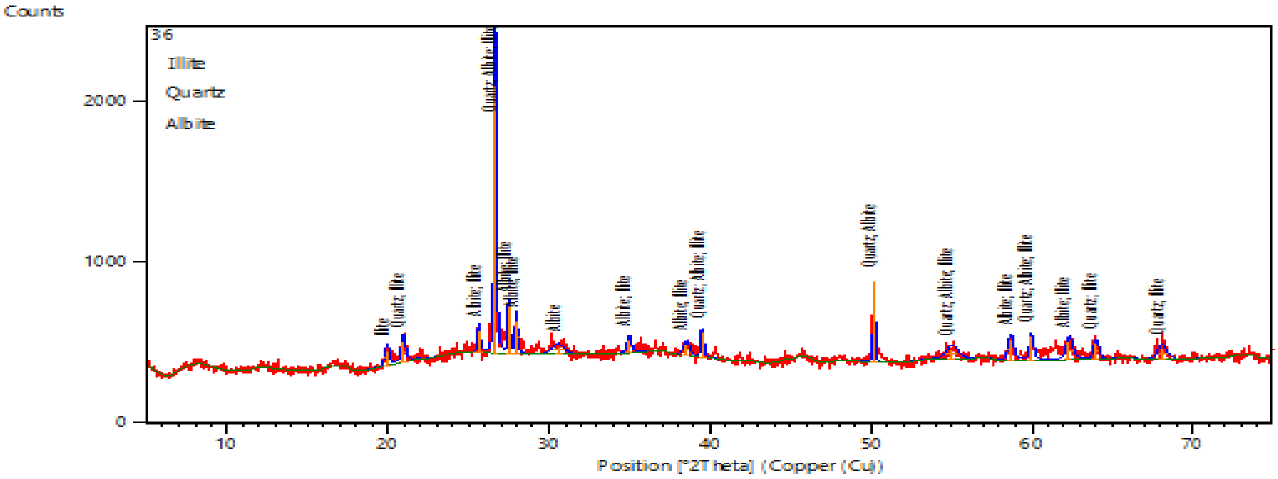
Wilson, S. G., Lambert, J., Nanzyo, M. and Dahlgren, R. A. (2017). Soilgenesis and Mineralogy across a volcanic lithosequence. Geoder,285: 301-312

Appendix

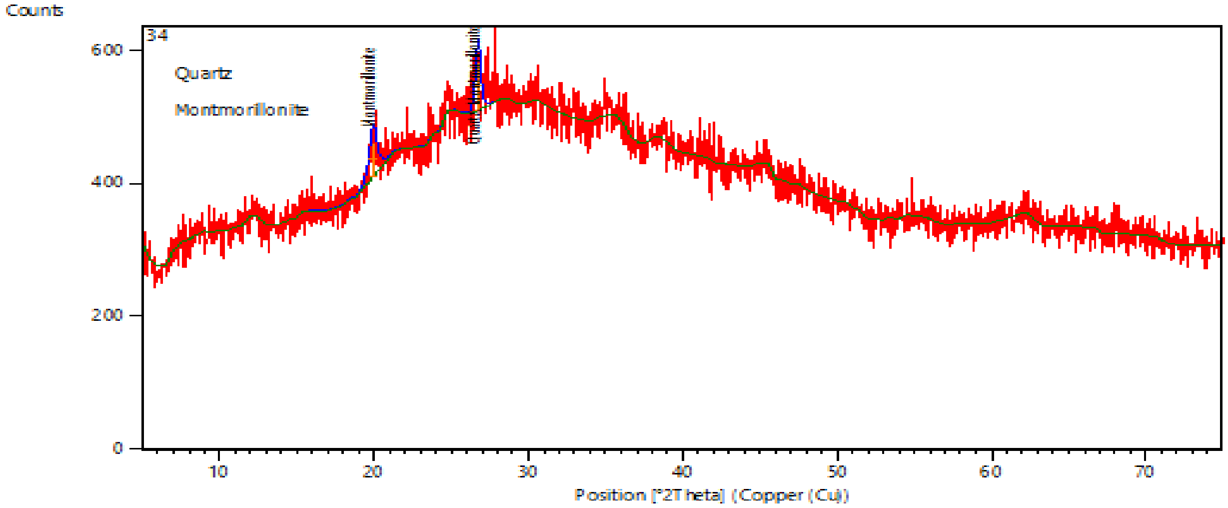
KCP1 – Kaolinite



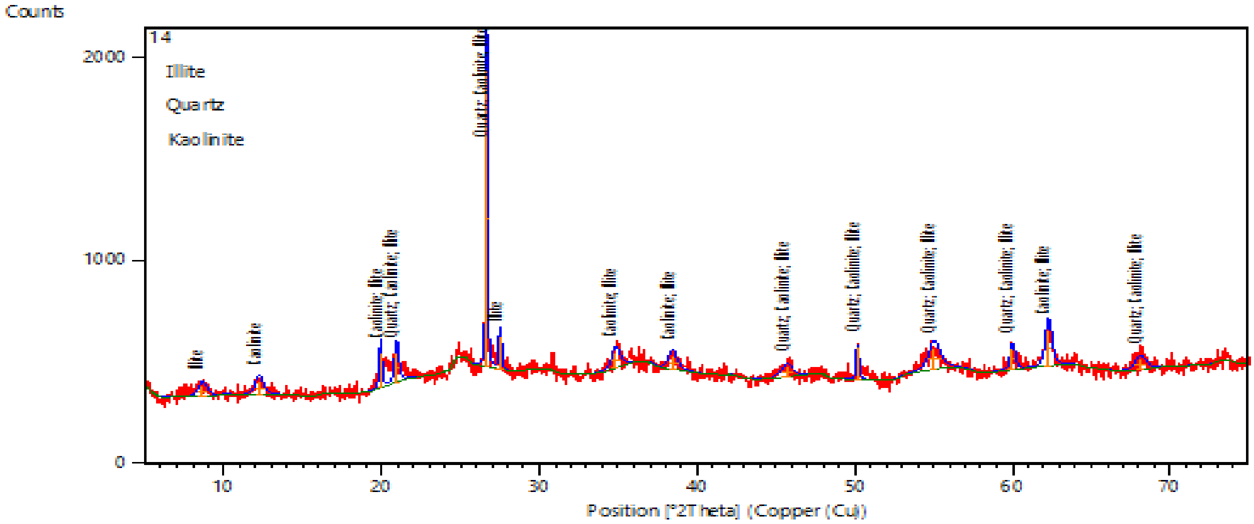
KCP2– Illite, Quartz, Albite



KCP3 – Quartz, Montmorillonite

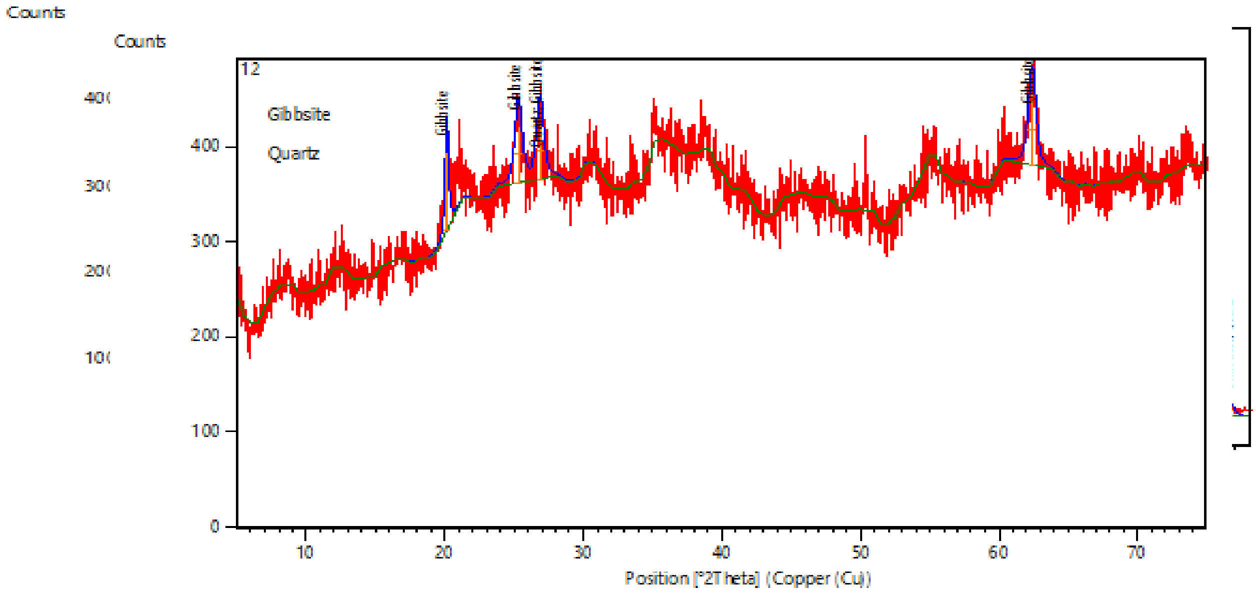


MCP1 – Quartz, Microcline, Dolomite

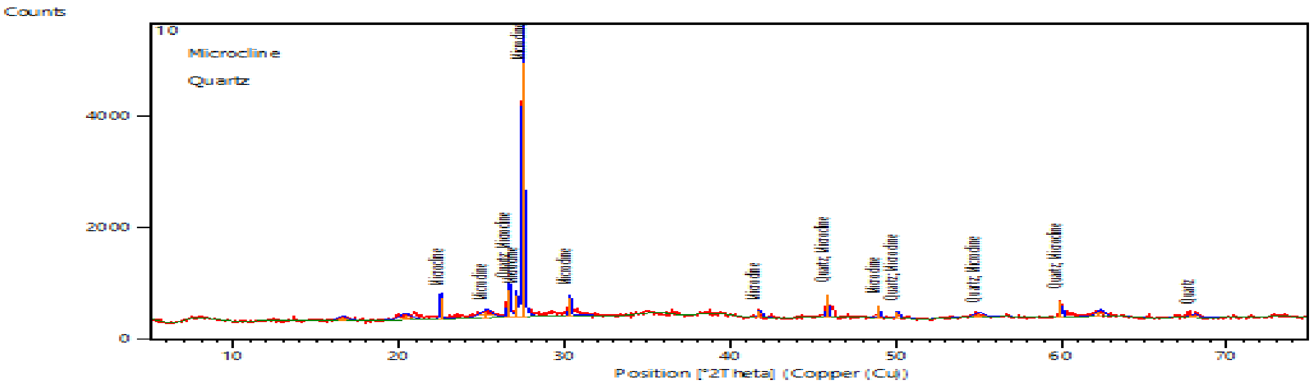


MCP2 – illite, Quartz, kaolinite

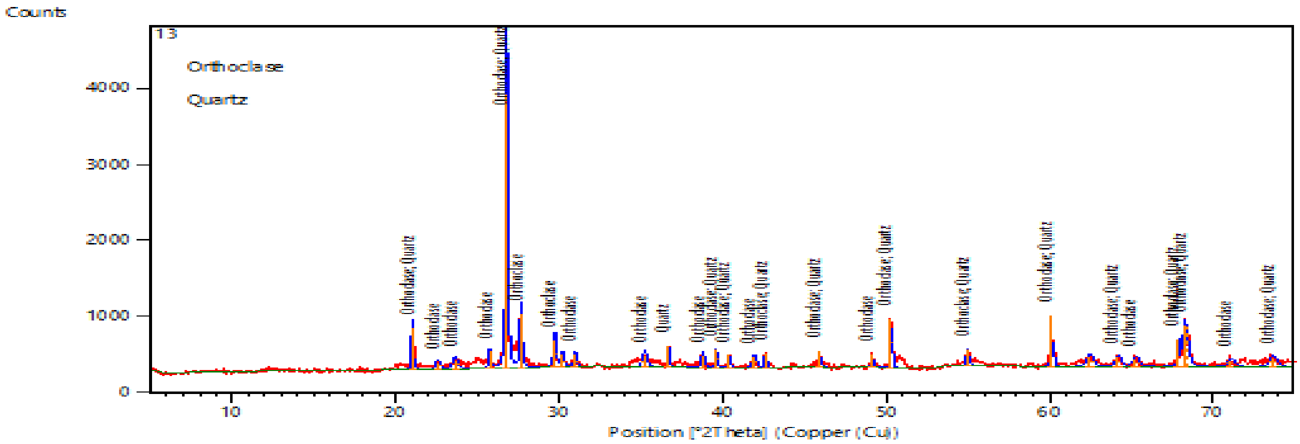
BDCP2 – Microcline, Quartz



BDCP3 – Microcline, Quartz, Chrysotile



MCP3: Orthoclase, quartz



BDCPI – Gibbsite, Quartz