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Properties, classification and agricultural potentials of lateritic soils of Minna in sub-humid agroecological zone, Nigeria

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Abstract

Two pedons located on the Experimental Farms of the Federal University of Technology (EF) and Maizube Farms (MF) all around Minna were studied. The result indicated that the pedons had surface texture of sandy loam and sandy clay loam respectively overlaying fine textured subsoil. In the same order, the sand content ranged from 529 to 794 g kg^{-1} and 417 to 597 g kg^{-1} and decreased with soil depth. Silt ranged from 55 to 105 g kg^{-1} and 104 to 154 g kg^{-1} and was irregularly distributed within the profiles. Clay ranged from 116 to 386 g kg^{-1} and 269 to 449 g kg^{-1} and unlike sand, it increased down the profiles. Both pedons were imperfectly drained and had plinthites in their subsurface. The pH ranged from 5.5 to 6.5 and 6.0 to 7.2. Organic C and TN were rated high in EF with values of 16.76 g kg^{-1} and 0.37 g kg^{-1} and medium in MF with values of 10.68 g kg^{-1} and 0.17 g kg^{-1} respectively. Also, available P was 11 and 8 mg kg^{-1} and was rated medium in both soils. The average ECEC values were 5.75 cmol kg^{-1} and 12.45 cmol kg^{-1}. The pedons were classified at subgroup level as Typic Plinthustalfs in USDA taxonomy which correlates as WRB-IUSS's Haplic Plinthosols (Eutric). The two sites are suitable for the cultivation of most crops but will require, especially for arable crops, drainage to enhance aeration within the root zone of the crops

Keywords: Basement complex rocks, Plinthitization, Sub-humid climate

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1. Introduction

Lateritic soils are described as product of highly weathered material, under tropical and subtropical condition, rich in secondary oxides of iron, aluminium or both. They are nearly void of bases and primary silicates, but may contain amounts of quartz or kaolinite. Also, the lateritic soils are either hard or capable of hardening on exposure to wetting and drying. Furthermore, the lateritic soils are composed of a wide variety of red, brown, and yellow fine-grained residual soils of light texture, as well as nodular gravels and cemented soils (Schellmann, 1994; Bourman and Ollier, 2002). The agricultural value of lateritic soils depends largely on the thickness of the overlying surface material. Those soils having concretionary layers below 50 cm depth were categorized to be moderately productive for paddy and other cereal crops. While in terms of physical and nutrients, the highly weathered lateritic soils were mostly rated poor for agriculture because of their compacted B-horizon which inhibits root penetration with relatively low moisture (Raychaudhuri, 1980).

Studies had shown that Minna is underlain predominantly by basement complex rocks dominated by granites, gneisses, migmatites, quartzites and schist which gave rise to a wide variety of soils (Bennett et al., 1979). The upland soils under the basement complex formation around Minna are generally deep, weakly to moderately structured sand to sandy clay with gravelly and concretionary layers in the upper or beneath the surface layers (Ojanuga, 2006). Alhassan et al. (2012) observed quartz to be the prominent mineral constituents of the soils around Minna. They also noticed high kaolinite clay content which was observed to be responsible for relatively low plasticity of the soils. Other workers identified some soils around Minna to have clay content in their B-horizons 1.2 times more than the overlying layer which indicated that they have well developed argillic horizons in their profiles (Adeboye et al., 2009). The argillic horizon, according to Soil Survey Staff (2010) is a subsurface diagnostic horizon with a significantly higher percentage of phyllosilicate clay than the overlying soil material.

The newly established Teaching and Research Farms of the Federal University of Technology, Minna is located on one of the identified soil units of the Minna lateritic soils while the integrated farm, Maizube Farms involved in mechanized production of different annual crops, fruits and vegetable under rain-fed and irrigation is also located on another soil unit. There is dearth of information on the lateritic soils of Minna area which are intensively cultivated with a variety of crops including cowpea, groundnuts, maize, apple, exotic mango trees, and citrus, and banana, and plantain on their management for profitable and sustainable productivity. This study reports two of the soil units identified during the semi-detailed soil survey of the Minna carried out to fully characterize, classify and advice on their management for sustainable productivity.

2. Materials and methods

2.1. The study area

The climate of Minna is sub-humid with mean annual rainfall of 1284 mm and a distinct dry season of about 5 months duration occurring from November to March (Ojanuga, 2006). The mean maximum temperature remains high throughout, about 32 ^oC, particularly in March and June. Minna area lies within the southern Guinea savanna vegetation belt of Nigeria. The physical features around Minna consist of gently undulating high plains developed on basement complex rocks made up of granites, migmatites, gneisses and schists. Inselbergs of "Older Granites" and low hills of schists rise conspicuously above the plains. Beneath the plains, bedrock is deeply weathered and constitutes the major soil parent material (saprolites) (Ojanuga, 2006). Two sites were selected for the study. One was cited on the Experimental Fields of the School of Agriculture and Agricultural Technology of the Federal University of Technology (EF), (lat. 9^o 31′ N; long. 6^o 30′ E) and the second was cited on Maizube Farms (MF), (09^o 25′ N; long. 06^o 22′ E) both in Minna.

2.2. Field study

The profile pits were dug and characterized following the guidelines outlined in Soil Survey Staff (1993) and FAO (2006). The genetic horizons were identified on the basis of observed differences in some morphological characteristics of the soils which included colour, texture, structure, depth of horizons, inclusions etc. Soil colours were described using Munsell Soil Colour Charts (Munsell Colour Company, 2009). Soil samples were collected from each genetic horizon into labelled polythene bags and taken to the laboratory for analysis.

2.3. Soil analysis

The soil samples were air-dried, gently crushed and passed through 2 mm-sieves to obtain fine earth separates. The processed soil samples were analysed for some physicochemical properties following the procedures outlined by the International Soil Reference and Information Centre and Food and Agricultural Organization (ISRIC/FAO, 2002). Briefly, particle size analysis was determined by Bouyoucos hydrometer method. The soil pH was measured in 1:2.5 soil/$CaCl_2$ suspensions with glass electrode pH meter and organic C by Walkley-Black method. Total nitrogen (TN) was determined by micro-Kjeldahl digestion procedure. Available phosphorus (P) was extracted by Bray P1 method. The P concentration in the extract was determined colorimetrically using the spectrophotometer. Exchangeable bases, Ca^{2+}, Mg^{2+}, K^+ and Na^+ were extracted with 1N NH_4OAc. Ca^{2+} and Mg^{2+} in the extract were determined using atomic absorption spectrophotometer (AAS) while K^+ and Na^+ were determined by flame photometry. Exchangeable acidity was determined by titrimetric titration with standard NaOH. Effective cation exchange capacity (ECEC) was determined by summation method and percent base saturation was by calculation.

2.4. Soil classification

The pedons were classified according to USDA Soil Taxonomy System (Soil Survey Staff, 2010) and correlated with World Reference Base for Resources (IUSS Working Group WRB, 2006). The fertility status was rated according to critical values recommended for Nigerian soils (Esu, 1991).

3. Results and discussions

3.1. Morphological and physical properties

The results of some morphological and physical properties of the soils of the two sites are shown in Table 1. The surface colour of EF was grayish brown (10YR5/2) over dark yellowish brown (10YR4/6) to various shades of brown colouration. Also, the surface colour of soils from MF was dark grayish brown (10YR3/2) over various shades of yellowish brown and graded to light brownish gray (10YR6/2) subsoil. The yellowish brown colour in their subsoil may be attributed to residual accumulation of goethite which imparted yellowish colouration. Another important morphological feature common to both pedons was the plinthite horizons starting from the depth of 24 cm in EF and 39 cm in MF. The plinthite must have developed as a result of migration of sesquioxides and clay into Btv1 and Btv2 horizons. However, the cementation was greater at Btv2 horizons which probably contributed to the deterioration of the structure of the subsoil which changed from moderate angular blocky to massive structure in both pedons. The implication was that the soils of the studied sites may remain saturated during peak rainy period and or irrigation in the case of MF, hence, creating anaerobic condition unfavourable for plant rooting. Sombroek (1987) had established that the denseness of the structure of plinthite horizons usually impacts physical drawback to root development and limits water storage.

The particle size analysis had shown that the sand particles dominate the other particles in both pedons. The dominance of sand may be due to the parent materials, granite, the soils were developed from. Sands particles are made of quartz mineral, an essential component in granite (Wilson, 2010) which is resistant to weathering. The two pedons had decrease in sand content down the profile. Clay was next to sand in dominance and unlike sand, the clay content increased with soil depth. Schaetzl and Anderson (2005) attributed increase of clay down the soil profile to pedogenic processes involving eluviation and illuviation of clay particles, neo-formation and transformation of primary minerals in the subsurface horizons. Furthermore, EF and MF had 2.4 and 1.4 times respectively more clay in Btv1 horizon than in their Ap-horizons. These results agreed with the findings of Adeboye et al. (2009) who recorded 1.2 times higher the value of clay for similar soils with well developed argillic horizons in Minna area. The absence of cracks on the exposed surfaces of the pedons may imply that the soils were dominated by non-expanding (1:1) clay minerals probably kaolinite. This further confirmed the reports of Ojanuga (2006) and Alhassan et al. (2012) that observed high kaolinite in some soils of Minna. The texture of the surface soil of pedon EF was sandy loam and changed into sandy clay loam and sandy clay with increasing soil depth. Similarly, for pedon MF, the texture varied from sandy clay loam surface soil to sandy clay and clay subsoil.

The silt/clay ratio for EF and MF were 0.33 and 0.35 respectively suggesting that the soils may still have weatherable minerals in them. Ashaye (1969) reported that a low silt:clay ratio of < 1 could mean that the soil had undergone ferralitic pedogenesis. This view may hold forth for both soils because of presence of plinthite materials dominating Btv1 and Btv2 horizons.

3.2. The chemical properties

The result of some chemical properties of the soils are shown in Table 2 and the interpretation was based on recommendations of Esu (1991) (Table 3). The soil reaction was moderately to slightly acidic in EF and strongly acidic to neutral in MF. On the average, the pH value was considered ideal for most crops (Brady and Weil, 2002). The exchangeable acidity was low with values ranged from 0.96 to 1.40 cmol kg^{-1} in EF and 0.63 to 0.89 cmol kg^{-1} in MF suggesting that the soils have no acidity threat for most crops. The organic carbon (OC) was rated high to medium in EF and MF respectively. The OC values were higher than the values reported by Adeboye et al. (2009) and Alhassan et al. (2012) for other soils around Minna. This may be as a result of improved management practices by those cultivating the two soils which encouraged return of plant residues or animal by-products to the soils. Total nitrogen (TN) ranged from 0.05 to 0.65 g kg^{-1} in EF and from 0.10 to 0.27 g kg^{-1} in MF and was rated high in EF and medium in MF. The trend in TN distribution within the pedons was similar to OC implying that the organic matter was the major source of TN in the soils investigated. According to Konnovora et al. (1966), organic matter accounts for between 90 and 98 % of soil nitrogen. The available P was rated medium in both soils which make application of P fertilizers not necessary for the successful cultivation of most cereal crops except legumes that are sensitive to P.

Calcium (Ca) dominated the exchange complexes of the soils studied. It has been reported that Ca usually dominates the exchange sites of most soils with Mg, K, NH_3 and Na having lower concentrations (Enloe *et al*., 2006). Calcium concentration was rated medium in EF and high in MF and increased with soil depth. However, the increase in Ca with depth in the two pedons may not be attributed to leaching process *per se* because both pedons have fine-textured clay with massive structure in their subsoil which may impede water percolation. Therefore, the higher concentration of Ca in the subsoil of the two soil pedons may be attributed to *in situ* weathering of parent materials rich in Ca-bearing feldspars. The magnesium (Mg) content was rated high in both soils while potassium (K) was rated low in EF and medium in MF. Sodium (Na) content was rated medium in EF and high in MF. The high value of Na in MF made the soil at that site in particular to be potentially sodic. The high Na content of MF might be linked to prolong irrigation coupled with deteriorated structure of subsoil and poor drainage characteristics. The percent base saturation ranged from 80 to 95 % in both soils and rated high, which according to Atofarati et al. (2012) reflects the dominance of basic cations in the exchange complex.

3.3. Soil classification

The pedons were classified according to criteria defined in Soil Survey Staff (2010). The two pedons have well established argillic horizons, that is, significant accumulation of clay in their subsoil (B-horizons) as earlier explained. On this criterion, they are classified at Order level as Alfisols. The ustic moisture regime, characteristics of the sub-humid climate around Minna, with well defined dry and wet seasons which make the soils usually moist for a period of over 180 days in a year or having a cumulative dry period of not less than 90-days, placed both soils at sub-order level as Ustalfs. The occurrence of continuous concretionary layers (plinthite layers) within 150 cm (precisely 24 and 39 cm for EF and MF respectively) from the mineral surface formed from accumulation of sesquioxide coupled with alternating dry and wet conditions which favoured the formation of plinthite, the soils fitted into the great-group Plinthustalfs. The absence of other diagnostic features that may allow the pedons to fit perfectly in to other sub-groups, hence both pedons were classified at sub-group level as Typic Plinthustalfs and which correlates with WRB-IUSS (2006)'s Haplic Plinthosols (Eutric).

4. Conclusions

The two sites are rated suitable for arable crops cultivation but they will require special management attention for optimum and sustainable productivity. Such management practices should not accelerate the formation of petroplinthites (ironstones). The management practices to be applied to both sites should include measures that will increase soil's biological activity, soil aeration as well as nutrients to plants and improve the soil structure. It is therefore suggested a farming system which may involves the adoption of a deliberate alternation of fallow and cultivation practices of equal duration, planting and incorporation of *Centrosema spp* or any suitable legume as green manure during fallow periods, and application of animal dung or fertilizers especially for the highly intensified cultivated lateritic soils of MF. In their present form both sites require P fertilization especially for leguminous crops such as soybean and groundnut that are sensitive to P for their optimum yield. Also, the two locations will require land preparation involving ploughing, harrowing and ridging in addition to provision of drainage infrastructures to conduct excess water away from the fields when arable crops such as cereals and legumes, that are non-tolerant to water-logging conditions are cultivated. There is a need to increase the organic matter content of the soils by incorporation of crop residues and organic manure to increase the N content of the soils and improve the soil structure.

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Table 1. Some morphological and physical properties of the soils

Pedon	Horizon	Soil Depth (cm)	Colour (moist)*		Structure**	Sand	Silt	Clay	Textural Class	Silt/clay ratio
			Matrix	Mottles		←	$g\ kg^{-1}$	→		
EF	Ap	0-24	10YR5/2 grayish brown		2cr	794	90	116	sl	0.77
	Btv1	24-54	10YR4/6 dark yellowish brown	mottled	2sbk	629	95	276	scl	0.34
	Btv2	54-120	7.5YR5/6 strong brown	mottled	ms	569	55	376	sc	0.15
	BCt1	120-157	10YR6/3 pale brown	mottled	ms	509	105	386	sc	0.27
	BCt2	157-206	10YR7/3 very pale brown	mottled	ms	529	90	381	sc	0.24
MF	Ap	0-19	10YR3/2 dark grayish brown		1sbk	597	134	269	scl	0.50
	BA	19-39	10YR4/4 dark yellowish brown		2sbk	527	104	369	sc	0.28
	Btv1	39-83	10YR5/4 yellowish brown	2.5YR4/6 red	2abk	487	114	399	sc	0.29
	Btv2	83-122	10YR5/4 yellowish brown	mottled	ms	437	124	439	c	0.28
	BCt1	122-150	10YR6/4 light yellowish brown	mottled	ms	427	124	449	c	0.28
	BCt2	150-207	10YR6/2 light brownish gray	mottled	ms	417	154	428	c	0.36

**Munsell Colour values (Munsell Colour Company, 2009).*

***1=weak; 2=moderate; 3=strong; cr=crumb; abk=angular blocky; sbk=sub-angular blocky; ms=massive*

Table 2. Some chemical properties of the soils

Pedon	Horizon	Depth	pH ($CaCl_2$) 1:2.5	Av. P	TN*	Org. C	Exchangeable cations				Exch. Acidity H + Al	ECEC*	BS*
							Ca^{2+}	Mg^{2+}	K^+	Na^+			
		cm		mg kg^{-1}	g kg^{-1}	g kg^{-1}	←		cmol$_{(+)}$ kg^{-1}			→	%
EF	Ap	0-24	6.0	9	0.65	22.05	2.76	0.38	0.05	0.27	0.89	4.35	80
	Btv1	24-54	5.6	14	0.61	22.05	3.68	0.98	0.04	0.26	0.76	5.72	87
	Btv2	54-120	5.5	10	0.37	15.44	3.90	1.76	0.05	0.27	0.71	6.69	89
	BCt1	120-157	6.4	10	0.19	15.44	3.84	1.06	0.03	0.12	0.65	5.70	89
	BCt2	157-206	6.5	13	0.05	8.82	4.06	1.48	0.02	0.11	0.63	6.31	90
MF	Ap	0 – 19	7.2	10	0.20	10.30	5.60	3.00	0.46	0.92	1.40	11.38	88
	BA	19 – 39	6.6	9	0.18	10.30	4.80	2.21	0.15	0.60	1.00	8.76	89
	Btv1	39 – 83	6.2	8	0.27	14.30	5.20	2.30	0.10	0.49	0.96	9.05	89
	Btv2	83 – 122	6.0	6	0.10	7.80	6.40	3.12	0.09	0.54	1.20	11.35	89
	BC1	122 – 150	6.1	6	0.10	NA	8.00	4.50	0.05	0.48	1.26	14.29	91
	BC2	150 – 207	6.3	6	0.17	NA	12.00	6.00	0.09	0.42	1.16	19.86	94

**Av. P=available phosphorus; TN=total nitrogen; Org. C=organic carbon; Exch. Ac.=exchangeable acidity; ECEC=effective cation exchange capacity BS=base saturation.*

Table 3. Critical limits for interpreting levels of analytical parameters

Parameter	Low	Medium	High
Ca^{2+} (cmol kg^{-1})	< 2.0	2.0-5.0	> 5.0
Mg^{2+} (cmol kg^{-1})	< 0.3	0.3-1.0	> 1.0
K^+ (cmol kg^{-1})	< 0.15	0.15-0.3	> 0.3
Na^+ (cmol kg^{-1})	< 0.1	0.1-0.3	> 0.3
CEC (cmol kg^{-1})	< 6.0	6.0-12.0	> 12.0
Org. C (g kg^{-1})	< 10.0	10.0-15.0	> 15.0
TN (g kg^{-1})	< 0.1	0.1-0.2	> 0.2
Av. P (mg kg^{-1})	< 10.0	10.0-20.0	> 20.0
BS (%)	< 50.0	50.0-80.0	> 80.0

Cited from Esu (1991)