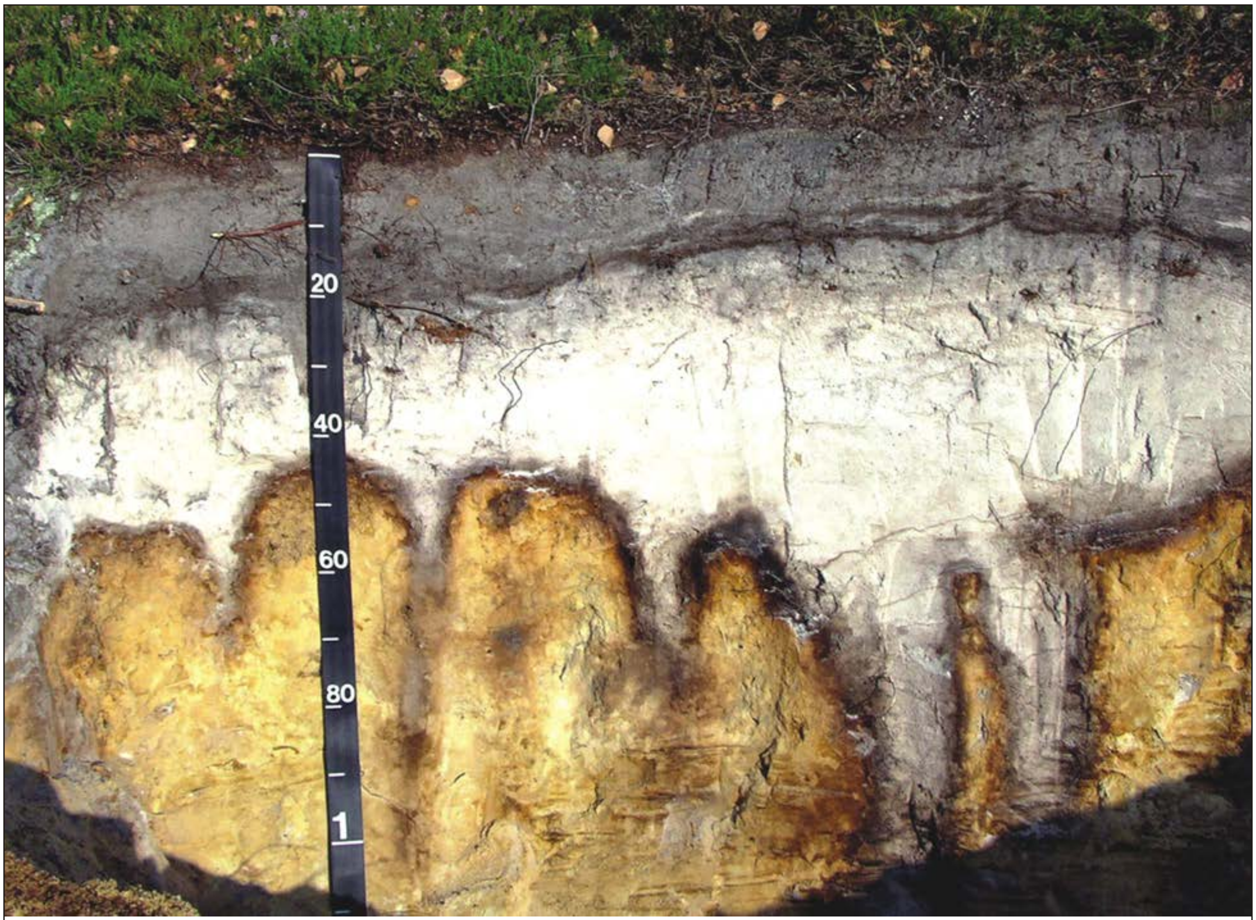

International Journal of
Soil Science

ISSN 1816-4978

Academic
Journals Inc.

www.academicjournals.com

International Journal of Soil Science 1 (3): 171-183, 2006
ISSN 1816-4978

The Extent and Properties of Plinthite in a Landscape at Zaria, Nigeria

[1]D.T. Yaro, [1]T. Kparmwang, [1]B.A. Raji and [2]V.O. Chude
[1]Department of Soil Science, Faculty of Agriculture/Institute for
Agricultural Research, Ahmadu Bello University, Zaria, Nigeria
[2]National Special programme on Food Security/Food and
Agricultural Organization (NSPFS/FAO) Abuja, Nigeria

Abstract: The hardening of plinthite into petroplinthite restricts soil depth. Subsequent exposure of the petroplinthite to the surface through erosion renders the land unusable for agriculture as plant growth is impaired. Topographic survey and soil survey both at a scale of 1:2,000 were carried out in a landscape to determine the extent of plinthite occurrence and to characterize the soils. Four distinct soil units were identified and mapped as soil units A, B, C and D. The soils were characterized in the field and analyzed for their physical and chemical properties in the laboratory and classified. Soil units A, B and C occupying the crystal to lower slope positions in the landscape contained plinthite in the profile, while soil unit D within the valley floor had no plinthite. Soil units A, B and D were deep to very deep (64 to 172 cm deep), while soil unit C ranged from shallow to deep (28 to 145 cm). Plinthite was found at depth range from 68 to 155 cm in soil unit A, 100 to 150 cm in soil unit B and 13 to 43 cm in soil unit C, while soil unit D was almost free of plinthite. The plinthitic soil units (A, B and C) generally had higher gravel and sand, but lower in clay contents than those of non-plinthitic horizons. Soil reaction varied from extremely acid to moderately acid in all soil units $(pH_{(H_2O)}\ 4.2-5.9)$. CEC (NH_4OAc, ECEC and clay) were statistically similar among the soil units. The organic carbon, total N and available phosphorus were lower in the plinthitic horizons than the non-plinthitic horizons. The soil are classified as Typic Plinthustults, Typic Haplustults and Typic Paleustults according to USDA, Soil Taxonomy System and as Plinthic Acrisols, Plinthic Alisols, Haplic Alisols and Haplic Acrisols by the FAO/UNESCO System.

Key words: Plinthite, soil properties, position in a landscape, ironstone, petroplinthite, soil classification

Introduction

Plinthite is a relatively new terminology coined by Soil Survey Staff (1975) to describe soil materials that would later form or develop into ironstone or petroplinthite. It has a verbose definition (Soil Survey Staff, 2003). But is formed mainly from iron (Fe) and to some extent, aluminium (Al) and manganese (Mn) oxides in the B horizons of soils. When formed plinthite is soft; however, when exposed to the surface (through erosion) and/or subjected to alternating wetting and drying conditions, it hardens irreversibly into what is known as ironstone or petroplinthite (Daniels *et al.*, 1978, dos Anjos *et al.*, 1995).

Petroplinthite constitutes a barrier to both water and air movements and root penetration (Carlan *et al.*, 1985; Blume *et al.*, 1987; Stolt *et al.*, 1993). The exposure of plinthite to the surface and

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Corresponding Author: D.T. Yaro, Department of Soil Science, Faculty of Agriculture/Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria

its subsequent hardening into petroplinthite may render the soil anything from very shallow to bare, thus greatly reducing the agricultural value of the land.

Plinthite is reported to develop more commonly in gently sloping to flat lying topography (McFarlane, 1976) and at the foot slopes of landscape (Theng, 1980; Esu *et al*., 1987; dos Anjos *et al*., 1995) which are more suitable for mechanized agriculture. The danger is the long-term reversal of topography as the petroplinthite caps the surface of the flat lying land rendering it almost useless for agriculture (Macleod *et al*., 1971). As erosion undermines the non-plinthitic soil circumventing the petroplinthite cap, eventually producing landforms known as mesas (Higgins, 1961). Mesas are more or less obstacles to agriculture. Even when not converted into petroplinthite, the formation of plinthite depletes the soil of bases (Magnien, 1966; Ibanga, 1980) due to desilication. Thus, plinthitic soils are generally poor in agricultural value.

The problem of rapid decline in agricultural land area and quality posed by plinthite and petroplinthite necessitated the need for information on the extent of plinthite occurrence in the landscape, the physical and chemical properties of the plinthitic soils. These pieces of information will help to develop management strategies for plinthitic soils to reduce their deterioration into agricultural badlands. In Nigeria there are few reports on plinthite (Ibanga, 1980) and its effects on the landscape has not been given much attention despite the apparent problem to agriculture.

The objectives of this study were to determine the extent of plinthite occurrence in the landscape, to determine the physical and chemical properties of the plinthitic soils and to characterize and classify the soils through modal profiles.

Materials and Methods

Site Description

The study site is located at Zaria, Nigeria (Fig. 1) approximately between latitudes 11° 10', 30" and 10° 11' 40" N and longitudes 7° 36', 30" and 7° 38' 6" E at an altitude of 680 m. Plinthite and petroplinthite occur extensively in Zaria in the northern Guinea Savanna zone of Nigeria. The northern

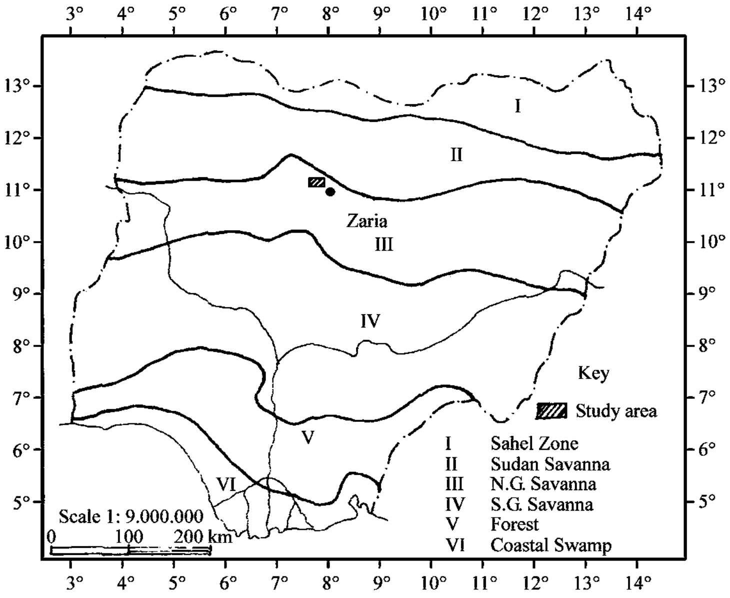


Fig. 1: Location of study area and ecological zones of Nigeria

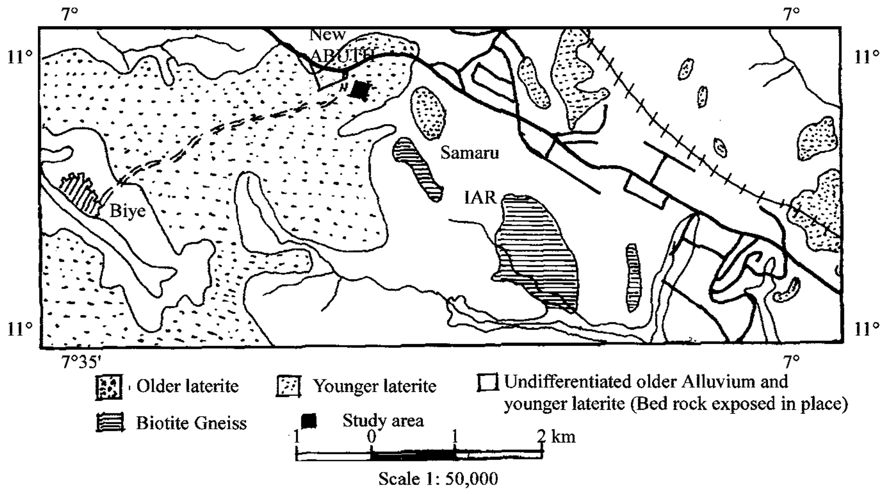


Fig. 2: Geological map of the study area

Guinea savanna zone has a strong seasonal dry and wet cycles. The mean (50 years mean) annual rainfall of the area is about 1060 mm and the length of rainy season ranges from 150-160 days (Kowal and Knabe, 1972). The study was conducted from 2000 to 2002.

The geological map of the study area is shown in Fig. 2. The geology of Zaria area have been studied by Olowu (1967), McCurry (1970), Wright and McCurry (1970). The study area is underlain by a mixture of metamorphic and igneous rocks termed the basement complex, because of their intricate pattern. Two types of laterite/plinthite have been identified in the area, namely: older laterite/plinthite and younger laterite/plinthite. The older laterite/plinthite forms widely spaced ironstone (petroplinthite)-capped mesas around the study area while strips of younger laterite/plinthite sheets are often found along present river valleys and pediment slopes.

The vegetation comprises of an open sub-humid broad leaved savanna woodland with a well developed short to medium grass layer.

Field Work

To achieve the objectives of the study, field studies were concentrated on a sample area located along Zaria-Sokoto road, east of the New Ahmadu Bello University Teaching Hospital, Zaria, Nigeria. The total area of the sample area is about 50 hectares. The field study included topographic survey and a detailed soil survey, both at a scale of 1:2,000. Four distinct soil units were identified and mapped as soil units A, B, C and D. Two profile pits each were dug in soil units A and B, five in soil unit C and three in soil unit D. The morphological characterizations of the soil profiles were also described following the procedure in soil survey manual (Soil Survey Division Staff, 1993). Following their descriptions, bulk soil and plinthite samples from pedogenic horizons were collected in polythene bags for laboratory analysis.

Undisturbed core samples were collected using 100 cm^3 metal cylinders for bulk density, hydraulic conductivity and available water determinations.

Laboratory Analysis

The soil samples were air-dried, crushed and sieved through a 2 mm sieve. The less than 2 mm portion (fine earth separates), were used to carry out the laboratory analysis. Particle size analysis was determined by dispersing the soil samples in 5% calgon (sodium hexametaphosphate) solution, by shaking on a reciprocating shaker for 24 h for proper or complete dispersion of the particles. On dispersion, particle size distribution was determined by the hydrometer method as described by Day (1965).

Bulk density was determined by oven drying the undisturbed core samples to a constant weight at 105°C and dividing the weight of the sample by the total volume of the sample.

$$\text{Bulk density (Db)[mg m}^{-3}] = \frac{\text{Weight of oven dry soil (mg)}}{\text{Volume of soil (m}^{-3})}$$

Available water capacity was calculated mathematically from the differences between moisture held at field capacity (10 and 30 kPa) and at permanent wilting point (1500 kPa) using the formula proposed by FAO (1979) as follows:

$$\text{AW} = (\text{WFC-WPwp}/100)\times\text{Db}/\text{Dw}\times\text{Depth}$$

where,

Dw = Available water in cm
WFC = Water at field capacity (percentage dry weight basis)
Wpwp = Water at permanent wilting points (percentage dry weight basis)
Db = Bulk density of soil Mg m^{-3}
Dw = Density of water in Mg m^{-3}
Depth = Depth of soil in cm.

Water held at field capacity and permanent wilting points were determined as described by Anderson and Ingram (1993). Hydraulic conductivity was determined with the undisturbed core samples by the constant head method (Anderson and Ingram, 1993).

Soil pH was determined in 1:2 soil to solution ratio. The exchangeable bases were extracted with neutral (pH 7.0) ammonium acetate (NH_4OAc) solution. Potassium and sodium were determined in the extract by flame photometry, while calcium and magnesium were determined by the atomic absorption spectrophotometry. Exchangeable acidity ($H^+ + Al^+$) was extracted by leaching the soils with 1 M KCl solution. Exchangeable acidity was determined by titrating the leachate with standard sodium hydroxide (NaOH) solution. Cation Exchange Capacity (CEC) was determined by the neutral (pH 7.0) NH_4OAc saturation method (Anderson and Ingram, 1993). The cation exchange capacity of the clay fraction was calculated using the method proposed by Sombroek and Zonneveld (1971) as follows:

$$\text{CEC}_{(\text{clay})} = \frac{\text{CEC NH}_4\text{OAc} - (3.5\times\%\text{OC})\times 100}{\%\text{clay}}$$

Percentage Base Saturation was calculated using the formula:

$$\%\text{Base saturation} = \frac{\text{Total exchangeable bases}\times 100}{\text{CEC}}$$

Organic Carbon (OC) was determined by acid-dichromate wet oxidation method of Walkley and Black as described by Nelson and Sommers (1982).

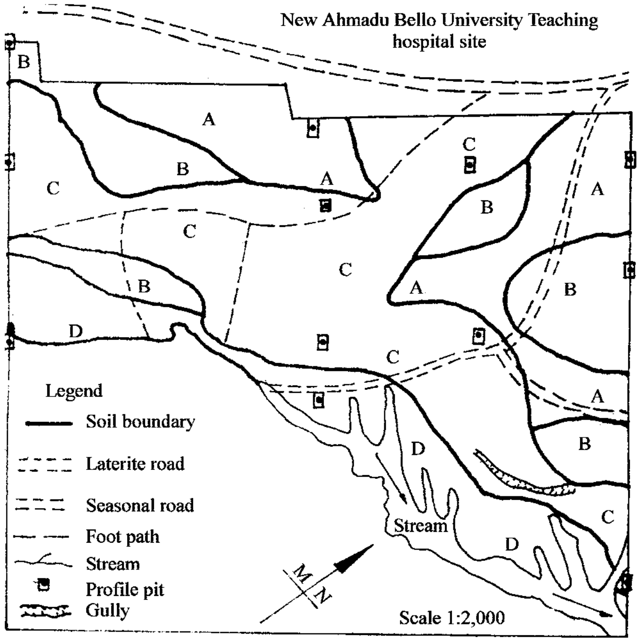
Available phosphorus (P) was extracted by the Bray No. 1 method (Bray and Kurtz, 1945) and P, in solution, determined calorimetrically by the ascorbic acid method (Murphy and Riley, 1962). Total N was determined by the Micro-Kjeldahl technique (Bremner, 1965).

The soils were classified using the USDA, Soil Taxonomy System (Soil Survey Staff, 1999) and Soil Map of the World Legend (FAO/UNESCO, 1988).

Results and Discussion

Soil Morphological Properties

The detailed soil map of the area is shown in Fig. 2 and 3. Four distinct soil units were identified. Soil units A and B occupy the crystal to upper slope positions, soil unit C, stretches from crystal to lower slope positions, while soil unit D occupies the valley floor position. Soil units A, B and D were deep to very deep (64 to 172 cm deep), whereas soil unit C ranged from very shallow to deep (28 to 145 cm). The depth of soil unit C was restricted by ironpan (petroplinthite or indurated plinthite).



Soil unit	Landorm	Major soil characteristics
A	Crest to Upper 0-2% slope	Deep, well drained, dark brown (7.5YR4/4 clay loam to loam over yellowish red (5YR5/8) to red (2.5YR4/8) clay loam, weak to moderate coarse subangular blocky structure, few scattered termiteria, plinthite as from 68-73 to 152-155 cm depths
B	Crest to Upper slope 0-2% slope	Deep to moderately deep, well drained, dark brown (7.5YR4/4) to strong brown (7.5 YR 5/6) slightly gravelly clay loam to clay loam, weak coarse subangular blocky structure, plinthite as from 20-52 to 64-150 cm depths
C	Crest to lower slope 2-7% slope	Shallow to deep, well drained dark brown (7.5YR4/4) to dark yellowish brown (10YR 4/4) gravelly loam over reddish yellow (5YR6/8) to yellowish red (5 YR4/4) gravelly sandy clay loam to clay loam, weak to moderate coarse subangular blocky structure, few scattered termiteria, many iron/manganese concretions, Plinthite from 13-26 to 19-54 cm
D	Valley floor 2-4% slope	Deep, Moderately well drained to well drained, dark yellowish brown (10 YR 4/4) to dark brown (7.5 YR 4/4 loam over strong brown (7.5 YR 5/8) to reddish yellow (7.5 YR 7/6) clay loam, weak coarse to thick subangular blocky, structure, no plinthite in this profile.

Fig. 3: Soil map of the project site

Table 1: Morphological properties of pedons of a plinthitic landscape at Zaria

Profile	Horizon	Depth (cm)	Colour (moist)	Texture	Structure	Boundary	Other features
Soil unit D (Crest to upper slope)							
A-1	Ap	0-11	7.5YR 4/4	GSCL	1csbk	cs	-
	Bt1	11-46	5YR 5/8	CL	Om	ds	Few medium hard iron nodules
	Bt2	46-68	5yr 5/8	CL	1csbk	cs	-
	Btcv1	68-100	2.5YR 4/8	VGCL	Om	gs	Many medium iron nodules with quartz grains common weathered granitic rocks.
	Btcv2	100-150	2.5YR 4/8	VGCL	Om	-	Common fine iron nodules with quartz grains.
A-2	Ap	0-21	7.5YR 4/4	L	2 csbk	cs	Common fine iron nodules
	Bt1	21-73	2.5YR 4/8	CL	1msbk	ds	Common fine iron nodules
	Bt2	73-122	2.5YR 4/8	GCL	1msbk	cs	Common fine iron nodules
	Bv	122-152	2.5YR 4/8	SCL	1msbk	-	Common fine iron and manganese nodules
Soil unit B (Crest to upper slope)							
B-3	Ap	0-10	7.5YR 4/4	Ll	1csbk	cs	-
	BA	10-20	7YR 5/8	GCL	1csbk	cs	Common medium iron nodules
	Btc1	20-45	5YR 5/8	EGCL	Om	gs	Common medium iron nodules
	Btc2	45-64	5YR 5/8	VGSCL	Om	-	Common medium iron nodules
B-4	Ap	0-15	7.5YR 5/6	L	1csbk	cs	Common fine iron nodules
	Bt1	15-59	2.5YR 5/8	CL	1csbk	gs	Few fine hard iron nodules
	Bt2	59-100	2.5YR 5/8	CL	1csbk	cs	Common fine iron nodules
	Btv	100-150	2.5YR 5/8	SCL	1csbk	-	Many medium iron and manganese nodules
Soil unit C (Crest to lower slope)							
C-5	Ap	0-10	7.5YR 4/4	L	1csbk	cs	Common fine iron nodules
	Bt1	10-26	5YR 6/8	CL	1csbk	cw	Common medium iron (Fe) and manganese (Mn) nodules
	Btc	26-43	5YR 6/8	EGL	Om	-	Common medium iron and manganese nodules
C-6	Ap	0-13	7.5YR 4/4	GL	1csbk	cs	Common medium iron and manganese nodules
	Btc	13-28	2.57R 4/8	VGL	Om	-	Common medium Fe and Mn nodules
C-7	Ap	0-19	7.5YR 4/4	SiL	2 csbk	cs	-
	Btv	19-94	57R 6/8	SCL	2csbk	-	-
C-8	Ap	0-16	10YR 4/4	L	2csbk	cs	Common fine iron and manganese nodules
	B1	16-39	5YR 4/8	L	2msbk	cs	Common fine iron and manganese nodules
	Bt1	39-85	2.5YR 5/8	CL	1csbk	ds	Common fine iron and manganese nodules
	Bt2	85-145	10YR 8/2	C	Om	-	Common fine iron and manganese nodules Mottled, 10YR 7/8 AND 5YR 6/8.
Soil unit D (Valley floor)							
D-10	Ap	0-13	10YR 4/4	L	1csbk	cs	-
	Bt1	13-48	7.5YR 5/8	CL	1csbk	gs	Common fine iron nodules
	Bt2	48-91	10YR 5/8	L	Om	cs	Common fine iron nodules, mottled, 5YR 4/8
	Btg1	41-140	10YR 6/2	L	Om	ds	Mottled, 7.5YR 6/8
	Btg2	140-172	10YR 7/2	CL	1vcsbk	-	Mottled, 2.5YR 4/8
D-11	Ap	0-16	10YR 4/4	L	1csbk	cs	Common fine iron nodules
	BA	16-37	7.5YR 5/8 and 10YR 6/2	L	1csbk	cs	Common fine iron nodules
	Bt1	3763	7.5YR 5/8	L	2csbk	cs	Common fine iron nodules
	Bt2	63-84	7.5YR 5/6	L	2csbk	cs	Common fine iron nodules
	Btg1	84-163	10YR 6/2	L	Om	-	Mottled, 2.5YR 3/6
D-12	Ap	0-16	7.5YR 4/4	L	1csbk	cs	-
	B1	16-38	7.5YR 7/6	CL	1csbk	gs	
	B2	38-72	7.5YR 5/8	CL	1csbk	gs	
	B3	72-117	7.5YR 7/4 and 10YR 7/3	CL	1csbk	gs	Mottled, 7.5YR 5/8
	B4	117-150	7.5YR 7/4	CL	1csbk	-	Mottled, 2.5YR 4/8

*Horizon designations and observations as used in Soil Survey Staff (1951). The meaning of the observation used are: L = Loam; GL-Gravelly Loam; VGL = Very Gravelly Loam, EGL = Extremely Gravelly Loam; SiL = Silt Loam; GCL = Gravelly Clay Loam; VGCL = Very Gravelly Clay Loam; EGCL = Extremely Gravelly Clay Loam; SCL = Sandy Clay Loam; GSCL = Gravelly Sandy Clay Loam; VGSCL = Very Gravelly Sandy Clay Loam; Om = Structureless massive; 1csbk = Weak coarse subangular blocky; 1vcsbk = Weak very coarse subangular blocky; 1msbk = weak medium subangular blocky; 2csbk = moderate coarse subangular blocky; 2msbk = Moderate medium subangular blocky; as = abrupt, smooth; cs = Clear, smooth; gs = gradual, smooth; ds = diffuse, smooth; CW = clear Wavy

Depth to plinthite range from 68 to 155 cm in soil unit A and 100 to 150 cm in soil unit B and 13 to 43 cm in soil unit C. Soil unit D was almost free of plinthite. Plinthite therefore, extended in the landscape from crystal to lower slope position.

The soils had mostly subangular blocky structure, with the plinthitic horizons having massive structure (Table 1). The massive structure of the plinthitic horizons could be as a result of strong aggregation by Fe and/or Mn oxides and silica which serve as cementing agents (Alexander and Cady, 1962). Iron nodules were almost absent in the Ap horizons of pedon A-1, B-3 and in soil unit D, but were present up to the Ap horizons of pedons, A-2, B-4 and soil unit C. This confirmed the presence of plinthite in soil unit C which is evident by the exposure already of ironpan at the surface. The plinthitic horizons of pedon A-2, B-4 and soil unit C had both iron and manganese nodules, indicating that plinthite is high in those plant essential nutrients as reported by (Aide *et al*., 2004; Yaro, 2005).

Particle Size Distribution of Soil

The plinthitic soil units (A, B and C) generally have higher gravel than the non-plinthitic soil unit D. The plinthitic (Btcv and Btc) horizons had higher sand and lower clay contents (Table 2). They had the highest bulk densities up to 1.76 mg m^{-3}, in conformity with the results of other workers (Daniels *et al*., 1978; Perkins and Kaihula, 1981; Carlan *et al*., 1985; Shaw *et al*., 1997) and lower saturated hydraulic conductivity (k_{sat}) due to their high bulk density and low total porosity. The plinthitic horizons also had lower available water (8.7%) compare to the non-plinthitic Bt1 horizon (15.8%) which indicated that plinthite restricts vertical water flow and induce lateral flow along the landscape (Bosch *et al*., 1994).

Table 2: Physical properties of selected pedons of a plinthitic landscape at Zaria

Horizon	Depth (cm)	Gravel >2 mm	Sand 200-50 (μm)	Silt 50-2 μm	Clay <2 (μm)	Silt/clay ratio	Bulk density (pb) Mg/m^3	K_{sat} cm min^{-1}	Avail. H_2O (%)
		%							
Soil unit A: Profile A-1									
Ap	0-11	15	50	24	26	0.92	1.51	24.44	8.8
Bt1	11-46	0	28	34	38	0.89	1.59	2.33	15.8
Bt2	46-68	0	26	34	40	0.85	1.60	30.81	4.7
Btcv1	68-100	54	42	24	34	0.71	1.76	15.77	5.7
Btcv2	100-155	50	52	22	26	0.89	1.51	9.47	9.3
Mean		24	40	28	33	0.84	1.59	16.54	8.9
Soil unit B: Profile B-3									
Ap	0-10	8	50	34	16	2.13	1.46	40.12	5.2
BA	10-20	17	30	40	30	1.33	1.57	14.00	16.6
Btc1	2045	75	40	30	30	1.00	1.72	25.08	14.3
Btc2	45-64	58	50	22	28	0.79	1.62	26.81	9.4
Mean		40	43	32	26	1.31	1.59	26.50	11.4
Soil unit C: Profile C-5									
Ap	0-10	0	32	48	20	2.40	ND	ND	ND
Bt1	10-26	4	22	44	34	1.29	ND	ND	ND
Btc	26-43	7	46	30	24	1.25	ND	ND	ND
Mean		26	33	41	26	1.65	ND	ND	ND
Soil unit D: Profile D-10									
Ap	0-13	0	34	48	18	2.67	1.49	5.50	5.2
Bt1	13-48	0	24	48	28	1.71	1.46	4.96	4.4
Bt2	48-91	4	36	38	26	1.46	1.63	15.65	10.8
Btg1	91-140	0	38	38	24	1.58	1.59	32.32	10.7
Btg2	140-172	0	32	36	32	1.13	1.71	51.89	8.8
Mean		0.8	33	42	26	1.71	1.58	22.06	8.0

*ND = Not Determined. The bulk density, hydraulic conductivity and available water in soil unit C could not be determined because of the already exposed ironpan at the surface which made core sampling difficult

Chemical Properties of Soil

Soil reaction varied from extremely acid to moderately acid in all soil units (Table 3). The dominant basic cations are calcium (Ca) and magnesium (Mg) followed by potassium (K) and sodium (Na). In most cases the plinthic horizons have lower total exchangeable bases than the non-plinthitic horizons. This result agrees with those of other workers elsewhere (Ahmed and Jones, 1969a, b; Pettry and Elder, 1970) who showed that plinthitic soils had lower exchangeable bases than the non-plinthitic soils. The CEC (NH_4OAc, ECEC and CEC-Clay) did not differ significantly among the soil units. The percentage base saturation of the plinthitic soil units (A, B and C) ranged from very low to very high (11-100%) while those of the nonplinthitic soil unit D ranged from very low to moderate. The base saturation was generally lower in the plinthitic horizon (except Btcv1 and Bv1 horizons in soil units A-1 and C-5, respectively) than the non-plinthitic horizons. Low base saturation of less than 15% has been reported in plinthitic soils (Mosugu, 1989; Kparmwang, 1993; Aide *et al*., 2004).

The Organic Carbon (OC) contents of the soils decreased with increase in depth in all the soil units. The surface soil values were generally rated low, whereas the subsoil was rated very low to low in all the soil units. The plinthitic horizons contained lower organic carbon than the nonplinthitic horizons. The mean value of total nitrogen for soil units A and C, were significantly ($p = 0.05$) higher than soil unit D. Plinthitic horizons generally have lower total N than the nonplinthitic soils. The values are similar to values reported by Ahmad and Jones (1969a) and Oikeh *et al*. (1999) for plinthitic soils. Available phosphorus generally decreased with increase in depth. The surface soils have higher available P than the subsoil. The distribution of available P follows the same trend with the organic carbon and total N in the soil, suggesting that these nutrients could be derived in the soil and its positive correlation ($p = 0.05$) with organic carbon ($r = 0.598^{**}$); confirms that organic matter is a source of P in these soils. The plinthitic horizons have lower available P than the nonplinthitic horizons. This confirms that plinthites are low in plant nutrients as reported by Ahmad and Jones (1969a).

Soil Classification

By the USDA soil Taxonomy System (Soil Survey Staff, 1999, 2003), all pedons in soil units A, B, C and D classified at the order level as Ultisols. This is because they have an Ochric epipedon, an argillic horizon and low base saturation percentage (35% or less) by sum of cations throughout or in the major part of the argillic horizons).

At the suborder level, all pedons are classified as Ustults, because they have ustic moisture regime. At the great group level, since pedons A-1, A-2, B-4, C-5, C-6, C-7 and C-9 have plinthite that formed a continuous phase or constitute one half or more of the value of some sub-horizons within 150 cm of the soil surface, they are therefore classified as plinthustults. Pedon B-3 of soil unit B, on the other hand is classified as Haplustults at the great group level, because it has colour value of 4 or more moist, in the epipedon and an argillic horizon that have a colour with hue less red than 2.5YR and

Table 3: Soil chemical properties of pedons of a plinthitic landscape at Zaria

			Exchangeable bases					CEC					
			Ca	Mg	K	Na	Total	NH_4OAc	Clay	Base saturation NH_4OAc	Org C	Total N	Avail. P
Horizon	Depth (cm)	pH (H_2O)	$cmol_{(+)}\ kg^{-1}$							(%)	$g\ kg^{-1}$		$mg\ kg^{-1}$
Soil Unit A													
Profile A-1													
Ap	0-11	5.5	1.75	0.29	0.20	0.05	2.29	4.38	4.73	52	9.00	0.35	20.63
Bt1	11-46	5.5	1.25	1.25	0.13	0.07	2.70	5.63	12.05	48	3.00	0.18	0.79
Bt2	46-68	4.5	1.62	1.14	0.14	0.09	2.99	8.13	18.40	37	2.20	0.18	0.72
Btcv1	68-100	4.4	1.75	1.04	0.21	0.12	3.12	3.13	7.56	100	1.60	0.18	0.36
Btcv2	100-155	4.4	9.62	9.83	0.19	0.09	1.73	9.38	34.19	18		0.18	0.14

Table 3: Continued

			Exchangeable bases					CEC					
			Ca	Mg	K	Na	Total	NH$_4$OAc	Clay	Base saturation NH$_4$OAc	Org C	Total N	Avail. P
Horizon	Depth (cm)	pH (H$_2$O)	cmol$_{(c)}$ kg^{-1}							(%)	g kg^{-1}		mg kg^{-1}
Profile A-2													
Ap	0-21	5.8	1.87	1.17	0.38	0.05	3.47	8.75	33.83	40	7.60	0.88	2.56
Bt1	21-73	5.9	1.67	1.42	1.06	0.05	4.15	6.25	13.00	66	3.00	0.88	0.28
Bt2	73-122	4.9	1.37	1.56	0.29	0.05	3.27	8.75	21.74	37	1.40	1.23	0.28
Bv	122-152	4.8	0.75	1.04	0.18	0.05	2.02	10.63	39.54	19	1.00	1.23	0.14
Mean		5.1	1.40	1.08	0.31	0.07	2.86	7.23	20.56	46	3.36	0.59	2.88
Soil unit B													
Profile B-3													
Ap	0-10	5.7	2.37	0.71	0.30	0.07	3.95	6.88	24.19	57	8.60	0.35	15.19
BA	10-20	5.2	2.37	0.75	0.21	0.10	3.43	6.88	12.13	50	5.60	0.18	1.56
Btc1	20-45	4.9	1.87	0.64	0.17	0.04	2.72	10.00	27.50	27	5.00	0.35	0.57
Btc2	45-64	5.0	1.25	0.83	0.15	0.04	2.27	8.75	27.75	26	2.80	0.18	0.18
Profile B-4													
Ap	0-15	5.6	0.62	0.54	0.20	0.07	1.43	12.50	68.96	11	4.19	0.53	0.21
Bt1	15-59	5.2	1.12	0.99	0.27	0.05	2.43	4.38	7.63	55	3.79	0.35	0.07
Bt2	59-100	4.9	1.50	2.08	0.38	0.09	4.05	8.13	20.11	50	1.40	0.18	0.07
Btv	100-150	4.3	0.50	0.71	0.34	0.12	1.67	8.13	29.38	21	1.40	0.35	5.32
Mean		5.1	1.51	0.91	0.25	0.07	2.74	8.21	27.21	37	4.10	0.31	2.90
Soil Unit C													
Profile C-5													
Ap	0-10	5.2	3.24	0.67	0.16	0.05	4.12	10.00	33.55	41	9.40	0.70	10.14
Bt1	10-26	4.4	1.25	0.42	0.42	0.15	1.87	10.00	23.65	19	5.60	0.53	2.10
Btc	26-43	4.4	0.87	0.27	0.27	0.17	1.38	9.38	32.96	15	4.20	0.35	1.44
Profile C-6													
Ap	0-13	5.1	1.00	0.48	0.18	0.07	1.73	7.50	33.75	23	6.00	0.88	24.44
Btc	13-28	4.8	1.50	0.60	0.13	0.05	2.28	5.63	17.00	40	5.40	0.88	0.72
Profile C-7													
Ap	0-19	5.0	1.87	0.96	0.37	0.04	3.24	7.51	23.79	43	9.20	0.26	6.15
Btv	19-54	4.3	0.62	0.62	0.21	0.05	1.30	6.88	19.43	19	3.00	0.88	8.94
Profile C-8													
Ap	0-16	5.1	2.74	0.88	0.34	0.05	4.01	8.88	21.56	58	9.80	0.70	4.43
B1	16-39	4.5	2.00	1.04	0.14	0.04	3.22	9.38	32.85	34	2.40	0.35	1.07
Bt1	39-85	4.7	2.74	1.25	0.16	0.07	4.22	8.75	22.94	48	1.40	0.18	1.26
Bt2	39-85	5.2	5.00	2.49	0.35	0.09	7.93	11.25	24.00	70	0.60	0.18	0.36
Profile C-9													
Ap	0-14	4.6	1.62	0.67	0.25	0.09	2.63	7.50	25.95	35	6.60	0.53	6.91
Btc	14-59	4.3	0.75	0.24	0.19	0.07	1.25	8.75	27.25	14	3.20	0.53	1.81
Mean		4.7	1.94	0.80	0.22	0.06	3.01	8.41	26.05	35	5.14	0.54	5.37
Soil Unit D													
Profile D-10													
Ap	0-13	4.9	0.37	0.60	0.27	0.05	1.29	9.38	43.94	14	4.20	0.35	2.75
Bt1	13-48	4.3	0.37	0.42	0.17	0.05	1.01	4.38	10.89	23	3.80	0.35	1.36
Bt2	48-91	4.0	0.25	0.42	0.12	0.04	0.83	6.25	21.08	13	2.20	0.18	0.54
Btg1	91-140	4.3	0.87	0.21	0.17	0.05	1.30	9.38	37.04	14	1.40	0.18	0.42
Btg2	140-172	4.0	0.50	0.27	0.18	0.07	1.02	5.63	16.06	18	1.40	0.18	0.36
Profile D-11													
Ap	0-16	4.6	0.87	0.54	0.18	0.05	1.64	8.76	40.06	19	4.40	1.05	6.91
BA	16-37	5.3	1.87	1.04	0.11	0.05	3.07	6.88	24.88	45	2.60	0.53	0.36
Bt1	37-63	5.3	1.75	0.83	0.10	0.04	2.72	6.88	25.17	40	2.40	0.35	0.28
Bt2	63-84	4.6	0.75	0.71	0.13	0.07	1.66	8.13	35.36	20	1.00	0.35	0.07
Btg	84-163	4.7	2.37	1.25	0.23	0.15	4.00	7.50	30.67	53	0.40	0.35	2.18
Profile D-12													
Ap	0-16	5.3	1.62	0.67	0.29	0.04	2.67	16.25	112.67	16	7.80	0.88	4.51
B1	16-38	5.3	1.50	0.96	0.15	0.05	2.66	6.88	23.07	39	1.20	0.18	1.07
B2	38-72	4.8	0.78	0.88	0.15	0.05	1.83	7.50	24.53	24	0.40	0.35	0.36
B3	72-117	4.3	1.12	0.88	0.21	0.05	2.26	8.13	21.42	28	1.20	0.35	0.21
B4	117-150	4.2	1.12	0.83	0.23	0.05	2.23	10.63	28.56	21	1.00	0.18	0.54
Mean		4.7	1.07	0.70	0.18	0.06	2.01	8.17	31.96	26	2.63	0.39	1.46

a value of 5 or more, dry. Pedons C-8 in soil unit C, D-10, D-11 and D-12 in soil unit D are classified as Paleustults at the great group level, because they do not have a clay decrease with increasing depth of 20% or more (relative) from the maximum clay content within the depth of 150 cm from the soil surface.

At the subgroup level, since pedons A-1, A-2, B-4, C-5, C-6, C-7 and C-9 have a clay distribution in which the percentage of clay does not decrease from its maximum amount by as much as 20% within a depth of 150 cm from the mineral soil surface. They are classified as Typic Plinthustults (Soil Survey Staff, 2003). Pedon B-3 is classified as Typic Haplustults at the subgroup level because it does not posses any of the special features that distinguish Haplustults from other subgroups. Pedons C-8, D-10, D-11 and D-12 are classified as Typic Paleustult at the subgroup level, because they did not possess any of the special features that distinguish Haplustults from other subgroups.

At the family level, all pedons A-1, A-2, B-4, C-5, C-6, C-7 and C-9 are classified as Typic Plinthustults, coarse loamy, kaolinitic, isohyperthermic, because the particle size class in the control section is loamy and the mineralogy is kaolinitic with an isohyperthermic soil temperature regime. Pedon B-3 is classified as Typic Haplustults, coarse loamy, kaolinitic isohyperthermic, because it has mostly gravelly sandy clay loam particle size class with kaolinitic mineralogy in the control section and isohyperthermic soil temperature. Pedons C-8, D-10, D-11 and D-12 are classified as Typic Paleustults, fine loamy, kaolinitic isohyperthermic, because they have loamy, particle size class in the control section with kaolinitic mineralogy and isohyperthermic soil temperature regime.

Using the FAO/UNESCO soil map of the World Legend (1974, 1988), pedons A-1 in soil unit A, B-4 in soil unit B; C-6 and C-7 in soil unit C are classified as Acrisols. These are soils with argic B horizons which had CEC of the clay fraction less than 24 $\text{cmol}_{(+)}\,\text{kg}^{-1}$ 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. The argic B horizons is a new terminology in the 1988 legend which replaces the argillic horizons but had modification of definition to permit easier field identification which is used to be a problem with the argillic horizon. In particular it gives a distinct textural differentiation even when clay skins cannot be identified, while clay accumulation which may occur in Ferrasols is excluded from the argillic B horizons on account of the low CEC, low content of water-dispersible clay and low silt-clay ratio (FAO-UNESCO, 1988). At the second level, pedons A-1, B-4, C-6 and C-7 are classified as plinthic Acrisols (Table 4), because they had plinthite within 125 cm of the surface parts of the B horizons within 125 cm of the surface. At the second level, A-2, C-5 and C-9 are classified as plinthitic Acrisols, because they had plinthite within 125 cm of the surface, while pedons B-3, C-8 and all pedons in soil unit D are classified at the second level as Haplic Alisols, because they had simple profiles, i.e., with no special features.

Table 4: Summaries of classification of soils of a plinthitic landscape at Zaria

Soil unit	Pedon	USDA system	FAO/UNESCO system
A	A-1	Typic Plinthustults, coarse loamy kaolinitic, isohyperthermic	Plinthitic acrisols
	A-2	Typic Plinthustults, coarse loamy kaolinitic, isohyperthermic	Plinthitic alisols
B	B-3	Typic Haplustults, coarse loamy, kaolinitic, isohyperthermic	Haplic alisols
	B-4	Typic Plinthustults, coarse loamy kaolinitic isohyperthermic	Plinthitic acrisols
C	C-5	Typic Plinthustults, coarse loamy kaolinitic, isohyperthermic	Plinthitic alisols
	C-6	Typic Plinthustults, coarse loamy, kaolinitic, isohyperthermic	Plinthitic acrisols
	C-7	Typic Plinthustults, coarse loamy kaolinitic, isohyperthermic	Haplic acrisols
	C-8	Typic Paleustults fine loamy, kaolinitic isohyperthermic	Haplic alisols
	C-9	Typic Plinthustults, coarse loamy kaolinitic isohyperthermic	Plinthitic alisols
D	D-10	Typic Paleustults, fine loamy, kaolinitic isohyperthermic	Haplic alisols
	D-11	Typic Paleustults, fine loamy kaolinitic isohyperthermic	Haplic alisols
	D-12	Typic Paleustults, fine loamy kaolinitic isohyperthermic	Haplic alisols

Conclusions

Soil units A and B occupied crystal to upper slope positions and they are generally deep, that is greater than 150 cm depth. Plinthite was found at depth range from 68 to 155 cm in soil unit A and 100 to 150 cm depth for soil unit B. Soil unit C is located in crystal to lower slope position and the soil depths were restricted by ironpan and plinthite from 13 to 43 cm. Soil unit D which occupied the valley floor position had the deepest soil; almost free of plinthite. The extent of plinthite occurrence in the landscape is from crystal to lower slope position. The common constraints of agricultural productivity of the plinthitic soils are low contents of organic matter, total N, available P, infiltration rates and high bulk densities and shallow depth with petroplinthite at the surface in some cases especially soil unit C. Thus for optimum agricultural productivity, the soils would need full recommended rates of N and P from inorganic fertilizers. Incorporation of crop residues and application of organic manure will also help improve soil physical and chemical properties which will increase the productivity of the soils.

In the soil units where plinthite and petroplinthite are close to the surface like in soil unit C (13-43 cm depth), growing pasture or forestry would be the best option as the soil unit is not good for arable cropping/agriculture. The hard ironstone can also be quarried and used for buildings or road constructions.

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