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Assessment of Dithionite and Oxalate Extractable Iron and Aluminium Oxides on a Landscape on Basement Complex Soil in South-Western Nigeria

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Abstract

The study investigats the morphological, physical and chemical characteristic of a toposequence on basement complex in Ejioku area, south-western Nigeria on latitude 07˚28.675'N; and longitude 004˚07.219'E; 180 m above sea level at the upper slope. It terminates at the valley bottom on latitude 07˚28.756'N; and longitude 004˚07.229'E; 175 m above sea level. The topography of the site is moderately slope (not greater than 10%). The aim is to examine the two forms of sesquioxides (crystalline-dithionite extractible Fe & Al and amorphous-oxalate Fe & Al) and their distribution on the toposequence. The crystalline form of Fe oxide dominates all the positions and ranges from 7.2 g/kg at the valley bottom to 444.3 g/kg at the crest compared to the amorphous forms that range from 2.7 g/kg to 10.9 g/kg. The crystalline and amorphous aluminium oxide contents of the soils are low (2.9 g/kg - 43.3 g/kg and 1.3 g/kg - 8.7 g/kg respectively). There is significant negative relationship between Fe_d and Fe_d/Fe_o ($r = -0.15$; $P < 0.01$; $n = 16$). There is also a correlation between Fe_o and Al_d ($r = 0.63$; $P < 0.01$; $n = 16$), Fe_0 and Fe_0/Fe_d ($r = 0.44$; $P < 0.01$; $n = 16$), signifying a high level of weathering. The relatively high amount of Fe_d virtually at all the horizons indicates that the crystalline and less active forms of the oxides exist more on the landscape and may be responsible for the non-availability of some nutrient like phosphorus that may be sorbed to their crystals lattice. All forms of Al in the soils are low especially, the oxalate extractable forms, when compare with the dithionite extractable forms. However, there is a significant correlation between Al_d and Fe_o/Fe_d ($r = 0.57$; $P < 0.01$). As a result of high accumulation of crystalline form of Fe and Al oxide with increasing depth, most especially, at the crest/upper slope, there is greater amount of concretions, nodules and plinthites which will lead to further deterioration of the soil for agricultural purposes.

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Keywords

Plinthites, Sesquioxides, Toposequence, Dithionite Extractable, Oxalate Extractable

1. Introduction

The features observable in a soil profile depend on the activity that goes on in it and how long they have taken place. It is however justifiable to say that characteristics of the soil as observed in a profile at a particular time depend on the interaction of factors and processes of soil formation. These factors have been enumerated as parent material, climate, organisms, relief and time [1]. Topography as a soil forming factor has dominant influence in determining differences among set of soils and their nutrient status. The set of soils are formed as a result of topography acting primarily as soil forming factors are called toposequence. Toposequence is also the succession of soils from a crest/plateau/summit to a valley bottom. The differences between soils of a toposequence are generally related to differences in their positions and drainage patterns, however, slope steepness is about the most important factor that causes variation in moisture condition along a toposequence [2]. According to [2], four groups of pedogenic processes result from slope effects are:

1) Powerful mechanical action (*i.e*. erosion);

2) Less powerful mechanical action *i.e*. lateral movement of clays (in suspension) and other materials in solution;

3) Transport in the form of pseudo and true solution;

4) Local changes in the moisture status and of the redox potential.

The different contribution of these will affect the type of variation observed at different location per time. In the basement complex area, there is a strong relationship between topographic position and soil genesis [2]. The differences in the rate of hydrologic and geomorphic process in various landform position causes differences in the types and intensity of pedogenic processes. This typically results in a non-random distribution of soil classes and properties on the landscape.

In tropical soils, free Fe oxides may be mobilized and deposited in soil profiles as Fe mottles, concretions, and hardpans [4]. Soils of the tropical region are dominantly alfisols, ultisols and oxisols and the dynamics of sesquioxides (iron and aluminum oxides) are progressively the determining factor for release of nutrient to planted crops [5].

Iron (Fe) and Aluminum (Al) found in soils are released during soil weathering and soil development; they are re-precipitated as amorphous or crystalline oxides, hydroxides or oxhydroxides [6]. Crystalline form is the predominant form of Fe in Alfisols which dominate the soils of Savanna region of Nigeria [5].

The crystalline form of Al-oxides is thought to be substituted into crystalline Fe-oxides such as geothites and heamatite [7]. The effect of such substitution is the structural distortion of crystalline Fe oxides with implications for anion retention and surface area [8] [9] studied the relationships between clay content and the acid oxalate extractable Fe and Al in some soils in Nigeria derived from sandstones and finds that the relationships are not significant. He, however, conclude that the amount and nature of the various forms of Fe and A1 oxides with organic complexes can greatly influence the physical and chemical properties of the soil. [10] conclude that the nature, amount and distribution of Iron (Fe) and Aluminum (Al) oxides in soil affect its ionic charge, chemical characteristics, and ion adsorption especially, phosphorus (P) sorption, surface charge and specific surface area. Swelling and aggregate formation may be significantly modified by the presence of amorphous Fe and Al oxides [11].

According to [12], the feature that distinguishes plinthites and accounts for hardness is greater degree of crystallinity and a continuity of the crystalline phase (*i.e*. the ratio of amorphous Iron (Fe_o) to crystalline (Fe_d), low Fe_o/Fe_d ratio indicated high degree of crystallinity).

A large area of the rain forest and savannah zone of south western Nigeria is developed on basement complex, mostly Gneiss [13]-[15] in the classification of soils of south western Nigeria, evaluated some soil association with Fe and Al sesquioxides and pointed out the different soil series in where these oxides are predominant. This should be investigated to provide information on the forms, proportions and relationship among sesquioxides in these soils.

More information is extremely needed for planning, uses and management of the soils. For these reasons Ejioku town, Lagelu Local Government area of Oyo State was selected haven't been an agrarian community producing most of the agricultural products of the state. Thus, this work was carried out to investigate the distribution and forms of sesquioxides on this landscape and determine the interrelationship between Fe and Al oxides with other soil properties.

2. Materials and Methods

2.1. Description of the Study Site (Figure 1)

The study area is Ejioku town; a derived savannah environment in south-western part of Nigeria. The location lies within latitude 07˚28.675'N and 07˚28.756'N with longitude 004˚07.219'E and 004˚07.229'E. The elevation was 273.41 m above sea level at the crest and 178.31 m at the valley bottom. The toposequence was about 328 m long. The area is characterised with distinct dry (November to early March) and wet (April to October) seasons. Rainfall pattern is bimodal with peak periods in June and September, mean annual rainfall is about 1312 mm. Temperature is about 27˚C, and reach its peak in February and March (29˚C to 32˚C) respectively. The topography of the site is moderately slope (<10%). The geology of the area is dominated by crystalline rock which forms part of the basement complex of south-western Nigeria and are generally of granitic parent materials.

Over the years, the soil had been put to different uses ranging from arable to permanent crops like maize, cassava, plantain and oil palm while some part had remained fallowed with tall grasses, trees and bush regrowth.

2.2. Field Studies

The whole area was mapped using the rigid grid method of soil survey in which transverses were cut and spaced at 50 m apart. Points of observation were fixed at the intersections of the perpendicularly running transects. After this, soils with similar characteristics were grouped together as same mapping unit. Soils on the landscape were delineated to upper slope, middle slope, lower slope and the valley bottom. Soil profile pits were located and dug (1.5 m × 1.5 m × 2.0 m) to represent each of the identified delineations on the field. Altogether a total of sixteen samples were collected from the four profile pits. Notes on morphological attributes in the soil profile were taken (soil colour, texture, structure, consistence, stoniness, mottles, Cutans and concretions).

2.3. Analytical Procedures

The samples collected were air dried and crushed to pass through 2 mm sieve. Prepared and labelled samples were taken to Soil Physics and Chemo-dynamics Laboratory, Soil Science Department, University of Manitoba,

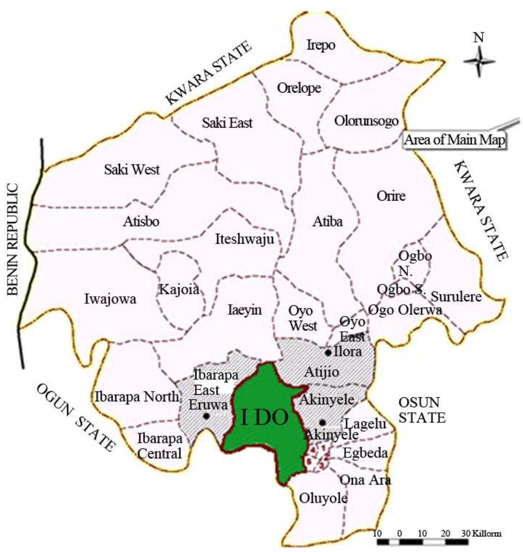

Figure 1. Map of Oyo State showing Lagelu Local Government area, area of the study site.

Winnipeg, Canada for analysis. Extractable phosphorus was determined in Mehlich-III extractant by equilibrating 2.5 g of air dried soil sample with 25 ml of Mehlich 3 extracting solution for 5 min and filtering through Whatman No. 40 filter paper [16] and the amount of phosphorus was determined using the colorimetric (ascorbic acid) method [17].

Ammonium oxalate extractable Fe, Al and Mn were determined by shaking 0.5 g of soil with 20 ml of ammonium oxalate extracting solution for 4 hours in the dark and then filtered using Whatman No. 40 filter paper [18]. Ammonium oxalate Fe, Al and Mn in the extractant were determined by Inductive coupled plasma technique. The exchangeable cations and the cation exchange capacity (CEC) of the soil were determined using the ammonium acetate method [19]. Particle size distribution was determined using Hydrometer method [20], pH in ratio 1:2 (Soil:H_2O), Organic carbon was by [21].

Dithionite-Citrate Fe, Al and Mn were determined using the [22] soil conservation method. A 0.5 g of soil sample, ground to pass a 35-mesh sieve was weighed into a 50 ml plastic centrifuge tube (0.2 g for clays and 1 g for coarse soils). 25 ml of the sodium citrate ($Na_3C_6H_5O_7 \cdot 2H_2O$), 0.68 M (200 g/L) solution was added. 0.4 g of dithionite (sodium hydrosulphite, $Na_2S_2O_4$) was also added. The centrifuge tube was covered tightly and put in an end-over-end shaker overnight and centrifuged for 20 minutes. The supernatant were filtered and determination of Fe, Al, and Mn was done by ICP-AES (inductive coupled plasma). This treatment is particularly useful for dissolving the "free" (non-silicate) Fe and Al in soils. The difference between the Al_d and Al_o was assumed to be the Al^{3+} substituted for Fe^{3+} in the crystalline [23]. Determination of Total Nitrogen and Total Phosphorus was done by the Kjeldahl Method using a digestion mixture of 350 ml H_2O_2, 0.42 g Se powder, 14 g $Li_2SO_4 \cdot H_2O$ and 420 mL conc. H_2SO_4 [24]. The concentration of P in solution was determined using the colorimetric method: Ascorbic method [25], while nitrogen was by titration method.

2.4. Soil Classification

The soils were classified according to soil taxonomy [22] and [26] soil legend while [15] soil classification was adopted at the series level.

3. Result and Discussion

3.1. Soil Morphological Characteristics

Generally 3 to 5 differentiated horizons were observed in all the profile pits, however; only 3 horizons were observable in the profile located at the valley bottom. This was due to the high water table encountered that prevented deeper examination. The important morphological characteristics of the soil are given in **Table 1**. Designation of the horizons are done according to the USDA soil taxonomy classification: AP represented the ploughed horizon, AB is the transitional point between the ploughed horizon and the B horizon. The B horizon is the subsoil with presence argillic features.

The landscape was delineated to upper slope, mid slope, lower slope and valley bottom. Pedon 1 was located at the upper slope and has a grayish yellow brown (10YR 5/2) topsoil coming down to bright yellowish brown (10YR 6/6) at the subsoil with five identified horizons.

Pedon 2 has a grayish brown (7.5YR 5/2). A horizon coming down to a (7.5YR 5/6) bright brown colour at the subsoil with four observable horizons.

Pedon 3 has grayish brown (7.5YR 4/2) topsoil that gradually changes to orange (7.5YR 6/8) at the subsoil while Pedon 4 was black (7.5YR 2/1) at the top and changes gradually to brown (7.5YR 4/4) at the subsoil.

At the valley bottom, the colour differs from the rest of the slope which was due to high water table content (7.5YR 2/1). The yellowish brown to orange colour observed at the upland subsoil is considered to be due to the mobilization and subsequent immobilization of iron during redox-cycles in the soil [3] [27] advanced this to be the causes of dispersion with progressive oxidation of iron. The bright subsoil colour in some of the profile may be an indication of good internal drainage, except the subsoil of pedon4 which was dull brown (7.5YR 4/4) as a result of high water table and poor internal drainage. Nearly all the soil profiles were mottled, however, mottleness was more prominent at the upland region, and this could be due to lack of mechanical mixing by plant roots and soil [28].

Surface soils were generally coarse sandy loam or sandy clay loam graduating into coarse fine sandy clay at the subsoil. The soil structure ranges from granular coarse at the surface of upland profiles to sub-angular blocky

Table 1. Field morphological description of Pedon studies.

Depth (cm)	Horizon	Colour hue (moist)	Mottles	Stoniness	Soil structure	Consistence (moist)	Texture	Concretion	Drainage
Pedon 1 **IWO series (Arenic Kandiustults)** "(N07˚28.675'; E004˚07.219'; 180 m asl.)"									
0 - 25	Ap	10 YR5/2	few fine	No stones	granular coarse	dry loose	sandy loam	unidentified few	well drain
26 - 59	AB	10 YR 6/1	few fine	No stones	sub angular blocky medium	loose	sandy clay loam	unidentified few	well drain
60 - 107	B1	10 YR 6/1	common medium	extremely stony	angular blocky v. coarse	extremely Hard	clayey coarse sand	ferruginous v. many	well drain
108 - 142	B2	10 YR6/4	common medium	fairly stony	columnar medium	Slightly Hard	sandy clay	Fe-Mn many	well drain
143 - 198	B3	10 YR 6/6	common medium	fairly stony	columnar medium	slightly Hard	sandy clay	gypsum many	well drain
Pedon 2 **IBADAN series (Kanhaplic Haplustults)** "(N07˚28.702'; E004˚07.221'; 178 m asl.)"									
0 - 20	Ap	7.5 YR 5/2		no stone	crumb fine or thin	friable	sandy clay loam	unidentified common	well drain
21 - 65	AB	7.5 YR 6/1		stony	granular fine	friable	sandy clay	ferruginous common	well drain
61 - 128	B1	7.5 YR 4/4	common medium	fairly stony	prismatic medium	firm	sandy clay	ferruginous v. many	well drain
129 - 192	B2	7.5 YR 5/6	common medium	fairly stony	platy coarse	firm	coarse sandy clay	ferruginous v. many	well drain
Pedon 3 **APOMU series (Typic Psammaquant)** "(N07˚28.747'; E004˚07.227'; 177 m asl.)"									
0 - 25	Ap	7.5 YR 4/2	few fine	No stone	granular coarse	friable	slightly sandy clay	unidentified few	well drain
26 - 55	AB	7.5 YR 5/3	few fine	No stone	sub angular blocky medium	friable	sandy clay	unidentified few	well drain
56 - 98	B1	7.5 YR 5/4	few fine	No stone	crumb medium	firm	sandy clay	unidentified few	well drain
99 - 180	B2	7.5 YR 6/8	few fine	No stone	angular blocky	firm	clay sandy	unidentified few	well drain
Pedon 4 **JAGO series (Aquic Haplustults)** "(N07˚28.756'; E004˚07.229'; 175 m asl.)"									
0 - 12	Ap	7.5 YR 2/1	few fine	fairly stony	sub angular blocky	slightly Sticky	silt clay sand	unidentified few	poor
13 - 59	AB	7.5 YR	few fine	fairly stony	sub angular blocky	sticky fine	sandy clay loam	unidentified few	poor
60 - 85	B	7.5 YR 4/4	few fine	fairly stony	sub angular blocky	very sticky	clayey sand	unidentified few	poor

and fine at the valley bottom but the structure graduated to columnar, platy and sub angular blocky down the profile. This was due to the increase in clay content down the profile. Concretion was more of Fe-Mn component at the upper slope and ferruginous at the middle slope to unidentified and few at the lower slope. Sesquioxides concretion was iron noodles concretion; however, petro-plinthite and quartz materials are dominants in the horizons of Pedon 1 and 2. These are indicative of the granitic parent materials and alternate wetting and drying of the solum. According to [23], the presence of iron stone gravels *in-situ* in residual upland soils suggests that there had been possible segregation of iron in the form of plintholes. This process requires an adequate supply of iron, alternating wet and dry seasons a relatively flat land surface with seasonally wet soils [3] which could be found in the study area. This was also in line with the observations of [23] on some soils of Africa.

3.2. Diagnostic Horizon and Intensity of Weathering

Silt: Clay ratio is an indicator of weathering intensity and a ratio of <0.15 indicates low to moderate (**Table 2**) while a ratio of >0.15 indicates high intensity [2]. Thus all the Pedons showed evidence of high weathering intensity. The high silt content however reflects the probability of the soil being formed from coarse colluvial material (hill wash). This tends to suggest that erosion is an important pedogenic process in the study area (transportation).

3.3. Physico-Chemical Properties of the Soils

The AP horizon of all the pedons has high sand content (78%) with low clay content. Generally, there was a decrease in sand with depth with clay accumulation at the subsoil. The silt/clay ratio is >1 at most horizons, however, in Pedon 4, silt/clay ratio was <1, suggesting a probability of ferallitic pedogenesis [29]. An outstanding feature of these soils across all the location on the topography is the moderate to high silt content (6% - 26%) down the profile. This increase in silt content can be due to the perturbation of soil aggregates during lessiviation and the washing down of the finer soil aggregate down the profile. This feature distinguishes the soils from most sandy soils at south-western Nigeria, which are characterized by low silt content (<10% - 15%) [2]. The high clay content in the deeper horizons of some of the soils (Pedon 1, 2 & 3) with some morphological properties (**Table 1** and **Table 2**) formed the basis for the recognition of argillic horizons in the region. Iron/Manganese (Fe/Mn) concretion ranges from many to common and occurred in most of the upland profiles (**Table 1**), suggesting the tendency of alternating wet and dry cycles, which could infer that plinthization may be a strong pedogenic processes in the study area. The high concentration of concretion may constitute a serious problem to crop production within the study area.

The soils on Pedon 1 was slightly acidic (5.7 - 6.7) to acidic and slightly acid in profile 2 (5.6 - 6.6), slightly acid in Pedon 3 (6.0 - 6.6) while Pedon 4 was strongly acidic (4.9 - 5.3). The factors that could be responsible for the strong acidic nature of Pedon 4 was the high water table condition of the valley bottom and poor drainage. The organic carbon content of the soil was generally low at the subsoil except on Pedon 2 and 3, where the organic carbon was higher at the subsoil. This is suggestive of a lithological discontinuity as a result of pedotransfer. Generally the organic carbon is considered to be low in all the soils which may be due partly to the impact of high temperature and high relative humidity, which favours rapid mineralization of organic matter components [30]. Also the different land use on landscape could be responsible for the lower organic carbon content at the topsoil when comparing the upland and with the valley bottom. However, the amount of organic carbon content cannot conveniently sustain a good crop production programme on a long term basis. Hence, a substantial improvement has to be made through effective crop residue incorporation management strategies.

The effective cation exchange capacity (ECEC) was low ranging from 2.1 to 15.8 Cmol/kg. This could be in part due to the nature of parent material. The value indicate that the soils have low potential for retaining plant nutrients, and therefore call for an adequate soil management strategies such as, split fertilizer application and use of organo-mineral fertilizers.

In addition, these low values of ECEC in combination with low organic carbon and pH are indications of low, inherent soil fertility status, which emphasis the need for improved soil management techniques. This should be incorporated into the traditional methods of bush fallowing if good and long term crop production is to be sustained. Mehlich III extractable phosphorus (P) was generally low and considered inadequate for crop production, when compared with critical values recommended for most tropical crops (8 - 15 ppm) [31].

Table 2. Physical and chemical properties of the soil in the study area.

Depth (cm)	Horizon designation	Sand %	Silt %	Clay %	Texture	Ca^{2+}	K^{+}	Na^{+}	Mg^{2+}	ECEC	TAB	Silt/Clay ratio	pH (H_2O)	Av. P (ppm)	Org. C %
						Cmol/kg									
						Exchangeable cations									
						Pedon 1 IWO series (Arenic Kandiustults)									
0 - 25	Ap	92	6	2	sand	1.20	1.27	2.19	2.00	8.69	2.04	3.00	6.17	53.40	6.65
26 - 59	AB	70	26	4	sandy loam	2.18	2.29	3.96	3.63	15.76	3.69	6.50	6.73	7.80	2.09
60 - 107	B1	68	20	12	sandy loam	1.02	1.07	1.85	1.7	7.36	1.72	1.67	6.38	2.60	1.36
108 - 142	B2	66	16	18	sandy loam	1.08	1.14	1.97	1.8	7.83	1.83	0.89	5.72	1.20	0.75
143 - 198	B3	62	18	20	sandy clay loam	0.50	0.53	0.91	0.84	3.64	0.85	0.90	6.2	0.98	0.66
						Pedon 2 IBADAN series (Kanhaplic Haplustults)									
0 - 20	Ap	82	12	6	sandy	0.69	0.73	1.26	1.15	5	1.17	2.00	5.8	5.38	2.06
21 - 65	AB	76	6	8	sandy loam	0.54	0.57	0.98	0.9	3.91	0.92	0.75	5.89	4.20	1.41
61 - 128	B1	70	14	16	sandy loam	0.94	0.98	1.7	1.56	6.76	1.58	0.88	5.6	1.70	3.11
129 - 192	B2	66	20	14	sandy loam	1.32	1.39	2.41	2.2	9.57	2.24	1.43	6.56	0.60	3.29
						Pedon 3 APOMU series (Typic Psammaquant)									
0 - 25	Ap	88	6	6	sand	0.81	0.86	1.48	1.36	5.89	1.38	1.00	6.2	7.50	3.92
26 - 55	AB	72	14	14	sandy loam	0.87	0.92	1.59	1.45	6.3	1.48	1.00	6.02	2.08	2.35
56 - 98	B1	74	13	13	sandy loam	0.59	0.62	1.07	0.98	4.24	0.99	1.00	6.05	1.00	2.57
99 - 180	B2	70	14	16	sandy loam	1.63	1.72	2.96	2.72	11.79	2.76	0.88	6.56	6.85	7.56
						Pedon 4 JAGO series (Aquic Haplustults)									
0 - 12	Ap	80	6	14	sand	1.12	1.18	2.04	1.87	8.1	1.9	0.43	4.93	3.90	8.39
13 - 59	AB	74	10	16	sandy loam	0.29	0.3	0.52	0.48	2.06	0.48	0.63	5.1	7.38	1.80
60 - 85	B	86	16	8	sand	0.77	0.81	1.4	1.29	5.58	1.31	2.00	5.28	2.40	2.78

3.4. Distribution of Dithionite and Oxalate Extractable Sesquioxides

The data on the oxides of Fe and Al are shown in **Table 3**. The distribution of crystalline, non-crystalline and amorphous (poorly crystalline) forms of Fe, Al and Mn oxides in the Pedons and their relationship are presented in **Table 3**. The citrate dithionate extractable only indicate the Fe and Al present in the soil are as free discrete bodies (*i.e.* crystalline and amorphous), and not as part of the structure of silicate minerals [28].

The free discrete bodies collectively referred to as un-combined or pedogenic free forms of the element [28] could either be mobile (amorphous) or immobile (crystalline). There was a wide margin in the distribution of dithionite and oxalate extractable Fe and Al within the horizons. The concentration of dithionite Fe and Al were greater than that of oxalate Fe and Al. However, there was a progressive increase in concentration of both dithionite and oxalate extractable Fe and Al down the profile in pedon1 and Pedon 3, while Pedon 2 did not show any regular pattern in the distribution. Pedon 4 however showed a remarkable decrease in concentration down the profile.

All the Pedons had a lower Fe_o and Al_o at the AB horizon and the highest at B_2. This phenomenon could be associated with topographic, parent material and land use effect on pedogenesis [28]. Among the pedons, B_2 had the highest amount of Fe_d except in Ibadan series where it was highest at B_1. The ratio of free Fe to clay tends to vary regularly in all the Pedons and highest at the AP horizon and decreased down the profile.

Table 3. Distribution of various kinds of Fe and Al oxides in the pedons.

Depth (cm)	Horizon Designation	% $Al_2O_{3(d)}$	% $Fe_2O_{3(d)}$	% $Mn_{(d)}$	% $Al_2O_{3(o)}$	% $Fe_2O_{3(o)}$	% $Mn_{(o)}$	$Fe_2O_{3(d)}$/Clay	$Fe_2O_{3(O)}$/$Fe_2O_{3(d)}$	$Al_2O_{3(o)}$/$Al_2O_{3(d)}$
Pedon 1										
IWO Series (Arenic Kandiustults)										
0 - 25	AP	6.66	38.15	1.33	3.04	7.34	1.78	19.08	0.19	0.46
26 - 59	AB	5.96	27.14	1.27	2.33	3.91	1.93	6.78	0.14	0.39
60 - 107	B1	15.77	128.9	4.42	3.49	6.01	4.59	10.74	0.05	0.22
108 - 142	B_2	10.31	42.68	0.51	5.06	2.90	1.05	2.37	0.07	0.49
143 - 198	B_3	43.31	444.3	14.42	8.66	10.86	12.82	22.22	0.02	0.20
Pedon 2										
IBADAN Series (Kanhaplic Haplustults)										
0 - 20	AP	22.14	222.75	3.84	6.10	6.75	4.13	37.13	0.03	0.28
21 - 65	AB	4.69	17.15	0.00	1.69	3.28	0.06	2.14	0.19	0.36
61 - 128	B_1	13.06	83.65	0.00	5.55	7.22	0.15	5.23	0.09	0.42
129 - 192	B_2	9.56	61.65	0.00	6.46	6.06	0.22	4.40	0.10	0.68
Pedon 3										
APOMU Series (Typic Psammaquant)										
0 - 25	AP	5.77	31.17	3.01	2.07	3.32	4.07	5.19	0.11	0.36
26 - 55	AB	7.76	44.94	2.89	2.40	3.55	3.53	3.21	0.08	0.31
56 - 98	B_1	8.56	57.25	2.22	2.80	3.64	2.74	4.40	0.06	0.33
99 - 180	B_2	9.37	59.70	3.19	3.22	4.23	4.68	3.73	0.07	0.34
Pedon 4										
JAGO Series (Aquic Haplustults)										
0 - 12	AP	15.82	104.50	0.25	3.43	12.76	0.51	7.46	0.12	0.22
13 - 59	AB	2.88	7.18	0.00	1.30	2.74	0.08	0.45	0.38	0.45
60 - 85	B	3.57	22.74	0.00	1.95	7.54	0.20	2.84	0.33	0.55

$_d$ = sodium citrate-bicarbonate-dithionite extractable; $_o$ = ammonium oxalate extractable; Fe = iron oxide; Al = aluminium oxide.

The ratio of Fe_o/Fe_d which serves as the index of the proportion of amorphous iron content and degree of crystalline of the soil was highest in the first two horizons at upper and lower slope. It increases down the profile at the valley bottom (Jago) except at the mid-slope where the ratio at the second horizon was almost double those of the other horizon in the Pedon.

Generally, there was significant negative relationship between Fe_d and Fe_d/Fe_o ($r = -0.15$; $P < 0.01$). There are also correlation between Fe_o and Al_d ($r = 0.63$; $P < 0.01$) and Fe_O and Fe_O/Fe_d ($r = 0.44$; $P < 0.01$). The relatively high amount of Fe_d virtually at all the horizons indicates that the crystalline and less active forms of the oxides exist more on the landscape and may be responsible for the non-availability of some nutrient like phosphorus that may be sorbed to their crystals lattice. Less emphasis is given to the distribution of various forms of Al in the soils as the quantities are much lowers especially the oxalate extractable forms. However, there are significant correlation between Al_d and Fe_o ($r = 0.63$; $P < 0.01$) and Al_d and Fe_o/Fe_d ($r = 0.57$; $P < 0.01$).

4. Conclusion

The results of this study have shown that the soils are relatively high in sesquioxides and their toxicity will definitely have an impact on the productive capacity of the soil. Crystalline forms as compared to the amorphous form dominate the free sesquioxides in the soils throughout the landscape. This shows that they have been highly weathered and the high proportion of crystalline form of Fe and Al will lead to structural distortion with implication for anion retention. The formation of hard pans and concretions can also lead to compaction of soil which can inhibit the penetration of plant root. Thus, very good and dynamic management technique and land uses are essential to ensure the preservation of the soil.

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