American-Eurasian J. Agric. & Environ. Sci., 2 (2): 189-195, 2007
ISSN 1818-6769
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Granitic Derived Soils in Humid Forest of Southwesthern Nigeria-Genesis, Classification and Sustainable Management

A.S. Fasina, F.O. Omolayo, A.A. Falodun and O.S. Ajayi

Department of Crop, Soil and Environmental Sciences, University of Ado-ekiti, Nigeria

Abstract: The genesis of four granitic derived soils in Ado-Ekiti, humid forest of Southwesthern Nigeria was studied. The soils have thick darkbrown (7.5YR4/3-10YR 4/3) coarse sandyloam/loamy sandy surface horizon, grading loan in the subsoils. The solum is strongly acidic (4.90) to moderately acidic (5.89), low in organic carbon, exchangeable bases and cation exchange capacity. Dominant pedogenic process which influence the rate of soil development in the area include hydrolytic weathering, which has resulted in ferrallitic pedogenesis. Others are lessivation pedoturbation, braunification, induration and colluvial deposition. Pedon A have been classified as Typic Udipsamment (ferralic Arenosol-Apomu series) Pedon B as Typic Plinthudult (Dystic Plinthosol-Iregun series), Pedon C as Typic Dystrudept (Ferralic cambisol-Balogun Series) and Pedon D as Plinthic Hapludox (Plinthic Ferralsol-Apomu series). Finally, recommendations for the sustainable use of these soils are discussed.

Key words: Granitic soils · genesis · classification · sustainable management · Southwestern Nigeria

INTRODUCTION

The relationship between landscape position and hydrological and geomorphic process has been well established for many landscapes [1-3]. Previous efforts at understanding the genesis, chemical and mineralogical properties of soils formed in the Basement complex of Southwestern Nigeria have been directed at the study of a veneer of pedisediment over saprolite [4, 5] suggested that a consideration of the interaction of episodic landscape erosion and pedogenesis was required to explain soil genesis. Earlier, a concept of cylic soil-landscape development which permits the recognition of lithologic discountinuities [6] was proposed for the genetic interpretation while [7] suggested ferralitic pedogenesis.

In the basement complex area there is a strong relationship between topographic position and soil genesis [8]. The difference in the rate of hydrologic and geomorphic process in various landform positions causes differences in the types and intensity of pedogenic processes and typically result in a non-random distribution of soil taxi and properties in a landscape.

Landscapes position influences runoff, drainage, soil erosion, hence soil genesis is affected. Different soil properties encountered along landscapes will affect pattern of plant production, soil physical properties such as clay content distribution with depth, sand content and pH have been shown to be highly correlated with soil genesis [9] while soil organic matter has been shown to vary with slope position [10].

Amusan and Ashaye [4] suggested that the genesis of soil begins with the physical and chemical alteration of minerals at the rock-saprolite interface. This study therefore examines the genesis of soils resulting from in-situ weathering of granitic parent material under humid tropical climate and attempts at classifying the soil and recommending appropriate sustainable management systems for the soils.

MATERIALS AND METHODS

Description of the study area: The location lies between latitude 7°31'N and 7°49'N and longitude 5°3'N and 5°2'N in Ado-Ekiti within the humid forest Southwestern Nigeria. The area is characterized with distinct dry (November to early March) and wet (March-October) seasons. Rainfall pattern is bimodal with peak periods in June and September, mean annual rainfall is about 1367mm and average number of raining days is about 112 per annum. Temperature in this area is almost uniform throughout the year with very little deviations from the mean annual temperature of 27°C, February and March are the hottest months with mean temperature of 28 and 29°C

Corresponding Author: Dr. A.S. Fasina, Department of Crop, Soil and Environmental Sciences, University of Ado-ekiti, Nigeria

respectively. The total number of sunshine h is about 5 h and mean annual radiation about 130 kcal/cm^3/year. The topography of the site is highly moderately steep slope with the highest point having slope not greater than 10%. The geology of the area is dominated by crystalline rock, which form part of the basement complex of southwestern Nigeria. The soils are mostly of granitic parent material.

The main vegetation of the area are trees, grasses, ferns, bush regrowth etc. some parts of the area have been put to cultivation of arable crops like maize and tubers such as Yam and Cassava while the remaining parts are allowed to fallow.

Field studies: The whole area was mapped using the rigid grid method of soil survey. Rigid grid method is a survey method in which points of observation were fixed at the intersection of perpendicularly running transects. The transverse were spaced 50 m apart. After the mapping exercise soils with similar characteristics were grouped together as the same mapping unit. Four soil types were identified Soil profile pits were located and dug to represent each of the soils identified on the field. Altogether fifteen soil samples were collected from the four profile pits. For the soil profile samples collected, notes were taken on soil colour, texture, structure, consistence, stoniness, mottles, cutans and concretions.

Laboratory analysis: Samples were prepared and routinely analyzed following the guidelines of IITA [11].

Soil classification: The soil identified were classified according to Smyth and Montgomery [12] at the series level, Soil Taxonomy (Soil Suvey Sytaff) [13] and (FAO/UNESCO) [14].

RESULTS AND DISCUSSION

Morphological and physical characteristics: The important morphological characteristics of the soil are given in Table 1. The pedon A has a yellowish red (5YR 5/6). A horizon coming down to redish yellow (5YR 6/8) sub soil. Pedon B has a darkbrown (10YR 4/3). A horizon coming down to a yellow (10YR 7/8) subsoil. Pedon C has a grayish brown (10YR 5/2) topsoil coming down to light reddish brown (2.5Y 6/3) subsoil, while pedon D has a very dark grayish brown (10YR 3/2) topsoil coming down to yellowish red (5YR 5/8) subsoil. From all the descriptions above subsoil matrix colour in the solum is redish, brownish or yellowish brown with occasional strong brown yellowish brown or yellow or red mottles. Reddening of upland subsoils is considered due to mobilization and subsequent immobilization of iron during redox-cycles in the soils [15] causing dispersion with progressive oxidation of iron [7] postulated a biogenetic process for the colouration, due to mechanical mixing by plant roots and soil Fauna (termites mainly). The bright subsoil colour in some of the profiles may be an indication of good internal drainage. Nearly all the soil profiles are highly mottled due to lack of mechanical mixing by plant roots and soil Fauna.

Surface soils are generally coarse loamy sand/sandy loam, grading into loamy sand/sandy loam/sandy clay loam (Table 2). Percentage sand content is high virtually in all the profiles indicating the sandy nature of the parent material. For profile B, there is percentage clay increase probably justifying the recognition of argillic horizon [16] observed that marked weathering and argillation of bedrock to saprolite had taken place in the Basement Complex of SW-Nigeria. Sesquioxidic concencretions [17], ferruginous skeleton [7], Iron nodules and concencretions [5], petroplinthite [18] and quartz materials are dominant in the gravelly horizons of the solum. These are indicative of different climatic or bioclimatic regimes as suggested by Amusan and Ashaye [4]. Dikerman and Medema [19] noted that the presence of iron stone gravels in-situ in residual upland soils suggests that there had at one time been conditions favourable for the segregations of iron possibly 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 such as occur in the study area. Thomas and Thorp [20] remarked that cyclic change of climate occurred during soil formation in West Africa.

Physico-chemical properties of the soils: The Ap horizon of all the pedons have high sand content (>75%) with low clay content except for pedon B. An outstanding feature of these soils irrespective of their location on the topography is the moderate to high silt content (11-17%) at the surface. This characteristic distinguishes these soils from most other sandy soils of southwestern Nigeria, characterized by low silt (<10-15%) content-21, 2002, Shittu and Fasina 2004. This high silt content reflects the fact that most of the soils were formed from coarse colluvial materials (Hillwash). This tends to suggest that erosion is a marked pedogenic process in this area.

For pedons B and C, the particle size of the subsoil horizons of the soils suggest that the B-horizons are influenced more by the rate of soil weathering and eluviation-illuviation process. The high clay content in the deeper horizons of some of the soils (profiles B and C) coupled with some morphological properties (Table 1)

Table 1: Field morphological description of pedon studies

Depth (cm)	Colour (Hne) (Mnist)	Mottles +++	Texture + + + +	Structure * *	Consistence Dry + Wet	Cutans k k	Drainage Class k k k	Concretions + + + +	Roots ++
Pedon A									
Apomu									
0-20	5yr 5/6	-	Between to Sl	Cr, Sab	d, L	-	IV	Pm Fe-Mn	M
20-60	5yr 6/8	M, yellow, red	LS	Ls	C r	F	IV	Pm Fe-Mn	F
60-125	5yr 6/8	M, yellow, red	LS	Sab, ab	h	F	IV	Pm Fe-Mn	F
Pedon B									
Iregun									
0-30	10yr 4/3	F, red	Sl	Cr,gr sab,	Sh	-	I	-	M
30-60	5yr 6/8	F, red	SL	Ab	h	F	I	Pf, Fe-Mn	F
90-130	10yr 7/8	F, yellow, red	SCL	sab, ab	h	F	I	Pf, Fe-Mn	-
Pedon C									
Balogun									
0-12	10yr 5/2	M, yellow; f, red	Sl	Sab, ab	Fr	-	I	-	M
12-28	10yr 7/4	F, yellow	SL	Sab, b	M	F	I		F
28-33	2.5y 6/4	F	SL	Sab,b	M	F	I	Pf, Fe-Mn	-
33-107	2.54 6/13	M, yellow	SL	ab	M	F	I	Pm, Fe-Mn	-
107-173	2.54 6/3	M, yellow	SC:	Sab, ab	M	M	I	-	-
Pedon D									
Apomu									
0-28	10yr 3/2	F, red	LS	CR	FR	-	IV	-	M
28-94	7.5YR 5/6	F, red	SL	Sab, ab	h	F	IV	Pm Fe-Mn	F
94-133	5yrs 6/8	M, yellow, red	SL	Sab, ab	h	M	IV	Pm	-
133-180	5 yr 5/8	M, yellow,	SL	Sab, ab	h	M	IV	Pm	-

Table 2: Physical and chemical properties of pedons studied

Sample	Gravel (%)	Sand (%)	Silt (%)	%/Clay	Texture	pH 1:2 H 20	Total N (%)	Avail P (ppm)	Exchangeable cations (Cmol kg^{-1}) Ca	Mg	Na	K	Exch acidity (Cmol kg^{-1})	ECEC Soil	B.S (%)	Organic carbon (%)
Depth (cm)																
A Pedon A Apomu																
0-20	48.13	75	15	10	Sl	5.36	0.32	1.68	3.2	0.36	0.28	0.18	1.2	85.98	85.98	0.64
20-60	55.77	81	9	10	LS	5.70	0.12	3.58	2.6	4.0	0.39	0.17	1.6	8.76	81.74	0.24
60-125	80.57	77	17	6	LS	5.59	0.07	3.47	3.2	5.2	0.35	0.13	0.4	9.28	95.69	0.14
B Pedon B																
Iregun																
0-30	15.83	75	11	14	Sl	5.89	0.02	4.26	3.6	1.1	0.29	0.07	1.6	6.66	75.98	0.04
30-90	38.78	69	15	16	SL	5.06	0.06	6.50	2.2	5.3	0.30	0.09	1.0	8.89	88.75	0.12
90-130	45.79	59	15	26	SCL	5.30	0.01	0.37	3.4	4.5	0.35	0.16	1.6	10.01	840.2	0.02
Pedon C																
Balogun																
0-12	6.85	75	17	8	SL	4.90	0.14	2.91	1.5	3.6	0.31	0.10	1.6	7.11	77.50	0.28
12-28	26.71	75	15	10	SL	5.38	0.16	2.24	2.0	4.2	0.35	0.06	0.4	7.01	94.29	0.32
28-33	48.57	69	15	16	SL	6.07	5.60	1.8	3.8	0.50	050	0.07	0.2	6.37	96.86	0.14
33-107	39.41	55	27	18	SL	8.14	0.01	4.70	2.3	9.67	1.20	0.06	0.2	13.36	98.50	0.02
107-173	57.42	61	19	20	SCL	8.12	0.06	1.68	3.2	5.7	0.96	0.07	0.6	10.53	94.30	0.12
Pedon D																
Apomu																
0-28	15.91	81	13	6	LS	5.88	0.27	4.36	2.9	3.0	0.31	0.11	2.0	8.32	75.96	0.54
28-94	49.40	77	13	10	SL	6.16	0.01	2.13	2.5	3.0	0.30	0.15	3.2	9.15	62.02	0.02
94-133	74.76	65	17	18	SL	6.11	0.10	3.70	3.5	3.3	0.41	0.23	2.8	10.24	72.66	0.18
133-180	58.39	63	19	18	SL	5.79	0.03	1.57	3.8	1.8	0..37	0.28	2.0	8.25	75.76	0.06

and 2) formed the basis for the recognition of argillic horizons in some of the soils.

Another property that is likely to affect crop production in these soils is the high percentage level of concretions and gravels. The depth of gravel content varied widely for all the profiles with values ranging from 6.85%-48.13% on the surface. Percentage concretions/gravels increased with depth (Table 2) in all the profiles. Many to common iron/manganese (Fe/Mn) concretions occur in most of the profiles (Table 1 and 2) right from the soil surface. This perhaps is an indication of alternating wet and dry cycles. This might in fact infer that pliinthization may be another pedogenic process responsible for the soil development of this area. The gravel content observed is a common feature of those soils formed in the upland portion of landscapes derived from granitic metamorphic rocks of central southwestern Nigeria [12, 17]. The high gravel/concretions may constitute a serious problem to crop production within the study area.

The soils are strongly acidic (4.90-profile C) to moderately acidic (5.89-profile B) at the surface. For profile C, the soil was moderately alkaline (8.12-8.14) in the subsoil. Factors suggested to be responsible for the acidic solum may include heavy rainfall, the acidic nature of the parent rock and the acidic precipitation around the study area. Annual rainfall around the study area is about 1367 mm [22] and most of this fall within five to seven months in the year. This distribution of rainfall is considered adequate for leaching and colloid translocation. Precipitation within the study area is acidic [22] and is believed to enhance soil acidity.

The organic matter content of the soil is generally low even less than 2% with the surface soil horizons consistently containing the highest amount Soil organic matter decreases with depth down the soil profile in virtually all the profiles expect profile C. The low organic matter obtained may be partly due to the effect of high temperature and relative humidity which favour rapid miniralization of organic matter. The low soil organic matter on the surface might also not be unconnected with the degradative effect of cultivation and other land use and management activities. The low organic matter content recorded on the average for most of the soils cannot sustain crop production program. Therefore, the organic matter content have to be substantially increase through effective crop residue management.

The nitrogen contents in the soils are on the average low with higher values concentrating in the top soils (0.32%-PA and 0.27-PD). The values of nitrogen decreased with increasing depth in most of the profiles. These nitrogen values obtained can be considered low to medium when compared to the critical value of plant nutrient for Nitrogen (0.20 kg^{-1}) for most tropical crops. These values were also in agreement with values recorded for Nigerian soils [21, 23, 24]. These values are generally low and the inadequate needs to be taken into consideration in managing these soils.

The effective action exchange capacity (ECEC meqlioosil) values of the soils are low. The low ECEC values indicate that the soils have low potential for retaining plant nutrients, hence the necessity for adequate soil management. These values are low when compared with values reported for Nigerian soils [21, 23, 24]. These low ECEC values, coupled with low pH and organic matter, are indications of low, inherent soil fertility status which underscores the need for improved soil management techniques, in addition to the traditional methods of bush fallowing, if crop production is to be sustained. Considering the critical values of exchangeable Mg (0.2 meqi/100g. soil) and 0.15 meq/100g soil for most crops, these two exchangeable bases appear adequate. The high levels of Exc Ca and Mg in these soils tends to suggest that the parent material from which the soils are formed contains these nutrients.

Available P is generally low and considered inadequate for crop production when compared with critical values recommended for most tropical crops (8-15 ppm) [25].

Soil genesis: A critical study of these soils reveal that hydrolytic weathering plays a significant role. High rainfall, high soil temperature, acid precipitaiton and goechemical nature of the parent rock all seems to encourage hydrolytic weathering since precipitation is higher than 0.8PET [22] in this region, leaching of basic cation is encouraged. High temperature encourages photolysis of water. Ojanuga [26] remarked that warm soil temperature causes marked dissolution of soil water, ending to a build up of hydrogen ions. Siever [27] reported that high soil temperature and extreme leaching favour rapid desilication and accumulation of iron, inmobilized in ferric oxide forms under oxidixing conditions. Most of the pedogenetic processes that do occur within the study area are being favoured by humid conditions, free internal drainage, geomorphic stability over prolonged period of time and strong weathering intensity [28]. In the Basement complex region of SW-Nigeria, the climate is humid as precipitation is greater than ET-for-greater part of the year with continually high

temperature. It therefore appears that both the climatic, geologic and physical setting of the region predispose the parent rock to Ferrallitization [29] which is the basis of ferrallitic pedogenesis. Tessens and Shamshuddin [29] noted that ferralitic weathering is the dominant soil forming process in the humid tropical regions. Lessivation, braunification, induration, floral and faunal pedoturbation, erosion, mobilization and subsequent immobilization of iron during redox cycles in soils and cyclic change of climate were considered as other dominant pedogenetic processes in the soils.

Soil classification: The classification of the soil was done according to the USDA Soil Taxonomy [30] and series system of [12]. Pedon A is distinguished by the presence of granular to crumby structure, texture ranger from sandyloam on top coming down to loamy sand. No major diagnostic horizon was noticed. These soils were formed on coarse colluvial texture materials with clay content less than 15% throughout the soil profile. The soils in this group have been classified at first level as Entisol. The presence of a texture of loamy fine sand or coarse in all layers within the particle size control section necessitates the classification of this pedon into suborder "psamment" and at the second level (subgroup) as Typic Udipsament and as Ferralic Arenisol with evidence of yellowish mottles at 20-60 cm. There is also presence of iron and manganese concretion from the topsoil to the lowest region (Table 1). They are classified as Apomu series at series level. This is because they displayed drainage mottling in pale yellowish and rusty orange brown colours. They are sandy in nature to a depth of more than 100cm. They are the concretionary variation of Apomu which are exceptional [12] in that they contain few to fragment large, knobby concretions, some of which was formed above a depth of 18-20 inches in this profile. They are large fragments of broken hardpan which from their rounded surfaces appear to have undergone partial resolution.

On the basis of the criteria of the USDA Soil Taxonomy [13], Peddon B have argillic horizon in the texture range with low base saturation and low apparent ECEC (<+99% by sum of bases method as documented by [30]<12 cmol(+) kg^{-1}clay) within the B horizons and the fufilment of the requirement of clay content increase with depth. Peddon B have been classified at first level as Ultisol because of their low base saturation<99% by sum of bases [30]. The prevalent Udic moisture regime in the ultisol necessittaes their classification into the suborders 'udult'. There is presence of iron and manganese concretions within 150 cm of the surface which made pedon B to be classified at second level as Typic Plinthudult and as Dystic Pilmthosol and Iregun Series.

Pedon C has been classified as an Inceptisol-young soil. There is slight increase in clay with depth though not appreciable. They have low base saturation (<99% by sum of bases method-soil survey staff 1990) and low ECEC (<12 cmol kg^{-1}). There is also precence of Fe-Mn concretions at 28-107cm with evidence of yellowish red mottles throughout the soil profile: The moisture regime is Udic. The soil has been place in suboder Udept and great group Dystrudept and subgroup Typic Dystrudept. It was classify as Ferralic cambisol [14] and as Balogun Series [12].

The last group of soils (Pedon D) has low base saturation (<99%) by sum of bases method and Low ECEC (<12cmol kg^{-1}). The moisture regime is Udic. The soil is highly weathered and leached as evidence by the soil colour and values of the Exchangeable soil bases in subsoil (5YR 5/8)-yellowish red). (Table 1). At first level the soil was classified as an oxisol and suborder Udox and great group Hapludox. At second level it was classified as Plinthic hapludox and Plinthic Ferralsol [14] and as Apomu Series [12].

Sustainable management of the soils: Most soil management practices are largely limited to the ploughed layer. For instance, it was found that 70% of crop yield variability were due to soil properties that occur in the ploughed layer [31].

The soil acidity warrants lime application especially in the subsurface layers which support the roots of most of the arable and tree crops. The organic matter which is low has to be substantially increased through effective crop residue management, increased use of leguminous plants as well as judicious use of organic fertilizers.

Appropriate use of chemical fertilizers will ameliotrate exchangeable bases limitations, but the use of ammonium fertilizers should be strictly guided against to prevent erosion and leaching. Post harvest incorporation of plant residue into the soil instead of the usual burning of crop residue to stimulate the emergence of new flushes for grazing will stabilize the soil aggregates. Minimum tillage is recommended because of the concretonary nature of the soils. The soil with hardpan concretions must always be under cover to prevent serious erosion.

In conclusion the framework for evaluating sustainable Land Management (FESLM) as proposed by Smyth and Dumanski [32] can be adopted in the sustainable management of these soils.

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