Soil Characterization and Classification in an Upland of Southern Guinea Savannah Zone of Nigeria

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ABSTRACT

Background: Soil characterization and classification is the foundation for sustainable land use and management. Upland soils are important in areas of high elevation and undulating terrain. This study characterized and classified Soils of an upland in southern guinea savannah of Nigeria.

Methods: The prominent elevation points of the area were read with GPS device and four locations identified were labelled: UP1, UP2, UP3 and UP4. Profile pits were dug in each location, described for the morphological properties and sampled for laboratory analysis of soil physico-chemical properties.

Result: The soils were slightly to strongly acidic with pH of 5.29 to 6.11, had low organic matter ranged of 1.52 to 1.79% and low soil nutrient reserve with the effective cation exchange capacity (CEC) of 5.9 to 9.26 mol kg\(^{-1}\). In-situ soil development, transportation and deposition of materials were the major soil formation processes in the area. The soils were classified as Alfisols and were marginally suitable (S3) for yam.

Key words: Classification, Evaluation, Upland, Suitability.

INTRODUCTION

Characterization of soils is necessary for easy soil identification, assessment of the potentials and limitations soils for specific kind of use. Agricultural land use, unlike other uses, is discriminatory (Adeyolanu et al., 2017). It is often found that a soil type suitable for a particular crop may not be suitable for another crop because crops are different in their requirements - in terms of nutrients composition and physical quality (Adeyolanu et al., 2017). Lack or inadequate information on the soil characteristics and potential of land for specified agricultural use can lead to misuse, mismanagement, and degradation (Maniyunda and Gwari, 2014).

The study location was an upland with intensive cultivation activities of smallholder yam farmers and important to the supply of food to the communities in the area. There was no information on the soil characteristics. This is a drawback to sustainable land use, optimal production and meeting the staple food demand of the immediate and neighboring community. Therefore, this study was undertaken to characterize and classify the soils of the area and evaluate their potential for sustainable yam production.

MATERIALS AND METHODS

Description of the study area

The study was conducted in year 2019 to 2020 in an upland area located in Kogi State, Nigeria. The area covers about 75 ha, within the southern guinea savannah zone. It is on latitude 7°52' and longitude 6°30' with a maximum elevation of 520 m above sea level. The climate was of the humid tropics with the raining season (wet) and dry season (hot). The area belongs to the basement complex geology of Nigeria.
N, available-P, effective CEC, base saturation (BS), exchangeable-Na percentage (ESP), and ECEC of clay were determined with standard procedures suggested by IITA (1979).

**Soil characterization and classification**

The soils were characterized with the interpretation guide for soil data (FAO, 2004) and classified according to FAO/UNESCO (2014) and USDA (2014) soil classification systems.

The suitability of soils in the location was evaluated for yam with the parametric approach of the land suitability evaluation as modified by Ogunkunle (1993).

**RESULTS AND DISCUSSION**

**Soil morphological characteristics**

The morphological characteristics of soils at the four positions in the landscape are presented in Table 1. The major elevation points were 479.20, 486.00, 489.30, and 515.70 m with a slope gradient of 5.4, 8.6, 11.5, and 15.6% at points UP1, UP2, UP3, and UP4, respectively. The landscape was divided into crest, upper and middle slope.

The dominant soil colour was 7.5YR and it indicates the release of Fe from the primary minerals, thereby giving the soils a reddish-brown coloration. The darker 10 YR at surface of UP4 can be attributed to deposition of materials being the lowest part of the landscape.

Generally, the surface soils were coarse textured sandy loam, while the subsurface horizons were sandy clay, sandy clay loam and clay textured. The textural change with increasing depth indicated *in situ* weathering and it was evident in the presence of bits of partly weathered granitic rocks and gravels within the pedons. Mottles was observed at UP1 and it indicated poor drainage condition as a result of the lower position in the landscape. The structure was medium, coarse granular at the UP1, UP2 and UP4. The subsurface soil had well developed structure of medium to strong coarse sub angular to angular block. The consistence was no-sticky and no-plastic at the soils surface. The degree of cohesion and adhesion increases with increasing depth and indicates increase in clay content down the soil depth. There is presence of roots down the soil depth which indicate that the soil depths are zones of rooting activities. The Fe-Mn concretions found in some parts indicate presence of plinthites and the erosion channels in some parts indicates movement of materials across the landscapes. The soil depth ranges from 42 to 80 cm, restriction to soil depth are stones, gravels, rocks, and hardpan.

**Soil physico-chemical characteristics**

The physico-chemical characteristics of soils at the four positions in the landscape are presented in Table 2. The soils were slightly to strongly acidic with Soil pH values range from 5.34 to 6.11 and 5.21 to 5.95 at the surface and subsurface horizons respectively. The surface horizon had higher pH values than the subsurface horizon, and higher values was recorded at the lower slope than the other slope positions. This could be attributed to phytocycling movement of bases due to intense evaporation during the dry season in the humid tropics and lateral leaching of bases from upland to the lowland (Adegbenro, 2017). Electrical Conductivity was from 0.010 to 0.031 dsm m\(^{-1}\) and 0.007 to 0.026 dsm m\(^{-1}\) at the surface and subsurface horizons respectively. The values were below the critical level at 4.00 dsm m\(^{-1}\) suggested by Brady and Weil (2005) for saline soils. Therefore, the soils were rated non-saline.

The organic matter percentage and total-N were low and had similar pattern of distribution. The organic matter values were higher at the surface (1.52 to 1.79%) than the subsurface (0.26 to 1.36%) horizons. Findings is similar to reports of Savalia and Gundalia (2010), this can be attributed to the presence of more decomposable plant materials and phytocycling. The total-N were below the critical value of 0.2% set for Nigerian soils (FFD, 2002). The available-P were high, it ranged from 15.75 to 29.10 ppm at the surface of the soils and it decreased with increasing depth.

Calcium values was from 1.81 to 4.30 cmol kg\(^{-1}\) soil. This was followed by Mg having between 0.85 to 2.83 cmol kg\(^{-1}\). The higher Ca content was due to the higher adsorptive power of Ca than the other cations in the soil (Amalu and Antigha 1999). The Mg values were moderate, and Na values were low. In general, the UP1 position had higher values of exchangeable cations than the other positions and could be due to lateral leaching of bases from the upland to the lowland. The effective CEC values of 5.9 to 9.26 mol kg\(^{-1}\) was low and in agreement with values reported for savannah soils in Nigeria by Odunze (2016). The values were indicative of low nutrient reserved of these soils. The ECEC clay values was below the boundary of 24 cmol kg\(^{-1}\) clay set by Juo (1980) for limit between high activity clay and low acidity clay at UP2, UP4 and sub soil part of UP1 and UP4, therefore, the soils were dominated by low activity clay, and nutrient loss through leaching was likely in the soils. The percentage base saturation values were very high ranging from 87.99 to 91.36%. The values indicated that the ability of the soils to hold and exchange nutrient was very high. The exchangeable Na percentage values ranged from 1.4 to 4.5%, below the critical level of 15% suggested for sodic soils by Brady and Weil (2005).

The sand content increased down the profile pit at UP1 and decreases at the other positions, this indicated that there was deposition of fine soil materials from the higher elevation to the lower UP1. There was evidence of accumulation of clay within the soil profile through the process of eluviation-illuviation because of the increase in clay content with increasing depth. The middle, upper and crest position had higher values (13-49%) of clay than the lower slope (16-35%).

**Soil classification**

In the USDA soil taxonomy soil classification, the soils were classified as Alfisols at the order level because they do not have a plagggen epipedon, had an argillic and kandic horizon as well as fragipan. They were classified as Ustolls at suborder level because they had an ustic moisture regime.
| Depth (cm) | Horizons | Colour | Drainage | Mottles | Texture | Structure | Consistence | Inclusion                                      |
|-----------|----------|--------|----------|---------|---------|-----------|------------|------------------------------------------------|
| 0-10      | A        | 10 YR  | well     | -       | SL      | s, co, gr. | so, vl, ns, np | Many Gravels, and roots                         |
| 10-19     | B        | 10 YR  | Well     | -       | GSL     | s, co, sb.k.| so, vl, ns, np | Few stone gravels and many roots                |
| 19-30     | Bt       | 7.5 YR | Poor     | Many    | GSC     | m, co, abk. | so, vl, sl, np | Few stones and gravels roots                    |
| 30-52     | BC       | 7.5 YR | Poor     | Many    | SC      | st, co, abk. | h, fi, vs, sp. | Few stones and gravels roots, rocks and boulders |
| 0-12      | A        | 7.5 YR | Well     | -       | SL      | m, me, gr.  | so, vfr, sl, np | Many roots, Few stones                          |
| 12-20     | B        | 5 YR   | Well     | -       | GSCL    | m, co, sbk. | lo, vfi, sl, np | Fe-Mn concretions, stones gravels roots         |
| 20-34     | BE       | 5 YR   | Well     | GSC     | m, co, sbk. | so, fi, vs, sp. | stones and gravels root Fe                       |
| 34-70     | BC       | 5 YR   | Well     | GSC     | st, co, abk.| h, fi, vs, sp  | Mn stones, gravels and roots, Hard pan at 70 cm |
| 0-22      | A        | 7.5 YR | Well     | -       | SL      | m, co, sbk. | lo, lo, ns, np | Many roots, many stones and gravels, erosion channels |
| 22-42     | B        | 7.5 YR | Well     | -       | GSCL    | m, co, sbk. | lo, fi, ns, np | Few roots many stones gravels                   |
| 42-80     | BE       | 7.5 YR | Well     | GSC     | m, co, sbk. | h, vfi, vs, np. | many stones and roots, rocks and boulders       |
| 0-7       | A        | 7.5 YR | Well     | -       | SL      | m, m, gr.  | so, v, ns, np. | Many roots and stones                           |
| 7-24      | BE       | 7.5 YR | Well     | -       | GSC     | m, co, cr.  | so, vfi, ns, np. | Fe-Mn concretions, many roots, few stones and many boulders |
| 24-42     | BC       | 5 YR   | Well     | -       | GC      | m, co, sbk. | h, vfi, vfi, vs | Few roots, many boulders and                     |

Texture: G= gravelly, S= sand, LS= loamy sand, SL= sandy loam, L= loam, SCL= sandy clay loam, CL= clay loam, SC= sandy clay, C= clay
Structure: 0= structureless 1= weak, 2= moderate, 3= strong, f= fine, m= medium, c= coarse, cr= crumbly, gr= granular, sbk= sub angular block, abk= angular blocky
Consistence: ns= non sticky, np= non plastic, ss= slightly sticky, sp= slightly plastic, vs= very sticky, vp= very plastic, lo= loose, vfr= very friable, fi= firm, vfi= very firm, l= loose, s= soft, h= hard, vh= very hard.
| Depth (cm) | pH | EC (H₂O) | OM | TN | AP | Ca²⁺ | Mg²⁺ | K⁺ | Na⁺ | Al³⁺ | H⁺ | ECEC | ESP | BS | Clay | Sand | Silt | EA | ECEC |
|-----------|----|-----------|----|----|----|------|------|----|----|------|----|------|-----|----|------|------|-----|----|-----|-----|
| UP1       |    |           |    |    |    |      |      |    |    |      |    |      |     |    |      |      |    |    |    |    |
| 0-10      | 6.11 | 0.031 | 1.73 | 0.20 | 16.44 | 4.30 | 2.59 | 1.21 | 0.36 | 0.3 | 0.5 | 9.26 | 3.8 | 91.36 | 55 | 29 | 16 | 0.8 | 33.38 |
| 10-19     | 5.95 | 0.026 | 1.36 | 0.15 | 13.48 | 3.82 | 1.41 | 1.13 | 0.33 | 0.3 | 0.4 | 7.39 | 4.5 | 90.52 | 61 | 20 | 19 | 0.7 | 24.31 |
| 19-30     | 5.75 | 0.020 | 0.91 | 0.13 | 9.27  | 2.57 | 1.63 | 1.11 | 0.21 | 0.2 | 0.3 | 6.03 | 3.5 | 91.54 | 63 | 09 | 28 | 0.5 | 14.89 |
| 30-45     | 5.55 | 0.011 | 0.85 | 0.10 | 8.94  | 3.21 | 0.85 | 1.01 | 0.15 | 0.3 | 0.3 | 5.82 | 2.5 | 89.69 | 63 | 02 | 16 | 0.8 | 14.89 |
| UP2       |    |           |    |    |    |      |      |    |    |      |    |      |     |    |      |      |    |    |    |    |
| 0-10      | 5.86 | 0.022 | 1.56 | 0.19 | 15.75 | 3.95 | 2.83 | 1.15 | 0.17 | 0.3 | 0.5 | 5.9  | 1.9 | 91.01 | 69 | 03 | 28 | 0.8 | 20.54 |
| 10-20     | 5.53 | 0.020 | 1.18 | 0.18 | 11.66 | 1.98 | 2.55 | 1.10 | 0.16 | 0.2 | 0.4 | 6.39 | 2.5 | 90.61 | 60 | 03 | 37 | 0.6 | 11.12 |
| 20-34     | 5.27 | 0.016 | 0.81 | 0.13 | 7.90  | 1.81 | 1.21 | 1.07 | 0.17 | 0.2 | 0.2 | 5.16 | 3.3 | 92.24 | 49 | 11 | 40 | 0.4 | 8.875 |
| 34-70     | 5.22 | 0.012 | 0.52 | 0.11 | 7.16  | 3.12 | 1.29 | 1.00 | 0.09 | 0.3 | 0.3 | 6.1  | 1.5 | 90.16 | 35 | 16 | 49 | 0.6 | 10.31 |
| UP3       |    |           |    |    |    |      |      |    |    |      |    |      |     |    |      |      |    |    |    |    |
| 0-22      | 5.93 | 0.013 | 1.79 | 0.17 | 29.10 | 2.80 | 2.44 | 1.12 | 0.19 | 0.2 | 0.5 | 7.25 | 2.6 | 90.34 | 73 | 14 | 13 | 0.7 | 27.76 |
| 22-42     | 5.90 | 0.011 | 0.95 | 0.16 | 21.48 | 2.65 | 2.38 | 1.03 | 0.14 | 0.1 | 0.3 | 6.6  | 2.1 | 93.93 | 70 | 07 | 23 | 0.4 | 26.30 |
| 42-80     | 5.83 | 0.011 | 0.31 | 0.14 | 16.21 | 3.60 | 1.67 | 1.10 | 0.10 | 0.3 | 0.3 | 6.97 | 1.4 | 91.39 | 49 | 09 | 42 | 0.6 | 15.17 |
| UP4       |    |           |    |    |    |      |      |    |    |      |    |      |     |    |      |      |    |    |    |    |
| 0-7       | 5.34 | 0.010 | 1.52 | 0.17 | 18.25 | 2.16 | 1.89 | 1.09 | 0.11 | 0.1 | 0.4 | 5.75 | 1.9 | 91.30 | 12 | 12 | 19 | 0.5 | 14.24 |
| 7-24      | 5.29 | 0.009 | 1.31 | 0.14 | 18.14 | 2.09 | 1.83 | 1.06 | 0.09 | 0.2 | 0.4 | 5.67 | 1.5 | 89.42 | 12 | 12 | 23 | 0.6 | 13.24 |
| 24-42     | 5.21 | 0.007 | 0.26 | 0.12 | 14.75 | 3.22 | 0.85 | 1.98 | 0.08 | 0.3 | 0.4 | 5.83 | 1.4 | 87.99 | 14 | 14 | 45 | 0.7 | 11.78 |
At the great group and subgroup levels, UP1 was classified as Paleustalfs and Kandic Paleustalf because there was an increasing clay with increasing depth, presence mottles, hue of 7.5YR in the horizon and had an ECEC clay of less than 24 cmol kg\(^{-1}\) within the kandic horizon, UP2 and UP4 were classified as Durustalfs and Typic Durustalfs because they had pan materials within 100 cm of the soil depth while UP3 was classified as Kanhaplustalf and Typic Kanhaplustalf because it was an Ustalfs with a kandic horizon.

In the FAO/UNESCO classification system, UP1 and UP3 are Lixisols at the higher category because of the presence of argic B horizon with low activity clay and base saturation above 50%. At the lower category, UP1 was Epistagnic Lixisols because it had a redoximorphic condition (mottles) within the 50 cm soil depth and UP3 was Haplic Lixisols because it had a typical expression of Lixisols. The higher and lower category classification of UP2 and UP4 were Plinthosols and Pisoplinthic Endoduric Plinthosols.

### Table 3: Land requirements for suitability classes for yam cultivation.

| Land qualities          | S1 (100) | S2 (80) | S3 (60) | N1 (40) | N2 (25) |
|-------------------------|----------|---------|---------|---------|---------|
| Climate (c):            |          |         |         |         |         |
| Annual rainfall (mm)    | >800     | 600-800 | 500-600 | <500    |         |
| Length dry season (months) | 3-4     | 4-5     | 5-6     | 6-7     |         |
| Mean annual temp (°C)   | 18-30    | >18     | >16     | >12     |         |
| Topography (t)          |          |         |         |         |         |
| Slope (%)               | 0-4      | 4-8     | 8-16    | 16-30   | 30-50   |
| Wetness (w):            |          |         |         |         |         |
| Drainage                | Good     | -       | Moderate| Imperfect| poor    |
| Soil physical properties (s): |        |         |         |         |         |
| Texture                 | L, SL, SCL | SiC, SiCL, CL, SIC, SCLFS, LS, LCS, FS | CS | -       |
| Soil Depth (cm)         | >75      | 75-50   | 50-35   | <35     |         |
| Fertility (f):          |          |         |         |         |         |
| Cation exchange capacity (cmol kg\(^{-1}\)) clay | >40 | 40-16 | 16-12 | 12-6 | <16 |
| Base saturation (%)     | >35      | 35-20   | <20     | -       | -       |
| Organic matter (%) 0-15cm | >2.5     | 1.5-2.5 | < 1.5   | -       | -       |
| Total N (%)             | >0.20    | 0.20-0.15 | 0.10-0.15 | <0.10  | -       |
| Exchangeable K (cmol kg\(^{-1}\)) | >0.6 | 0.6-0.2 | >0.2   | -       | -       |

CL, clay loam; SCL, sandy clay loam; L, loam; LFS, loamy fine sand; Loamy coarse sand; FS. Fine sand; C, clay; CS, clayey sand; C – clay; SiC, silty clay; SiCL, silt

### Table 4: Suitability class score for maize

| Land qualities                       | UP1          | UP2          | UP3          | UP4          |
|--------------------------------------|--------------|--------------|--------------|--------------|
| Climate (c):                         |              |              |              |              |
| Annual rainfall (mm)                 | 100(S1)      | 100(S1)      | 100(S1)      | 100(S1)      |
| Length dry season (months)           | 60(S3)       | 60(S3)       | 60(S3)       | 60(S3)       |
| Mean annual temp (°C)                | 100(S1)      | 100(S1)      | 100(S1)      | 100(S1)      |
| Topography (t)                       | 100(S1)      | 100(S1)      | 100(S1)      | 100(S1)      |
| Wetness (w):                         |              |              |              |              |
| Drainage                             | 100(S1)      | 100(S1)      | 100(S1)      | 100(S1)      |
| Soil physical properties (s):        |              |              |              |              |
| Texture                              | 100(S1)      | 100(S1)      | 100(S1)      | 100(S1)      |
| Soil Depth (cm)                      | 60(S3)       | 80(S2)       | 100(S1)      | 60(S3)       |
| Fertility (f):                       |              |              |              |              |
| Cation exchange capacity (cmol kg\(^{-1}\)) clay | 80(S2) | 80(S2)      | 80(S2)      | 60(S3)       |
| Base saturation (%)                  | 100(S1)      | 100(S1)      | 100(S1)      | 100(S1)      |
| Organic carbon (g kg\(^{-1}\) 0-15cm | 80(S2)       | 80(S2)       | 80(S2)       | 80(S2)       |
| Total N (%)                          | 100(S1)      | 100(S1)      | 100(S1)      | 100(S1)      |
| Exchangeable K (cmol kg\(^{-1}\))   | 100(S1)      | 100(S1)      | 100(S1)      | 100(S1)      |
| Current Aggregate Suitability        | 27.89(S3)    | 41.56(S3)    | 37.18(S3)    | 32.19(S3)    |
| Potential Aggregate Suitability      | 36.00(S3)    | 46.48(S3)    | 41.56(S3)    | 36.00(S3)    |
because they had hard pan and Fe-Mn concretions in one of the horizons.

Land suitability evaluation

The land use requirement for yam and result of suitability assessment (Tables 3 and 4). Revealed that soils at the four positions were currently and potentially marginally suitable (S3) with current and potential suitability index of 32.19 and 36.00, 37.18 and 41.56, 41.56 and 46.48, and 27.89 and 36.00 at UP1, UP2, UP3 and UP4 respectively. The soils were placed in classes lower than S1 as a result of length of dry season which is more than six months, slope, soil depth, effective CEC, organic-C, and total-N.

Among the limitations to yam production in the soils of the study area, effective CEC, organic-C, and total-N were fertility limitations that can be improved upon with the adoption of proper soil and crop management practices and will lead to better performance of the crops on the soils.

CONCLUSION

Soil development in the study area was characterized with in-situ formation as well as removal and deposition of materials. The limitations to crop production were slope, low total-N, and organic matter, moderate effective CEC, and high leaching potential. These limitations can be managed through the following sustainable practices: Tilling, construction of ridges and heaps as well as construction of contour ridges across the slope. Cultivation of legumes and cover crops as sole or intercrop with and yam. Incorporation of organic manure, proper post-harvest residue management and judicious fertilizer use.

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