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# Land Use limitations and management option for a Savanna Zone Alfisol

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*Abstract*: A 50 by 50 m rigid grid survey of part of the Institute For Agricultural Research (IAR) farm in Zaria (11° 10'N and 7°35'E) was carried out to characterize the morphological, physical and chemical properties of soils at the site. Quick crosschecks in areas outside the rigid grid but having seemingly varying soil units was also studied in the field. Two soil units ('Oxyaquic Vertic Paleustalfs / Gleyic Lixisol' and 'Aquic Kandiustalfs / Gleyic Lixisols') were delineated.

Soil samples were obtained from identified horizons of each pedon, air dried, sieved through 2.0mm sieve to obtain sub samples less than 2.0mm for laboratory analysis. Results obtained showed soils of the 'Oxyaquic Vertic Paleustalfs / Gleyic Lixisol' to have within its subsoil 'Argillic' pedogénetic features, mottling and 'Gleyic' properties, and no subsoil acidity problems.

The subsoil has increasing clay with depth, and temporary stagnation of water. Soil condition in this unit would however be improved for sustainable crop production by liming and /or incorporation of farmyard manure, contour ridging and construction of field drainage ditches to conduct excess field and subsoil stagnated water away from the fields. Soils of the 'Aquic Kandiustalfs / Gleyic Lixisols' have 'Kandic' subsoil properties, 'Gleyic' and mottled subsoil horizons at shallow depths to the surface horizons, and exchange acidity ($H^{+}+Al^{3+}$) values ranging between 0.6 and 1.4 cmolkg $^{-1}$, suggesting acid soil problem in this unit. Also, extractable Zn values were very high and could adversely affect growth and production of crops. This problem would be corrected by liming, adequate drainage to remove stagnating subsoil and excess field water, and incorporation of farmyard manure to enhance the soils' nutrient availability/exchange capacity, control soil acidity build up and improve aeration conditions in the plow layer.

*Keywords: soil limitations, sub soil drainage, soil and water conservation*

## Introduction

Following bleached leaves and reports of reduced yield of legume crops planted in parts of the Institute For Agricultural Research Farm, Zaria (11° 10'N and 7° 35'E), farm in 2002, it became necessary to undertake a soil study with a view to find out causative problems responsible for this identified problem. Also, this was aimed at understanding the inherent qualities and land use limitations of the soils. A detailed survey of the trial field was therefore commissioned in 2003 with the following objectives.

- To determine morphological properties of the soils;
- To determine physicochemical properties of the soil;
- To determine land use limitations of the study area.

## Materials and Methods

Field Plan

The study was carried out in plots V (6.0 ha) located at the Institute For Agricultural Research Zaria (11° 10'N and 7°35'E), along Samaru-Shika road, in the Northern Guinea Savanna (NGS) zone of Nigeria. The fields were used for legumes and maize cultivation in 1995-2003.This study followed rigid grid pattern with 50m inter-traverse and 50m inter-auger point intervals. The baseline was on the Northeast direction, and for a distance of 200.0 m, giving a total of five (5) traverses (0,50, 100, 150, & 200 m lines). Each traverse distance was 100.0 m long, and gave three auger points per traverse (0,50, 100 m points).

However, quick crosschecks were conducted on areas where a seemingly different soil unit occurred. Four profile pits were sunk; two for each unit, and studied in detail to characterize morphologically and physicochemical properties of identified soil units. This study resulted in the delineation of two soil units (Units 1 & 2). Profiles for pedon/Unit 1 were located at 11° 10.798' North, and 7° 37.415' East, with an elevation of 2248 m above sea level; and 11° 8'North and 7° 37.417' East with elevation of 2255m above sea level. Soil Unit 2 profiles were located at 11° 10.77'North, and 7° 37.389' East, with elevation of 2233 m above sea level; and 11° 10.772'North, and 7° 37.417' East, with elevation of 2251 m above sea level.

Field and profile locations were determined by use of a 'Geographical Positioning Systems' instrument (GPS).

Soil Sampling

Composite soil samples were obtained from identified horizons in each profile pit, and described in the moist state of their full range of morphological characteristics. Moist soil colour was determined using the Munsell colour chart 2000 edition. Soil description followed the pattern described in the Soil Survey Manual (Soil Survey Staff, 1951) except that the horizons' designations were those of the reversed version of May 1981 (Guthrie and Witty, 1982) and updated by Soil Survey Staff (USDA, 1999).

*Laboratory Studies*

Soil samples were air-dried, ground and sieved to remove materials greater than 2.Omm in diameter. The samples less than 2.0 mm in diameter were then analyzed for pH, particle-size distribution, organic carbon, total nitrogen, available phosphorus, exchange acidity ($H^+$ + $AL^{3+}$), exchangeable cations, (Ca, Mg, K, & Na), and Cation exchange capacity (CEC by 1N $NH_4OAC$ at pH 7 method). Micronutrient content of the soils (B, Fe, Mn, and Zn) were also investigated following methods described in Juo (1979), and Page *et. al.* (1982).

**Results and Discussion**

Soil Morphological Properties

*Soils of Unit 1: Oxyaquic vertic paleustalfs*

Soils of Unit 1 have Ap horizons ranging from 0 to 23 cm (Table 1). They also have increasing clay with increase in profile depths that is diagnostic of 'argillic' subsurface pedogenesis. The soils were generally loam in texture at the Ap and AB horizons, and clay loam and clay in the subsoil horizons. Unit 1 soils were located at lower slope positions that are gently slopping (2-4 %) and were moderately well drained, have moist colour of brown (l0YR 4/3) and Yellowish brown (10YR 5/4) at the surface horizon. The surface soils were weak, medium, sub angular blocky in structure; and had few Fe & Mn oxides nodules and concretions. The subsoil Bt horizons had moist colour of very pale brown (10YR7/3), grayish brown (10YR5/2), and light gray (10YR7/2). They were also mottled at these depth with strong brown (7.5YR5/6), Yellowish red (5YR4/6), red (2.5YR4/8) and Yellowish brown (10YR5/6). Mottles were many, medium,

*Table 1 – Field morphological description and classification of Soil units Sampled*

| Horizon | Depth (Cm) | Munsell color (Moist) | Mottles | Texture | Structure | Consisten | Boundary | Remarks |
|---|---|---|---|---|---|---|---|---|
| Unit 1: Oxyaquic Vertic Paleustalf/Gleyic lixisols (USDA soil Taxonomy/FAO -UNESCO Legend); Profiles 2&4) | | | | | | | | |
| Ap | 0-23 | 10YR5/4 | - | Loam | 1msbk | mvfr | cw | Many fine roots |
| AB | 23-50 | IOYR7/4 | 2.5YR5/8 | Loam | 2msbk | mfr | cw | Few quartz minerals |
| $Bt_1$ | 50-80 | 10YR7/3 | 7.5YR5/6 | Clay loam | 2msbk | svfi | cw | Clay skin in peds |
| $Bt_2$ | 80-150 | 10YR5/2 | 10YR5/6 | Clay loam | 2msbk | svfi | - | Clay skin in peds |
| Ap | 0-20 | 10YR4/3 | - | Loam | 1msbk | mvfr | dw | Many fine roots |
| AB | 20-40 | 7.5YR5/3 | 7.5YR5/6 | Loam | 2msbk | mfr | cw | Many quartz fragments |
| B | 40-80 | 7.5YR5/4 | 2.5YR5/8 | Clay loam | 2msbk | sfi | ds | Clay skin in peds |
| $Bt_1$ | 80-130 | 10YR7/3 | 2.5YR4/8 | Clay loam | 2msbk | svfi | cw | Clay skin in peds |
| $Bt_2$ | 130-160 | 10YR7/2 | 5YR4/6 | Clay | 2msbk | svfi | - | Clay skin in peds |
| Unit 2: Aquic Kandiustalfs/Gleyic Lixisols (USDA soil Taxonomy/FAO-UNESCO Legend); Profiles 1&3)Loam | | | | | | | | |
| Ap | 0-20 | 10YR3/6 | - | Loam | 1msbk | mvfr | cs | Commom fine roots |
| AB | 20-38 | 10YR3/6 | - | Loam | 1msbk | sfr | cs | Fine quartz minerals |
| Bt | 38-65 | 7.5YR5/6 | 2.5YR4/6 | Clay loam | 2msbk | sfi | cs | Few Clay skin in peds |
| $BC_1$ | 65-95 | 7.5YR5/6 | 2.5YR4/8 | Clay loam | 2msbk | sfi | cs | Few Clay skin |
| $BC_2$ | 95-150 | 10YR7/3 | 10YR4/6 | Clay loam | 2msbk | svfi | - | Common clay skin |
| Ap | 0-40 | 7.5YR4/2 | - | Clay | 2msbk | sfr | cs | Commom fine roots |
| AB | 40-100 | 10YR6/6 | 5YR5/8 | Clay | 2msbk | sfi | cs | Commom clay skin |
| $BC_1$ | 100-110 | 10YR7/3 | 2.5YR4/6 | Clay loam | 1msbk | sfr | cw | Few clay skin in peds |
| $BC_2$ | 110-150 | 10YR7/3 | 7.5YR5/6 | Clay loam | 1msbk | mfi | - | Few clay skin in peds |

Abbreviations are as in Soil Survey Manual (U.S. Department of Agriculture, 1951,Pp 139-140) and distinct in the subsoil depths. The presence of mottles at these depths suggest that soils of Unit 1 experience seasonal subsurface hydromorphic conditions, resulting from impaired drainage caused by increasing clay content at the subsurface depths.

*Soils of Unit 2: Aquic kandiustalfs*

Unit 2 soils had Ap horizon depth ranging between 20 and 40 cm. Soils of the Unit also have clay values that ranged between 22 and 42 % even at the Ap horizons. Clay decreased in subsoil of this Unit but without maintaining any regular sequence (Table 1). The Unit does not therefore qualify to be diagnosed with 'argillic' pedogenetic properties. However, texture in this Unit was Clay loam and Clay in some Ap horizons.

Moist soil colour of Unit 2 soils ranged between yellowish brown (10YR5/4) to dark yellowish brown (10YR3/6) at the Ap horizons, and have weak medium sub angular blocky structure. Few iron and Manganese oxides and hydroxides nodules and concretions were also noticed at the soil surfaces. Unit 2 soils showed mottling from the shallow depth of 23 cm up to the 150 cm depth. Common mottle colour were red (2.5YR5/8), strong brown (7.5YR5/6), yellowish brown (10YR5/6), and red (2.5YR4/6), 4/8, & 10YR4/6). Mottling at such shallow depths of 23 cm would suggest that roots of most field crops would be located within the temporarily water logged depth during peak of rainy season in the zone (July to September).

Physicochemical Properties

*Physical Properties*

Table 2 presents information on particle size distribution of the soils. It showed that soils of Units 1 (profiles 2 &4) & 2 (profiles 1 & 3) contain high silt and clay separates throughout the pedons. Even at the surface horizons, silt and clay dominated over sand. Silt values ranged between 26 and 44 % both at the surface and subsurface horizons, while clay values ranged between 14 % at the surface horizons to 46 % in the sub soils. The high silt content in these soils could account for the surface crusting, a common surface feature (Ike, 1987). Crusting of the soil surfaces would impair gaseous exchange between soil and atmosphere, impair aeration of the crop root zone and obstruct seed germination (Tan, 2000; Horst, 1998). Crusting phenomena in these soils would necessitate ploughing and

*Table 2 - Particle-size Distribution of DFID-Striga Project Field Soils; Samaru-Zaria*

| Profile N° | Horizon | Depth | Coarse Sand | Medium Sand | Fine Sand | V. Fine Sand | Total Sand | Silt | Clay | Texture |
|---|---|---|---|---|---|---|---|---|---|---|
| | | cm | 2-1 | 1-.5 | .5-.25 | .25-.01 | 2-.01 | .01-.05 | <.002 | USDA, 1951 |
| | | | -----------mm----------- | | | | | | | |
| | | | -----------%----------- | | | | | | | |
| Oxyaquic vertic | | paleustalfs/Gleyic lixisols | | | | | | | | |
| 4 | Ap | 0-20 | 4.0 | 4.6 | 6.7 | 16.7 | 32 | 44 | 24 | Loam |
| | AB | 20-40 | 4.9 | 10.9 | 6.8 | 11.4 | 34 | 38 | 28 | Loam |
| | B | 40-80 | 3.3 | 10.8 | 7.8 | 10.1 | 32 | 40 | 28 | Loam |
| | $Bt_1$ | 80-130 | 4.4 | 7.7 | 5.4 | 12.5 | 30 | 30 | 40 | Clay Loam |
| | $Bt_2$ | 130-160 | 5.0 | 5.3 | 4.8 | 12.9 | 28 | 26 | 46 | Clay |
| 2 | Ap | 0-23 | 7.7 | 20.2 | 7.1 | 11.0 | 46 | 40 | 14 | Loam |
| | AB | 23-50 | 4.8 | 18.2 | 12.0 | 6.4 | 42 | 42 | 16 | Loam |
| | $Bt_1$ | 50-80 | 1.6 | 7.7 | 2.8 | 9.9 | 22 | 38 | 40 | Clay Loam |
| | $Bt_2$ | 80-150 | 1.7 | 6.2 | 3.4 | 12.7 | 24 | 34 | 42 | Clay Loam |
| Aquic kandiustalfs/Gleyic lixisols | | | | | | | | | | |
| 1 | Ap | 0-20 | 4.1 | 15.6 | 2.4 | 11.9 | 34 | 44 | 22 | Loam |
| | AB | 20-38 | 3.5 | 13.1 | 6.8 | 10.6 | 34 | 44 | 22 | Loam |
| | Bt | 38-65 | 3.7 | 7.2 | 5.6 | 11.5 | 28 | 36 | 36 | Clay Loam |
| | $BC_1$ | 65-95 | 3.4 | 9.6 | 6.1 | 10.9 | 30 | 38 | 32 | Clay Loam |
| | $BC_2$ | 95-150 | 3.0 | 9.3 | 6.6 | 11.1 | 30 | 38 | 32 | Clay Loam |
| 3 | Ap | 0-40 | 1.5 | 9.6 | 2.2 | 8.7 | 22 | 36 | 42 | Clay |
| | AB | 40-100 | 2.6 | 7.0 | 4.1 | 10.3 | 24 | 34 | 42 | Clay |
| | $BC_1$ | 100-110 | 7.1 | 8.1 | 5.5 | 13.3 | 34 | 28 | 38 | Clay Loam |
| | $BC_2$ | 110-150 | 4.8 | 7.0 | 5.2 | 15.0 | 33 | 28 | 40 | Clay Loam |

harrowing of the soils to allow for better aeration and infiltration of water into the crop root zone. Clay values in the soil units were high, especially at the subsoil horizons (Bt & Bc horizons). Clay values ranged between 32 and 46 in these subsoil depths, and occurred from shallow depths of 38 cm in Unit 2, and 50 cm in Unit 1. This would imply that in Unit 2 soils high subsoil clays would cause temporary stagnation of water at such shallow depths as 38 cm in some places. Commonly, rooting zone of most field crops average about 50 cm. The shallow depth (38 cm) at which temporary stagnation of water occurred would imply that in Unit 2 some crop roots would be located within the flooded depth; thus, impairing root growth, aeration, and nutrient uptake (Horst, 1998; Tan, 2000) and may account for the identified bleached legume leaves in the fields. In Unit 1 soils with clay 'lessivation' / 'argillation' occurrence from about 50 cm depths, roots of field crops may not reach the temporarily water stagnation zone, especially when the fields are ridged on the contour. Field crops in Unit 1 soils may not therefore readily show adverse signs of flooded root zone on crops. Texture of the surface soils in Unit 1 was Loam, while the subsoil was Clay-loam or Clay, indicating increasing heaviness of finer soil separates in the subsoil. In Unit 2 soils, surface soil texture ranged from Loam to Clay, with Clay-loam at the subsoil horizons.

*Chemical Properties*

A - Unit 1 Soils: Oxyaquic Vertic Paleustalfs

Soils of Unit 1 had pH values (in Water) ranging between 5.3 and 6.0, and 4.3 to 5.1 in $CaCl_2$ solution (Table 3). Exchange acidity ($H^+ + Al^{3+}$) values were also very low (< 1.0 cmolkg$^{-1}$) and suggest that the soils have no acidity problems. However, the strong acidity range of pH values would suggest that liming and /or use of farmyard manure incorporated into the soils would restore pH values to the range of pH 5.0 to 6.0, at which most nutrients are readily available to crop roots (Horst, 1998).

Organic carbon content of Unit 1 soils ranged from 6.0 to 8.3 gkg$^{-1}$ at the surface horizons, and decreased to 1.0 gkg$^{-1}$ at the Bc horizons. This would suggest that the soils have low organic colloidal fraction, especially at the solum, and the soils would therefore be prone to leaching of nutrients. Total nitrogen content of the soils were very low; and ranged from 0.53 to 0.7 gkg$^{-1}$ at the surface horizons, and as low as 0.18 gkg$^{-1}$ at the subsurface horizons. Available phosphorus content of soils of Unit 1 was also very low; 1.49 to 1.80 mgkg$^{-1}$ at the surface horizons, and as low as 0.72 mgkg$^{-1}$ P in the subsoil depths. These would confirm that soils of the Nigerian Savanna have inherently poor fertility status (Jones and Wild,

*Table 3 - Chemical Properties of DFID-Striga Project Field Soils; Samaru-Zaria*

| Profile N° | Horizon | Depth | pH | | Org. C | Total N | Avail. P |
|---|---|---|---|---|---|---|---|
| | | Cm | $H_2O$ | $CaCl_2$ | --------- $gkg^{-1}$ ------- | | $mgkg^{-1}$ |
| Oxyaquic vertic aleustalfs/Gleyic lixisols | | | | | | | |
| 4 | Ap | 0-20 | 5.9 | 4.9 | 8.3 | 0.70 | 1.80 |
| | AB | 20-40 | 6.2 | 5.1 | 3.4 | 0.53 | 1.80 |
| | B | 40-80 | 5.5 | 4.8 | 2.8 | 0.35 | 1.18 |
| | $Bt_1$ | 80-130 | 5.7 | 4.5 | 1.5 | 0.35 | 0.72 |
| | $Bt_2$ | 130-160 | 5.7 | 4.6 | 1.4 | 0.53 | 0.87 |
| 2 | Ap | 0-23 | 5.6 | 4.8 | 3.3 | 0.53 | 1.49 |
| | AB | 23-50 | 5.3 | 4.3 | 3.8 | 0.53 | 3.15 |
| | $Bt_1$ | 50-80 | 5.6 | 4.7 | 1.2 | 0.35 | 1.64 |
| | $Bt_2$ | 80-150 | 6.0 | 5.0 | 1.0 | 0.18 | 1.18 |
| Aquic kandiustalfs/Gleyic lixisols | | | | | | | |
| 1 | Ap | 0-20 | 5.3 | 4.3 | 6.2 | 0.70 | 0.72 |
| | AB | 20-38 | 5.5 | 4.4 | 4.0 | 0.35 | 2.29 |
| | Bt | 38-65 | 5.5 | 4.4 | 2.6 | 0.53 | 0.72 |
| | $BC_1$ | 65-95 | 5.4 | 4.3 | 1.2 | 0.35 | 1.33 |
| | $BC_2$ | 95-150 | 5.2 | 4.0 | 1.0 | 0.35 | 1.18 |
| 3 | Ap | 0-40 | 5.6 | 4.9 | 2.9 | 0.35 | 1.61 |
| | AB | 40-100 | 6.0 | 5.0 | 2.2 | 0.35 | 0.58 |
| | $BC_1$ | 100-110 | 5.5 | 4.7 | 1.2 | 0.35 | 5.86 |
| | $BC_2$ | 110-150 | 5.7 | 4.8 | 0.9 | 0.35 | 0.58 |

*Table 3 Cont. - Chemical Properties of DFID-Stria Project Field Soils; Samaru-Zaria*

| Profile N° | Horizon | Depth | Exchangeable bases Ca | Mg | K | Na | Base Sat | Exch. Acidity ($Al^{3+}H^+$) | CEC | ECEC |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Cm | -------------$Cmolkg^{-1}$ ----------- | | | | % | --------------$Cmolkg^{-1}$ ------------ | | |
| Oxyaquic vertic paleustalfs/Gleyic lixisols | | | | | | | | | | |
| 4 | Ap | 0-20 | 2.50 | 0.68 | 0.31 | 0.08 | 97.3 | 0.10 | 7.7 | 3.7 |
| | AB | 20-40 | 5.00 | 0.52 | 0.23 | 0.10 | 139.3 | 0.20 | 4.2 | 6.1 |
| | B | 40-80 | 2.50 | 0.52 | 0.26 | 0.11 | 25.1 | 0.10 | 13.5 | 3.5 |
| | $Bt_1$ | 80-130 | 3.80 | 0.77 | 0.32 | 0.07 | 60.5 | 0.30 | 8.2 | 5.0 |
| | $Bt_2$ | 130-160 | 5.00 | 0.83 | 0.65 | 0.11 | 115.6 | 0.10 | 5.7 | 6.6 |
| 2 | Ap | 0-23 | 1.80 | 0.36 | 0.33 | 0.05 | 63.5 | 0.10 | 4.0 | 2.6 |
| | AB | 23-50 | 1.40 | 0.33 | 0.32 | 0.07 | 21.4 | 0.20 | 9.9 | 2.2 |
| | $Bt_1$ | 50-80 | 5.00 | 2.08 | 0.70 | 0.11 | 50.3 | 0.20 | 15.7 | 8.1 |
| | $Bt_2$ | 80-150 | 5.00 | 2.08 | 0.70 | 0.12 | 79.8 | 0.20 | 9.9 | 8.1 |
| Aquic kandiustalfs/Gleyic lixisols | | | | | | | | | | |
| 1 | Ap | 0-20 | 2.50 | 0.36 | 0.35 | 0.05 | 62.7 | 0.30 | 5.2 | 3.6 |
| | AB | 20-38 | 3.80 | 0.33 | 0.22 | 0.07 | 44.7 | 0.20 | 9.9 | 4.6 |
| | Bt | 38-65 | 2.50 | 0.59 | 0.36 | 0.06 | 24.0 | 0.60 | 14.6 | 4.1 |
| | $BC_1$ | 65-95 | 2.50 | 0.52 | 0.27 | 0.07 | 41.5 | 0.70 | 8.1 | 4.1 |
| | $BC_2$ | 95-150 | 2.50 | 0.36 | 0.36 | 0.05 | 43.6 | 0.30 | 7.5 | 3.6 |
| 3 | Ap | 0-40 | 5.00 | 1.47 | 0.45 | 0.12 | 61.8 | 0.20 | 11.4 | 7.2 |
| | AB | 40-100 | 3.80 | 0.92 | 0.36 | 0.05 | 53.4 | 1.40 | 9.6 | 6.5 |
| | $BC_1$ | 100-110 | 2.50 | 0.68 | 0.36 | 0.08 | 43.1 | 0.20 | 8.4 | 3.7 |
| | $BC_2$ | 110-150 | 3.80 | 0.99 | 0.33 | 0.10 | 43.1 | 0.20 | 12.1 | 5.4 |

1975; Lombin, 1987; Odunze *et al.*, 2003; Odunze *et al.*, 2004).

Exchangeable Ca of the surface soils ranged between 2.5 and 1.8 $cmolkg^{-1}$, and increased to 5.0 $cmolkg^{-1}$ in the subsurface depths. This range of exchangeable Ca at the surface horizons is in the low to medium range, and medium to high in the subsurface depths (Tisdale and Nelson, 1975; Enwezor *et al.*, 1989; Esu, 1991). Exchangeable Mg values were in the medium range (0.36-0.68 $cmolkg^{-1}$) at the surface horizons, and increased to 2.08 $cmolkg^{-1}$ in the subsoil depths.

Also, moderate K values (0.31-0.33 $cmolkg^{-1}$) were obtained at the surface horizons, and high values (>0.3 $cmolkg^{-1}$) were obtained at the subsoil horizons (Bt). Very low (< 0.1 $cmolkg^{-1}$) exchangeable Na values were obtained at the surface horizons whereas low (0.1-0.3 $cmolkg^{-1}$) range of Na values were obtained at the subsoil horizons (Table 3). The generally increasing subsoil exchangeable cation values could imply that nutrient minerals leached from the surface horizons may have accumulated in the illuvial layers (Bt horizons).

Cation exchange capacity (CEC) values of Units 1 & 2 soils were in the range of 4.0 and 11.4 $cmolkg^{-1}$ at the surface horizons, suggesting a dominance of sesquioxides and kaolinite clays (Tan 2000) at these layers. At the subsurface horizons also, CEC values were in the range of 4.2 and 15.7 $cmolkg^{-1}$ in both soil, perhaps indicating presence of some 2:1 clay minerals in the subsoil's. Units. Base saturation percent of the soils were also in the range 61.8 and 97.3 percents, suggesting that over 60% of cations could be exchanged into the soil solution for crop root uptake.

The effective cation exchange capacity (ECEC) of the soils (Table 2) is very low (3.67-2.64 $cmolkg^{-1}$) at the surface horizons and 2.23 to 8.10 $cmolkg^{-1}$ in the subsoil horizons, and could suggest that the surface soils were dominated by low activity clays and sesquioxides (Tan, 2000), and the organic colloidal fractions are equally low in the soils. However, that the soil surface horizons have ECEC values less than 4 $cmolkg^{-1}$ suggests that the soils would be very susceptible to leaching (Sanchez, 1976). Perhaps therefore, the ECEC values > 4.0 $cmolkg^{-1}$ in the subsoil horizons represents zones in the pedons at which soil nutrients are retained against leaching.

## Micronutrients

Table 4 contains data on micronutrients (Mn, Fe, Cu, & Zn) content of the soils.

A - Soils of Unit 1: Oxyaquic vertic paleustalfs/Gleyic lixisols

In Unit 1 soils, extractable Mn ranged at the surface horizons from 17 to 8 $mgkg^{-1}$, and further decreased to 2.0 $mgkg^{-1}$ in the subsurface horizons. The soil surface Mn values were therefore high, as the critical deficiency of Mn ranges between 1 $mgkg^{-1}$, for low and 5 $mgkg^{-1}$ for high (Esu, 1991). Extractable Fe values were however moderate to high, and ranged from 32 to 112 $mgkg^{-1}$. The requirements for micronutrient by plants is generally less than 50 mg/1(Ashworth, 1991), and the critical deficiency limit of Fe in leaves is in the range of 50 to 150 mg Fe $kg^{-1}$ dry wt. (Horst, 1998). However, the moderate to high Fe and Mn content of the soils may account for the observed Fe & Mn oxides nodules and concretions at the soil surfaces. Available Cu values were in the high ranges (> 1.0 $mgkg^{-1}$) at the surface horizons, but decreased to 1.0 $mgkg^{-1}$ at the subsoil horizons. Extractable Zn values were also high (> 2.0 $mgkg^{-1}$) in the entire pedon, though still less than 50 mg/1. Therefore, extractable zinc is adequately available in the soils.

B - Unit 2 Soils: Aquic kandiustalfs/Gleyic lixisols

Unit 2 soils (Profiles 1 & 3) have pH values (in water) ranging between 5.3 and 5.6, and between 4.3 and 4.9 in 1N $CaCl_2$ solution at the surface horizons. These range of values are in the strongly acid range, and suggests liming to bring the soil acidity to the range pH 5.5 and 6.0 (Horst, 1998), at which most nutrients are readily available to crop roots for absorption / uptake. Also, exchange acidity ($H^+ + Al^{3+}$) of the soils showed values less than 1.0 $cmolkg^{-1}$ at the surface horizons (0.2-0.3 $cmolkg^{-1}$). At the subsurface horizons of Unit 2 soils, the exchange acidity values attained 0.6, 0.7, and 1.40 $cmolkg^{-1}$ at some subsoil horizons. Perhaps, this acidity would have resulted from increasing subsoil exchangeable $Al^{3+}$ and $Fe^{2+}$ and $Mn^{4+}$ reduction under anaerobic conditions. Also, $Al^{3+}$ and aluminum hydroxyl ions may be bound in non-exchangeable forms by the subsoil silicates (Tan, 2000). Increasing acidity problems at these shallow depths (38-100 cm), coupled with the high clay content at these depths would imply that the root zone of most field crops would be located in the acid water temporarily stagnating at the 38 cm depth and below. Root growth, nutrient uptake by roots, and oxygen supply to roots would be impaired by the acid conditions of the root zone soils. Contour ridging and construction of field drainages, coupled with liming and /or incorporation of farmyard manure is recommended in Unit 2 soils to stem soil acidity buildup. Organic carbon content of the soils of Unit 2 (Table 3) was very low (2.9-6.2

$gkg^{-1}$) at the surface horizons, and further decreased to the range 0.9 to 1.0 $gkg^{-1}$ at the Bc horizons. This would suggest that Unit 2 soils were very deficient in organic colloidal fractions. Also, total nitrogen values of the soils were very low (0.35 to 0.70 $gkg^{-1}$) at both the surface and subsoil horizons. Available phosphorus content of Unit 2 soils were very low (0.72-1.61 $mgkg^{-1}$) at both surface and subsurface horizons (0.58-5.86 $mgkg^{-1}$), and justify the view of Jones and Wild (1975), Lombin (1987), Esu and Ojanuga (1987), and Odunze *et al.*, (2003), that soils of tropical Savannas (Nigeria inclusive) have inherently poor fertility status.

Exchangeable Ca of the soils was in the moderate to high range (2 to 5 $cmolkg^{-1}$) in the entire pedon, but appear to decrease with increasing profile depth. Also, exchangeable Mg and K in the soils were in the moderate to high range (0.3-> 1.0; and 0.15 to > 0.3 $cmolkg^{-1}$ respectively). Exchangeable Na values were generally very low, ranging between 0.05 and 0.12 $cmolkg^{-1}$ at the surface horizons, and 0.05 to 0.10 $cmolkg^{-1}$ in the subsoil horizons. This would suggest that the soils do not present any sodicity threats.

The CEC and ECEC value of the soils were generally low ($\leq$ 16 $cmolkg^{-1}$ clay by 1N $NH_4OAC$ pH 7) and ECEC$\leq$12 $cmolkg^{-1}$ ($\Sigma$ bases extracted with 1N $NH_4OAC$ pH 7 plus 1N KCl extractable Al). This would suggest a dominance of sesquioxides and kaolinite clays in this pedon. However, the ECEC values of most of the horizons were greater than 4 $cmolkg^{-1}$, suggesting that Unit 2 soils would not be prone to leaching of nutrients.

## Micronutrients

Table 4 contains data on micronutrient extracted from soils of Unit 2. Manganese values were high ($\geq$ 5 $mgkg^{-1}$) at the surface horizons, and decreased to 1.0 $mgkg^{-1}$ in the subsoil depths. Also, extractable Fe was relatively low at the surface horizons (18 - 50 $mgkg^{-1}$), but decreased as profile depth increased. However, extractable Cu ranged from 1.0 to 2.0 $mgkg^{-1}$ in the entire pedons and this range is high ($\geq$1.0 $mgkg^{-1}$) in soils (Esu, 1991). Available zinc ranged between 5.6 and 33.0 $mgkg^{-1}$ at both surface and subsurface horizons, and are said to be high in soils.

The high clay content, stagnated water conditions and exchange acidity buildup in soils of Unit 2 could encourage this high availability of micronutrients such as Zinc in soils. In strongly to very strongly acid soils, the micronutrients Al, Fe, Cu, Zn, and Mn may exist in very high quantities, creating micronutrient toxicity (Tan, 2000).

*Table 4 - Micronutrients of DFID-Striga Project Field Soils; Samaru-Zaria*

| Profile N° | Horizon | Depth Cm | Mn | Fe | Cu | Zn |
|---|---|---|---|---|---|---|
| | | | -------------------------- | mgkg$^{-1}$ | ----------------------- | |
| Oxyaquic vertic paleustalfs/Gleyic lixisols | | | | | | |
| 4 | Ap | 0-20 | 17.0 | 112.0 | 1.0 | 17.2 |
| | AB | 20-40 | 12.0 | 100.0 | 1.0 | 1.5 |
| | B | 40-80 | 5.0 | 44.0 | 1.0 | 17.7 |
| | $Bt_1$ | 80-130 | - | - | - | - |
| | $Bt_2$ | 130-160 | 3.5 | 10.0 | 1.0 | 5.6 |
| 2 | Ap | 0-23 | 8.0 | 32.0 | 2.0 | 30.0 |
| | AB | 23-50 | 6.5 | 28.0 | 1.0 | 17.2 |
| | Bt, | 50-80 | 2.0 | 18.0 | 1.0 | 31.0 |
| | $Bt_2$ | 80-150 | 2.0 | 22.0 | 1.0 | 15.0 |
| Aquic kandiustalfs/Gleyic lixisols | | | | | | |
| 1 | Ap | 0-20 | 10.0 | 50.0 | 1.0 | 5.6 |
| | AB | 20-38 | 5.0 | 44.0 | 1.0 | 27.0 |
| | Bt | 38-65 | 2.0 | 22.0 | 1.0 | 12.5 |
| | $BC_1$ | 65-95 | 2.0 | 14.0 | 1.0 | 33.0 |
| | $BC_2$ | 95-150 | 1.0 | 14.0 | 1.0 | 33.0 |
| 3 | Ap | 0-40 | 5.0 | 18.0 | 1.0 | 33.0 |
| | AB | 40-100 | 3.5 | 10.0 | 2.0 | 30.0 |
| | $BC_1$ | 100-110 | 1.0 | 18.0 | 2.0 | 30.0 |
| | $BC_2$ | 110-150 | 1.0 | 10.0 | 1.0 | 5.6 |

## Limitations and Management Recommendations

Soils of Unit 1 (Oxyaquic vertic paleustalfs/ Gleyic lixisols) have the following limitations to sustainable crop production.

- Shallow Ap horizons (20-23 cm) below which are zones of increasing clay that impair sub soil drainage and root proliferation.
- The soils have high silt contents even at the surface horizons that would facilitate crust formation at the soil surfaces.
- Organic carbon, total nitrogen, available phosphorus and cation exchange capacity of the soils are inherently low; hence, it has inherently poor fertility status.
- pH of the soils was in strongly acid values and require restoration to pH 5.0 to 6.5 range.

To remedy these limitations and ensure their use for sustainable crop production, it is recommended as follows.

- Land preparation (ploughing, harrowing, and ridging) for rain fed crop production should be done when the soil is moist; preferably early June, using reduced tillage, contour ridging, and incorporation of farmyard manure and crop residues. This practice is aimed at reducing compaction of the thin plough layer and improving the seed bed for enhanced crop production. The practice would also improve organic matter (organic colloidal fraction), total nitrogen and the soils nutrient buffering capacity. Also, control of leaching of nutrients, and acidity buildup in the soils would be achieved.
- Construction of field drainage ditches to conduct excess field and subsurface stagnated water away from the fields. This practice would deter the occurrence of anaerobic sub surface soil conditions resulting from temporarily stagnated subsurface water and its adverse consequence on micronutrient availability and exchange acidity buildup.

Soils of Unit 2 (Aquic kandiustalfs/Gleyic lixisols) have the following limitations to sustainable crop production.

- Increasing sub soil exchange acidity (0.6 to 1.4 $cmolkg^{-1}$), and exceeded acidity threshold limit for acidity problem soils (> 1.0$cmolkg^{-1}$) in some horizons within the subsurface depths.
- Very low organic carbon, total nitrogen, available phosphorus, and cation exchange capacity to be inherently poor in fertility status.
- Very high zinc availability, even at some surface horizons, which could result in zinc toxicity effects on plants.

Recommended soil management measures in the case of 'Aquic kandiustalfs/Gleyic lixisols' include

- At land preparation, contour ridging, incorporation of farmyard manures and crop residues, and the construction of field drainage systems/canal would be necessary. This practice would ensure adequate drainage of the fields and sub soil depths, enhance soil organic matter, nitrogen, available phosphorus, and cation exchange capacity of the soils. Also, the practice would improve the root zone aeration, control sub soil exchange acidity buildup, and moderate micronutrient availability for optimal root growth and nutrients uptake. Liming in this soil Unit would be necessary to bring pH of the soils to the range pH 5.0 to 6.5.

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