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Assessment of sesquioxides status of some uplands soils in humid southwest Nigeria

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ABSTRACT

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Assessment of some sesquioxides in the upland soils in southwestern Nigeria was undertaken to evaluate their degree of weathering under humid tropical conditions. Samples were taken from genetic horizons of eight soil profile pits sited at different physiographic positions along two toposequences in southwestern Nigeria. The samples were analyzed for gravel content, particle size distribution, bulk density, pH, organic carbon, total nitrogen, available P, exchangeable bases, crystalline and amorphous forms of Fe and Al, using standard procedures. Sand fraction ranged from 31–76% (54.49±11.34), silt from 3–19% (10.21±3.61) and clay from 10–55% (35.3±9.7). Bulk density increased with profile depth, ranging between 1.12 and 1.64g cm^{-3} (1.39±0.13). The pH was low (4.2–6.1; 5.0±0.55), organic carbon content ranged from 0.75–15.99g kg^{-1} (5.79±3.49) with higher values in the surface horizons. Total nitrogen content ranged from low to medium (0.13–2.75g kg^{-1}; 1.16±0.49) while available phosphorus ranged from 0.49–11.63mg kg^{-1} (4.30±3.57) across the horizons. Crystalline forms of Fe (Fe_d) and Al (Al_d) ranged from 10.26–39.82g kg^{-1} and 0.41–1.80g kg^{-1}, respectively while the amorphous forms (Fe_o and Al_o) ranged from 0.41–2.60g kg^{-1} and 0.83–1.64g kg^{-1}, respectively. The crystalline forms of Fe_d and Al_d were more dominant over the amorphous forms of Fe_o and Al_o. The argillic (Bt) horizons of pedons had significant accumulation of clay particles and free iron. The weathering indices of clay and free iron accumulation in argillic (Bt) horizons of the pedons indicated that the soils of the study area were well-drained, deeply weathered and intensely leached with few weatherable minerals available for plant uptake.

Keywords: Sesquioxides, Upland Soils, Nigeria

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INTRODUCTION

Oxides, hydroxides and oxy-hydroxides of iron (Fe), aluminum (Al), manganese (Mn) and titanium (Ti) are referred to as sesquioxides. They occur in soils mainly as crystalline and amorphous inorganic compounds. The Fe and Al are present in soils as both primary and secondary minerals (Ciolkosz et al 1993). During weathering, Fe in primary silicate minerals is released and forms secondary Fe oxides such as goethite (FeOOH) and hematite (Fe_2O_3) while Al present in the primary silicate minerals frequently weathers into secondary silicate minerals such as kaolinite, although Al oxides such as gibbsite can also be formed. However, a small fraction of these oxides may be present in the organic complexes (Maniyunda et al 2015). The formation of secondary Fe oxides is a function of the weathering process over time (Michalyna 1971). Also, the nature, content and distribution of sesquioxides influence pedogenetic processes as well as the physical and chemical properties of soils, such as phosphate retention (making it unavailable in highly weathered tropical soils), surface charge, specific surface area, aggregate formation and stabilization (Igwe 2001, Duiker et al 2003, Jelic et al 2011). The nature and content of sesquioxides in soils have also been used to make predictions with regards to type, direction, degree and stage of pedogenesis (Durn et al 2001, Igwe 2001, Kurihara et al 2002, Osodeke et al 2005, Maniyunda et al 2015). Swelling and aggregate formation may be significantly modified by the presence of amorphous Fe and Al oxides (Angers and Chenu 1998). According to Yaro (2006), the features that distinguish plinthites and account for their hardness are the greater degree of crystallinity and a continuity of the crystalline phase (ie, the ratio of amorphous iron (Fe_o) to crystalline iron (Fe_d); where a low Fe_o/Fe_d ratio indicates a high degree of crystallinity). There is limited information on the status of sesquioxides in the soils of southwestern Nigeria. The objective of this study was to evaluate the degree of weathering of upland soils under humid tropical conditions.

MATERIALS AND METHODS

Description of the Study Area

The study was carried out on soil that was developed on coarse-grained granite and gneiss parent material (Smyth and Montgomery 1962). The specific site was the Teaching and Research Farm of the Obafemi Awolowo University, Ile-Ife, Nigeria, located between latitudes 7°32'N and 7°33'N and longitudes 4°32'E and 4°34'E (Figure 1). The climate is hot, humid tropical with distinct dry and rainy seasons. The rainy season, which is bimodal in distribution pattern, ranges between March and October with peaks in June and September. There are about four months of dry season annually (November–February). The mean annual rainfall is about 1400mm while the mean annual temperature is 27°C (Okusami and Oyediran 1985).

Soil Sample Collection and Preparation

Soil samples were collected from the pedogenic horizons of eight profile pits located at different physiographic units (upper, mid and lower slope positions) along two toposequences.

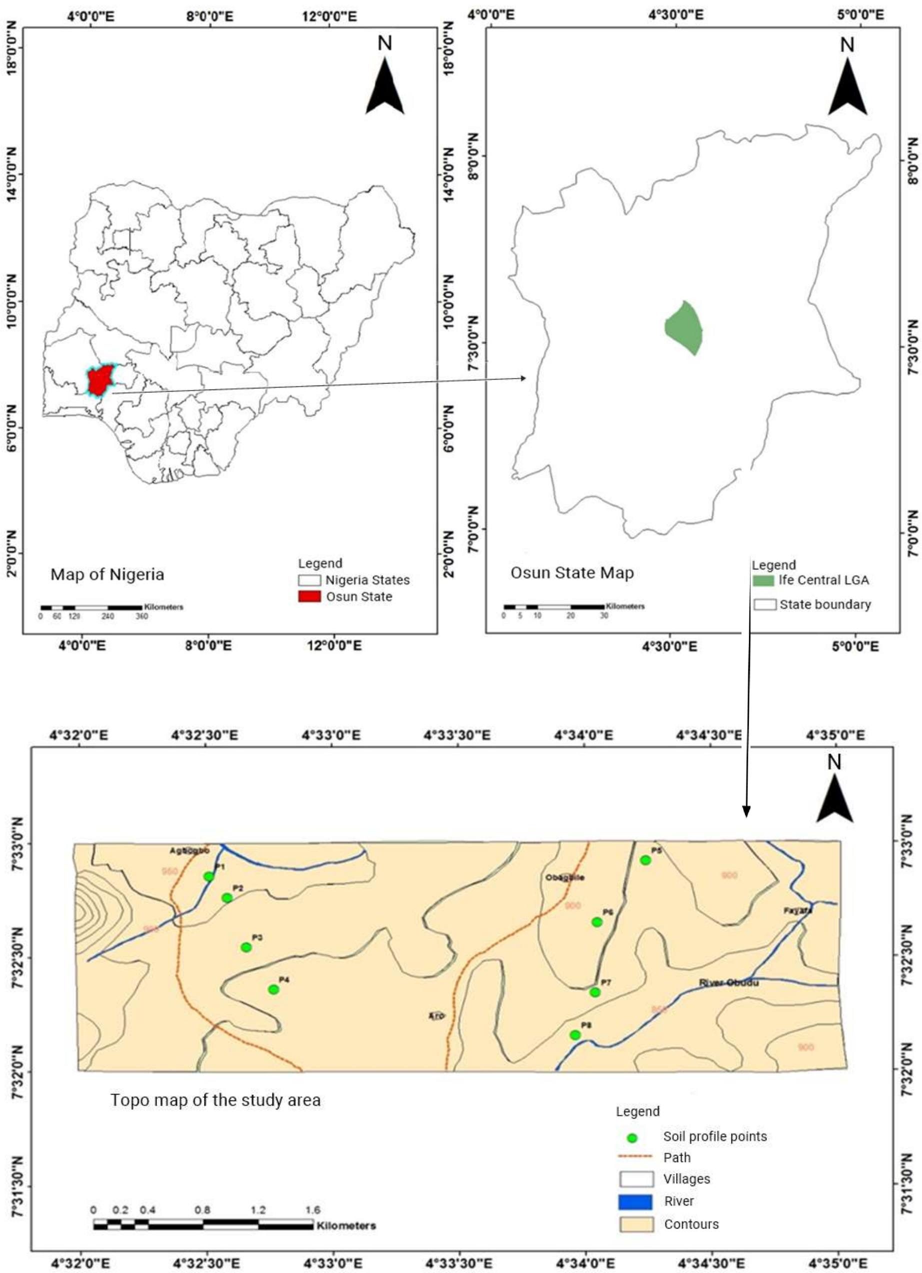


Figure 1. Maps of the study area showing the location of soil profile pits

The samples were air-dried and passed through a 2mm sieve to separate gravel from the soil component. The less than 2mm fractions were retained for physical and chemical analyses. Gravel content (materials >2mm) was determined and expressed as a percentage of the total weight of the sample. Particle size distribution analysis was carried out using the hydrometer method (Gee and Or 2002). Bulk density was determined by the core method (Blake and Hartge 1986). The pH was determined in 1.0M KCl employing a 1:1 soil/solution mixture (Thomas 1996) and the reading was taken with a digital pH meter after equilibration. Exchangeable cations were determined by extracting with neutral 1.0N ammonium acetate (NH_4OAc) solution (Thomas 1982). The concentrations of Ca, Mg, K and Na in the filtrate were then determined. Calcium, Na and K concentrations were determined using a flame photometer while Mg was determined using Atomic Absorption Spectrophotometer (AAS). Organic carbon was determined using the Walkley-Black method (Nelson and Sommers 1996), the total nitrogen was determined using the Kjeldahl method (Bremner 1996) and available Phosphorus was determined by the Bray-1 method (Kuo 1996). Total free Fe (Fe_d) and Al (Al_d) otherwise referred to as the crystalline Fe and Al oxides were determined by the Mehra and Jackson (1960) method using the dithionite-citrate system buffered with sodium bicarbonate (Jackson et al 1986, Loeppert and Inskeep 1996, Soil Survey Staff 2004). The amorphous (non-crystalline) iron (Fe_o) and aluminum (Al_o) oxides were extracted with ammonium oxalate-oxalic acid buffer (Tamn's reagent) adjusted to pH3 with HCl (McKeague 1981, Loeppert and Inskeep 1996, Soil Survey Staff 2004). The dithionite-citrate-bicarbonate and acid ammonium oxalate extracts were analyzed for Fe (Fe_d and Fe_o) using the atomic absorption spectroscopy while Al (Al_d and Al_o) in the extract was determined using colorimetry. The extent of soil development/degree of weathering was evaluated by estimating the ratios of silt/clay (Van Wambeke 1962, Asemoa 1973, Ajiboye et al 2015), silt/(silt+clay) ratio (Muda 2011, Ajiboye et al 2015), Fe_o/Fe_d and Fe_d/Clay (Okusami et al 1997, Navarrete et al 2007, Obi et al 2009, Muda 2011, Ajiboye et al 2015).

RESULTS AND DISCUSSION

Characteristics of the Soils

The soils of the study area were fairly to very deeply weathered with depths ranging between 135cm and greater than 200cm. Prominent resistant quartz veins were observed in the soils at the midslope position of the landscape. Soils occupying this position are usually sedentary/residual and formed in situ (Smyth and Montgomery 1962, Ojanuga 1978, Calvert et al 1980, Amusan 1991). The color of the soils varied from dark reddish brown through reddish brown to yellowish red probably resulting from differences in the physiographic positions and drainage conditions of the soils. The variation in color could also be due to changes in the Fe forms because of seasonal changes in the groundwater table as well as the sequence of drainage (Gerrard 1981). Soils at the upper to mid slope positions were well drained while those at the lower slope were poorly drained. Lower down the landscape, where soil moisture content increases and drainage conditions become poorer, the hues become yellower. Color changes along a toposequence has been reported by Fagbami (1981) and Okusami and Oyediran (1985). The bright color of soils in the higher topographical sites (pits 1, 2, 5 and 6) indicated good drainage (Periaswamy and Ashaye 1982).

The darker color of the surface horizons, compared to the subsurface horizons, could be attributed to organic material deposition from litter which subsequently decomposed and mineralized (Olayinka 2009). The color, however, became lighter with depth in all the profile pits examined. Coarse gravels were noticed to be slightly concentrated in the upper subsoil of all the horizons studied. This could have resulted from the eluviation of fine materials with residual concentration of stones and gravel and was responsible for the fine texture of the subsurface horizons. This hypothesis is based on the argillic (Bt) horizons and clay skin, commonly observed in soil horizons occurring below the slightly concentrated gravel layers. The structure of the surface horizons was generally moderate medium crumb resulting from the effects of vegetal cover on the soils since the roots of plants have binding effects on soil thereby preventing the loss of soil aggregates.

Boundaries between the A and B horizons were clear and easily discernible as a result of the darkening effect of organic matter on the surface horizons (Driessen et al 2001). The horizon boundaries of the B horizons of nearly all the profile pits studied were not easily discernible being mainly diffuse wavy, which is a common characteristic of strongly weathered soils (Navarrete et al 2007). The subsoil was likely to have gone through reorganization and homogenization that resulted in the formation of “stronger” structure and well-expressed B-horizons. The morphological characteristics exhibited by the profile pits were indicative of an advanced stage of weathering (Mohr et al 1972, Navarrete et al 2007). Root concentration was restricted to the surface horizons and decreased with depth in all the profile pits examined.

Table 1 shows the results of physical analyses of the soils. The surface horizons of profile pits 1, 4, 5 and 8 were sandy clay loam while those of 2, 3, 6 and 7 were sandy loam. The vegetation on the soil aided good aggregation of the surface horizons. This was reflected in the non-gravelly and crumbly nature of the surface soils. The surface horizons had lower gravel content (8.5–18.8%) compared to the subsurface horizons (6.6–62.5%). The soils would be easier to cultivate. Seed emergence and root proliferation through the surface soils would also be easier. Lower gravel contents (6.6 and 8.5%) were recorded at the lower slope position of profile pits 4 and 8, respectively. This could be adduced to the fact that soils at the lower topographic position were formed from colluvial/alluvial parent materials in which there had been thorough sorting of materials before deposition down slope.

Sand fraction was higher than silt and clay in the surface horizons. The predominance of sand fraction in the surface horizons was attributed to the preferential removal of clay and silt by soil erosion (Ojanuga 1975). Higher content of sand in the surface horizon could also be attributed to the translocation of colloidal clay particles deep into the profile with percolating water, and the selective erosion as well as transport of fine particles down the slope by rainwater (Amusan 1991). Sand content decreased, while clay content increased, with soil depth.

The bulk density values of the soils ranged between 1.12 and 1.64g cm^{-3}. These values are within the range (1.0–1.6g cm^{-3}) reported by Wild (1993) as ideal for agronomic activities in most mineral soils. Soils with low bulk densities are usually associated with high total porosity (Payne 1988). Russell (1976) and Payne (1988) reported that root penetration and seedling emergence were difficult when bulk density exceeded 1.6g cm^{-3}. The values generally increased with depth. The porosity was generally high, varying between 37.15 and 57.62%. Therefore, the soils in the study area were well-drained and well-aerated.

Table 1. Physical properties of the soils

Horizon	Depth (cm)	Gravel content	Sand ←	Silt (%)	Clay →	Bulk density (g cm^{-3})	Porosity (%)	Textural class
Pedon 1 (Upper slope): Typic isohyperthemic paleustults								
A	0-15	19.5	59	12	29	1.20	54.6	SCL
AB	15-35	43.5	53	12	35	1.29	51.2	SCL
Bt1	35-53	54.6	50	9	41	1.17	55.7	SC
Bt2	53-65	54.4	43	18	39	1.38	47.9	CL
BC1	65-140	38.9	55	15	30	1.29	51.4	SC
BC2	140-200	29.1	55	11	34	1.37	48.4	SCL
Pedon 2 (Mid slope): Typic isohyperthemic paleustults								
Ap	0-9	18.8	76	6	18	1.35	49.1	SL
AB	9-18	62.5	75	7	18	1.55	41.4	SL
Bt1	18-57	54.5	31	14	55	1.51	43.1	C
Bt2	57-140	31.5	41	14	45	1.57	40.7	C
BCm	140-182	33.6	35	19	46	1.50	43.3	C
Pedon 3 (Lower slope): Plinthic isohyperthemic paleustults								
A	0-20	20.8	71	11	11	18.0	47.0	SL
Bt	20-56	35.8	43	10	10	47.0	46.1	C
Btv1	56-110	36.0	43	10	10	47.0	45.3	C
Btv2	110-160	34.1	55	14	14	31.0	53.8	SCL
Pedon 4 (Lower slope): Typic isohyperthemic paleustults								
A	0-20	8.5	59	16	25	1.47	44.4	SCL
AB	20-35	18.3	51	12	37	1.53	42.1	SC
Bt1	35-67	31.4	51	10	39	1.40	47.1	SC
Bt2	67-97	34.6	61	12	27	1.48	44.3	SCL
2BC1	97-130	43.2	58	11	31	1.47	44.7	SCL
2BC2	130-180	40.0	60	10	30	1.49	43.8	SC
Pedon 5 (Upper slope): Typic isohyperthemic paleustults								
A	0-18	21.1	71	5	24	1.18	55.6	SCL
AB	18-45	42.3	61	8	31	1.38	47.9	SCL
Bt1	45-71	51.6	51	6	43	1.29	51.5	SC
Bt2	71-102	44.9	48	11	41	1.38	47.9	SC
BC1	102-133	33.2	43	13	44	1.44	45.7	C
BC2	133-180	42.1	45	15	40	1.41	46.8	SC
Pedon 6 (Mid slope): Typic isohyperthemic paleustults								
Ap	0-18	17.5	76	8	16	1.51	43.1	SL
AB	18-46	42.9	57	6	37	1.53	42.3	SC
Bt1	46-72	46.0	43	12	45	1.32	50.2	C
Bt2	72-110	39.1	43	8	49	1.42	46.25	C
BC1	110-145	32.9	43	12	45	1.43	45.9	C
BC2	145-200	27.1	41	12	47	1.33	49.8	C
Pedon 7 (Lower slope): Typic isohyperthemic paleustults								
Ap	0-18	13.8	76	4	20	1.50	43.3	SL
AB	18-42	18.9	58	3	39	1.64	37.2	SC
Bt1	42-70	25.2	47	8	45	1.56	41.0	SC
Bt2	70-105	37.4	59	8	33	1.54	41.9	SCL
2Bt3	105-146	25.9	49	9	42	1.28	51.6	SC
2BC	146-200	8.3	61	10	29	1.18	55.3	SCL
Profile 8 (Lower slope): Typic isohyperthemic paleustults								
A	0-19	13.0	69	6	25	1.12	57.6	SCL
AB	19-34	6.6	61	8	31	1.20	54.9	SC
Btv1	34-69	9.5	55	6	39	1.18	55.4	SC
Btv2	69-135	31.8	61	8	31	1.45	45.2	SCL

Table 2 shows the chemical properties of the soils. The pH was generally low, ranging between 4.2 and 6.1, indicating that the soils are acidic. Uptake of basic cations by plants and/or leaching, and the coarse-textured nature of the soils which enhances permeability of soils and leaching of basic cations, which is prevalent in the humid tropics, could be some of the factors responsible. The organic carbon content of the soils ranged from low to medium across the entire study area. It was, however, higher on the surface horizons and decreased with horizon depth across the profile pits examined. Higher content at the surface horizons could have resulted from decomposition of leaf litters, phytocycling and enhanced activities of soil microbes due to better aeration and moisture regimes at the surface horizons (Olayinka 2009). Total nitrogen content ranged from low to medium. Sobulo and Adepetu (1987) classified soil nitrogen fertility class range into low (<0.1%), medium (0.1–0.2%) and high (>0.2%). Higher values were recorded for the surface horizons across the study area. The trend was similar to that of organic carbon. Available phosphorus (P) ranged from medium to high on the surface horizons and from low to medium in the subsurface horizons of the profile pits examined. The values decreased with profile depth. The trend was also similar to that of organic carbon content thus confirming the direct relationship between organic matter content and soil nutrients. Olayinka (2009) reported that organic matter content serves as a storehouse and source of plant nutrients. The available P content ranged from 0.49–14.08mg kg^{-1}. The contents of exchangeable bases across the profile pits examined were low. Smyth and Montgomery (1962) reported that soils of upland areas of central western Nigeria had low exchange capacity due to the kaolinitic nature of their clay. The values for exchangeable calcium were higher than any of the other basic cations while the values for the exchangeable sodium were the least in all the profile pits examined. However, the values of the exchangeable cations were higher at the surface than the subsurface horizons (Table 2). Sehgal et al (1972) attributed the relative abundance of exchangeable cations on the surface soils to the fact that it was being continuously recharged by mobile constituents liberated by the decomposition of organic residues, irrespective of its exposure to leaching and runoff.

Iron and Aluminum Oxides Content and Weathering Indices of the Soils

The dithionite extractable iron, Fe_d (10.26–39.82; 25.40±7.95) was higher than the oxalate extractable iron, Fe_o (0.83–1.64; 1.10±0.15) (Table 3). Similar observations were made by Ojanuga (1975), Gallez et al (1981) and Maniyunda et al (2015). This suggests that a considerable fraction of the sesquioxides was present in the crystalline form of Fe. The dithionite citrate extract removes all oxalate extractable Fe in the soil, hence the higher values (Mckeaque and Day 1966, Amusan 1991, Moon et al 2006). However, Muda (2011) observed that the values for dithionite aluminum were lower than those of the oxalate Al which can be attributed to the fact that more amorphous and paracrystalline aluminum was present in the soils studied. This observation is in line with that of Childs et al (1983). In many of the profile pits examined, the values of Fe_d and Al_d increased with depth. A similar pattern was also recorded for the clay content (Table 1). This indicates co-migration of Fe and Al oxides with clay into the subsoil (Ogunsola et al 1989, Ogunsola and Omueti 1990, Amusan 1991, Muda 2011).

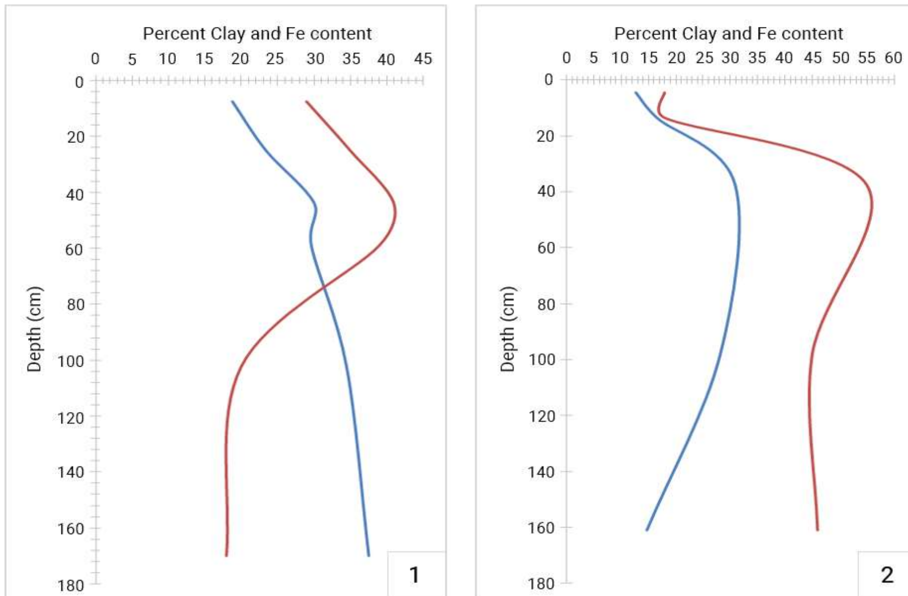
Table 2. Chemical properties of the soils

Horizon	Depth (cm)	pH (KCl)	Organic C	Total N	Available P (mg kg^{-1})	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}
			← (g kg^{-1}) →			← (cmol(+) kg^{-1}) →			
Pedon 1 (Upper slope): Typic isohyperthemic paleustults									
A	0-15	4.7	12.5	2.15	1.37	14.1	2.4	0.37	0.22
AB	15-35	4.6	5.05	0.87	1.09	9.18	1.8	0.36	0.19
Bt1	35-53	4.6	5.05	0.87	1.26	6.53	1.3	0.35	0.19
Bt2	53-65	4.7	4.64	0.80	1.12	5.10	0.9	0.33	0.18
BC1	65-140	4.5	3.13	0.54	1.09	8.37	0.1	0.29	0.15
BC2	140-200	5.2	12.5	2.15	1.12	6.94	0.8	0.34	0.16
Pedon 2 (Upper slope): Typic isohyperthemic paleustults									
Ap	0-9	5.4	15.9	2.75	1.26	6.33	1.7	0.31	0.18
AB	9-18	5.4	6.61	1.14	1.12	9.80	1.0	0.37	0.20
Bt1	18-57	4.3	5.28	0.91	1.19	7.14	0.6	0.31	0.35
Bt2	57-140	5.3	3.13	0.54	1.12	3.88	0.6	0.30	0.40
BCm	140-182	4.3	0.75	0.13	1.19	3.27	0.9	0.38	0.31
Pedon 3 (Lower slope): Plinthic isohyperthemic paleustults									
A	0-20	5.4	10.1	1.74	1.26	13.2	1.3	0.35	0.20
Bt	20-56	5.2	4.29	0.74	1.26	11.9	3.1	0.37	0.20
Btv1	56-110	4.7	5.45	0.94	1.19	2.04	1.3	0.32	0.30
Btv2	110-160	4.5	4.64	0.80	1.12	2.65	1.1	0.35	0.25
Pedon 4 (Lower slope): Typic isohyperthemic paleustults									
A	0-20	5.1	4.29	0.74	2.87	11.4	1.9	0.38	0.18
AB	20-35	4.3	7.19	1.24	1.37	10.8	0.9	0.36	0.14
Bt1	35-67	4.5	7.60	1.31	1.19	8.37	0.9	0.38	0.16
Bt2	67-97	4.8	4.29	0.74	2.87	3.67	1.9	0.37	0.21
2BC1	97-130	4.2	5.05	0.87	0.60	6.33	0.7	0.38	0.17
2BC2	130-180	4.2	4.06	0.70	0.49	5.50	0.7	0.34	0.14
Pedon 5: (Upper slope): Typic isohyperthemic paleustults									
A	0-18	5.9	15.2	1.54	7.76	5.65	0.4	0.61	0.23
AB	18-45	5.6	4.64	1.58	11.0	9.25	0.4	0.44	0.18
Bt1	45-71	5.4	5.86	1.33	7.76	9.57	0.4	0.61	0.26
Bt2	71-102	5.4	3.89	1.12	4.08	8.86	0.4	0.49	0.21
BC1	102-133	5.2	1.57	1.12	5.92	10.1	0.4	0.58	0.12
Pedon 6 (Mid slope): Typic isohyperthemic paleustults									
Ap	0-18	4.9	5.05	1.26	11.6	9.18	0.7	0.48	0.23
AB	18-46	5.0	3.48	1.30	10.4	10.3	0.4	0.74	0.11
Bt1	46-72	4.6	5.86	1.19	4.08	8.60	0.4	0.72	0.09
Bt2	72-110	4.4	2.32	1.05	6.53	10.4	0.4	0.73	0.09
BC1	110-145	4.3	5.45	1.09	9.6	9.93	0.4	0.52	0.09
BC2	145-200	4.3	2.73	1.05	10.2	10.2	0.4	0.44	0.19
Pedon 7 (Lower slope): Typic isohyperthemic paleustults									
Ap	0-18	5.4	5.45	1.23	5.92	8.41	0.4	0.27	0.22
AB	18-42	5.2	3.48	1.16	11.4	9.74	0.4	0.25	0.20
Bt1	42-70	5.4	5.45	1.05	7.55	8.32	0.4	0.31	0.20
Bt2	70-105	5.9	5.86	1.09	2.86	10.0	0.4	0.44	0.18
2Bt3	105-146	6.0	4.64	1.05	4.08	9.02	0.4	0.53	0.19
2BC	146-200	5.6	1.97	1.05	6.12	10.1	0.4	0.45	0.14
Pedon 8 (Lower slope): Plinthic isohyperthemic paleustults									
A	0-19	5.8	12.8	2.45	6.12	3.30	0.4	0.26	0.24
AB	19-34	5.6	8.58	1.26	8.16	3.57	0.4	0.19	0.18
Btv1	34-69	5.6	7.37	1.05	6.33	3.39	0.4	0.22	0.19
Btv2	69-135	6.1	3.89	1.05	2.25	3.85	0.4	0.27	0.12

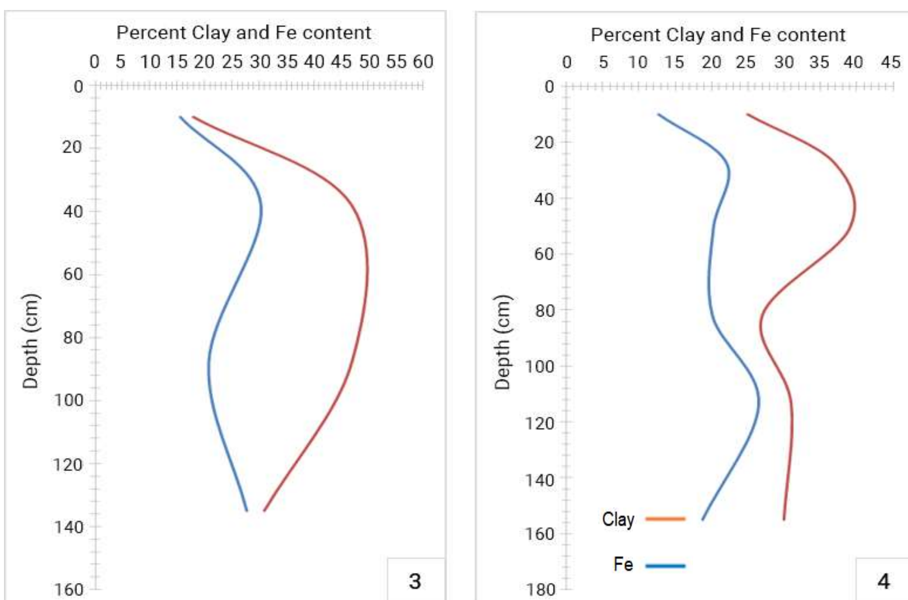
The Fe_d/clay ratio was calculated to determine whether the Fe_d was associated with the clay fraction (Blume and Schewetmann 1969, Robertus and Buol 1985). The ratio ranged from 0.03–0.14. The values were less than 1. Lower values indicate that the soils are at an advanced stage of weathering (Mahaney et al 1991). There was significant positive correlation (r=0.454; $p \leq 95\%$) between Fe_d and clay, an indication of co-migration of Fe oxides and clay (Figure 2a and b). Similar results had been reported for some upland soils in southwestern Nigeria (Ogunsola et al 1989, Ogunsola and Omueti 1990, Amusan 1991, Muda 2011). Argillic (Bt) horizons of the pedons have significant accumulation of clay particles and free Fe. The weathering indices of clay and free Fe accumulation in argillic horizon (Bt) of the pedons indicated that the soils of the study area were deeply weathered and intensely leached with few weatherable minerals.

The distribution of oxalate extractable iron (Fe_o) and aluminum (Al_o) to dithionate extractable Fe (Fe_d) and Al (Al_d) within each pedon is expressed as the active Fe and Al ratio (Soil Survey Staff 2004) or degree of crystallinity (Yaro 2006). The ratio did not follow the same order in all the profile pits examined. It decreased in pedons 1, 4, 5, 6, 7 and 8 while it increased in pedons 2 and 3. The decrease in active Fe ratio with depth in these horizons indicated that higher proportions of Fe were present in crystalline forms in the lower horizons. Observation of an increase in active Fe ratio possibly indicates a predominance of the amorphous form of Fe which is a reflection of a less intensively weathered horizon (Amusan 1991). There was no consistent pattern of extractable Al for all the pedons studied. However, many of the pedons showed that extractable Al values decreased with depth, indicating that there had been little or no period of water saturation in these soils. This could be attributed to good internal drainage of the soils as indicated by their bright colors. This might also be linked with the porous nature of the soils formed from coarse-grained granite and gneiss (Smyth and Mongomery 1962, Amusan 1991).

The calculated silt/clay ratio in all the profile pits studied varied from 0.08 to 0.64 (Table 3). It was observed that the values were higher at the surface horizons than the subsurface horizons since the clay content was less in the surface soils. However, the decrease in value with profile depth was erratic. This implies that the relative intensity of weathering was more in the subsurface horizons (Ojo-Atere and Ogunwale 1982). The values of silt/(silt+clay) ratios of the soils were less than 0.7; ranging from 0.07 to 0.39. 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 with the lowest values occurring in the horizons with the higher clay content. Since these values were lower than 0.7 across the profiles, the soils could be said to have been severely weathered (Stewart et al 1970, Azeez 1998).

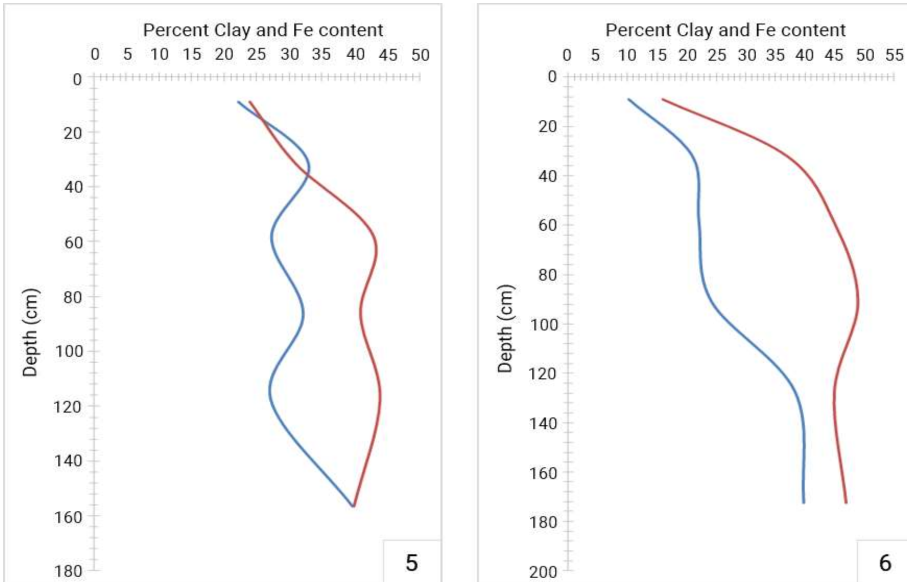


Upper -Mid slope area

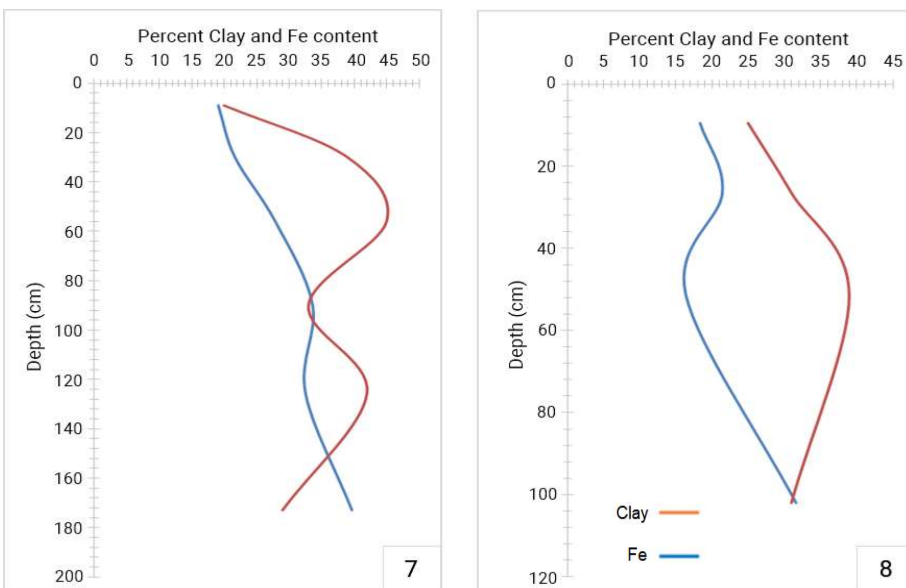


Lower slope

Figure 2a. Variation in clay and Fe contents with depth in profile pits 1-4



Upper -Mid slope area



Lower slope

Figure 2b. Variation in clay and Fe contents with depth in profile pits 5-8

Table 3. Profile distribution of sesquioxides and weathering indices of the soils

Horizon	Depth (cm)	Dithionite Extract Fe_d	Dithionite Extract Al_d	Oxalate Extract Fe_o	Oxalate Extract Al_o	Fe_o/ Fe_d	Al_o/ Al_d	Fe_d/ Clay	Silt/ Clay	Silt/ (Silt+Clay
		← (g kg^{-1}) →				← Weathering ratio →				
Pedon 1 (Upper slope): Typic isohyperthemic paleustults										
A	0-15	18.8	0.53	2.01	1.35	0.65	2.55	0.07	0.41	0.29
AB	15-35	23.4	1.04	0.96	1.05	0.67	1.01	0.07	0.34	0.26
Bt1	35-53	30.1	0.91	0.81	1.05	0.73	1.15	0.07	0.22	0.18
Bt2	53-65	29.7	0.55	0.90	1.03	0.76	1.87	0.08	0.46	0.32
BC1	65-140	34.5	0.54	1.14	1.15	1.73	2.13	0.12	0.50	0.30
BC2	140-200	37.6	1.36	0.41	0.97	2.09	0.71	0.11	0.32	0.24
Pedon 2 (Mid slope): Typic isohyperthemic paleustults										
Ap	0-9	12.7	1.74	1.32	1.27	0.92	0.73	0.07	0.33	0.25
AB	9-18	16.6	0.96	1.03	1.25	0.56	1.30	0.09	0.39	0.28
Bt1	18-57	30.9	0.69	1.83	1.47	0.63	2.12	0.06	0.25	0.20
Bt2	57-140	28.2	1.80	0.92	1.15	0.32	0.64	0.06	0.31	0.24
BCm	140-182	14.8	0.55	1.03	1.01	0.92	1.84	0.03	0.41	0.29
Pedon 3 (Lower slope): Plinthic isohyperthemic paleustults										
A	0-20	15.6	0.95	1.14	1.05	0.87	1.11	0.09	0.61	0.38
Bt	20-56	30.4	1.11	1.14	1.01	0.65	0.91	0.07	0.21	0.18
Btv1	56-110	20.8	0.95	1.20	1.12	0.44	1.18	0.04	0.21	0.18
Btv2	110-160	27.8	0.83	2.60	1.27	0.90	1.53	0.09	0.45	0.31
Pedon 4 (Lower slope): Typic isohyperthemic paleustults										
A	0-20	12.7	1.41	1.81	1.15	0.14	0.82	0.05	0.64	0.39
AB	20-35	22.1	1.49	1.84	1.16	0.08	0.78	0.06	0.32	0.24
Bt1	35-67	20.3	1.50	1.84	1.08	0.09	0.72	0.05	0.26	0.20
Bt2	67-97	20.2	1.48	2.05	1.32	0.10	0.89	0.08	0.44	0.31
2BC1	97-130	26.5	1.17	1.20	1.02	0.05	0.87	0.09	0.35	0.26
2BC2	130-180	18.8	1.06	0.96	1.01	0.05	0.95	0.06	0.33	0.25
Pedon 5 (Upper slope): Typic isohyperthemic paleustults										
A	0-18	22.2	0.82	1.34	0.97	0.06	1.18	0.09	0.21	0.17
AB	18-45	33.0	1.24	1.45	1.02	0.04	0.83	0.11	0.26	0.21
Bt1	45-71	27.4	1.58	1.62	0.96	0.06	0.61	0.06	0.14	0.12
Bt2	71-102	32.2	0.56	1.89	1.04	0.06	1.84	0.08	0.27	0.21
BC1	102-133	27.2	1.01	0.81	1.01	0.03	1.00	0.06	0.30	0.23
BC2	133-180	39.8	0.76	0.55	0.93	0.01	1.23	0.10	0.38	0.27
Pedon 6 (Mid slope): Typic isohyperthemic paleustults										
Ap	0-18	10.3	0.62	0.74	0.99	0.07	1.58	0.06	0.50	0.33
AB	18-46	21.0	1.40	0.90	0.99	0.04	0.70	0.06	0.16	0.14
Bt1	46-72	22.1	0.94	1.29	1.08	0.06	1.15	0.05	0.27	0.21
Bt2	72-110	24.3	0.66	0.79	1.00	0.03	1.50	0.05	0.16	0.14
BC1	110-145	38.4	1.61	0.90	1.13	0.02	0.70	0.09	0.27	0.21
BC2	145-200	39.8	1.28	1.18	1.17	0.03	0.91	0.09	0.26	0.20
Pedon 7 (Lower slope): Typic isohyperthemic paleustults										
Ap	0-18	19.1	1.25	0.53	1.00	0.03	0.80	0.10	0.20	0.17
AB	18-42	21.7	0.44	0.73	1.01	0.03	2.33	0.06	0.08	0.07
Bt1	42-70	27.9	1.44	0.58	1.64	0.02	1.14	0.06	0.18	0.15
Bt2	70-105	33.6	1.21	0.64	1.21	0.02	1.00	0.10	0.24	0.20
2Bt3	105-146	32.5	0.59	0.64	1.06	0.02	1.78	0.08	0.21	0.15
2BCm	146-200	39.7	0.41	0.53	0.83	0.01	2.02	0.14	0.34	0.26
Pedon 8 (Lower slope): Plinthic isohyperthemic paleustults										
A	0-19	18.4	1.61	0.84	1.09	0.05	0.68	0.07	0.24	0.19
AB	19-34	21.4	1.08	0.74	1.11	0.03	1.02	0.07	0.26	0.21
Btv1	34-69	16.4	1.28	0.67	1.18	0.04	0.92	0.04	0.15	0.13
Btv2	69-135	31.7	1.45	0.74	0.97	0.02	0.67	0.10	0.26	0.21

CONCLUSION

The sesquioxides in some upland soils of humid southwestern Nigeria were studied. A considerable fraction of the sesquioxides was present in the crystalline form for Fe. The values were much higher than the dithionite extractable Al. Argillic (Bt) horizons of pedons had significant accumulation of clay particles and free iron. The weathering indices of clay and free Fe accumulation in argillic (Bt) horizons of the pedons indicated that the soils of the study area were well-drained, deeply weathered and intensely leached with few weatherable minerals for plant uptake. It is therefore necessary that proper management strategies be put in place for sustainable utilization of these soil resources.

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