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PROFILE DISTRIBUTION OF CRYSTALLINE AND AMORPHOUS SESQUIOXIDES IN TALC OVERBURDEN SOILS OF SOUTHERN GUINEA SAVANNA ECOLOGY IN NIGERIA

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ABSTRACT

The stage of development of soils developed over talc overburden in two locations (Ejiba and Odo-Ogbe) within the Southern Guinea Savanna Agro-ecology of Kogi State, Nigeria, were evaluated using the dithionite and oxalate extractable Fe, Al oxides and the ratios of silt : clay and silt : silt +clay of the soils. Soil samples collected from the pedogenic horizons of nine profile pits dug in the two sites were analyzed using standard procedures. The soils had higher values of dithionite-extractable Fe and Al oxides (Fed, Ald) than oxalate- extractable forms (Feo, Alo), indicating that these soils had higher content of the crystalline forms of these sesquioxides. The pattern of profile distribution of the sesquioxides and clay sized particles were similar, resulting in a significant correlation ($P<0.5$) between Fed and clay content of the soils ($r = 0.736$ for Ejiba and 0.533 for Odo-Ogbe). The plinthite (Fe-Mn concretions) content of the soils at the first location (Ejiba) was significantly ($P<0.01$) correlated with the Fed ($r = 0.537$). The ratio of Feo/Fed as well as the pedogenic Fe oxide content of the soils indicated that the soils were at an advanced stage of development. There were, however, conflicting results in the evaluation of the stage of development of the soils using the silt: clay and silt: silt + clay ratios. While the silt : clay ratio indicated low to moderate stage of development, the silt : silt + clay indicated an advanced stage of soil development in agreement with the Feo/Fed ratio and pedogenic Fe content of the soils. It was concluded that using the Feo/Fed, silt: silt + clay ratios as well as the pedogenic Fe oxide content of the soils gave a better evaluation of the stage of soil development.

Keywords: Crystalline sesquioxides, Amorphous sesquioxides, Weathering ratio, Pedogenesis, Guinea Savanna

INTRODUCTION

Wilson (2004) defined weathering as the processes responsible for the formation of soils and playing a central role in controlling the inherent fertility status of soils through the supply of many of the nutrients that enable plants to grow. Soil develops during chemical alteration or decomposition, movement and redistribution of certain mineral components of the rock or superficial deposits and is often accompanied by a change in colour due to the formation of iron oxide minerals (Delvigne, 1998). The process of changes that occur during weathering is a continuous and complex combination of destruction, transformation and synthesis of minerals. The ease, nature and rate of the weathering process clearly depend upon the nature of the primary minerals themselves (Wilson, 2004).

As the weathering advances, the amount of weatherable minerals in the soil reduces. At a very advanced stage of soil development, especially in the tropical environment like Nigeria, the only minerals left in the soil are mainly kaolinite, oxides of aluminum and iron and clay size quartz (Kronberg and Nesbitt, 1981). At this stage, the native fertility of the soils becomes very low because of the low CEC resulting from the predominance of the low activity clays and sesquioxides.

Identification of the stage of soil development becomes a good tool at predicting soil fertility. Several ratios exist for the measurement of the stage of soil development (intensity of weathering). These ratios include the silt to clay ratio (FAO, 1988; Stewart et al,.1970), silt to silt + clay ratio (Stewart et al., 1970; Azeez, 1998), calculation of ratios of more soluble to less soluble elements in the soil profile (Birkeland, 1989), and measurement of the ratio of DCB-extractable iron to Oxalate–acid extractable iron in soils (Ogunkunle and Onasanya, 1992; Hao and Guo, 2001; Agbenin, 2003; Obi et al., 2009).

Hao and Guo (2001) used the ratio of Dithionite-Citrate-Bicarbonate (DCB) extractable free Fe2O3 and the total Fe2O3, an index widely used by pedologist (Duchaufour, 1983), to evaluate weathering intensity. According to these authors, the ratio is a measurement of the quantity of iron liberated from iron-bearing silicate minerals by chemical weathering relative to the total amount of iron present. The DCB extractable iron is mainly pedological in origin (Singer et al., 1995; Hunt, et al., 1995). The ratio of free Fe2O3 (Fe-D) extractable by DCB method (Mehra and Jackson, 1960) to total Fe2O3 (Fe-Ox) extracted in acid (McKeague, 1981) dissolved samples (Fe-D/Fe-Ox) is said to be a better reflection of the pedogenic intensity of weathering than Rb/Sr ratio by these authors.

In Nigeria, Ogunkunle and Onasanya (1992) indicated the crystalline form of iron and aluminum oxides as the dominant oxyhyroxides in the basement complex soils of southwestern Nigeria. They concluded that the predominance of the crystalline form of the sesquioxide represent a more advanced stage of soil development than the presence of the amorphous forms that are mobile in the soil and could be associated with organic matter.

Ojanuga (1985) reported that the crystalline forms of Fe were goethite and hematite and occurs either singly or in association within the hard nodules and concretions in the soil environment. The level of the crystalline form of Fe can thus serve as an estimate of the degree of soil development and formation of hard nodules and concretions. Obi et al., (2009) concluded that the dominance or higher proportion of the crystalline form of Fe will lead to structural distortions with implications for anion retention which affects the surface area and leads to hardness of the soil. Higher crystalline Fe content of the soil will affect both the physical and chemical properties of the soils as well as its management and land use. This study is specifically important because the study area covers a large proportion of the irrigable land of Kampe-Omi irrigation project.

The objective of this work is to determine the profile distribution of both Dithionite-Citrate-Bicarbonate (DCB) and Acid Oxalate (Ox) extractable Iron and Aluminum in soils developed over talc; evaluate the stage of development of the soils using the calculated ratios of Feo/ Fed, silt: clay and silt: silt + clay and to determine the relationships between the different forms of Fe and the level of Fe-Mn concretions of the soils.

MATERIALS AND METHODS

Soil samples used were collected from the pedogenic horizons of nine profile pits dug in soils formed over talc in two locations within the southern Guinea savanna Agro-ecology of Kogi State of Nigeria. One of the locations is within the confines of Kampe Irrigation Project at Ejiba (Latitude 8º 18'N and Longitude 5º 39' E), while the other is within Kampe forest reserves at Odo-Ogbe (Latitude 8º 25' N and Longitude 5º 46'E). The two sites represent intensively used and virgin or unused lands respectively. The sites lie across two main geological materials: undifferentiated meta-sediments and undifferentiated basement complex (NGSA, 2004), having commercial deposits of talc in association with varying quantities of biotite and mica schists, granite gneiss and quartz-schist.

Collected soil samples were are air–dried and sieved with a 2-mm sieve. The particle size analysis was done by using the modified Bouyoucous hydrometer method (1962). Determination of organic carbon was done using the wet oxidation method (Shamshuddin et al., 1995) while the pH was determined in distilled water (1:1 soil: water ratio) using a glass electrode pH meter. Extraction of Dithionite-Citrate-Bicarbonate (DCB) extractable iron (Fed) and aluminum (Ald) was carried out according to the procedure of Mehra and Jackson (1960) while the total iron (Feo) and aluminum were extracted with oxalic acid according to the procedure of McKeague (1981). The Oxalic acid-extractable Fe2O3 and Al2O3 were digested with 50 % hydrogen peroxide on a sand bath for an hour to break down all the organic materials present in the extract. Similarly, the DCB extract was digested in a mixture of concentrated nitric acid and perchloric acid to destroy all sulphides present in the extract.

Determination of Al2O3 in all the digests was done by the Xylenol–orange colorimetric method using a spectrophotometer (McKeague, 1981). The Fe2O3 was determined colorimetrically using the Ortho-phenathrolin method (Mehra and Jackson, 1960).

RESULTS

The colours of the soils were very dark grayish brown (10YR) to very dark gray (5YR) in the surface, but had different shades of gray, brown and red colours in the subsurface horizons. In most of the somewhat poorly drained profiles, mottling occurred right from the second horizon through to the last horizon (Table 1). The mottles ranged in colour from yellowish red (5YR 4/6) to yellowish brown (10YR 6/8) while the colour of the horizons varied from gray (2.5 Y) to light olive gray (5 Y). The well-drained pedons, however, had subsurface colour in the red range (2.5YR). Where mottling occurred in the well-drained pedon, the mottles were brownish in colour.

The soils had sand-sized particles ranging from 606 g kg-1 to 906 g kg-1(Table 2). Generally, the values of these sand–sized particles were highest at the surface horizons and decreased irregularly down the profile with the lowest sand value occurring at the subsurface horizons of all the profiles. In most cases, the differences between the sand content of the first (surface) and last (subsurface) horizons were greater than 10 %. The silt-sized particles were comparatively lower than those of the sand and clay sized fractions. There was no consistent pattern of distribution of silt in all the profiles. The surface horizons had silt-sized particles ranging in value between 34 g kg-1 and 134 g kg-1,

Table 1: Soil morphological characteristics of the soils

Field ID	Depth (cm)	Soil Colour	Mottling	Structure	Taxonomic Class†
EJ1-A	0-19	Very dark grayish brown (10YR 3/2)		ME, SB	Aquic Haplustepts (Endogleyic Cambisols (Eutric))
EJ1-B1	19-75	Dark grayish brown (10YR 4/2)	Yellowish red mottles (5YR 4/6)	ME, SB	
EJ1-B2	75-170	Gray (10YR 5/1)	Brownish yellow mottles (10YR 6/8)	CO, SB	
EJ1-C	170-190	Olive gray (5Y 5/2)	Brownish yellow mottles (10YR 6/8)	CO, SB	
EJ2-A	0-8	Dark brown (7.5YR 3/2)		FI, SB	Psammentic Haplustalfs (Lixisols (Hypereutric, Arenic))
EJ2-B1	8-50	Dark brown (7.5YR 3/ 4)		ME, SB	
EJ2-B2	50-120	Dark brown (7.5YR 4/4)		ME, SB	
EJ2-C	120-178	Strong brown (7.5YR 4/6)		ME, SB	
EJ3-A	0-25	Very dark grayish brown (10YR 3/2)		ME, SB	Arenic Haplustalf (Lixisols (Hypereutric, Arenic))
EJ3-B	25-124	Dark grayish brown (10YR 4/2)		PR	
EJ3-C	124-163	Gray (10YR 5/1)		CO, SB	
EJ4-A1	0-15	Very dark gray (2.5Y 3/0)		ME, SB	Typic Plinthaqualf (Gleyic Luvisols (Arenic))
EJ4-A2	15-40	Dark gray (2.5Y 4/1)	Yellowish brown mottles (10YR 5/6)	ME, SB	
EJ4-B1	40-75	Gray (2.5Y 5/0)	Yellowish brown mottles (10YR 5/6)	ME, SB	
EJ4-B2	75-106	Gray (2.5Y 6/0)	Brownish yellow mottles (10YR 6/8)	ME, SB	
EJ4-B3	106-123	Gray (2.5Y 5/0)	Yellowish brown mottles (10YR 5/8)	CO, SB	
EJ4-C	123-170	Light olive gray (5Y 6/2)	Yellowish brown mottles (10YR 5/8)	CO, SB	
EJ6-A	0-14	Very dark gray (5YR 3/1)		FI, SB	Rhodic Plinthustalf (Plinthic Lixisols (Rhodic))
EJ6-B1	14-60	Dark red (2.5YR 3/6)		ME, SB	
EJ6-B2	60-120	Dark red (2.5YR 3/6)		CO, SB	
EJ6-C	120-160	Red (2.5YR 4/6)		CO, SB	
OD1-A1	0-10	Dark grayish brown (10YR 4/2)		GR	Aquic Haplustept (Endogleyic Cambisols (Eutric))
OD1-A2	10-28	Dark yellowish brown (10YR 4/6)		ME, SB	
OD1-B1	28-45	Dark yellowish brown (10YR 4/4)		ME, SB	
OD1-B2	45-105	Strong brown (7.5YR 4/6)	Light brownish gray mottles (2.5YR 6/2)	ME, SB	
OD1-C	105-140	Yellowish red (5YR 5/8)	Light brownish gray mottles (2.5Y 6/2)	ME, SB	
OD2-A	0-15	Dark brown (7.5YR 3 /4)		ME, SB	Typic Haplustept (Cambisols (Rhodic))
OD2-B1	15-43	Dark brown (7.5YR 4/4)		CO, SB	
OD2-B2	43-110	Weak red (2.5YR 5/2)	Strong brown mottles (7.5YR 5/8)	CO, SB	
OD2-C	110-140	Weak red (2.5YR 5/2)	Strong brown mottles (7.5YR 5/8)	CO, SB	
OD3-A	0-9	Very dusky red (2.5YR 2.5/2)		ME, SB	Psammentic Rhodustults (Acrisols (Rhodic))
OD3-B	9-120	Dark reddish brown (2.5YR 3/ 4)		ME, SB	
OD3-C	120-180	Dark red (2.5YR 3/6)	Very pale brown mottles (10YR 7/3)	ME, SB	
OD4-A	0-10	Black (10YR 2/1)		FI, SB	Typic Dystrustept (Plinthic Cambisols (Dystric, Rhodic))
OD4-B1	10-30	Dark yellowish brown (10YR 3 /4)		FI, SB	
OD4-B2	30-95	Dark red (2.5YR 3/6)		ME, SB	
OD4-C	95-140	Red (2.5YR 4/6)		ME, SB	

FI = Fine; ME =Medium; CO = Coarse; GR =Granular; SB = Subangular blocky; PR = Prismatic

† = Taxonomic class (see Ajiboye et al., 2008; Ajiboye and Ogunwale, 2011)

while the subsurface horizons had silt contents that ranged from 60 g kg-1 to 184 g kg-1. The clay-sized particles of the soils increased down the profile with some horizons having argillic properties. The soils' clay content ranged from 34 g kg-1 to 80 g kg-1 in the surface horizons and from 94 g kg-1 to 274 g kg-1 in the subsurface horizons. A characteristic feature of the

soils is high sand and low silt contents. The textures of these soils were largely determined by the relative proportion of sand and clay. Thus, the soils had textural classes that ranged from sand to sandy clay loam. The soils had structures that ranged from granular (GR) and fine-sub-angular blocky (FI, SB) in the surface horizons to coarse-sub-angular–blocky (CO, SB) in the sub soils. More than 90 % of the subsurface horizons had medium sub-angular blocky (ME, SB) structure. The plinthite content of the soils does not have a definite pattern of distribution; however it ranged from 3.5 g kg-1 to 568.3g kg-1. However, pedon OD3 had no plinthite.

Distribution of Iron and Aluminum oxides

The values of dithionite-extractable iron (Fed) and aluminium (Ald) were higher than those of oxalate-extractable iron (Feo) and aluminium (Alo) in all the horizons, pedons and locations (Table 3). The Fed ranged from 2.03 g kg-1 to 20.54 g kg-1, with a mean of 7.89 g kg-1 and standard error of 0.791 g kg-1. In most of the pedons, the highest Fed value occurred in the B horizons. However, in pedon OD4 and EJ4, the highest value of Fed was observed at the lowest horizon.

Oxalate extractable Fe (Feo) which is essentially a measure of poorly crystalline (amorphous) and organically bound Fe in the soil (Parfitt and Childs, 1988, Obi et al., 2009) ranged from 0.39 g kg-1 to 4.35 g kg-1 with a mean of 1.31 g kg-1 and standard error of 0.189 g kg-1. The pattern of distribution of Feo within the profiles was similar to the pattern of Fed distribution, with the highest values of Feo occurring in the B horizons. However, the horizons that had the highest value of Feo did not correspond with the horizons having the highest value of Fed in most cases. In pedon EJ3, OD1, OD2 and OD3, the highest values of Feo and Fed occurred in the same horizons while the lowest value of Feo in all the pedons except EJ2 and OD1 occurred in the surface horizons.

The quantity of Ald, that is, Al substitution in Fe oxides, and organic matter-bound Al (Parfitt and Childs, 1988) in the soils was lower than Fed and ranged from 1.56 g kg-1 to 3.36 g kg-1 with a mean of 2.41 g kg-1 in Ejiba, but ranged in from 1.50 g kg-1 to 3.41 g kg-1 with a mean of 2.80 g kg-1 in Odo-Ogbe. The pattern of distribution of Ald was similar to the pattern of Fed distribution with the same horizons having the highest values of both Fed and Ald. However, the total pedogenic aluminum (Alo), which is an estimate of the poorly crystalline (amorphous) Al and Al associated with humus (Parfitt and Childs, 1988) was lower in value than Fed and in value ranged from 009 g kg-1 to 0.61g kg-1, with a mean of 0.32 g kg-1 and standard error of 0.02 g kg-1. An estimate of pedogenic or inorganic iron (Fep), that is the Fe sequestered in crystalline Fe oxides, was calculated as the difference between Fed and Feo (Fed–Feo) (Allen, 2005) and ranged in value from 1.61 – 19.56 g kg-1. The pattern of distribution of Fep was similar to the pattern of distribution of the clay particle size in all the pedons. The B horizons had the highest values of Fep in all the pedons except pedon OD4 that had the highest value at the last horizon. Similarly, the first horizon of all the pedons had the lowest values of Fep apart from pedon EJ1 where the lowest value occurred at the last horizon.

The Fed/clay ratios were calculated to determine whether the Fed was associated with the clay fraction (Blume and Schwertmann, 1969; Rebertus and Buol, 1985). This ratio ranged from 0.01 – 0.27, with a mean of 0.08, stand error of 0.01 and decreased with increasing soil depth in pedons EJ1, EJ2, EJ6 at Ejiba and pedon OD3 at Odo-Ogbe. In pedons OD1, OD2 and OD4 the values of the Fed/clay ratio were highest in the B horizon but lowest either at the surface horizon (OD4) or at the last horizons (OD1 and OD2). In pedon EJ4 however, Fed/clay ratio increased irregularly down the profile, appearing as if two profiles were combined to make up the profile. Pedon EJ3 on the other hand had a constant value of Fed/clay throughout the profile.

The first location (Ejiba) had more plinthite occurring in pedon EJ2, EJ3, EJ4 and EJ6 than in the second location which had plinthite only in pedon OD4. The plinthite (Fe-Mn concretions) content of the soils at the first location (Ejiba) was significantly ($P<0.01$) correlated with the values of Fed ($r = 0.537$) and Feo ($r = 0.545$) (Table 4). However, in the second location (Odo-Ogbe), the correlation between the Fed or Feo and the plinthite content of the soils was not significant ($p<0.05$). Furthermore, there was significant correlation between Fed and quantity of clay sized particle fraction of the soils of both location with r values of 0.736**

Table 3: Profile Distribution of DCB and Oxalate Iron and Aluminium Oxides and weathering ratios

Field ID	Depth (cm)	Feo g kg^{-1}	Fe_d g kg^{-1}	Alo g kg^{-1}	Al_d g kg^{-1}	Fe_p (Fe_d– Feo) g kg^{-1}	Fe_d/Clay	Al_d/Clay	Fe_d/Al_d	Feo/Fe_d	Silt/Clay	Silt /(silt+ clay)
EJ1-A	0-19	0.28	2.70	0.25	2.14	2.42	0.05	0.04	1.26	0.10	1.90	0.66
EJ1-B1	19-75	0.43	3.92	0.27	3.13	3.49	0.03	0.02	1.25	0.11	0.24	0.20
EJ1-B2	75-170	0.69	4.05	0.26	2.03	3.36	0.02	0.01	2.00	0.17	1.08	0.52
EJ1-C	170-190	0.42	2.57	0.09	2.89	2.15	0.01	0.02	0.89	0.16	0.47	0.32
EJ2-A	0-8	0.49	3.24	0.51	1.85	2.75	0.06	0.04	1.75	0.15	1.88	0.65
EJ2-B1	8 -50	0.53	4.59	0.30	1.85	4.06	0.06	0.02	2.48	0.12	1.05	0.51
EJ2-B2	50-120	0.87	4.46	0.32	2.20	3.59	0.04	0.02	2.03	0.20	1.12	0.53
EJ2-C	120-178	0.45	3.51	0.30	2.78	3.06	0.05	0.04	1.26	0.13	1.63	0.62
EJ3-A	0-25	0.42	2.03	0.46	1.56	1.61	0.04	0.03	1.30	0.21	0.88	0.47
EJ3-B	25-124	0.87	8.92	0.36	2.72	8.05	0.04	0.01	3.28	0.10	0.32	0.24
EJ3-C	124-163	0.45	5.81	0.17	1.74	5.36	0.04	0.01	3.34	0.08	1.28	0.56
EJ4-A1	0-15	0.40	3.89	0.39	2.43	3.49	0.06	0.04	1.60	0.10	2.23	0.69
EJ4-A2	15-40	0.72	5.68	0.35	1.97	4.96	0.08	0.03	2.88	0.13	1.77	0.64
EJ4-B1	40-75	1.17	8.38	0.25	2.78	7.21	0.09	0.03	3.01	0.14	1.17	0.54
EJ4-B2	75-106	1.29	16.49	0.59	1.74	15.2	0.06	0.01	9.48	0.08	0.30	0.23
EJ4-B3	106-123	0.98	20.54	0.49	2.84	19.56	0.10	0.01	7.23	0.05	0.78	0.44
EJ4-C	123-170	0.52	11.08	0.52	2.6	10.56	0.05	0.01	4.26	0.05	0.54	0.35
EJ6-A	0-14	0.68	5.00	0.23	2.84	4.32	0.15	0.08	1.76	0.14	3.24	0.76
EJ6-B1	14-60	1.87	8.38	0.36	2.43	6.51	0.04	0.01	3.45	0.22	0.49	0.33
EJ6-B2	60-120	1.53	13.49	0.42	3.36	11.96	0.05	0.01	4.01	0.11	0.44	0.30
EJ6-C	120-160	1.52	12.08	0.33	2.66	10.56	0.05	0.01	4.54	0.13	0.57	0.36
OD1-A1	0-10	1.11	6.35	0.35	3.24	5.24	0.19	0.10	1.96	0.17	2.65	0.73
OD1-A2	10 – 28	3.71	9.05	0.61	2.72	5.34	0.27	0.08	3.33	0.41	2.35	0.70
OD1-B1	28-45	4.35	12.70	0.61	3.36	8.35	0.24	0.06	3.78	0.34	1.11	0.53
OD1-B2	45-105	1.78	11.00	0.29	3.36	9.22	0.13	0.04	3.27	0.16	1.55	0.61
OD1-C	105-140	0.39	6.35	0.23	2.49	5.96	0.04	0.02	2.55	0.06	0.49	0.33
OD2-A	0-15	0.49	3.51	0.22	3.01	3.02	0.08	0.07	1.17	0.14	2.27	0.69
OD2-B1	15-43	3.74	14.05	0.23	2.03	10.31	0.11	0.02	6.92	0.27	0.81	0.45
OD2-B2	43-110	4.05	20.54	0.30	2.95	16.49	0.11	0.02	6.96	0.20	0.60	0.37
OD2-C	110-140	0.83	6.76	0.29	3.07	5.93	0.04	0.02	2.20	0.12	0.60	0.37
OD3-A	0-9	0.60	4.46	0.20	2.84	3.86	0.10	0.06	1.57	0.13	2.05	0.67
OD3-B	9-120	2.48	9.73	0.22	1.50	7.25	0.06	0.01	6.49	0.25	0.58	0.37
OD3-C	120-180	0.90	6.08	0.26	2.84	5.18	0.06	0.03	2.14	0.15	1.17	0.54
OD4-A	0-10	0.50	3.78	0.19	2.03	3.28	0.07	0.04	1.86	0.13	0.93	0.48
OD4-B1	10 -30	1.52	5.00	0.38	3.41	3.48	0.09	0.06	1.47	0.30	0.81	0.45
OD4-B2	30-95	3.30	9.73	0.29	2.55	6.43	0.09	0.02	3.82	0.34	0.71	0.42
OD4-C	95-140	2.31	12.16	0.09	3.41	9.85	0.08	0.02	3.57	0.19	0.68	0.40
Mean		**1.31**	**7.89**	**0.32**	**2.58**	**6.58**	**0.08**	**0.03**	**3.14**	**0.16**	**1.16**	**0.49**
Range		**0.28-4.35**	**2.03-20.54**	**0.09-0.61**	**1.50-3.41**	**1.61-19.56**	**0.01-0.27**	**0.01-0.10**	**0.89-9.48**	**0.05-0.41**	**0.24-3.24**	**0.20-0.76**
SE		**0.189**	**0.791**	**0.022**	**0.092**	**0.687**	**0.009**	**0.004**	**0.330**	**0.014**	**0.122**	**0.025**

and 0.533* respectively for the first (Ejiba) and second locations (Odo-Ogbe). In addition, the Feo content of Ejiba soils was significantly (P<0.01) correlated (r=0.637) with the clay sized particle fraction of the soils while a significant positive correlation (p<0.01; r=0.640) was also observed between Fed and Alo. Moreover, in Odo-Ogbe, the Feo was significantly correlated with Fed (r=0.824**), Alo (r=0.515*) but significant and negatively correlated with the soil pH (r = -0.526*).

Evaluation of the stage of development of the soils

The stage of soil development, soil age and some relic properties of soil have been evaluated in the past using simple weathering ratios. These weathering ratios included silt/clay (FAO, 1988), silt/silt + clay (Stewart et al., 1970); silica/alumina (Mohr et al., 1972); Fed/FeT (Hao and Guo, 2001); Rb/Sr (Cheng et al., 1999); quartz/feldspar (Ojo-Atere and Ogunwale, 1982) and (zircon + tourmaline)/(amphibole + pyroxene) (Ojo – Atere and Ogunwale, 1982). However, the most commonly and easily calculated ratios (silt/clay, FAO, 1980 and silt/silt + clay, Stewart et al., 1970) were used here to evaluate the stage of the development of these soils.The calculated silt: clay ratio in all the profiles across the two sites ranged between 0.24 and 3.24 (Table 3). In Ejiba, it was observed that the weathering ratio values of silt: clay was higher in the surface soils than in the subsurface soils. However, the decrease in value down the profile did not follow any specific pattern. The values of silt: clay ratios were lowest in the horizons with some evidence of clay accumulation. Similarly, Odo-Ogbe soils had silt: clay ratios ranging between 0.49 and 2.82. Also, the surface horizons had higher values of silt: clay ratio than the subsurface horizons and there was irregular decrease in these values down the profile with the last horizon in most cases having the lowest value of silt: clay ratio. The observed silt: clay ratio pattern may be due to the absence of clay illuviation in most pedons in Odo-Ogbe.

The second weathering ratio (silt: silt + clay ratio) ranged in value between 0.20 and 0.76 in Ejiba soils. The highest value of 0.76 was recorded in the surface horizon (Ao) of profile EJ6 while the lowest value was recorded in the subsurface soils of profile EJ1. In Odo-Ogbe, the values of this index ranged between 0.31 and 0.73. The values of silt:silt + clay ratio of these soils were < 0.7, except in the surface horizon of pedons EJ6 and

OD1. According to Stewart et al., (1970) and Azeez (1998), silt: silt+ clay ratio of 0.7 indicates moderate weathering, < 0.7 for severe weathering and > 0.7 for incipient weathering. Generally, the higher values of this index were recorded in the surface horizons while the subsurface horizon had the lower values with the lowest values occurring in horizons with the highest quantity of clay. Since these values were lower than 0.70, the soils could be said to have been severely weathered (Stewart et al, 1970; Azeez, 1998).

DISCUSSION

The subsurface colours of these soils reflected their drainage conditions. The grayish subsurface colours were associated with mottling and occur in profiles that were imperfectly drained or laid close to seasonal rivulets and at the lowest portion of the toposequence (valley bottom).

The values of Fed and Ald that was found to be higher than those of Feo and Alo indicates that a considerable fraction of the Fe and Al were present in crystalline form. The quantity of Fed in the soil provides an estimate of the degree of soil development, since Fed represents the total pedogenic Fe (Blume and Schwertmann, 1969; Birkeland, 1999), an increase in the concentration of free Fed invariably corresponds with increased in situ weathering (Buol et al., 1997; Allen, 2005). Active Fe ratios (Feo/Fed) which constitute an index of the proportion of the amorphous and crystalline iron content of the soils (Allen, 2005; Obi et al., 2009) were low (≤ 0.4). Since this ratio is used as a relative measure of the degree of crystallinity of free Fe oxides (Blume and Schwertmann, 1969), the ratios confirmed that most of the Fe in these soils was crystalline. The values of Fed and Feo obtained in this study further suggests that the degree of crystallinity of the Fe and Al fraction of these soils is higher than those reported by Obi et al., (2009) for some basement complex soils in the southwestern Nigeria soils but lower than those reported by Igwe (2005) for the soils of river Niger floodplain in Eastern Nigeria.

The pattern of distribution of the Fed was similar to those of clay particle size in all the profiles. The significant correlation between Fed and clay and the observed Fed/clay ratio indicated co-migration of Fe and clay in some of the profiles, especially at Ejiba (Obi et al., 2009; Ogunsola et al., 1989) while in some other profiles Fed, accumulation is independent of clay; that is, the Fed accumulation is a product of weathering and not necessarily the translocation of clay with Fe and Al (Allen, 2005). However, the colours of the horizons having the highest values of Fed were not all redish, but some had colour variations between gray and dark brown. This suggests that the crystalline Fe forms in these soils are not only hematite (red colour) but could also be goethite (brown colour) especially in the poorly drained pedons as observed by Ojanuga (1985).

It was also observed that the pedons which had values of Fep > 10g kg-1 in Ejiba were those having argillic horizons and high plinthite contents. The significant correlation coefficient values between Fed and plinthite and the substantially higher Fep content of these pedons is indicative of their advanced stage of development. The highest plinthite content corresponded with the highest value of Fed in Ejiba soils but in Odo-Ogbe, apart from pedon OD4, the crystalline Fe forms in the soils may not have occurred in association with the plinthite nodules. The mineralogy of these soils indicated the predominance of goethite in the clay mineral fraction of pedon OD4 of Odo-ogbe and apart from pedon OD4, the crystalline Fe forms in the soils may have existed more in form of hematite in pedons OD2 and OD and as goethite in pedon OD4 (Ajiboye et al., 2008).

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The Ald values were comparable with those reported by Obi et al., (2009) for the basement complex soils of southwestern Nigeria, but lower than values of Ald reported by Obi et al., (2008) in termite-infested Alfisols in the Guinea savanna agro-ecology of Nigeria. The crystalline form of Al-oxides is thought to be substituted into crystalline Fe-oxide in goethite and hematite (Holgen, 1967). The effect of such substitution is the structural distortion of crystalline Fe oxides with implication for anion retention (Schwertmann and Herbillon, 1992) leading to higher P sorption in Al-substituted goethite. However, Igwe (2005) noted that the oxides of Fe and Al were not correlated significantly with available phosphorus but correlated significantly with total P. He further noted that the correlation between Al oxides and total P were not significant but total P and Fe oxides were significantly correlated. Thus Fe oxides may be accounting for more fixation of P than Al oxides.

The total pedogenic Al (Alo) had values that were lower than those reported by Obi et al., (2008) in termite-infested Alfisols in the Guinea savanna agro-ecology of Nigeria but slightly higher than those reported by Obi et al., (2009) for the basement complex soils of southwestern Nigeria. However, the amount of Alo was higher than in most incipient soils (Graham et al., 1988). The moderate pH, medium texture, and the low organic matter content of the soils may have resulted in situation where almost all the Al in these soils occurred as inorganic form since there were no increased Alo values nearer the soil surface where organic matter was high.

The values of silt: clay ratios (> 0.15) obtained for most of the horizons in this study indicates that the soils have not been subjected to severe weathering but were relatively 'young' with a lot of weatherable minerals. Young (1980) showed that the silt: clay ratio is higher than 0.15 in younger soils; below 0.15 in old soils and 0.15 in moderately weathered soils. Comparing the soils of the two sites, Ejiba soils seem to have lower values of silt: clay ratio than Odo-Ogbe soils; indicating that Ejiba soils might slightly be more weathered than Odo-Ogbe soils.

Although the values of silt + clay : clay ratio were lower than those of silt: clay ratio, the trend was similar in all the profiles and in both locations. The low to moderate values of this index is an indication that some proportion of the silt had weathered to clay (Adegbite and Ogunwale, 1994). This result agrees with those of Feo/Fed ratios, which were very low (< 0.4), and suggests that the soils have been highly weathered but at variance with the result of the evaluation of the stage of development of these soils using the silt: clay ratio. The silt: clay ratios of these soils were greater than 0.15, indicating that the soils have not been severely weathered. Thus, it seems that the silt: silt + clay and Feo/Fed ratios of these soils presented a better picture of the stage of development (Ogunsola et al., 1989; Pai et al., 2004) of the soils than the silt : clay ratio.

CONCLUSION

Using the Feo/Fed, silt:silt + clay ratios as well as the pedogenic Fe oxide content of the soils gave a better evaluation of the stage of development of the soils studied. The significant correlation coefficient values between Fed and plinthite and the substantially higher pedogenic Fe content of these pedons is indicative of their advanced stage of development. Most of the Fe in these soils was crystalline. The Fed and Ald values were comparable with those reported for the basement complex soils of south-western Nigeria, but lower than values reported for the Alfisols of the Guinea savanna agro-ecology of Nigeria

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REFERENCES

Adegbite, K. A. and Ogunwale, J. A. (1994). Morphological, chemical and mineralogical properties of the soils of Abugi, Nigeria and their agricultural potential. Pertanlka Journal of Tropical Agricultural Sciences, 17 (3): 191-196

Agbenin, J. O. (2003). Extractable iron and aluminum effects on phosphate sorption in a savanna Alfisol. Soil Science Society of America Journal. 67: 569 – 593.

Ajiboye, G. A.; Ogunwale, J. A. and J. Talbot (2008). Characteristics and pedogenesis of soils developed over talc at Odo-Ogbe, Kogi state, Nigeria. America Eurasian Journal of Agriculture and Environmental Sciences., 4(4): 489 - 498.

Allen, C. E. (2005). Physical and chemical characteristics of soils forming on Boulder Tops, Kärkevagge, Sweden. Soil Science Society of America Journal. 69:148-158.

Azeez, K. O. (1998). Pedogenesis and Potassium distribution in marble overburden at Igbeti, Oyo State, Nigeria. M. Sc. Thesis, Faculty of Agriculture, University of Ilorin, Nigeria.

Birkeland, P.W., R.M. Burke, and J.B. Benedict. 1989. Pedogenic gradients for iron and aluminum accumulation and phosphorus depletion in arctic and alpine soils as a function of time and climate. Quaternary Research. 32:193–204.

Birkeland, P.W. (1999). Soils and geomorphology. 3rd Ed. Oxford University Press, Oxford.

Blume, H. P. and Schwertmann, U. (1969). Genetic evaluation of distribution of Al, Fe and Mn oxides. Soil Science Society of America Proceedings. 33: 438 – 444.

Buol, S. W., Hole, F. D and Mc Cracken, R. J. (1980). "Soil genesis and classification." The Iowa state University Press. 404 pp.

Cheng Mingfang, Jin Jiyun and Huang Shaowen (1999): Release of native and non-exchangeable soil potassium and adsorption in selected soils of North China. Better Crops International 13 (2), 3-5.

Delvigne, J. E. (1998). Atlas of Micro morphology of Mineral Alteration and weathering. The Canadian Mineralogist, special publication No 3. Mineralogy Association of Canada, 495 pp

Duchaufour, P. H. (1983). Pedologie, Tome 1: Pedogenese et Classification. Masson: Paris-New York-Barcelone – Milan: pp 1- 477.

FAO. 1988. Soil Map of the World. Revised Legend. Reprinted with corrections. World Soil Resources Report 60. FAO, Rome.

Graham, R.C., B.E. Herbert, and J.O. Ervin. 1988. Mineralogy and incipient pedogenesis of Entisols in anorthosite terrane of the San Gabriel Mountains, California. Soil Science Society of America Journal. 52:738–746.

Hao Qingzhen and Guo Zhengtang (2001). Quantitative measure on Paleo-weathering intensity of Loess-soil sequence and implication on Paleomonsoon. Science in China, Series D; 44(6): 566-576

Holgen, G. G. S. (1967). A rapid citrate dithionite extractable iron procedure. Soil Science Society of America Proceedings. 24: 420 – 421.

Hunt, C. P.; Singer, M. J. and Kletetschka, G. (1995). Effect of citrate-bicarbonate-dithionite treatment on fine-grained magnetite and maghemite. Earth Planet. Sci. Lett. 130:; 87-94.

Igwe, C. A. (2005). Free oxide distribution in Niger flood plain soils in relation to their total and available phosphorus. Proceedings of the 27th conference of Soil Science Society of Nigeria pp. 196 -211

Kronberg, B. L. and Nesbitt, H. W. (1981). Quantification of weathering, soil geochemistry and soil fertility. Journal of Soil Science. 32: 453.

Mckeague, J. A. (1981). Manual on soil sampling and methods of analysis, Toronto. Canadian Society of Soil Science. 212Pp.

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

Mohr, E. C. J., Van Baren, F. A. and Schuylenborgh, J. (1972). "Tropical soils, a comprehensive study of their genesis." Third revised edition. Mouton Publishers, The Hague. Pp 481.

NGSA (2004) Geologic map of Nigeria, Nigeria Geological Survey Agency. 2004 edition

Obi , J. C., Ogunkunle, A. O. and Adetunji, O. O. (2008). Extractable iron and aluminum distribution in Macrotermitinae nigeriensis infested Guinea Savanna Alfisol. Agricultural Journal 3(5): 345 – 348.

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. Nigerian Journal of Soil Science. 19(1):100-108.

Ogunkunle, A.O. and Onasanya, O.S. (1992). Soil - landscape relationship in a forest zone in southwestern Nigeria. Samaru Journal of Agricultural Research. 9: 19 – 33.

Ogunsola, O. A.; Omueti, J. A., Olade, O. and Udo, J. E. (1989). Free oxide status and distribution in soils overlying limestone area in Nigeria. Soil Science. 147 (4): 425 – 251.

Ojanuga, A. G. (1985). Forms of sesquioxides in Iwo soils. Nigeria Agricultural Journal 19/20: 39 – 49

Ojo_Atere, J. O. and Ogunwale J. A.(1982). Detrital evaluation of pedogenesis in some Alfisols in south-western Nigeria. Nigeria Agricultural Journal 17/18: 86-10.

Pai, Chuan-Wen; Wang, Ming-Kuang; Zhuang, Shun-Yao; King, Hen-Biau (2004). Free and non-crystalline Fe-oxides to total iron concentration ratios correlated with 14C ages of three forest soils in central Taiwan. Soil Science. 169(8):582-589.

Parfitt, R.L., and C.W. Childs. 1988. Estimation of forms of Fe and Al: A review, and analysis of contrasting soils by dissolution and Moessbauer methods. Australia Journal of Soil Research 26:121–144.

Rebertus, R.A., and S.W. Buol. 1985. Iron distribution in a developmental sequence of soils from mica gneiss and schist. Soil Science Society of America Journal 49:713–720.

Schwertmann, U. and Herbillon, A. J. (1992). Some aspects of fertility associated with the mineralogy of highly weathered tropical soils. In: R Lal and P. A. Sanchez (Ed). Myths and science of soils of the tropics. SSS Spec. Publ. 29. SSSA and ASA. Madison WI, pp: 49 – 59.

Shamshuddin, J., Jamailah, I. and Ogunwale, J. A. (1995). Organic Carbon Determination in Acid Sulfate Soils. Pertanika Journal of Tropical Agricultural Science; 17 (3): 197 -200.

Singer, M. J.; Bowen, L. H.; and Verosub, K. L. (1995). Mossbauer spectroscopic evidence for Citrate-bicarbonate-dithionite extraction of maghemite from soils. Clay and Clay Minerals. 43: 1 –7.

Stewart, V. I., Adams, W. A. and Abdulla, H. H. (1970). Quantitative pedological studies on soils derived from Silurian mudstone. I. Parent material and the significance of the weathering process. Journal of Soil Science. 21: 242-247.

Wilson, M.J. (2004). Weathering of the primary rock-forming minerals: Processes, products and rates. Clay Minerals. 39: 233-266.

Young, A. (1980). Tropical soils and Soil Survey. Cambridge University Press, New York.