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CHARACTERIZATION AND CLASSIFICATION OF THE SOILS OF A TOPOSEQUENCE AT GBAGBA, KWARA STATE, NIGERIA.

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ABSTRACT

The morphological, chemical and physical characteristics of the soils of a toposequence developed over banded gneiss at Gbagba, in Kwara State were studied. The soils are generally sandy on the surface with high gravel content in the sub-surface horizons. Bulk density values ranged from 1.01 to 1.65g/cm³ and are generally higher in the coarser textured soils. The soils are slightly acidic, the base saturation and cation exchange capacity values are moderate, while organic carbon values are low. It was only pedon 1 that exhibited pedogenic clay. The δpH values ranged between 1.00 and 1.27. The soils are classified according to the USDA Soil Survey Staff as Plinthic Dystrustalf (Pedon 1), Typic Plinthustalf (Pedon 2) and Psammentic Alaquept (Pedon 3). They are also classified as Dystric Plinthisols (Pedons 1 and 2) and Dystric Fluvisol (Pedon 3) of the FAO/UNESCO Revised Legend of the Soil Map of the World.

INTRODUCTION

A toposequence is a succession of sites from a crest to a valley bottom which contains a range of soil profiles that are representative of the landscape and soils. The landform in the humid and sub-humid tropics of West Africa is generally characterized by such landforms (Juo and Moorman, 1980). Soils formed along a slope differ in their pedological, mineralogical, physical and chemical characteristics. This leads to differing agricultural land use capabilities (Nye, 1954; Gallez et al, 1975; Okusami *et al*, 1985).

Ojanuga and Awujoola (1981) gave the characteristics and classification of soils developed over granitic and basaltic areas of Jos Plateau. They reported that soil characteristics such as the amount of exchangeable cations, cation exchange capacity (CEC) and clay contents are related to kinds of soil parent materials. Ogunwole *et al* (2001) reported that soils in the Samaru area of Nigeria had very high silt content (22-44%) with moderate to high exchangeable bases. The soils in Samaru area of Nigeria were classified as Typic Haplustalfs according to the USDA soil taxonomy and as Haplic Luvisols in the FAO/UNESCO soil legend. Information on pedological characteristics of the soils of an area assists in determining soil qualities that can be utilized for the development of a sustainable soil management programme. Despite the fact that Asa Local Government Area (LGA) of Kwara State houses major agricultural enterprises, there is dearth of information on the characteristics of the soils of the series of toposequence in this LGA to which Gbagba belongs. This study was therefore carried out to obtain detailed characterization of the morphology and physico-chemical properties of Gbagba soils, and give a taxonomic classification of the soils using the criteria of the USDA Soil Taxonomy (Soil Survey Staff, 1998) and the FAO/UNESCO Revised Legend of the Soil Map of the World (FAO/UNESCO, 1989).

MATERIALS AND METHODS

Study area

The study area is Gbagba, a settlement about 25km south of Ilorin, the capital city of Kwara state. Gbagba lies approximately on latitude 8⁰20'44" N and longitude 4⁰25'05" E of the meridian at an altitude of 325m above the sea level. It lies within the southern guinea savanna vegetation zone, with a mean annual rainfall of 1000 to 1500mm, and dry season lasting from October to March. The terrain at Gbagba is drained by rivulets which run into Apon River, which inturn runs into river Awun. The natural vegetation of this zone includes *Parkia biglobosa, Mangifera indica, Terminalia glaucesense, Daniella oliverii, Andropogon tectorum, Imperata cylindrica.*

Field studies

The terrain at Gbagba was divided into three segments along the slope. Forty soil auger borings were made in each segment of the slope. Each auger boring collected soil samples from 0-15,15-30, 30-45, 45-60 and 60-90cm and these were morphologically described using the FAO (1977) soil description guideline. The morphological characters of the soil auger borings were used to determine the spot that represents the modal soil of each segment. Soil profiles were sited, as described above, and dug at points that represented the upper-, mid- and lower- slopes of the toposequence. Each soil profile was morphologically described in the field using the FAO (1977) soil description guideline. Soil thickness, colour, texture, structure, consistence, distribution of roots and horizon boundary conditions were some of the indices used in describing the morphology of the pedons. After the profile description, bulk soil samples were collected from identified genetic horizons for laboratory analyses.

Laboratory Analyses

The soil samples were air dried and sieved to remove materials larger than 2mm in diameter. Bulk density was determined using core method. Gravel content was determined as a percentage of soil particles greater than 2mm in diameter of a given weight of soil. Particle size analysis was by the hydrometer method (Buoyoucos, 1962). Soil pH was determined in both water and KCl (1:1) with a pH meter. Exchangeable cations (Ca, Mg, Na, K) were determined in 1N NH_4OAc extract buffered at pH 7 (Jackson, 1958). Calcium and magnesium were determined by titrimetric method with 0.02N versenate (Jackson, 1958) and sodium and potassium by flame photometry. Organic carbon was determined by the chromate wet oxidation method (Jackson, 1958). Total acidity was extracted with 1N KCl solution and the acidity was titrimetrically determined using phenolphthalein indicator (Juo et al. 1976). Effective cation exchange capacity (ECEC) was obtained by the summation of ammonium acetate extractable cations and total acidity (Juo et al, 1976). Free iron and aluminium oxides were extracted by the sodium dithionite-citrate-bicarbonate method (Jackson, 1968). Amorphous iron and aluminium oxides were extracted by the ammonium oxalate method (Jackson, 1968). Iron and aluminium were determined colorimetrically by the orthophenanthroline and xylenol orange methods respectively. Cation exchange capacity was determined using NN NH_4 OAc saturation and distillation method (Hossner, 1970). Abrasion pH was determined in 1:2.5 soil:water suspension (Grant, 1969). Pedogenic clay was obtained by calculation (Ojo-Atere and Ogunwale, 1982). Base saturation was obtained by calculation.

RESULTS AND DISCUSSION

Morphological characteristics

The surface horizon of Pedon 1 is dark reddish brown (Table 1) with the underlying horizons having a dominant red colour (2.5YR 4/6 – 2.5YR 4/8). Pedon 2 has a dark reddish brown surface horizon with the underlying horizons having reddish yellow, reddish brown and yellowish red colours respectively (5YR 4/3 - 5YR 4/6). Pedon 3 has dark brown and brown sub-surface horizons respectively (7.5YR 3/2 and 7.5YR 5/4) while the surface horizon is very dark grayish brown in colour (10YR 3/2).

All the pedons have sandy surface horizons (89.52% - 91.52%) with Pedon 3 having sandy texture throughout the profile. Pedon 1 has sandy clay loam sub-surface horizons while pedon 2 has sandy, sandy loam and sandy clay sub-surface horizons respectively. The sandy textured horizons have granular structured particles with the other remaining horizons being dominated by particles having sub-angular blocky structure.

Common manganiferous nodules occur down the profiles of Pedons 1 and 2 but are distinctly absent in Pedon 3. These nodules appear from a depth of 34cm and 24cm in Pedons 1 and 2 respectively. The occurrence of the manganiferous nodules may be indicative of the active zone of alternating wet and dry zones (Ogunwole et al, 2001; Weisenborn and Schaetzl, 2005). Additional formation of concretions would not occur in the wettest or driest profile along a toposequence but somewhere between them (Ram et al, 2001)

The boundaries delineating each pedogenic horizon are clear and wavy, diffuse and smooth boundaries respectively in Pedon 1; clear and wavy, clear and irregular, diffuse and clear respectively for Pedon 2; and diffuse and smooth and clear and wavy respectively for Pedon 3.

Physical characteristics

The percentage gravel content for the profiles range between 14.5 and 93.8% (Table 2). There is an increase in gravel content down the profile with Pedons 1 and 2 having very high gravel contents in the sub-surface horizons between 34 and 175cm and 24 to 165cm respectively. Increase in gravel concentration in the sub-surface horizon has been reported by Juo and Moorman (1980) and Ogunwale and Azeez (2000). High gravel content is a severe limitation to food crop production with soil erosion and inhibition to root development among the important limiting factors (Babalola and Lal, 1976).

Bulk density varied between 1.01 to 1.65g/cm^3. Bulk density values were generally higher for coarser textured soils than for finer textured soils. The sandy textured horizons had relatively higher bulk density values. The last horizon of Pedon 2 had a relatively high bulk density value for a finer textured soil. Root growth has been reported to be inhibited by excessively dense soils (Brady and Weil, 1999).

Particle size analysis shows that sand occupies a greater proportion of the soils with low silt values. The general increases in clay down the profiles of Pedons 1 and 2 (Table 2) indicate the presence of argillic horizons. The textural classes of these soils range from sandy surface soils to sandy clay loam in the sub-surface horizons of Pedon 1, and sandy loam and sandy clay sub-surface horizons in Pedon 2.

Chemical Characteristics

The pH values (Table 3) obtained show that the soils are slightly acidic. The surface horizons all have relatively higher pH values. In Pedon 1, pH values initially decreased then increased down the profile, Pedon 2 recorded general decrease down the profile while Pedon 3 showed a trend similar to that of Pedon 1. Higher pH values on surface horizons have been attributed to relatively higher organic carbon levels (Jones and Wild, 1975). It is generally accepted that the higher pH on the surface is due to cations being brought up from the sub-soil by the roots of plants and deposited on the surface in plant remains. It may be deduced that the rise in pH after a decline down the profile is due to cations being largely removed by leaching or extraction by roots down the capillary fringe (Nye, 1955).

The exchangeable cations in order of abundance, in this finding, are Ca^{2+},$Mg^{2+}K^+$ and Na^+. Allen (2005) observed a similar trend in the order of abundance of exchangeable cations in the soils of boulder tops in Sweden. High calcium values may be an indication that the soils have a high affinity for calcium and also that Ca^{2+} is more strongly bound to exchange sites than other cations (Beckett, 1965). On the other hand, high Ca^{2+} values may be indicative of the influence of parent material (Ojanuga and Awujoola, 1981). The values of K^+ are low relative to Ca^{2+} and Mg^{2+}, hence the uptake of K^+ may be affected. Total acidity values for the soils are generally low (Table 3). Low total acidity values are associated with high pH values and indicate low acid weathering in soils.

Effective cation exchange capacity values (ECEC) ranged between 5.06 and 6.79 cmol/Kg for surface soils, and 3.59 to 10.46 cmol/Kg in the sub-surface horizons. The higher

ECEC values in the sub-surface horizons of Pedons 1 and 2 were greatly contributed to by the relatively high calcium values.

Cation exchange capacity (CEC) values were decisively higher than ECEC values. Surface values ranged between 8.92 and 10.20 cmol/Kg. The highest value of 68.08 cmol/kg was recorded in the third horizon of Pedon 1. The higher sub-surface CEC values, as compared with surface values, might be indicative of mineralogical nature and composition rather than the presence of organic carbon. Ojanuga and Awujoola (1981) reported that CEC is influenced by texture and nature of soil parent material, CEC being lower in coarser textured soils than in finer textured soils. Cation exchange capacity is important for nutrient retention and supply (Leinweber et al, 1993).

Organic carbon values generally were low and decreased down the profile, showing that CEC values obtained in the soils may not mainly be due to organic matter content. Rapid mineralization of organic carbon by micro-organisms which are active due to favourable environmental conditions and subsequent translocation down the profile by leaching and action of fauna (Folster et al, 1971) may explain the gradual decrease of organic carbon down the profiles of these soils.

Base saturation values are moderate. Sub-surface horizons recorded lower base saturation values. The third horizon in Pedon 1 recorded the lowest value of 13.82% inspite of the high CEC value, which indicates that the exchange capacity is not optimally utilized.

Free iron and aluminium oxide values are higher than those of amorphous iron and aluminium oxides (Table 3). High values of free iron in well drained upper slope are suggestive of high degree of weathering. The lower free iron oxide content of poorly drained soils as compared with those of well drained soils was attributed to removal of dissolved iron oxide from the poorly drained soils (Ojanuga et al, 1976). Hakiman (1977) suggested that iron is more soluble and may form ferrous compounds in wetter soils of lower physiographic units and may appear as mottles.

Free aluminum oxide increased down the profile with a maximum value of 47.25mg/g of soil in the last horizons of Pedons 2 and 3. Ragland and Coleman (1959) reported that increase in aluminium is an indication of weathering. It was suggested that aluminium is higher in hydromorphic profiles.

Amorphous iron and aluminium values are inconsistently distributed in Pedons 1 and 2. Amorphous iron oxide values ranged from 5.36 to 20.11mg/g of soil while amorphous aluminium oxide values ranged from 2.95 to 14.18mg/g of soil in these soils.

Pedogenic clay

Pedons 2 and 3 showed no evidence of clay translocation, however Pedon 1 did (Table 2). The clay losses/gains were calculated on a volume percent basis by subtracting the percent clay of the lower clay horizons from that of the argillic horizon and then multiplying this percentage by the bulk density and horizon thickness (Ojo-Atere and Ogunwale, 1982). The volume of clay gained per 100cm^3 of solum in Pedon 1 is 216g while that lost is 1164.64g of clay/100cm^3/solum, within a solum depth of 112cm (Table 4). This amount of pedogenic clay falls within the area of lower rainfall (100-150cm per annum). These soils are not as highly weathered as soils which fall within 125-150cm per annum, accepting that weathering intensity and profile differentiation increase as rainfall increases (Ojo-Atere and Ogunwale, 1982).

Evaluation of weathering by the use of abrasion pH

The relationship between δpH, base saturation and weathering classes as postulated by Ferrari and Magaldi, (1983) is shown in Table 5. The δpH values obtained from abrasion pH grouped the degree of weathering into three: <0.2 is indicative of low weathering, 0.2 to 1.9 is indicative of moderate weathering and >1.9 is indicative of high weathering (Ferrari and

Magaldi, 1983). All the pedons have δpH values falling between 0.2 and 1.9 and this is indicative of moderate weathering. The moderate weathering class is expected to have between 35 to 80% base saturation.

Classification

Using the USDA Taxonomy System (Soil Survey Staff, 1998) and the FAO/UNESCO (1989) system, the soils have been thus classified: Pedon 1 exhibits the presence of ochric epipedon and argillic B horizon with base saturation greater than 35% and moderate weathering. This meets the requirements of soil order alfisols. The moisture regime is ustic and this puts this pedon into the sub-order ustalf. A base saturation value lower than 35% in the B horizon puts it in great-group dystrustalf. Increase in plinthite from a depth of 34cm with a plinthite content already exceeding 50% in the second horizon puts this soil in the plinthic dystrustalf sub-group. Pedon 1 has 25% or more plinthite by volume in a horizon which is at least 15cm thick within 50 cm of the surface. It has an ochric A horizon and a base saturation (by NH_4OAc) of less than 50 percent in the plinthite horizon. It therefore classifies as Dystric Plinthisol (FAO/UNESCO, 1989).

Pedon 2 is classified as order alfisol and sub-order ustalf for the same reasons as Pedon 1. Presence of plinthite in this pedon with a sharp increase from a depth of 24cm and a value exceeding 50% places this pedon in the great-group plintustalf. The predominance of plinthite in the sub-surface horizon places this soil in the sub-group typic plinthustalf. Pedon 2 is classified as Dystric Plinthisol (FAO/UNESCO, 1989) because of the same reasons given for Pedon 1 above.

Pedon 3 was sited near a valley bottom. The presence of an ochric epipedon, and absence of an argillic horizon and indistinct horizon differentiation classifies this pedon as order inceptisol and sub-order aquept. This pedon has low iron and high aluminium content (DCB extractable). It therefore classifies, at the great-group level, as alaquept. The soil is very sandy throughout the profile depth and this classifies the soil into sub-group psammentic alaquept. This Pedon has fluvic properties. It has a base saturation less than 50 percent between 20 and 50cm from the surface and lacks a sulphuric horizon and sulphidic material within 125cm of the surface. It therefore classifies as Dystric Fluvisol (FAO/UNESCO, 1989).

CONCLUSION

Owing to the moderate cation exchange capacity values and high gravel content of the soils at Gbagba, production of crops would be limited. The surface soils have to be protected against erosion because of the prevalent plinthic sub-surface horizons. Retention and promotion of vegetal cover will improve organic matter and facilitate formation of good soil structure, protection against erosion and also improve the fertility of the soils for crop production.

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Table 1: Morphological characteristics of the soils of a toposequence at Gbagba

Profile Designation	Depth (cm)	Munsell colour	Texture*	Structure⁺	Boundary#	Miscellaneous features
Pedon 1 (Upper slope) Plinthic Dystrustalf						
Ap	0-34	5YR3/2 (moist)	s	g	cw	Common medium and few coarse fibrous roots.
Bt	34-67	2.5YR4/6 (moist)	scl	sbk	ds	Very few fine roots and very few coarse roots; few coarse manganiferous nodules.
Bc	67-112	2.5YR5/6(moist)	scl	sbk	-	Few fine fibrous roots; few yellowish mottles; common coarse manganferous nodules.
B2c	112-175	2.5YR4/8(moist)	scl	sbk	-	Few coarse roots; common coarse manganiferous nodules; water table below.
Pedon 2 (Middle slope) Typic Plinthustalf						
Ap	0-24	5YR3/2(moist)	s	g	cw	Common medium and few coarse fibrous roots.
AB	24-62	5YR4/3(moist)	s	g	ci	Common medium fibrous roots; common coarse manganiferous nodules.
Btc	62-115	5YR4/4(moist)	sl	sbk	dc	Few medium coarse roots; abundant coarse manganiferous nodules.
Bc	115-165	5YR4/6(moist)	sc	sbk	-	Few medium fibrous roots; abundant coarse manganiferous nodules.
Pedon 3 (Lower slope) Psammentic Alaquept						
Ap	0-20	10YR3/2(moist)	s	g	ds	Common coarse fibrous roots.
A	20-40	7.5YR3/2(moist)	s	g	cw	Common medium fibrous and few coarse roots.
AC	40-75	7.5YR5/4(wet)	s	g	-	Common fine fibrous roots and few coarse fibrous roots; (false) water table below.

*s-sandy, scl-sandy clay loam, sl-sandy loam, sc-sandy clay
⁺g-granular, sbk-sub-angular blocky
#cw-clear and wavy, ds-diffuse and smooth, ci-clear and irregular, dc-diffuse and clear

Table 2: Physical characteristics of the soils of a toposequence at Gbagba

Profile Designation	Depth (cm)	Gravel (%)	Bulk Density (g/cm^3)	Sand (%)	Silt (%)	Clay (%)	Texture
Pedon 1							
Ap	0-34	24.7	1.60	91.52	2.0	6.48	Sand
Bt	34-67	61.6	1.42	63.52	16.0	20.48	Sandy clay loam
Bc	67-112	64.6	1.20	65.52	6.0	28.48	Sandy clay loam
B2c	112-175	71.4	1.01	73.52	2.0	24.48	Sandy clay loam
Pedon 2							
Ap	0-24	14.7	1.55	89.52	2.0	8.48	Sand
AB	24-62	84.6	1.32	89.52	4.0	6.48	Sand
Btc	62-115	93.8	1.25	79.52	4.0	16.48	Sandy loam
Bc	115-165	93.1	1.45	63.52	6.0	30.48	Sandy clay
Pedon 3							
Ap	0-20	14.5	1.45	91.52	2.0	6.48	Sand
A	20-40	30.0	1.55	89.52	2.0	8.48	Sand
AC	40-75	14.8	1.65	87.52	4.0	8.48	Sand

Table 3: Chemical characteristics of the soils of a toposequence at Gbagba

Profile Designation	Depth (cm)	pH (1:1) H_2O	pH (1:1) KCl	Ca	Mg	K	Na	TA	ECEC	CEC	OC (%)	%BS	Fe_2O_3 DCB		Al_2O_3 DCB	Al_2O_3 AO
				mol/Kg of soil											mg/g of soil	
Pedon 1																
Ap	0-34	5.6	5.3	3.6	0.8	0.39	0.02	0.25	5.06	8.92	1.72	53.92	7.15	5.36	27.18	4.73
Bt	34-67	4.6	4.5	4.8	2.0	0.09	0.02	0.25	7.16	12.08	2.19	57.20	40.21	16.09	28.35	4.73
Bc	67-112	5.5	4.6	7.6	1.6	0.19	0.02	0.20	9.61	68.08	1.64	13.82	44.69	17.88	27.18	2.95
B2c	112-175	5.6	5.0	6.8	3.2	0.23	0.03	0.20	10.46	29.16	1.52	35.19	50.95	16.09	29.54	9.45
Pedon 2																
Ap	0-24	6.0	5.1	4.0	1.6	0.13	0.03	0.20	5.96	10.20	1.68	56.47	26.81	15.20	37.80	7.09
AB	24-62	5.8	5.3	3.6	1.6	0.16	0.02	0.24	5.62	9.48	1.60	56.75	57.20	18.78	46.08	4.73
Btc	62-115	5.7	5.2	2.0	1.6	0.22	0.02	0.20	4.04	11.08	1.20	34.66	53.63	20.11	24.82	9.45
Bc	115-165	5.1	4.9	7.2	2.0	0.45	0.03	0.20	9.88	21.02	0.52	46.05	67.92	19.22	47.25	14.18
Pedon 3																
Ap	0-20	6.0	5.3	5.6	0.8	0.18	0.01	0.20	6.79	10.0	1.64	65.90	13.41	12.96	23.63	2.95
A	20-40	5.5	5.0	3.2	0.8	0.16	0.02	0.20	4.38	9.44	1.28	44.28	16.09	14.74	42.53	2.95
AC	40-75	5.6	5.0	2.4	0.8	0.14	0.01	0.24	3.59	9.08	0.32	36.89	15.20	14.74	47.25	7.07

TA-Total acidity; ECEC-Effective cation exchange capacity; CEC-Cation exchange capacity; OC-Organic carbon; BS-Base saturation; DCB-Dithionite-citrate-bicarbonate extraction; AO-Ammonium oxalate extraction.