Particle size and free iron oxide distribution in some tropical soils derived from amphibolite

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SUMMARY

The patterns of distribution of particle size and free Fe_2O_3 (Na-dithionite-extractable (Fe(d) and NH_4-oxalate-extractable (Fe(o) were studied in five representative soil profiles in south-western Nigeria. The soils were found to vary from slightly acid to strongly acid. Organic carbon decreased with increasing depth. The pattern of distribution of free Fe_2O_3 was related to that of clay in two of the soil profiles (Ibule and Adio series). However, in the other three soil profiles (Ijare, Owena and Itagunmodi series), free Fe_2O_3 distribution was not related to clay. Silt content did not show any definite pattern of distribution. The content of free Fe_2O_3 had reached advanced stage of crystallinity or aging in the soils because of the low Fe(o)/Fe(d) ratios in the soil profiles.

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RÉSUMÉ

OSEI, B. A. : *La distribution de dimension de particule et d'oxyde de fer libre dans quelques sols tropicaux dérivés d'amphibolite.* Les modéles de distribution de dimension de particule et de libre Fe_2O_3 (Na - dithionite - extractible [Fe (d)] et NH_4 oxalate - extractible [Fe (O)] étaient étudiés en cinq profiles de sol représentatif au sud-ouest du Nigéria. Les sols étaient découvert de varier de légèrement acide à profondément acide. La carbone organique diminuait avec la croissance en profondeur. Le modéle de distribution de Fe_2O_3 libre était apparenté à celui d'argile dans deux des profiles de sol (Les séries Ibule et Adio). Toute fois, dans les trois autres profiles de sol (Les séries Ijare, Owena et Itagunmodi), la libre distribution de Fe_2O_3 n'était apparentée à l' argile. La contenance de limon n'a pas montré aucun modèle précis de distribution. La contenance de Fe_2O_3 libre avait atteint une étape avancée de cristallinité ou de vieillissement dans les sols due à la faible Fe(O)/ Fe(d) proportions dans les profiles de sols.

Introduction

The oxides and oxyhydroxides of iron are present in most soils (Singh & Gilkes, 1992) and are the most metallic oxides in most soils (Schwertmann & Taylor, 1989). These oxides are often in the form of discrete particles, coatings on soil minerals, and as cement between mineral particles.

The secondary Fe oxides are the most important pigmenting agents in soils having a low content of organic matter. Goethite (yellowish brown) and hematite (red) are very common in soils, whereas ferrihydride (reddish brown), lepidocrocite (orange) and maghemite (reddish brown) are less abundant (Torrent *et al.*, 1983). Iron oxides are important constituents of highly weathered soils of tropical and sub-tropical regions that contain kaolinite as their major clay mineral (Singh & Gilkes, 1992). Iron oxides are also reported to be sensitive indicators of pedogenic environment (Schwertmann, 1985; Mirabella & Carnicelli, 1992).

Particle size and iron oxide distribution in some tropical soils has been studied by some researchers (e.g. Ashaye, 1969; Asamoa, 1973; Juo, Moormann & Maduakor, 1974; Gallez *et al.*, 1975). Ashaye (1969) examined the relationships between clay content and acid-oxalate extractable Fe and Al in some Nigerian soils derived from sandstone and reported that the relationships were not significant. Asamoa (1973), working on some Ghanaian soils, found out that the pattern of distribution of free Fe_2O_3 was a function of silt content in some soils while in other soils it followed clay distribution. Juo, Moormann & Moduakor (1974) also reported that the amount of free Fe_2O_3 in some soils of Nigeria followed the same pattern of distribution as clay content within the same soil profile.

The objective of this study was to investigate the distribution of free Fe_2O_3 in relation to particle size in some soils developed from amphibolite in south-western Nigeria with the view to establishing which particle size is most closely associated with free Fe_2O_3 distribution in the soils.

Materials and methods

Soils and sampling

The field work for this study was carried out at Itagunmodi (Fig. 1). The area lies approximately on latitude 7° 34'N and longitude 4° 37'E. The climate of the study area is sub-humid tropical with average annual rainfall 1348.4 mm. The rocks in the area belong to amphibolite complex (Ajayi, 1980). Five soil profile pits were excavated along a toposequence at different physiographic points (Fig. 2). The soils were identified as Ibule, Ijare, Owena, Itagunmodi and Adio series using local classification by Smyth & Montgomery (1962). Following Soil Taxonomy (Soil Survey Staff, 1987), Ibule, Ijare, Owena and Itagunmodi series were classified as Ultisols while Adio series was classified as Alfisol (Osei, 1990). Morphological descriptions of the soils are shown in Table 1. Soil samples were taken from genetic horizons of the five soil profiles. The soil samples were air-dried and the fine earth fraction (<2 mm) of each sample was used for the analyses.

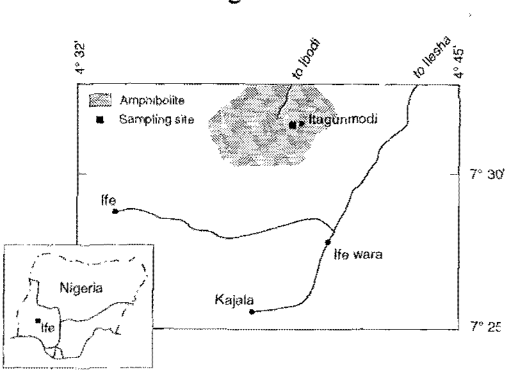

Fig. 1. Site location and geology of the sampling site.

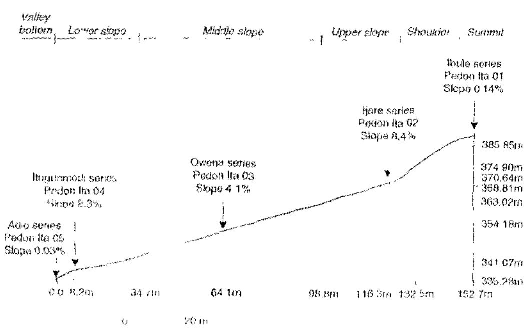

Fig. 2. Landform and location of soil profiles in toposequence.

Analyses

Particle size distribution of the samples was determined by the hydrometer method (Boyoucos, 1962) by dispersing in 5 per cent sodium hexametaphosphate. Soil *p*H was measured in soil-water suspension at 1:1 soil:solution ratio using glass electrode *p*H meter. Soil organic C was determined by Walkley-Black (1934) dichromate titration method. Free (extractable) iron oxide was also extracted by dithionite citrate-bicarbonate method of Mehra & Jackson (1960) and the quantity of iron oxide extracted was measured by the colorimetric orthophenanthroline method.

Amorphous iron oxide was also extracted by Tamm's reagent (acidified ammonium oxalate at *p*H 3.0). The procedure of extraction by McKeague & Day (1966) was used and the amorphous iron oxide extracted was determined colorimetrically.

Statistical analysis

Correlation analysis was carried out for the free oxides and particle size fractions.

Results

In this paper free iron oxide extracted by Na dithionite is designated as Fe(d) while the NH_4-oxalate extractable iron oxide is denoted by Fe(o) for ease of reference.

Amount and distribution of free iron oxide in relation to particle size

Ibule profile. The distribution of free Fe_2O_3 is illustrated in Fig. 3. The distribution of Fe(o) with

TABLE 1

Morrphological Characteristics of the Soils Studied

Horizon	*Depth (cm)*	*Munsell colour (dry)*	*Mottles*	*Texture*	*Structure*	*Consistency (moist)*	*Fe concre-tions*
Pedon Ita 01		Ibule Series					
Apc	0-7	2.5 YR 4/4	-	GRVSC	M2C	VFR	Few
ABc	7-22	2.5 YR 4/4	-	GRVSC	M2SBK	VFR	V. Freq.
B	22-64	2.5 YR 4/6	-	GRVC	M2SBK	VFI	V. Freq.
Pedon Ita 02:		Ijare Series					
Apc	0-8	5.0 YR 5/2	-	GRVSC	M2C	VFR	V. Freq.
BAc	8-40	2.5 YR 4/6	-	GRSCL	F3SBK	VFI	Frequent
Btc1	40-70	2.5 YR 4/6	-	GRC	F3SBK	VFI	Frequent
Btc2	70-100	2.5 YR 5/6	-	GRC	F3SBK	VRI	Frequent
Btc3	100-140	2.5 YR 4/6	-	GRC	F3SBK	VRI	Frequent
Cc	140-226	5.0 YR 6/8	-	SC	F3SBK	FRFI	V. Few
Pedon Ita 03:		Owena Series					
Ap	0-4	2.5 YR 4/4	-	C	M2C	FRFI	-
AB	4-44	2.5 YR 4/6	-	C	M2C	FRFI	V. Few
BAc	44-80	2.5 YR 4/6	-	C	M2SBK	FRFI	V. Few
Btc1	80-117	2.5 YR 4/6	-	C	M3SBK	FRFI	Frequent
Btc2	117-149	2.5 YR 4/6	-	GRC	M3SBK	FRFI	Few
BCc	149-189	2.5 YR 5/8	-	SCL	M3SBK	FRFI	-
C	189-249	2.5 YR 4/6	10 YR 8/6	SC	M2SBK	FRFI	-
Pedon Ita 04:		Itaqunmodi Series					
Ap	0-3	5.0 YR 4/3	-	SCL	M2C	VFR	-
BA	3-11	2.5 YR 4/6	-	SC	F2SBK	FRFI	-
B	11-70	2.5 YR 4/6	-	C	F2SBK	FRFI	-
Bt1	70-143	2.5 YR 4/6	-	C	M2SBK	FRFI	-
Bt2	143-183	2.5 YR 4/6	-	C	M2SBK	FRFI	-
C	183-223	2.5 YR 4/6	-	SC	F2SBK	FRFI	-
Pedon Ita 0.5:		Adio Series					
Ap	0-5	10 YR 4/2	-	L	M2C	FRFI	-
Bt1	5-44	7.5 YR 5/4	10 YR 5/8	SCL	F2SBK	FRFI	-
Bt2	44-70	10 YR 5/3	10 YR 5/8	C	F2SBK	FRFI	-
Bt3	70-143	10 YR 5/3	7.5 YR 7/8	C	M3SBK	FRFI	-
BC	143-183	10 YR 5/3	7.5 YR 7/8	C	M3SBK	FRFI	-
C	183-223	10 YR 6/8	10 YR 5/8	SC	F2SBK	FRFI	-

Texture

GR = Gravelly
GRV = Very gravelly
S = Sand
C = Clay
SC = Sandy clay
SCl = Sandy clay loam
L = Loam

Structure

1 = Weak
2 = Moderate
3 = Strong
F = Fine
M = Medium
C = Crumb
SBK = Subangular blocky

Consistency (moist)

VVFR = Very friable
VFI = Very firm
FRFI = Friable firm

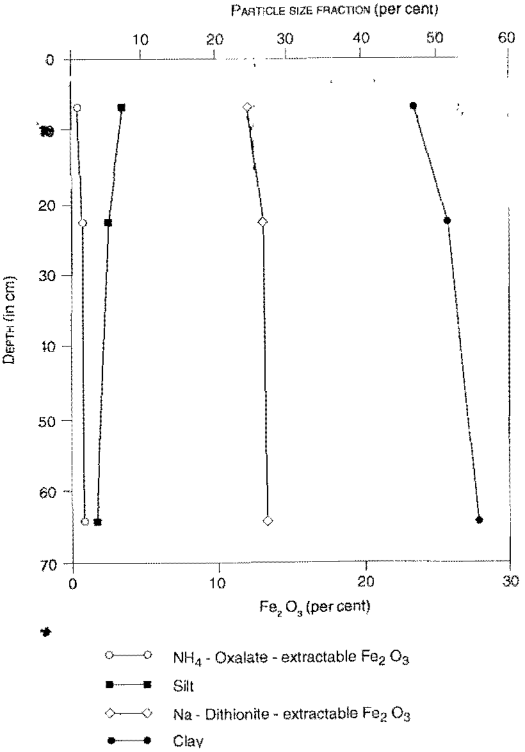

Fig. 3. Particle size and extractable Fe_2O_3 distribution in bulk soil profile of south-western Nigeria.

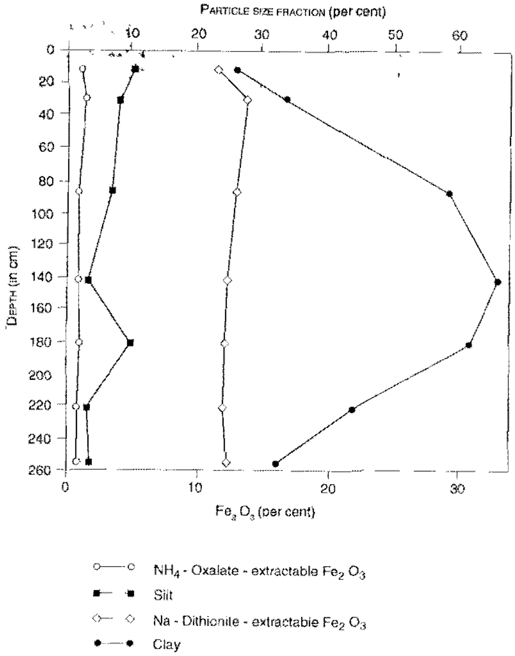

Fig. 4. Particle size and extractable Fe_2O_3 distribution in bulk soil profile of south-western Nigeria.

depth seemed to be uniform throughout the soil profile (0.55-0.65 %). However, Fe(d) increased from A-horizon to B-horizon (11.61-8.78 %). It then increased in B after which it became almost constant (Fig. 5). The distribution of Fe(o) was almost uniform.

Clay distribution also showed a bulge in the B-horizons while silt had no definite pattern of distribution. Thus, there was no co-migration of Fe with clay (Fig. 5) and the difference in amounts of Fe(d) and Fe(o) ranged from 4.40 to 10.16 per cent

Itagunmodi profile. The patterns of distribution of Fe(d) and Fe(o) were similar in the soil profile (Fig. 6). The amounts of Fe(d) and Fe(o) were uniform in the profile (8 and 1.0 % respectively) and the difference between the amounts of Fe(d) and Fe(o) was 7 per cent. There was no co-migration of clay with iron (Fig. 6). The amount of silt generally decreased with increasing depth.

Adio profile. The distribution of Fe(d) and clay seemed to be similar (Fig. 7). Thus, there was an increase from A-horizon to the B-horizon of Fe(d) and clay contents. These values then decreased in the C-horizon, implying co-migration of clay and Fe(d). The amount of Fe(o) was almost constant (1 %) in the soil profile while silt content decreased with increasing depth. The difference between Fe(d) and Fe(o) was 6 per cent.

Relationships between free Fe_2O_3 and particle size fractions

The relationships between Fe(o) and clay and Fe(d) and clay in the soils are displayed in Fig. 3, 4, 5, 6 and 7. In the Ibule series, the relationships between Fe(d) clay and Fe(d) silt were significant both at 1 per cent and 5 per cent levels (Table 2). There was significant correlation between free Fe_2O_3 and clay, free Fe_2O_3 and silt and Fe(o) and

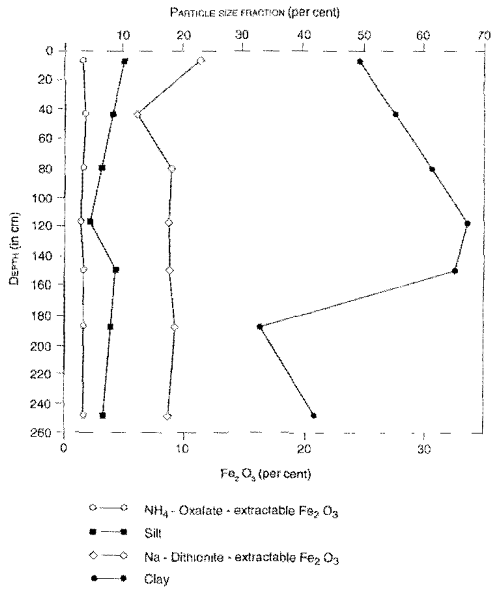

Fig. 5. Particle size and extractable Fe_2O_3 distribution in Owena soil profile of south-western Nigeria.

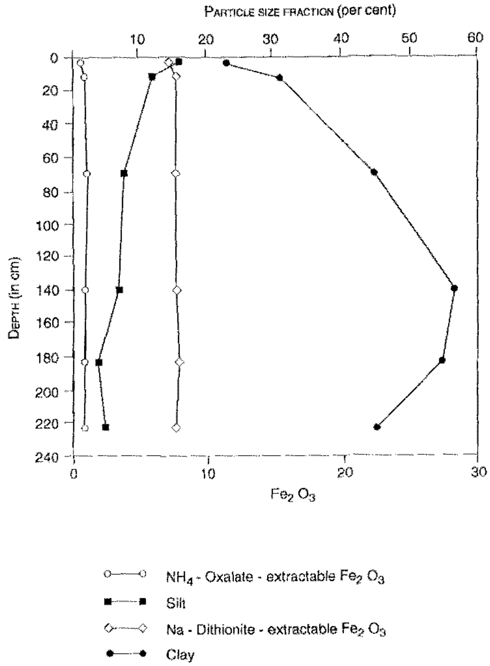

Fig. 6. Particle size and extractable Fe_2O_3 distribution in Itagunmodi soil profile of south-western Nigeria.

TABLE 2

Coefficients of Correlation between Extractable Iron Oxides and Particle Size Fractions in Soil Profiles Studied

Soil series	*Fe(o)/ clay*	*Fe(d)/ clay*	*Fe(o)/ Fe(d)*	*Fe(o)/ silt*	*Fe(d)/ silt*
Ibule	0.81	0.98***	0.77	-0.08	-0.99***
Ijare	0.48	0.12	0.48	0.58	0.61
Owena	0.07	0.15	-0.02	0.32	0.03
Itagunmodi	0.04	0.12	0.64	-0.68	-0.13
Adio	0.95***	0.96***	0.90***	-0.98***	-0.92***

Fe(o) = NH_4-oxalate extractable Fe_2O_3
Fe(d) = Na-dithionite extractable FeO_3
*** Significant at both 1% and 5% levels.

Fe(d) at $P = 0.01$ and $P = 0.05$ (Table 3).

Soil pH and organic carbon

The reaction of the soils varied from slightly acid to strongly acid (Table 4). Apart from soils of Ibule series, the upper horizons (0-14 cm) of the soil profiles were slightly acid (pH H_2O = 5.1 - 6.2) and soils of the B-horizons were strongly acid. Organic carbon content ranged from 0.02 to 3.37 per cent. The upper 0.14 cm of the soil profiles had the highest content of organic C (Table 4).

Discussion

The distribution of Fe(o) and Fe(d) in all the soil profiles, except Ibule and Adio profiles, indicated that there was no illuviation of iron. The presence of B-horizons (Table 1), however, implied there was translocation of clay. The nearly-constant iron

TABLE 3

Ratio of Fe(o)/Fe(d), Fe(d)/Clay and Silt/Clay in the Soil Profiles Studied

Soil series	Horizon	Fe(o)/ Fe(d)	Fe(d)/ Clay	Silt/ Clay
Ibule	Ap	0.05	0.30	0.15
	AB	0.05	0.25	0.10
	B	0.05	0.25	0.06
Ijare	Ap	0.09	0.46	0.40
	BA	0.09	0.41	0.24
	Bt1	0.05	0.22	0.12
	Bt2	0.06	0.19	0.06
	Bt3	0.06	0.20	0.15
	BC	0.06	0.27	0.05
	C	0.06	0.38	0.10
Owena	Ap	0.13	0.24	0.20
	AB	0.27	0.11	0.15
	BA	0.17	0.14	0.10
	Bt1	0.17	0.13	0.06
	Bt2	0.18	0.14	0.12
	BC	0.19	0.25	0.22
	C	0.18	0.20	0.15
Itagunmodi	Ap	0.13	0.33	0.70
	BA	0.14	0.26	0.39
	Bt1	0.15	0.18	0.18
	Bt2	0.14	0.14	0.12
	BC	0.14	0.14	0.07
	C	0.12	0.17	0.11
Adio	Ap	0.17	0.39	1.20
	Bt1	0.21	0.23	0.17
	Bt2	0.22	0.22	0.09
	Bt3	0.25	0.20	0.05
	BC	0.25	0.20	0.08
	C	0.25	0.24	0.13

Fe(o) = NH_4-oxalate extractable Fe_2O_3
Fe(d) = Na-dithionite extractable Fe_2O_3

TABLE 4

Soil pH and Organic Carbon Distribution

Soil series	Depth (cm)	pH H_2O	Organic per cent
Ibule	0-7	5.5	3.32
	7-22	4.1	1.56
	22-64	4.0	1.13
Ijare	0-14	6.2	3.30
	14-31	5.9	1.76
	31-87	5.7	0.50
	87-140	5.6	0.27
	140-179	5.3	0.04
	179-219	4.7	0.03
	219-259	5.2	0.02
Owena	0-4	5.6	1.56
	4-44	5.5	1.13
	44-80	5.2	0.18
	80-117	5.2	0.29
	117-149	5.0	0.04
	149-189	5.1	0.04
	189-249	5.0	0.02
Itagunmodi	0-3	6.2	2.40
	3-11	6.1	1.48
	11-70	5.3	0.82
	70-148	5.2	0.23
	148-183	5.4	0.26
	183-213	4.8	0.12
Adio	0-5	6.1	3.37
	5-44	5.7	0.66
	44-105	5.8	0.65
	105-130	5.7	0.52
	130-177	5.4	0.35
	177-219	5.3	0.05

content in the soil profile might come from the parent material which is rich in ferromagnesian minerals (Smyth & Montgomery, 1962).

The patterns of distribution of Fe(o) appeared uniform in soils of Ibule, Owena, Ijare and Itagunmodi. The NH_4-oxalate extractable iron content of Adio series seemed to increase from A-horizon to B-horizon and then decreased in the C-horizon. The soils of upper slope of the toposequence (Ibule and Ijare) (Fig. 2) had less amount of Fe(o) (0.55-1.29%) compared to Fe(o) contents of soils of middle slope (Owena & Itagunmodi) (0.96-1.66 %). Adio series had the least amount of Fe(o) (0.98 %) and this could be due to low weathering rate which occurs in poorly-drained soil and hence reducing rate of release of Fe(o) from parent material. The soils of Ibule, Ijare and Itagunmodi had similar patterns of distribution of Fe(d). Free Fe_2O_3 contents increased from A-horizon up to a maximum at about 20 cm depth and then remained constant throughout the profile.

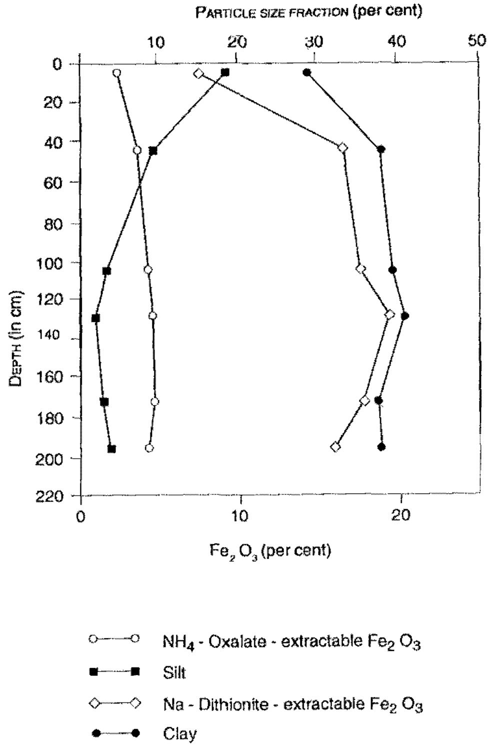

Fig. 7. Particle size and extractable Fe_2O_3 distribution in Adio soil profile of south-western Nigeria.

Free Fe_2O_3 content of Owena decreased from surface soil up to 40 cm and then increased to an amount which remained constant throughout the profile (Fig. 5). The distribution of Fe(d) showed a bulge in the B-horizons of Adio profile. However, the poorly-drained soil (Adio series) had the least amount of Fe(d) (about 7%). Thus, the well-drained soils (Ibule, Ijare, Owena and Itagunmodi) which occur on the summit, upper, middle slopes respectively of the toposequence had more well- crystallized form of iron whose formation is favoured by presence of oxygen.

High temperature condition and dry season prevalent in the study area may be responsible for the low content of amorphous Fe fractions in the well-drained soil. Sherman *et al.* (1964) reported that drying at elevated temperatures caused the amorphous Fe and Al oxides to dehydrate and subsequently shift to a system of greater crystallinity.

The patterns of distribution of Fe(o) and Fe(d) were not similar to that of clay in soils of Ijare, Owena and Itagunmodi series. However, soils of Adio and Ibule had significant correlation between Fe(d) and clay content which is in line with findings of Juo, Moormann & Maduakor (1974). Adio series characteristically had significant correlation between Fe(o) and Fe(d), free Fe_2O_3 and silt.

The well-drained soils were generally reddish in colour as shown by their hues (2.5YR), while the poorly drained soil (Adio series) had colour ranging from brown to brownish yellow (7.5YR-10YR) with mottles (Table 1). The differences in colour could be attributed to the fact that well-drained soils had high content of hematite which is responsible for red colour of soils (Torrent *et al.*, 1983) and the poorly-drained soils had geothite (Schwertmann, 1985; Davey *et al.*, 1975).

The high contents of Fe-concretions in the well-drained soils accounted for the gravelly nature of the soils especially, Ibule and Ijare (Table 1). The relatively high silt contents of surface soil of Adio and Itagunmodi series could be explained by the fact that the intensity of weathering is not as high as it is in the surface soils of other soils.

The ratios of Fe(o)/Fe(d) (active Fe ratio) in all the soil profiles were low, being less that 1 (Table 3). This implied that free Fe_2O_3 in the soils was at advanced stage of aging (Blume & Schwertmann, 1969). The content of Fe(d) in B horizon is used to assess the degree of development of soils formed from the same parent material (Asamoa, 1973). Thus, soils of Ibule and Ijare were found to be higher in degree of development since they had higher amounts of Fe(d) than the other soils. Soils of Adio series were the least developed in view of the fact that it contained the least amount of Fe(d). This supported the view that the intensity of soil development could be determined by the amount of sesqui oxides and their distribution in the soil profile (Gorbunov, Dzadevich & Tunik, 1961).

All the soils profiles had silt/clay ratios of less than 0.20 in the B-horizons (Table 3). The soils, especially the well-drained types, were at an advanced weathering stage. The ratio between Fe(d)/clay had low values (< 0.4).

Conclusion

The contents of Fe(d) were quite high in all the soil profiles and this could be ascribed to the high iron content of the parent material, amphibolite (Smyth & Montgomery, 1962). Drainage influenced distribution of Fe(d) and Fe(o) in the soils. The well drained soils had more Fe(d) than Fe(o).

The patterns of distribution of clay were not similar to that of Fe(o) and Fe(d) in three soils (Ijare, Owena and Itagunmodi). However, Adio series had significant correlation between Fe(o) and and Fe(d), free Fe_2O_3 and silt. There were low ratios of Fe(o)/Fe(d) in all the soil profiles. However, the poorly-drained soil (Adio series) had comparatively high ratios, indicating the soil development was not as advanced as that of the well-draid soils.

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