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The basaltic soils of Plateau State, Nigeria: Properties, classification and management practices

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Characterization of soils is helpful in the appraisal of soil productivity. The study investigated detailed physico-chemical characterize of the soils developed on basaltic parent materials on the Jos plateau, Nigeria. The aim was to assess appropriate management practice for their sustainability in agricultural production. Four profiles pits were dug and studied, soil samples collected from pedogenetic horizons were analysed for particle size distribution, pH, fertility related properties. Results indicated that the soils were deep, clayey and reddish in colour (2.5YR 3/3-5YR 3/4). In terms of chemical characteristic, the soils are acidic (pH ranged between 4.6 and 5.6) with low to high CEC values (between 4.3 and 14.8 cmol (+) kg^{-1}) and generally low in organic matter on the average (<1.5%) and exchangeable bases. The four profiles developed on basaltic parent materials on the Jos Plateau of Nigeria were characterized and classified as Typic Haplustusts and Andic Haplustepts. All the soils were well drained in spite of high percent clay above 40% and silt fraction of 20 to 30%, which is apparently kaolinitic, with moderate to high aluminium saturation. Higher agricultural productivity of these soils is constraint by low nutrient-holding capacities and strong acidity. Ways to ameliorate these problems include; to raise the exchangeable Al^{3+} above toxicity and to supply Ca and Mg contents besides improving soil physical conditions.

Key words: Basaltic, typic haplustusts, andic haplustepts, kaolinitic, aluminium toxicity.

INTRODUCTION

Soil properties vary in spatial and temporal directions (Sokouti and Mahdian, 2011) and such variation depicts systematic changes as a functions of the geology and derived landforms (Burke, 2002), soil parent materials (Koojman et al., 2005) and soil management practices (landuse) (Amusan et al., 2006). Accordingly, Markus et al. (2008) reported that soil derived from basaltic rocks under tropical and sub-tropical environments are reported to contain kaolinite and sesquioxides as the major clay constituents and are variously classified as Oxisols, Ultisols and Alfisols (Soil Taxonomy) Jos Plateau covers an area of about 8600 km^2 in the central part of Nigeria with varying parent rocks. These parent rocks include basaltic, biotite-granites, alluvium, unconsolidated

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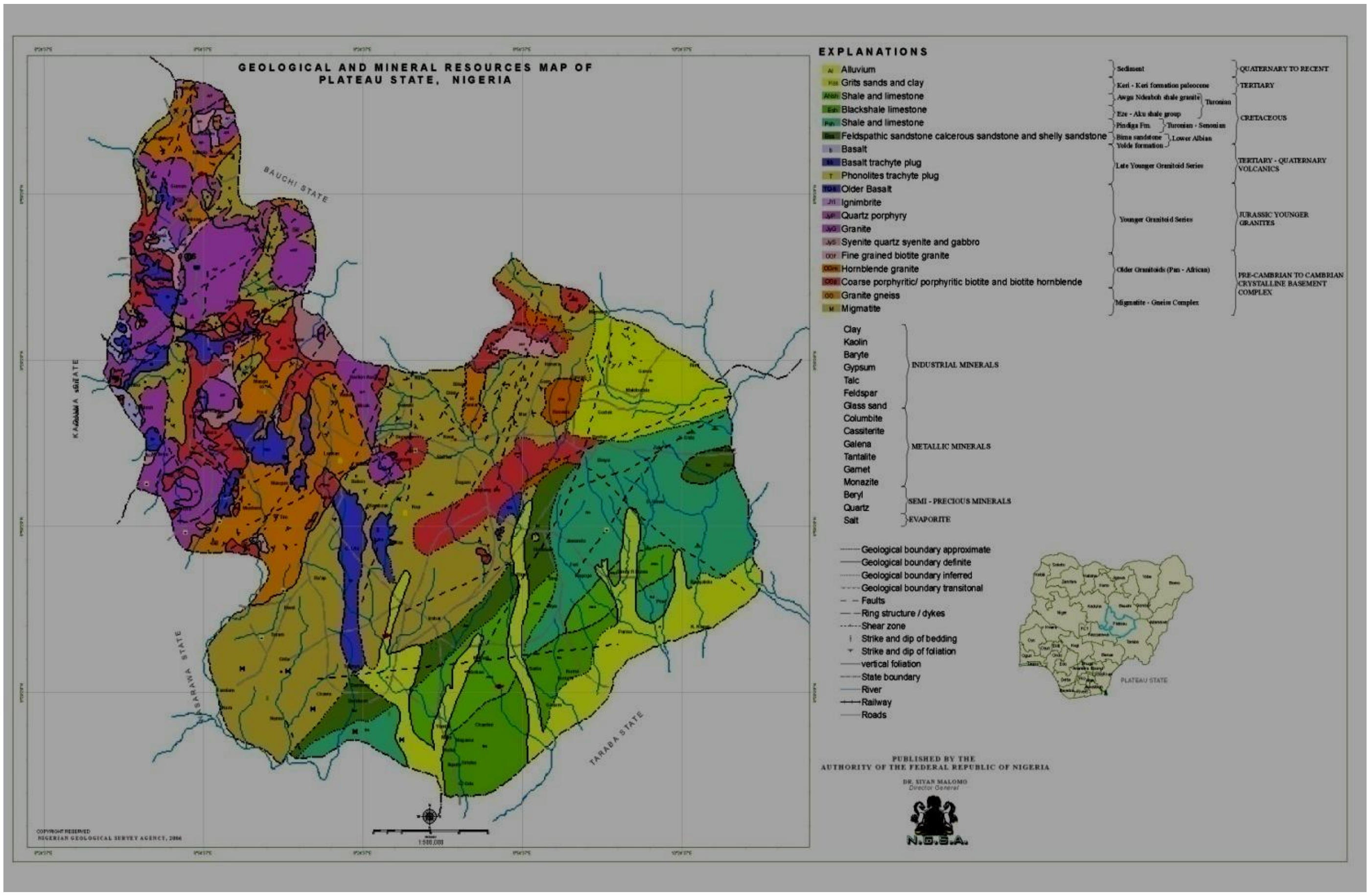

Figure 1. Geological and mineral resources map of Plateau State.

the central part of Nigeria with varying parent rocks. These parent rocks include basaltic, biotite-granites, alluvium, unconsolidated quaternary deposits and granite-gneiss on the Plateau (Olowolafe, 2002). The reddish basaltic soils are the major agricultural activities of thousands of smallholders in the Jos Plateau highland characterized by sub-humid tropical climate. These soils have developed from basaltic rocks and they occur over a wide range of altitudes 1600 to 3000 m above sea level (Olowolafe, 2002).

The productivity of these soils appears to have declined drastically following intensified land-use with poor management. This situation called for investigation that would provide a proper assessment and lead to formation of better management practices to increase yields on these soils. However, detailed information on their properties useful for management practices is lacking. The objective of this study were to investigate more detailed physico-chemical characterization of the soils developed on basaltic parent material on the Jos Plateau and classified them and subsequently recommend appropriate management practices for their sustained and continuous utilization in order to prevent their degradation.

MATERIALS AND METHODS

Description of study area

The study was carried out in the Jos Plateau, which forms a highland area standing above the surrounding plains in the central part of Nigeria. It lies between latitude 8° 30' and 10° 10'N and longitudes 8° 20' and 9° 30'E (Figure 1). Its boundary is marked for the most part by a steep fall to the surrounding plains, though it is more gradual in the east (Hill, 1978). Tropical wet and dry climate prevails in the area with long-term mean annual rainfall of 1300 mm (1008.6 to 2184.70) and mean annual temperature of about 22°C. The soil moisture regime is ustic while soil temperature regime is isohyperthermic (Eswaran et al., 1997). The area falls within the northern Guinea Savannah vegetation zone which is open woodland with tall grasses but the native vegetation has been considerably altered by human activities (Keay, 1953). The Jos Plateau geo-morphologically consists of gently undulating plains of low relative relief to hill ranges on the plains. It comprises of Precambrian Basement Complex rocks: gneisses, migmatites, granites and the Tertiary and Quaternary volcanic rocks: basalts, pumic etc. The survey areas which this paper report is a volcanic activity from Tertiary to recent times. They are distinguished as: Lateralized older basalts, unlateralized older basalts and newer basalts.

The study was conducted from November to March 2007-2008 only on those areas where basaltic soils were exposed already by erosion. A semi-detailed soil survey was carried out with the aid of aerial photo interpretation. Nine profile pits were dug in the basaltic parent material soils of the Jos Plateau but four modal representative profiles were reported. The pedons were described for their morphological properties which include soil colour, texture, structure, consistence, horizon boundary conditions and miscellaneous features such as cutans, roots, pores, etc. Following profile description, bulk and soil samples were collected from the genetic horizons for laboratory analyses.

Soil samples were air-dried in the laboratory, ground and sieved through 2 mm sieve, and the fine earth (< 2 mm) used for laboratory analyses. Particle size distribution was determined by the hydrometer method, using sodium hexametephosphate (Calgon) as the dispersant (Day, 1965). Measurement of soil pH was done in a 1:2.5 suspension in water and $CaCl_2$, the extraction of Ca, Mg, K and Na was made using 1N NH_4OAc (pH7) solution, Ca^{2+} and Mg^{2+} in solution were read on an atomic absorption spectrophotometer, while K^+ and Na^+ were read on the flame emission photometer. Cation exchange capacity was determined by the NH_4OAc saturation method. The CEC of the clay fraction was estimated from the equation of Sombrock and Zonneveld (1971) as follow:

$$\text{CEC (clay)} = \frac{\text{CEC (soil)} - 3.5 \times \%\text{OC} \times 100}{\%\text{Clay}}$$

Exchangeable acidity was extracted by 1 M KCl solution and determined by titration with standard NaOH solution. Organic carbon was determined by the dichromate wet oxidation method. Bulk density was determined gravimetrically using cores.

RESULTS AND DISCUSSION

The morphological characteristics of the soils developed on basalts parent material was presented in Table 1. Soil profiles BST01, BST02, BST03, and BST04 were generally very deep, that is greater than 150 cm depth. The Ap horizons of BST02 and BST04 are generally thin due to the high clay content of the soils, which complexes humus and thus reduces its ability to move downwards in the profiles. Accordingly, Kparmwang et al. (1998) opined that the thin Ap horizons might be partly due to cultivation which is usually on the flat, resulting in minimal deep mixing of the topsoil which is prone to moderate sheet erosion.

The surface horizons of soils were dominantly dark reddish brown as determined on moist state: 5YR 3/3; 5YR 3/4; 5YR 3/4; 5YR 3/3 in profiles BST01; BST02; BST03, and BST04 respectively. Profiles BST01 and BST02 have dark reddish brown (2.5YR 3/4) subsoils, while pedons BST03 and BST04 have a dark reddish brown (5YR 3/4; 5YR 3/4) subsoils. Similarly, the only difference in the surface and subsoils is the hue in pedons BST01 and BST02 and brightness of the subsoils of pedons BST03 and BST04. Oxidation-reduction of goethite coupled with leaching was suggested by Fanning and Fanning (1989) to give hues 5YR to 2.5YR in some soils formed under the tropical conditions. Presumably, hematite could cause the reddish colour in the subsoils. The darker colour of the Ap horizons is probably a result of melanization from humified organic matter, while the bright colour of pedons BST03 and BST04 are probably due to better drainage conditions in those pedons, thus allowing greater oxidation of iron thereby imparting the red colour to the soils (Table 1). The variation in soil colour among the soils was principally due to physiographic position of each pedon and differences in degree of profile development.

Soil horizon boundary conditions in basaltic soils were generally clear and smooth with the exception of BST03 and BST04. Though, the Ap horizons were quite distinct from the B horizons and marked by clear boundary due to melanization by organic matter in the Ap horizons. Thus, there is a greater degree of horizon differentiation in profiles BST01 and BST02 than BST03 and BST04, indicating a greater degree of soil development in BST02, but in pedon BST04 this is due to non-soil layers. The granitic soils posses' clear and smooth boundary differentiation in the surface horizons with irregular subsoils.

Particle size distribution data for the soils is presented in Table 2. The sand fraction in the surface horizon of soils developed on basaltic parent material had values ranging from 10 to 38% with a mean (26%). One striking feature of the sand fraction in the soil type is decrease with abrupt increase in the third horizons of the profiles except Profile BST03. The sand fraction in profile BST03 had near similar values with depth except for horizon 2BC1 that has increased (Table 2). The clay fraction was generally above 40%, giving a dominantly clay texture to the soils. The fraction ranged between 28 to 66% in the studied soils. The surface horizon ranged from 28 to 64% with a mean of 49%. The clay content was high in surface horizon with the exception of BST02 (28%) and increased with depth, nevertheless an irregular distribution pattern was observed in the study. The clay content shows marked increases in the Bt horizons of the profiles (Table 2), but it decreases with depth in profile BST03. Thus, the field evidence of clay translocation (cutans) from the surface horizons into Bt horizons of the pedons, strongly suggesting that the Bt horizons of this parent material is argillic/kandic horizons. Studies conducted on basaltic parent material revealed high clay contents with iron oxides as subsidiary weathering products (Singer, 1966; Ogunwale, 1985; Eshett, 1987; Markus et al., 2008).

The bulk density values for surface horizons in the basaltic soils ranged from 0.770 to 1.171 Mgm^{-3} with a (mean 0.992 Mgm^{-3}) Table 2. The bulk density decreased with depth, except profile BST01 that increased with depth which is irregular in distribution. Bulk density is <1.0 Mgm^{-3} in all horizons of profiles BST03 and BST04. The low bulk density, a requirement of, but not exclusive to andic properties, occurs in volcanic soils as a consequence of the development of a porous soil structure arising from the interaction of non-crystalline materials and soil organic matter content (Vacca et al., 2009).

Table 1. Summary of the morphological features of soil profiles**.

Horizon	Depth	Munsell colour		Mottle			Consistency				
	(cm)	Moist	Dry	Colour	Texture	Structure	Wet	moist	dry	Boundary	Miscellaneous observations
					Basaltic parent materials						
					Profile No: BST 01						
Ap	0-35	5YR 3/3	5YR 4/6	-	C	2msbk	SP	fi	sh	gs	Many fine-medium roots; common hard fine gravel, common fine tubular pores, few empty fine medium termite/ant holes.
Bw1	35-60	2.5YR ¾	2.5YR 4/6	-	C	2msbk	SSPS	fi	sh	cs	Few fine tubular pores; few medium-coarse roots; many fine hard Mn gravel; clay cutans along pores.
Bw2	60-88	2.5YR 3/6	2.5YR 4/6	-	CL	1fsbk	SP	fi	sh	cs	Few fine roots; few fine tubular pores; many medium-hard Fe/Mn concretions.
Bt1	88-130	2.5YR ¾	2.5YR 3/6	-	C	2msbk	SP	fi	sh	ds	Few fine-medium roots; irregular common medium hard Fe/Mn concretions; common fine tubular pores.
Bt2	130-178+	2.5YR ¾	2.5YR 3/6	-	C	2msbk	SSPS	fi	sh	-	Very few fine roots; common soft to slightly hard Fe/Mn concretions; common very fine pores.
					Profile No: BST 02						
Ap	0-16	5YR ¾	-	-	CL	2msbk	SP	fi	S	cs	Many fine roots; many fine few-medium pores; few ant nests.
Bt1	16-70	2.5YR ¾	2.5YR 3/6	-	C	2msbk	SP	fi	H	cs	Many fine roots; many fine-medium pores; vertical cracks, many medium ant nests.
Bt2	70-117	10YR ¾	2.5YR 3/6	7.5R 4/8	C	2msbk	SP	fi	H	cs	Many fine roots; many fine pores; few fine Fe/Mn concretions.
BC	117-152	5YR ¾	-	-	C	2msbk	SSPS	fi	H	cs	Few fine roots; many medium-coarse Fe/Mn concretions; few medium weathered basaltic boulders.
C	152-175+	5YR ¾	2.5YR 3/6	-	C	2msbk	SP	fi	h	-	Few fine roots; many medium soft Fe/Mn concretions; many medium-coarse partially weathered basaltic parent materials.
					Profile No: BST 03						
Ap	0-37	5YR ¾	-	-	C	1msbk	SSPO	Fi	S	gs	Many fine-medium pores; many fine-medium roots; common ant/termites nests.
Bw1	37-100	5YR ¾	-	-	C	2msbk	SP	Fi	H	cw	Many fine pores; few fine soft iron nodules.
2BC1	100-110		-	-	C	-	-	-	-	-	Partially weathered basaltic materials.
2BC2	110-143	5YR ¾	-	-	C	2msbk	SP	Fi	H	cs	Common medium pores.
2Cr	143-190	5YR ¾	-	-	C	2msbk	SP	Fi	H	-	Many coarse partially weathered basaltic materials.
					Profile No: BST 04						
Ap	0-15	5YR 3/3	-	-	C	1fsbk	SPO	Vfr	S	cs	Many fine pores; many fine-medium roots; few termites/ant nests.

Table 1. Contd**.**

Bw1	15-110	5YR ¾	5YR 4/6	-	C	2csbk	SP	Fi	H	ds	Many fine-common pores; many fine roots; many medium Fe/Mn concretions; few termites' nests.
Bw2	110-156	5YR ¾	5YR 4/6	-	C	2msbk	SP	Fi	H	cg	Many fine pores; few medium-coarse Fe/Mn concretions; partially weathered basaltic boulder of medium-coarse size.

Table 2. Particle size distribution, bulk density and porosity of the pedons

Horizon	**Depth**	**Sand**	**Silt**	**Clay**	**Bulk density**	**Porosity**	**Textural class**
	(cm)	**(2000-50 μm)**	**(50-2 μm)**	**(<2 μm)**	**Mgm^{-3}**	**$m^{-3}m^{-3}$**	
				BST01 CHAHA			
Ap	0-35	30	20	50	1.049	0.396	Clay
Bw1	35-60	16	20	64	1.141	0.431	Clay
Bw2	60-88	44	22	34	1.304	0.492	Clayloam
Bt1	88-130	20	22	58	1.212	0.457	Clay
Bt2	130-170+	18	26	56	1.008	0.380	Clay
				BST02 NITA			
Ap	0-16	38	34	28	1.171	0.442	Clayloam
Bt1	16-70	12	22	66	1.010	0.381	Clay
Bt2	70-117	20	22	58	1.008	0.380	Clay
BC	117-152	26	26	48	1.010	0.381	Clay
C	152-175+	38	18	44			Clay
				BST03 RA-HOSS			
Ap	0-37	10	26	64	0.978	0.369	Clay
Bw1	37-100	14	26	60	0.945	0.357	Clay
2BC1	100-110	24	28	48			Clay
2BC2	110-143	14	24	62	0.544	0.205	Clay
2Cr	143-190	14	32	54	0.913	0.345	Clay
				BST04 TA-HOSS			
Ap	0-15	24	22	54	0.770	0.291	Clay
Bw1	15-110	20	22	58	0.602	0.227	Clay
Bw2	110-156	38	24	46	0.783	0.295	Clay
BC	156-190	38	26	36	0.641	0.242	Clayloam

Table 3. Soil chemical properties of the pedons.

Horizon	Depth	pH		Exch acidity		OC	Exchangeable bases Cmol(+)kg^{-1}					CEC	CEC (clay)	ECEC	Base Sat
	(cm)	(H_2O)	$CaCl_2$	$Al^+ + H^+$	H^+	%	Ca	Mg	K	Na	Σbases		Cmol(+)kg^{-1}		(%)
							Basaltic parent material BST01								
Ap	0-35	5.3	4.9	2.3	1.0	0.54	0.90	0.026	0.266	0.045	1.237	12.2	20.62	3.537	10.0
Bw1	35-60	5.2	4.6	1.2	0.4	0.66	1.53	0.324	0.296	0.071	2.221	8.2	9.20	3.421	27.0
Bw2	60-88	4.6	4.2	2.2	0.8	0.68	1.26	0.501	0.197	0.039	1.997	4.3	5.35	4.197	46.0
Bt1	88-130	5.4	4.6	0.8	0.4	0.24	1.46	0.063	0.297	0.036	1.856	7.0	10.62	2.656	27.0
Bt2	130-170+	5.4	4.6	0.9	0.4	0.41	0.89	0.097	0.164	0.055	1.206	9.6	14.58	2.106	13.0
							BST02 NITA								
Ap	0-16	5.0	4.5	1.3	0.3	0.68	1.57	0.247	0.230	0.030	2.077	14.2	42.21	5.377	15.0
Bt1	16-70	5.4	4.8	1.6	0.5	0.60	1.42	0.314	0.294	0.082	2.110	14.8	19.24	3.710	14.0
Bt2	70-117	5.6	4.5	2.8	0.5	0.39	1.53	0.339	0.114	0.050	2.033	12.6	19.37	4.833	16.0
BC	117-152	5.3	4.7	3.2	1.2	0.40	ND	0.195	0.228	0.066	0.489	10.2	18.33	3.689	05.0
C	152-175+	5.2	5.0	3.3	1.2	0.41	2.68	0.287	0.147	0.084	3.198	12.4	24.92	6.498	26.0
							BST03 RA-HOSS								
Ap	0-37	5.2	4.6	2.1	0.6	1.08	1.47	0.002	0.049	0.042	1.563	11.6	12.22	3.663	14.0
Bw1	37-100	5.2	4.2	1.3	0.4	0.33	1.35	0.028	0.068	0.124	1.570	9.2	13.41	2.870	17.0
2BC1	100-110	4.6	4.2	1.1	0.2	0.55	1.50	0.028	0.188	0.077	1.793	9.8	16.41	2.893	18.0
2BC2	110-143	4.9	4.5	2.2	0.7	0.51	1.30	0.176	0.246	0.032	1.754	9.0	11.61	3.954	20.0
2Cr	143-190	5.0	4.6	3.8	1.5	0.42	4.83	0.029	0.278	0.062	5.199	18.7	31.91	8.999	28.0
							BST04 TA-HOSS								
Ap	0-15	5.5	5.4	1.4	0.6	1.23	1.19	0.152	0.181	0.045	1.568	8.5	7.77	2.968	18.0
Bw1	15-110	5.3	5.0	1.3	0.4	0.43	1.60	0.026	0.242	0.046	1.914	9.2	13.27	3.214	21.0
Bw2	110-156	4.8	4.7	1.7	0.8	0.31	1.22	0.115	ND	0.071	1.406	8.2	15.47	3.106	17.0
BC	156-190	5.6	5.2	1.2	0.2	0.41	1.48	0.152	0.027	0.102	1.761	5.0	9.90	2.961	15.0

Nutrient status of the soils

Generally the soils are acidic (pH values mostly < 5.5) (Table 2). Lower values were reported by Eshett (1987) on basaltic soils at Ikom in the humid forest zone (range 4.6 to 5.2) and on basaltic soils on the sub-humid Jos Plateau (range 4.2 to 5.5). The pH values increase slightly down the profiles, in consonance with the less leached conditions of the area. Exchangeable bases contents of the soils are low to very low. Olowolafe (1995) reported similar results on the Jos Plateau soils; he urged that the silicate clay mineral in the Inceptisols, Alfisols and Ultisols was kaolinite. As pointed out earlier, annual rainfall was about 1260 mm. leaching of basic cations by rainfall and the low pH values of the soils are among the factors that favour kaolinite formation. The dominance of low activity clay minerals has undoubtedly contributed to their low to very low CEC (Table 3). Certainly these have pronounced influences on the productivity of the soils.

The exchangeable acidity for the soils ranged from 0.8 to 3.3 cmol (+) kg^{-1} (mean 1.763). Indeed, the Ap horizons had highest values across the profiles (Table 3). This result is similar with the low exchangeable bases and high exchangeable acidity of Eshett (1987) for the Ikom soils and Markus et al. (2008) for Kuantan series. Buol et al., 1980) reported that exchangeable

(Al is generally low in basaltic soils. It is therefore possible that the high exchangeable Al obtained is a result of excessive weathering that might have led to the subsequent release of structural Al from clay minerals. Aluminium toxicity might be a problem to crop production in the study area. The percentage aluminium saturation was above 30% critical level (Fageria et al., 1988).

The organic carbon (OC) contents of the soils decreased with increase in depth in all the pedons. The surface soil values were generally rated low with the exception of profiles BST03 and BST04 that have moderate values (>1.0%). This is in conformity with the findings of Yaro et al. (2006). The low in OC content is attributed to paucity in vegetation, low return of crop residues and mineralization in the region.

Soil classification

The diagnostic criteria for classification according to the USDA Soil Taxonomy (Soil Survey Staff, 2003) include an ustic soil moisture regime due to a pronounced dry season lasting between 5 to 6 months and an isohyperthermic soil temperature regime characteristic of the tropics. Pedons BST01 and BST02 are characterised by ochric epipedons and argillic/kandic B horizons, whilst pedons BST03 and BST04 have cambic B horizons. Base saturation (NH_4OAc) is low, generally lower than 50% (Tables 2 and 3). The clay mineralogy of the soils was dominated by kaolinite, oxides of Fe and Al with traces of 2:1 minerals (Hassan, 2010). Ogunwale (1985) also found kaolinite as the dominant clay minerals on the basaltic soils of the Jos Plateau.

Pedons BST01 and BST02 are therefore classified at the family level of Soil Taxonomy as Typic Haplustults, fine clayey, vermiculitic, isohyperthermic, while pedon BST03 as Andic Haplustepts, very fine clayey, kaolinitic, isohyperthermic and BST04 qualifies as Andic Haplustepts, fine clayey kaolinitic, isohyperthermic.

According to the World Reference Base for Soil Resources (2006), pedons BST01 and BST02 qualified to be Ferralic Acrisols. These are soils with argic B horizons which had CEC of clay fractions less than 24 cmol (+) kg^{-1} clay and base saturation (by NH_4OAc) of less than 50% in at least, part of the B horizons within 125 cm of the surface. Pedons BST03 and BST04 were classified as Cambisols because they have weakly developed soils with a B horizon (cambic horizon). At the second level, BST03 and BST04 were placed on Andic due to andic horizon within 100 cm from the soil surface. The clay mineralogy revealed short-range-order minerals; allophone and imogihite (Hassan, 2010).

Management options

Generally, the particle sizes in basaltic soils are dominantly clay fraction with values above 40% and with low sand content. Low bulk density was evidence in soils with some profiles (BST03 and BST04) <1.0 Mgm^{-3}. Thus, consequence of the development of a porous soil structure arising from the interaction of non-crystalline materials and soil organic matter. However, the soils were found to be very strongly to moderately acid in the Ap horizons with inconsistence vertical variation down the profiles. Exchangeable Al^{3+} constituted the larger proportion of exchangeable acidity, especially in the surface horizons. Thus, aluminium saturation >20% is commonly regarded as a potential Al toxicity in sensitive crops.

Similarly, low OC and exchangeable bases observed in the soils constitute to decline in crop productivity as was reported by earlier researchers. In the same vein, the soils possesses excellent physical condition (friable and highly porous) although they are plastic and sticky when wet as, it is usual for clayey soils. The ability to supply nutrients can be improved in soils containing amorphous materials through the addition of organic matter. Since OM has a large CEC under most soil conditions, addition of OM enhances the CEC of the soil. The sticky nature of the soil when wet, farmers are advice to use knife to scoop the sticky blades. Further, experimentally determined rate of slow reacting liming materials can neutralize the acidity, that is, to raise the exchangeable Al^{3+} above toxicity and as well as supply Ca^{2+} and Mg^{2+} as nutrients besides improving soil physical conditions.

Conclusion

Soils developed on basaltic parent materials on the Jos Plateau, Nigeria are intensely leached and have acidity problems. The soils are inherently low in soil fertility related properties (Hassan, 2010) and exchangeable bases. With the present low-input agriculture in the area, nutrient depletion will certainly continue, a situation which can lead to total loss of crop productivity and degradability of the soil quality and/or environment.

Sustainable crop production calls for improved management practices that will effectively minimize erosion and also enhance and maintain soil quality and productivity. Incorporation of crop residues, animal wastes and full recommended rate of N and P from inorganic fertilizer may be advantageous for boosting the fertility of the soils. Further, experimentally determined rate of slow reacting liming materials can neutralize the acidity, that is, to raise the exchangeable Al^{3+} above toxicity and as well as supply Ca^{2+} and Mg^{2+} as nutrients besides improving soil physical conditions.

Conflict of Interest

The authors have not declared any conflict of interest.

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