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## Characterization and Classification of Soils Derived from Coarse-Grained Granite and Gneiss in Humid Rainforest Area of Southwestern Nigeria

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### abstract

This study investigated soils derived from coarse-grained granite and gneiss in southwestern Nigeria, focusing on their characterization and classification. Eight soil profile pits were established across varying topographic positions, and samples were collected from generic horizons. Standard procedures were used to analyze physical and chemical properties. The soils were generally deep and well-drained, except at valley bottoms where they were shallow and poorly drained. Surface horizons displayed colours ranging from dark reddish brown (5YR3/4) to dark yellowish brown (10YR3/4), while subsurface horizons varied from yellowish red (7.5YR5/6) to yellowish brown (10YR5/8). Textures ranged from loamy sand to gravelly sandy clay at the surface, and sandy loam to clay in the subsoil, with moderate, medium, sub-angular blocky structures. Gravel content varied widely (8.5–67.1%), bulk density ranged from 1.17 to 1.81 g/cm<sup>3</sup>, and porosity values spanned 38.07–54.63% at the surface and 31.88–55.63% in the subsurface. The soils were slightly to moderately acidic, with variable levels of exchangeable bases, organic matter, nitrogen, and phosphorus. Organic matter was particularly important for nutrient availability. Classification revealed upper and mid-slope soils as Typic isohyperthermic Paleustults, lower slope soils as Plinthic isohyperthermic Paleustults, and valley bottom soils as Aquic Psamments under USDA taxonomy. FAO/UNESCO categories included Lixisols, Plinthic Lixisols, and Fluvisols. Overall, the soils exhibited low to medium fertility, highlighting the need for sustainable management. Recommended strategies include applying fertilizers, incorporating crop residues, and using organic manures to enhance productivity and ensure long-term soil resource sustainability.

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### INTRODUCTION

Soil is one of the world's most important natural resources, sustaining most lives on Earth either directly or indirectly (FAO, 2022). It is fundamental to the ecosystem functioning, food production, and the survival of human civilizations, and therefore must be properly valued and protected. A fertile soil is essential for thriving agriculture. Thus, one strategy for achieving sustainable agriculture in a sustainable environment is to investigate soil attributes, specifically through soil characterization and land appraisal for various land utilization types (Esu, 2004). Characterization provides useful information and knowledge about soil features, as well as a thorough grasp of soil genesis, morphology, categorization, and spatial distribution of soils in an area (Karuma et al., 2015). Detailed information on soil characteristics is essential in making choices on soil management strategies for sustainable agricultural production, rehabilitation of damaged ecosystems, and sound soil fertility research (Isola et al., 2020). Soil fertility management performance is mostly dependent on understanding how soils respond to various agricultural activities across time (Ehsetu et al., 2011). Soil fertility specialists use the knowledge collected from characterization to conduct fertilizer experiments and make valid fertilizer recommendations (Njuguna et al., 2019). Due to incorrect usage and poor management of land resources on various terrains, a

lack of information on the soil resources of any location contributes to the problem of soil degradation and the global food crisis (Nsor and Adesemuyi, 2016). A fundamental limitation restricting agricultural development in Nigeria is the lack of information on the potential of soil resources. Erosion and fertility depletion cause upland soils to deteriorate quickly. To ensure that the soil is put to the most appropriate and sustainable use, soil characterization and categorization are required for effective identification, management, and technical transfer. At present, detailed data on these soils remain scarce, although generating comprehensive soil information is essential to enhance agricultural output and for a better understanding of their potentials and limitations for sustainable use. Thus, the objective of the study was to characterize and classify the soils formed by coarse-grained granite and gneiss in southwestern Nigeria.

### MATERIALS AND METHODS

#### THE STUDY AREA

The study was carried out in the Teaching and Research Farm, Obafemi Awolowo University, Ile-Ife, Nigeria, between latitudes 7°32' N and 7°33' N and longitudes 4°32' E and 4°40' E, on soil developed on coarse-grained granite and gneiss parent material (Smyth and Montgomery 1962). The soils derived from coarse-grained granite and gneiss form the most widespread and agriculturally significant soils in the study area. Despite their extent, these soils are highly weathered, leached, and acidic, with rapid decomposition and mineralization of organic matter that diminishes their natural fertility. They

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are fragile, dominated by low-activity clays, and exhibit low cation exchange capacity and base saturation, all of which contribute to poor productivity. The climate is hot and humid, with distinct dry and rainy seasons. The rainy season, which follows a bimodal distribution pattern, lasts from March to October, with peaks in June and September. Annually, the dry season lasts around four months (November-February). The average annual rainfall is approximately 1400mm, and the average annual temperature is 27 °C (Okusami and Oyediran 1985).

### Field Work

Eight soil profile pits were newly established along two toposequences and each soil profile pit was described using the FAO/UNESCO (2006) guidelines for soil profile description and then sampled. Core soil samples were collected from each designated genetic horizon and utilized to determine bulk density and estimate soil porosity. To avoid contamination, soil samples were collected from the designated genetic layers of each of the soil profiles, beginning at the bottom and working up.

### LABORATORY ANALYSIS

The soil samples were air-dried, crushed gently and sieved through a 2 mm sieve to separate gravel from the earth fraction. The gravel content (materials > 2 mm) was determined and expressed as a percentage of the soil's total weight. The fraction less than 2 mm was retained for analysis. The core method was used to determine soil bulk density (Blake, 1965; Blake and Hartge, 1986) using a core sampler of known volume, and the soil was oven-dried at 105°C until a constant weight was attained (72 hours). Soil porosity was calculated using bulk density values, following the methods outlined by Brady and Weil (2002). The particle size distribution was determined using

the hydrometer method of Gee and Or (2002). Soil pH was determined in both water and 1.0 M KCl solution employing a 1:1 soil/solution mixture and the reading was taken with a digital pH meter after equilibration using a combined glass electrode digital pH meter (Thomas, 1996). Electrical conductivity was determined in the saturated extract using a conductivity meter (Clay et al., 2012). Total exchangeable acidity and Al were determined by titration method using 1.0 M KCl (Sims, 1996) and titrated with 0.05N NaOH solution (Black, 1975). The exchangeable cations were extracted with neutral 1.0 N ammonium acetate solution, the concentration of the exchangeable potassium and sodium in the extract were determined using a Flame Photometer while exchangeable calcium and magnesium concentration were determined using the Atomic Absorption Spectrophotometer (Rhoades, 1982). The effective Cation Exchangeable Capacity (ECEC) was calculated by the summation of exchangeable bases (Sumner and Miller, 1996) plus exchangeable Al. The cation exchange capacity of the soils was determined by the neutral K-Acetate saturation and neutral NH<sub>4</sub>OAc displacement methods and by the sum of cations' method, (i.e.), acidity by 0.5 M BaCl<sub>2</sub> with 0.005 Triethanolamine (TEA) at pH 8.2) plus bases by 1.0 M neutral NH<sub>4</sub>OAc (Soil Survey Staff, 2014). The organic carbon was determined by the Walkley-Black method (Nelson and Sommers, 1996). Total nitrogen was determined by the kjeldahl digestion and distillation method (Bremner, 1996) while the available phosphorus was determined by the Bray-1 method (Kuo, 1996).

### DATA ANALYSIS

All the data generated were subjected to inferential statistics (correlation) using SPSS (Version 23)

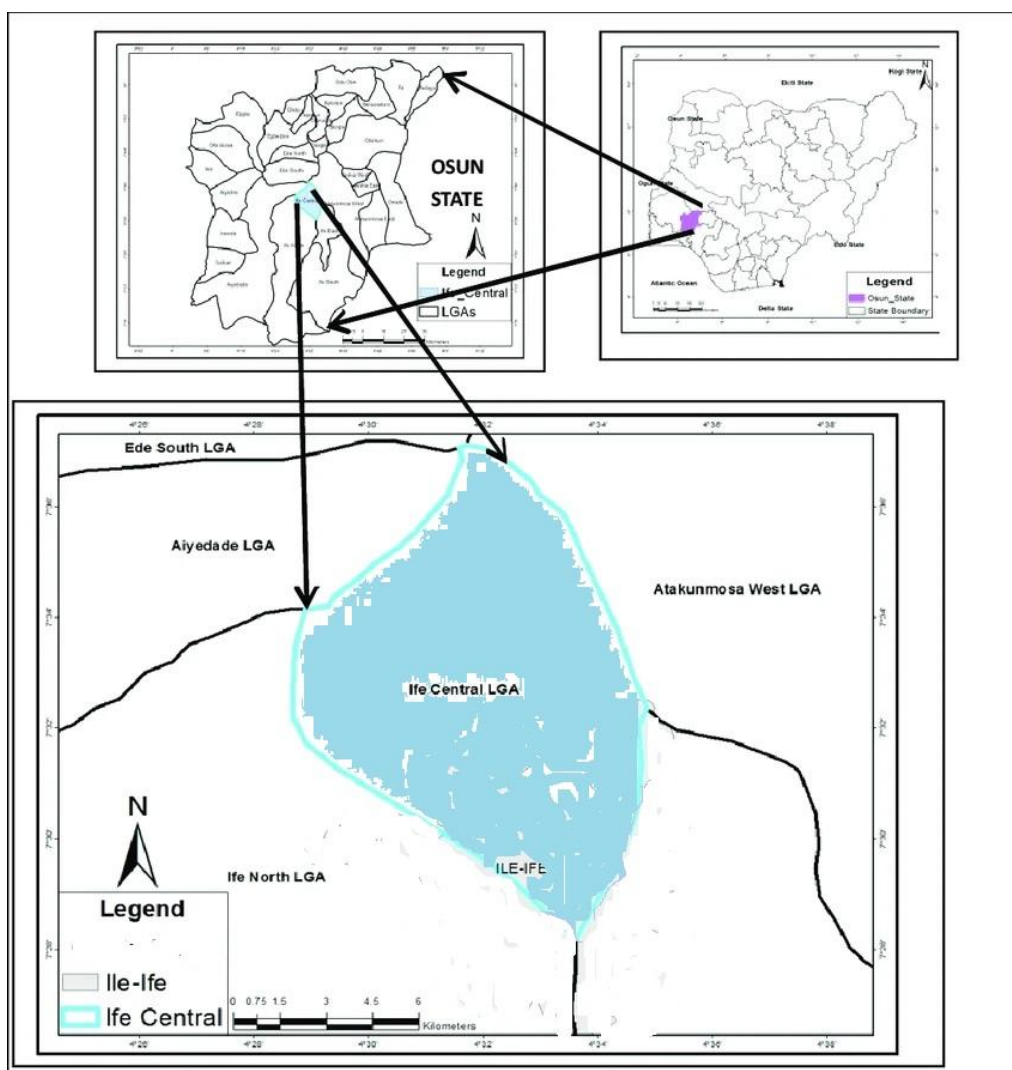


Fig. 1 Map showing the study area

## RESULTS AND DISCUSSION

Table 1a -1d show that the colour of the soils varied from dark reddish brown through brown to yellowish red (Hues-10 YR through 7.5-2.5 YR) in most layers, depicting that a residual developed on granite-gneiss in southwestern Nigeria was characterized by a Hue range of 2.5 - 7.5 YR. According to Akpan-Idiok et al. (2013), the colour variation could be associated with minerals such as goethite ( $\alpha$ -FeOOH), maghemite ( $\beta$ -Fe<sub>2</sub>O<sub>3</sub>), Hematite ( $\alpha$  Fe<sub>2</sub>O<sub>3</sub>) and Gibbsite [Al (OH)<sub>3</sub>]. The bright colour of soils in the higher topographical sites is an indication of good internal drainage (Amusan, 1991). The darker colour of the surface horizons, compared to the subsurface horizons, could be attributed to organic material deposition from litter which subsequently decomposed and mineralized (Olayinka 2009). The colour, however, became lighter with depth in all the profile pits that were examined. The Hue of 5 YR and chroma of 1 in the surface of Jago series and gray (10 YR 5/1) at the subsurface are associated with poor drainage in the pedo environment and this is an indication that the soils are somewhat poorly drained (formerly imperfectly drained) during the rainy season. The texture of the soils varied from loamy sand to very gravelly sandy clay in the surface and sandy loam to clay in the subsoil. However, there was lithologic discontinuity at the lower slope soils (profile 4) as shown by the abrupt shift in texture (Table 1a). The soils are well-developed with deep (mostly >120 cm) profiles and are characterized by gravelly sandy loam to sandy clay loam in the surface horizons and sandy loam to clay in the subsurface horizons. The coarse texture (loam to sand) is typical of the surface horizon of soils derived from crystalline basement complex rocks (Murdoch et al., 1976). This textural variation might be due to differences in the composition of the parent material, physiographic unit locations, in-situ weathering and translocation of the clay by illuviations and age of the soils (Geetha and Naidu, 2013). Coarse gravels

were slightly concentrated in the upper subsoil of all the horizons studied. This could have resulted from the eluviation of fine materials with residual concentration of stones and gravel. This probably was responsible for the fine texture of the horizons below. The surface horizons exhibited a moderate, medium crumb structure. This pedogenic feature is primarily attributed to the stabilizing influence of vegetative cover, wherein root systems exert tensile and cohesive forces that enhance aggregate stability and reduce susceptibility to disintegration. The subsurface horizons displayed a moderate, medium blocky ped structure, with aggregates ranging from sub-angular to angular blocky forms. The structure of the subsurface soils was moderate, medium, sub-angular blocky to moderate, medium, angular blocky. The blocky structure was attributed to the presence of clay fraction (Sharma et al., 2004) while the consistence (wet) of the soils varied from slightly sticky to sticky, and slightly plastic to plastic, indicating differential responses to moisture and reflecting the activity of clay minerals in relation to soil-water interactions. Boundaries between the A and B horizons were clear because of the darkening effect of soil organic matter on the surface horizons (Driessen et al., 2001). The horizon boundaries of the subsoil horizons of nearly all the soil profile pits were not easily discernible, being mainly diffuse and wavy. This, according to Naverrete et al. (2007), is common to strongly-weathered soils. The subsoil had probably passed through a process of reorganization and homogenization, resulting in the formation of "stronger" structure and well-expressed B-horizons. In all the profile pits examined, there were abundance of macro and micro pores while root concentration was restricted to the surface horizons and decreased with depth. However, soils at the valley bottom were shallow because of high water table at about 67 cm soil depth with loamy sand to sandy loam texture.

Table 1a: Morphological description of the soils

| Horizon designation                        | Depth (cm) | Colour (moist)              | Texture <sup>a</sup> | Structure <sup>b</sup> | Consistence <sup>c</sup> moist/wet | Boundary <sup>d</sup> | Concretions <sup>f</sup> | Other features                                 |
|--------------------------------------------|------------|-----------------------------|----------------------|------------------------|------------------------------------|-----------------------|--------------------------|------------------------------------------------|
| <b>Profile 1: Iwo series (upper slope)</b> |            |                             |                      |                        |                                    |                       |                          |                                                |
| A                                          | 0-15       | 5YR3/4 (Dark reddish brown) | ngrscl               | 2sbk                   | mfmssstspl                         | Dw                    | St                       | common fine and very fine and few medium roots |
| AB                                         | 15-35      | 10YR5/8 (Yellowish brown)   | grscl                | 2sbk                   | mfmssstspl                         | Dw                    | St                       | common fine and very fine and few medium roots |
| B1                                         | 35-53      | 5YR5/8 (Yellowish red)      | ngrel                | 2sbk                   | mfmstpl                            | Dw                    | Fst                      | few roots                                      |
| B2                                         | 53-65      | 5YR4/6 (Yellowish red)      | ngrel                | 3abk                   | mvfmvstpl                          | Dw                    | Fst                      | few roots                                      |
| BC1                                        | 65-140     | 5YR5/6 (Yellowish brown)    | ngrsl                | 2sbk                   | mfmstpl                            | W                     | -                        | absence of roots                               |
| BC2                                        | 140-200    | 2.5YR4/6 (Reddish brown)    | ngrc                 | 2sbk                   | mfmstpl                            | Nd                    | -                        | absence of roots                               |
| <b>Profile 2: Iwo series (mid slope)</b>   |            |                             |                      |                        |                                    |                       |                          |                                                |
| Ap                                         | 0-9        | 10YR3/3 (Dark brown)        | vgrsl                | 2cr                    | mfrnnstnpl                         | Cs                    | Fgrst                    | abundant very fine, fine and few medium roots  |
| AB                                         | 9-18       | 10YR4/4 (yellowish brown)   | vgrsl                | 2cr                    | mfrnnstnpl                         | Cs                    | Fgrst                    | abundant very fine, fine and few medium roots  |
| Bt1                                        | 18-57      | 10YR5/8 (Yellowish brown)   | vgrc                 | 3sbk                   | mfmssstspl                         | Cs                    | Fgrst                    | few fine and medium roots                      |
| Bt2                                        | 57-140     | 7.5YR5/6 (Strong brown)     | vgrc                 | 3abk                   | mvfmstpl                           | Cs                    | St                       | few gravels                                    |
| BCm                                        | 140-180    | 7.5YYR5/6 (Strong brown)    | vgrc                 | 3sbk                   | mvfmstpl                           | Nd                    | Vf                       | few gravels                                    |

<sup>a</sup>Texture: vgr =very gravelly, gr = gravelly, sgl = slightly gravelly, ng = non gravelly, sc = sandy clay, sl= sandy loam, scl = sandy clay loam, l = Loamy, ls = loamy sand, c =clay, cl = Clay Loam;

<sup>b</sup>Structure: 1 = weak, 2 = moderate, 3 = strong, cr = crumb, sbk = subangular blocky, abk = angular blocky, vf = very fine, f = fine, m = medium, c = coarse;

<sup>c</sup>Consistence: m = moist, w = wet, vfr = very friable, fr =friable, fm = firm, vfm = very firm, nst = non sticky, sst = slightly sticky, vst = very sticky, st = sticky, npl = non plastic, spl = slightly plastic pl = plastic, vpl =very plastic;

<sup>d</sup>Boundary: a = abrupt, c = clear, g = gradual, d = diffuse, s = smooth, w = wavy, ir = irregular, b = broken, ND = not determined;

<sup>e</sup>Concretions: vf = very few, f = few, fr = frequent, gr = gravel, st = stone, rd = rounded, bd = boulder.

Table 1b: Morphological description of the soils

| Horizon designation                               | Depth (cm) | Colour (moist)            | Texture <sup>a</sup> | Structure <sup>b</sup> | Consistence <sup>c</sup><br>moist/wet | Boundary <sup>d</sup> | Concretions <sup>f</sup> | Other features                                                               |
|---------------------------------------------------|------------|---------------------------|----------------------|------------------------|---------------------------------------|-----------------------|--------------------------|------------------------------------------------------------------------------|
| <b>Profile 3: Gambari series (break of slope)</b> |            |                           |                      |                        |                                       |                       |                          |                                                                              |
| A                                                 | 0-20       | 5YR5/3 (Reddish brown)    | ngsl                 | 2sbk                   | mfrsstnpl                             | dw                    | St                       | abundant fine and medium roots                                               |
| Bt                                                | 20-56      | 5YR5/8 (Yellowish red)    | sgc                  | 3abk                   | mvfmstpl                              | dw                    | Fst                      | few fine and medium roots                                                    |
| Bv1                                               | 56-110     | 5YR6/6 (Reddish yellow)   | gc                   | 3abk                   | mvfmvstpl                             | dw                    | Fst                      | few quartz materials with plinthic layer and ironstone                       |
| Bv2                                               | 110-160    | 5YR6/8 (Reddish yellow)   | vg scl               | 2sbk                   | mfmvstpl                              | nd                    | Fr                       | frequent concretionary and quartz material with plinthic layer and ironstone |
| <b>Profile 4: Oba series (lower slope)</b>        |            |                           |                      |                        |                                       |                       |                          |                                                                              |
| A                                                 | 0-20       | 5YR4/4 (Yellowish Brown)  | ng scl               | 2sbk                   | mfrsstspl                             | cs                    | -                        | abundance of very fine, fine, and few medium roots                           |
| AB                                                | 20-35      | 7.5YR5/6 (Strong brown)   | ngsc                 | 2sbk                   | mfmstpl                               | dw                    | Fgr                      | abundance of very fine, fine, and few medium roots                           |
| Bt1                                               | 35-67      | 7.5YR6/6 (Reddish yellow) | sgsc                 | 2sbk                   | mfmstpl                               | dw                    | Fgr                      | few fine and medium roots                                                    |
| Bt2                                               | 67-97      | 7.5YR7/6 (Reddish yellow) | sg scl               | 2sbk                   | mfmstpl                               | dw                    | F                        | few gravels                                                                  |
| 2BC1                                              | 97-130     | 7.5YR6/8 (Reddish yellow) | g scl                | 2sbk                   | mfmstpl                               | dw                    | Frst                     | frequent gravel and stone size and quartz materials                          |
| 2BC2                                              | 130-180    | 7.5YR6/8 (Reddish yellow) | sgsc                 | 3sbk                   | mfmvst                                | nd                    | Frst                     | frequent gravel and stone size and quartz materials                          |

<sup>a</sup>Texture: vgr = very gravelly, gr = gravelly, sgl = slightly gravelly, ng = non gravelly, c = clay, l = loam/loamy, s = sand/sandy, scl = sandy clay loam, cs = sandy clay

<sup>b</sup>Structure: 1 = weak, 2 = moderate, 3 = strong, cr = crumb, sbk = subangular blocky, abk = angular blocky, vf = very fine, f = fine, m = medium, c = coarse;

<sup>c</sup>Consistence: m = moist, w = wet, vfr = very friable, fr = friable, fm = firm, vfm = very firm, nst = non sticky, sst = slightly sticky, vst = very sticky, st = sticky, npl = non plastic, spl = slightly plastic, pl = plastic, vpl = very plastic;

<sup>d</sup>Boundary: a = abrupt, c = clear, g = gradual, d = diffuse, s = smooth, w = wavy, ir = irregular, b = broken, ND = not determined;

<sup>e</sup>Concretions: vf = very few, f = few, fr = frequent, gr = gravel, st = stone, rd = rounded, bd = boulder.

Table 1c: Morphological description of the soils

| Horizon Designation                        | Depth (cm) | Colour (moist)                 | Texture <sup>a</sup> | Structure <sup>b</sup> | Consistence <sup>c</sup><br>moist/wet | Boundary <sup>d</sup> | Concretions <sup>f</sup> | Other features                            |
|--------------------------------------------|------------|--------------------------------|----------------------|------------------------|---------------------------------------|-----------------------|--------------------------|-------------------------------------------|
| <b>Profile 5: Iwo series (upper slope)</b> |            |                                |                      |                        |                                       |                       |                          |                                           |
| A                                          | 0-33       | 7.5YR5/4 (Brown)               | sgsl                 | 2sbk                   | mfmstspl                              | cs                    | -                        | abundant very fine, fine and medium roots |
| Bt1                                        | 33-72      | 10YR5/8 (Yellowish brown)      |                      | 2sbk                   | mfmstspl                              | dw                    | fst                      | common fine and medium roots              |
| Bt2                                        | 72-95      | 7.5YR5/6 (Strong brown)        | gsc                  | 2sbk                   | mfmstspl                              | cs                    | fst                      | common fine and medium roots              |
| B                                          | 95-130     | 5YR6/8 (Reddish yellow)        | sgsc                 | 2sbk                   | mfmstpl                               | cs                    | -                        | few medium roots                          |
| BCm                                        | 130-187    | 5YR5/8 (Yellowish red)         | sgsc                 | 2sbk                   | mfmstspl                              | nd                    | -                        | -                                         |
| <b>Profile 6: Iwo series (mid slope)</b>   |            |                                |                      |                        |                                       |                       |                          |                                           |
| Ap                                         | 0-37       | 10YR3/4 (dark yellowish brown) | sgsl                 | 2sbk                   | mfmnstnpl                             | cs                    | fst                      | abundant very fine, fine and medium roots |
| Bt1                                        | 37-66      | 7.5YR5/4 (Brown)               | g scl                | 2sbk                   | mfmstspl                              | cs                    | fgrst                    | common fine and medium roots              |
| Bt2                                        | 66-94      | 7.5YR5/6 (Strong brown)        | sgc                  | 3sbk                   | mvfmstpl                              | dw                    | fst                      | few medium roots                          |
| BCm                                        | 94-150     | 7.5YR5/6 (Strong brown)        | sc                   | 2sbk                   | mfmstpl                               | nd                    | -                        | -                                         |

<sup>a</sup>Texture: vgr = very gravelly, gr = gravelly, sgl = slightly gravelly, ng = non gravelly, sc = sandy clay, sl = sandy loam, scl = sandy clay loam, l = loamy, ls = loamy sand, c = clay, cl = clay loam;

<sup>b</sup>Structure: 1 = weak, 2 = moderate, 3 = strong, cr = crumb, sbk = subangular blocky, abk = angular blocky, vf = very fine, f = fine, m = medium, c = coarse;

<sup>c</sup>Consistence: m = moist, w = wet, vfr = very friable, fr = friable, fm = firm, vfm = very firm, nst = non sticky, sst = slightly sticky, vst = very sticky, st = sticky, npl = non plastic, spl = slightly plastic, pl = plastic, vpl = very plastic;

<sup>d</sup>Boundary: a = abrupt, c = clear, g = gradual, d = diffuse, s = smooth, w = wavy, ir = irregular, b = broken, ND = not determined;

<sup>e</sup>Concretions: vf = very few, f = few, fr = frequent, gr = gravel, st = stone, rd = rounded, bd = boulder

Table 1d: Morphological description of the soils

| Horizon Designation                           | Depth (cm) | Colour (moist)            | Texture <sup>a</sup> | Structure <sup>b</sup> | Consistence <sup>c</sup><br>moist/wet | Boundary <sup>d</sup> | Concretions <sup>f</sup> | Other features                            |
|-----------------------------------------------|------------|---------------------------|----------------------|------------------------|---------------------------------------|-----------------------|--------------------------|-------------------------------------------|
| <b>Profile 7: Oba series (lower slope)</b>    |            |                           |                      |                        |                                       |                       |                          |                                           |
| Ap                                            | 0-33       | 10YR4/4 (Yellowish brown) | sgsl                 | 2sbk                   | mcrsstnpl                             | cs                    | frst                     | abundant very fine, fine and medium roots |
| Bt1                                           | 33-55      | 7.5YR5/4 (Brown)          | sgsc                 | 2sbk                   | mfmstnpl                              | dw                    | frgrst                   | common fine and medium roots              |
| Bt2                                           | 55-89      | 7.5YR5/6 (Strong brown)   | sg c                 | 3abk                   | mfmstpl                               | dw                    | vfst                     | few roots                                 |
| B                                             | 89-130     | 10YR5/8 (Yellowish brown) | sgc                  | 3abk                   | mfmvstvpl                             | cs                    | fst                      | -                                         |
| BC                                            | 130-200    | 10YR5/8 (Yellowish brown) | c                    | 3abk                   | mfmvstvpl                             | nd                    | -                        | -                                         |
| <b>Profile 8: Jago series (valley bottom)</b> |            |                           |                      |                        |                                       |                       |                          |                                           |
| Ap                                            | 0-7        | 5YR8/1 (White)            | ls                   | 1cr                    | wvfrstnpl                             | cs                    | -                        | abundant very fine, fine and medium roots |
| BCg1                                          | 7-24       | 10YR5/1 (Gray)            | ls                   | 2sbk                   | wfrstspl                              | cs                    | -                        | common fine and medium roots              |
| BCg2                                          | 24-67      | 10YR5/4 (Yellowish brown) | sl                   | 2sbk                   | wvfrstnpl                             | nd                    | -                        | common fine and medium roots              |

<sup>a</sup>Texture: sgl = slightly gravelly, ng = non gravelly, sc = sandy clay, sl = sandy loam, scl = sandy clay loam, l = loamy, ls = loamy sand, c = clay, cl = clay loam;

<sup>b</sup>Structure: 1 = weak, 2 = moderate, 3 = strong, cr = crumb, sbk = subangular blocky, abk = angular blocky, vf = very fine, f = fine, m = medium, c = coarse;

<sup>c</sup>Consistence: m = moist, w = wet, vfr = very friable, fr = friable, fm = firm, vfm = very firm, nst = non sticky, sst = slightly sticky, vst = very sticky, st = sticky, npl = non plastic, spl = slightly plastic, pl = plastic, vpl = very plastic;

<sup>d</sup>Boundary: a = abrupt, c = clear, g = gradual, d = diffuse, s = smooth, w = wavy, ir = irregular, b = broken, ND = not determined;

<sup>e</sup>Concretions: vf = very few, f = few, fr = frequent, gr = gravel, st = stone, rd = rounded, bd = boulder

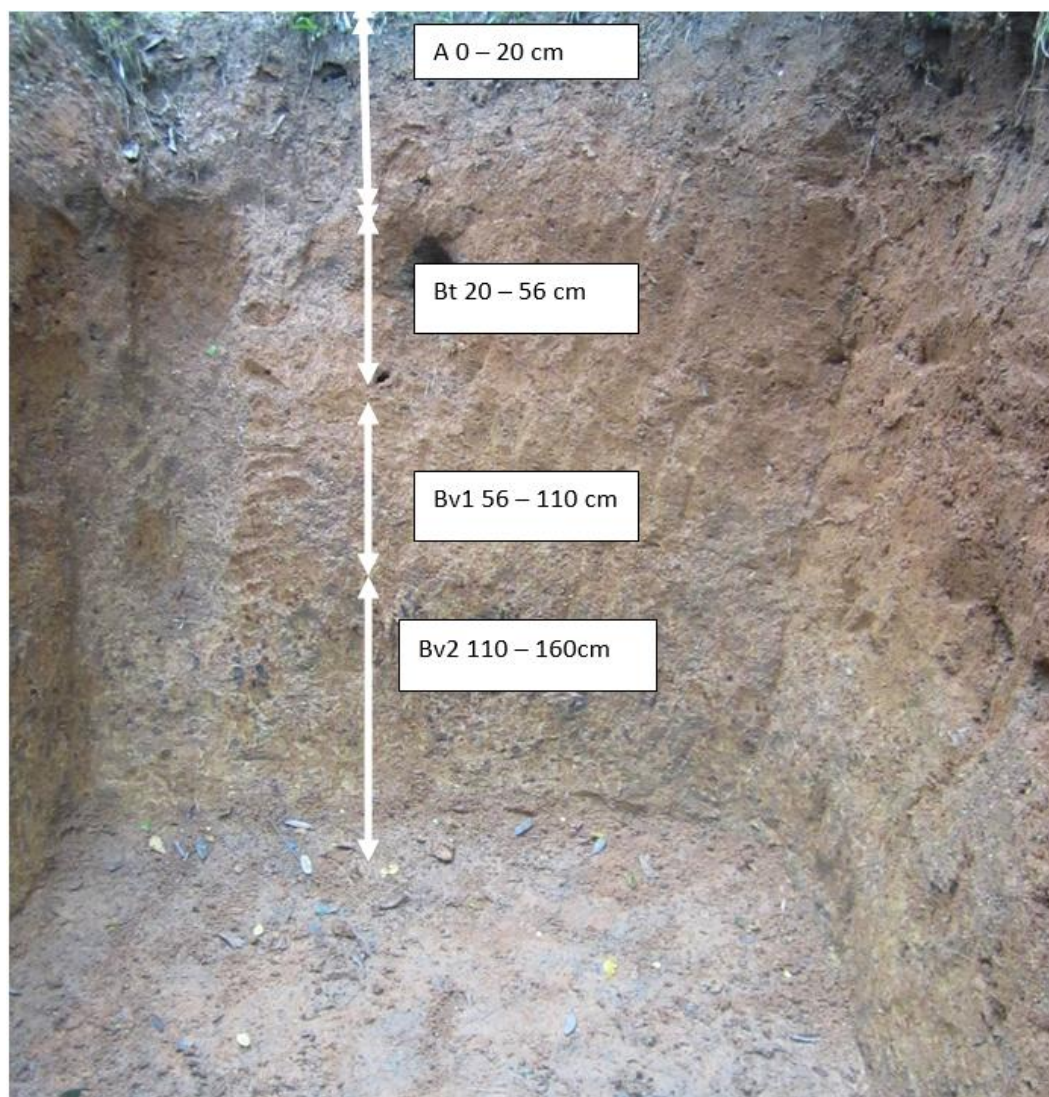


Fig. 2: One of the Gambari series soil profile pit in the study area (Profile 3)

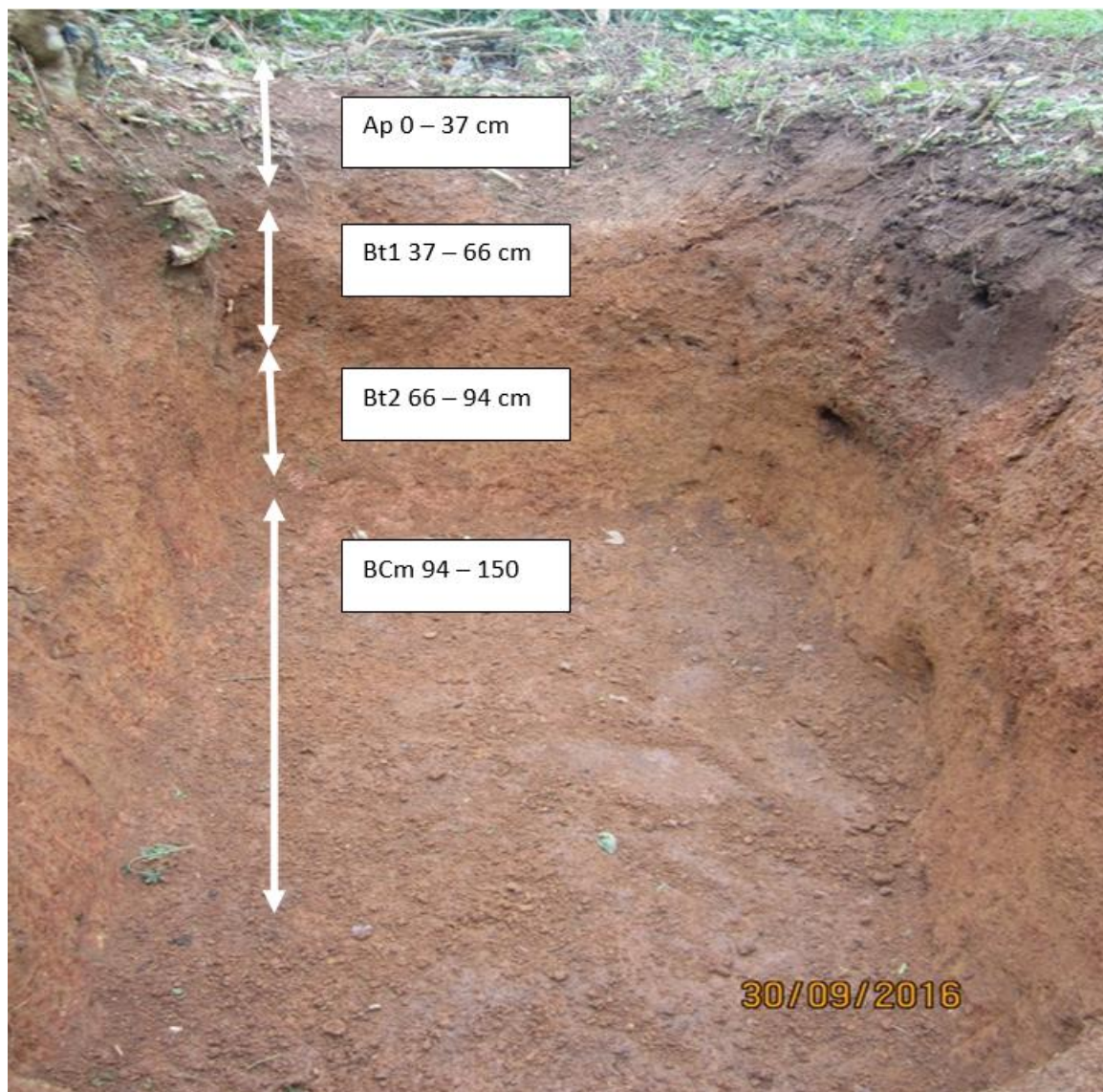


Fig. 3: One of the Iwo series soil profile pits in the study area (Profile 6)

### Physical characteristics of the soils

Tables 2a and 2b show the result of the selected physical properties of the soils. The gravel content of the soils ranged from 10.8 to 67.1 % and generally, the values increased down the profiles in all the topographic sites except that of profile 02 which fluctuated irregularly with soil depth. The high gravel content in both the surface and subsurface horizons of the Iwo series (mid slope) indicated that the soils had been formed in-situ (Adekayode, 2006). The very coarse sand fraction was more than any other sand fraction, irrespective of profile or location. This could be attributed to the fact that the soils were formed from coarse-grained granite and gneiss which are the parent rocks of the soils of Iwo Association. This is the more reason why they gave rise to coarse-grained soils (Smyth and Montgomery, 1962; Makinde et al., 2009). The predominance of sand in the surface horizons might be attributable to the fact that the soils were developed from coarse grained acidic rocks. This could also be due to preferential removal of clay and silt by soil erosion (Udo et al., 2009). The particle size distribution data showed that the total sand content ranged from 59 – 80% in the surface and 31 to 61 % in subsurface horizons of all of the soil profiles. The highest sand content recorded at the valley bottom (profile 08, Jago series) of toposequence 2 could be as a result of deposition of alluvial sediment in the valley floor (Esu et al., 2008). Generally, the sand content decreased irregularly down the profile with the exception of soil horizons with the lithologic discontinuity (profile 4). The content of silt in the soils was comparatively lower than that of the sand fraction. Okusami and Oyediran (1985) reported that most of the soils derived

from the basement complex in Southwestern Nigeria had low silt content. The silt content ranged from 6 to 19% in the soils. However, the percentage silt content was lower than that of the clay content in all the soils. The clay content varied from 6 to 41% in soils. Clay was next to sand in dominance and unlike sand, the clay content increased with soil depth in most of the soil profiles except profiles 01 and 08. Soil profiles: 02, 03, 05, 06 and 07 showed evidence of clay accumulation at some depths and this qualified the depths as argillic horizon (Bt). Schaetzl and Anderson (2005) attributed the 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. Most of the soils except profile 08 are free draining but with the clay content exceeding 20% in the subsurface horizons therefore, the soils can retain a considerable amount of water for crop production. The bulk density values showed an irregular variation among and within the soil's units pointing to differences in mineralogy, clay content and structural development. The values ranged from 1.20 to 1.64g/cm<sup>3</sup> in the Ap horizons and 1.17 to 1.81 g/cm<sup>3</sup> in the subsurface horizons. A relatively high bulk density recorded in some of the soil profiles may be related to a decrease in the pore space and possible concentration of iron oxide minerals into a gravelly layer. It had been observed that good plant growth is obtained with bulk density below 1.40 g/cm<sup>3</sup> for clay and 1.60 g/cm<sup>3</sup> for sandy soils (Donahue et al., 1990). Results of bulk density were less than the critical limits for root restriction (1.75 – 1.85 g/cm<sup>3</sup>) (Soil Survey, 2003). With the Ap horizon bulk density of 1.20 to 1.64g/cm<sup>3</sup>, the surface soils of the study

area do not appear to impose significant resistance to root penetration and growth, while still allowing adequate aeration, nutrient uptake, and water movement (Akpan-Idiok et al., 2012). The total porosity varied from 38.07 to 54.63% in the surface and 31.88 to 55.63% subsurface of the soils. Donahue et al. (1990) and Spositol (1991) noted that soils with porosity of over 50% and 40% of their volume are good agricultural soils. With the 40.72 - 55.66% in most of the horizons, the soils appear to have favourable aeration, root penetration and free water movement. The soil porosity of soil profile 06 (38.07%) at the surface and soil profile 08 (31.88 – 37.38%) at the subsurface horizons were lower than 40% when compared to other soils studied. This could be attributed to the clay nature of the soil profile 06 and the physiographic position of soil profile 08. This is in agreement with the findings of Donahue et al. (1990) and Akpan-Idiok et al. (2012) who indicated

that porosity less than 40% may lower moisture retention for crops and affect root growth adversely. The silt/clay ratios varied from 0.33-0.94 and 0.17-2.00 in the surface and subsurface soils in all the soils suggesting that the parent material may still have considerable weatherable minerals. It could also be inferred that the soils of the study area were characterized by a low to moderate degree of weathering because the silt/clay ratio in most of the horizons was greater than 0.25. Asemoa (1973) reported that soils with a silt/clay ratio of less than 0.25 were at an advanced stage of weathering, while those with ratios greater than 0.25 are indicative of a low degree of weathering. The values decreased with depth in all the soil profiles. It was observed that the values were higher at the surface horizons than the subsurface horizons; this implies that the relative intensity of weathering was greater in the subsurface horizons (Ojo-Atere and Ogunwale, 1982b).

Table 2a\*: Physical Properties of the soils

| Horizon                                    | Depth   | Gravel content | Sand Fractions |      |      |      |      | TS | Silt | Clay | Textural Class | BD<br>(g/cm <sup>3</sup> ) | Porosity<br>(%) | Silt/Clay | Silt/Silt+Clay |
|--------------------------------------------|---------|----------------|----------------|------|------|------|------|----|------|------|----------------|----------------------------|-----------------|-----------|----------------|
|                                            |         |                | VCS            | CS   | MS   | FS   | VFS  |    |      |      |                |                            |                 |           |                |
|                                            |         |                | %              |      |      |      |      |    |      |      |                |                            |                 |           |                |
| Profile 1: Iwo series (upper slope)        |         |                |                |      |      |      |      |    |      |      |                |                            |                 |           |                |
| A                                          | 0-15    | 19.5           | 18.2           | 11   | 10.1 | 15.6 | 3.6  | 59 | 12   | 29   | SCL            | 1.2                        | 54.63           | 0.41      | 0.29           |
| AB                                         | 15-35   | 43.5           | 18.3           | 9.8  | 8.6  | 13.3 | 3.1  | 53 | 12   | 35   | SCL            | 1.29                       | 51.17           | 0.34      | 0.26           |
| B1                                         | 35-53   | 54.6           | 24.2           | 9.3  | 6.5  | 8.3  | 1.8  | 50 | 9    | 41   | SC             | 1.17                       | 55.66           | 0.22      | 0.18           |
| B2                                         | 53-65   | 54.4           | 14.8           | 8.1  | 6.7  | 11.1 | 2.2  | 43 | 18   | 39   | CL             | 1.38                       | 47.98           | 0.46      | 0.32           |
| BC1                                        | 65-140  | 38.9           | 8              | 9.2  | 12.4 | 20.4 | 5.0  | 55 | 15   | 30   | SC             | 1.29                       | 51.4            | 0.5       | 0.3            |
| BC2                                        | 140-200 | 29.1           | 10.2           | 11.2 | 11.3 | 17.1 | 5.2  | 55 | 11   | 34   | SCL            | 1.37                       | 48.44           | 0.32      | 0.24           |
| Profile 2: Iwo series (mid slope)          |         |                |                |      |      |      |      |    |      |      |                |                            |                 |           |                |
| Ap                                         | 0-9     | 36.8           | 22.4           | 14.5 | 16.1 | 19.8 | 22.4 | 76 | 6    | 18   | SL             | 1.35                       | 49.13           | 0.33      | 0.25           |
| AB                                         | 9-18    | 62.5           | 28.4           | 12.5 | 12.5 | 18.8 | 28.4 | 75 | 7    | 18   | SL             | 1.55                       | 41.41           | 0.39      | 0.28           |
| Bt1                                        | 18-57   | 54.5           | 14.8           | 5.2  | 3.9  | 5.5  | 14.8 | 31 | 14   | 55   | C              | 1.51                       | 43.14           | 0.25      | 0.2            |
| Bt2                                        | 57-140  | 31.5           | 17.6           | 8.3  | 5.7  | 7.4  | 17.6 | 41 | 14   | 45   | C              | 1.57                       | 40.72           | 0.31      | 0.24           |
| BCm                                        | 140-182 | 33.6           | 12.5           | 8.2  | 5.3  | 7.6  | 12.5 | 35 | 19   | 46   | C              | 1.5                        | 43.25           | 0.41      | 0.29           |
| Profile 3: Gambari series (break of slope) |         |                |                |      |      |      |      |    |      |      |                |                            |                 |           |                |
| A                                          | 0-20    | 20.8           | 17.9           | 12.9 | 15.2 | 22.1 | 2.9  | 71 | 11   | 18   | SL             | 1.40                       | 47.02           | 0.61      | 0.38           |
| Bt                                         | 20-56   | 35.8           | 15.6           | 8.2  | 7.7  | 9.7  | 1.8  | 43 | 10   | 47   | C              | 1.43                       | 46.1            | 0.21      | 0.18           |
| Bv1                                        | 56-110  | 36             | 15.9           | 8.1  | 6.8  | 10.1 | 2.1  | 43 | 10   | 47   | C              | 1.45                       | 45.33           | 0.21      | 0.18           |
| Bv2                                        | 110-160 | 34.1           | 18.2           | 11.1 | 7.7  | 15.8 | 2.3  | 55 | 14   | 31   | SCL            | 1.22                       | 53.78           | 0.45      | 0.31           |
| Profile 4: Oba series (lower slope)        |         |                |                |      |      |      |      |    |      |      |                |                            |                 |           |                |
| A                                          | 0-20    | 8.5            | 11.3           | 9.7  | 12.7 | 21.2 | 4.1  | 59 | 16   | 25   | SCL            | 1.47                       | 44.37           | 0.64      | 0.39           |
| AB                                         | 20-35   | 18.3           | 11.8           | 9.7  | 10.8 | 16   | 2.6  | 51 | 12   | 37   | SC             | 1.53                       | 42.1            | 0.32      | 0.24           |
| Bt1                                        | 35-67   | 31.4           | 11.2           | 9.3  | 10.1 | 16.7 | 3.7  | 51 | 10   | 39   | SC             | 1.4                        | 47.06           | 0.26      | 0.2            |
| Bt2                                        | 67-97   | 34.6           | 13.6           | 8.9  | 12.7 | 22.8 | 3    | 61 | 12   | 27   | SCL            | 1.48                       | 44.33           | 0.44      | 0.31           |
| 2BC1                                       | 97-130  | 43.2           | 15             | 12   | 11.2 | 16.6 | 3.1  | 58 | 11   | 31   | SCL            | 1.47                       | 44.68           | 0.35      | 0.26           |
| 2BC2                                       | 130-180 | 40             | 18             | 14   | 12   | 13.1 | 2.9  | 60 | 10   | 30   | SC             | 1.49                       | 43.8            | 0.33      | 0.25           |

TS= Total Sand; VCS= very coarse sand; CS= Coarse sand; MS= Medium sand; FS= Fine sand; VFS= Very fine sand; BD= Bulk Density

Table 2b: Physical properties of the soils

| Horizon                                | Depth   | Sand Fractions |      |      |      |      |     |    |      |      | Textural Class | BD<br>(g/cm³) | Porosity<br>(%) | Silt/Clay | Silt/Silt+Clay |  |
|----------------------------------------|---------|----------------|------|------|------|------|-----|----|------|------|----------------|---------------|-----------------|-----------|----------------|--|
|                                        |         | Gravel content | VCS  | CS   | MS   | FS   | VFS | TS | Silt | Clay |                |               |                 |           |                |  |
|                                        |         |                | %    |      |      |      |     |    |      |      |                |               |                 |           |                |  |
| Profile 5: Iwo series (upper slope)    |         |                |      |      |      |      |     |    |      |      |                |               |                 |           |                |  |
| A                                      | 0-33    | 15.4           | 14   | 11.7 | 14.5 | 24.8 | 4   | 69 | 11   | 20   | SL             | 1.54          | 41.91           | 0.55      | 0.35           |  |
| Bt1                                    | 33-72   | 38.2           | 14.9 | 8.2  | 8.3  | 10.9 | 2.7 | 45 | 12   | 43   | SC             | 1.48          | 44.06           | 0.28      | 0.22           |  |
| Bt2                                    | 72-95   | 28.1           | 15.8 | 8.4  | 8    | 10.7 | 2   | 45 | 8    | 47   | SC             | 1.49          | 43.75           | 0.17      | 0.15           |  |
| B                                      | 95-130  | 29.1           | 15.4 | 10.1 | 9.6  | 14   | 3.8 | 53 | 8    | 39   | SC             | 1.48          | 44.33           | 0.21      | 0.17           |  |
| BCm                                    | 130-187 | 28.6           | 16.9 | 9.3  | 8.8  | 12.3 | 3.6 | 51 | 10   | 39   | SC             | 1.18          | 55.63           | 0.26      | 0.2            |  |
| Profile 6: Iwo series (mid slope)      |         |                |      |      |      |      |     |    |      |      |                |               |                 |           |                |  |
| Ap                                     | 0-37    | 21.3           | 11.5 | 9.2  | 15.5 | 25.6 | 3.1 | 65 | 17   | 18   | SL             | 1.64          | 38.07           | 0.94      | 0.49           |  |
| Bt1                                    | 37-66   | 41.8           | 15.1 | 12.3 | 8.9  | 18.9 | 3.8 | 59 | 14   | 27   | SCL            | 1.46          | 44.75           | 0.52      | 0.34           |  |
| Bt2                                    | 66-94   | 43.4           | 7.7  | 16.7 | 5.3  | 10.3 | 2.9 | 43 | 12   | 45   | C              | 1.38          | 47.9            | 0.27      | 0.21           |  |
| BCm                                    | 94-150  | 33             | 14.1 | 9.9  | 7.9  | 12.2 | 2.9 | 47 | 13   | 40   | SC             | 1.49          | 43.79           | 0.33      | 0.25           |  |
| Profile 7: Oba series (lower slope)    |         |                |      |      |      |      |     |    |      |      |                |               |                 |           |                |  |
| Ap                                     | 0-33    | 28.8           | 13.8 | 10.3 | 18.6 | 28.9 | 3.4 | 75 | 10   | 15   | SL             | 1.27          | 51.9            | 0.67      | 0.4            |  |
| Bt1                                    | 33-55   | 67.1           | 12.9 | 9.1  | 8.9  | 12.6 | 2.6 | 46 | 11   | 43   | SC             | 1.45          | 45.1            | 0.26      | 0.2            |  |
| Bt2                                    | 55-89   | 56             | 14.8 | 7.5  | 4.8  | 9.3  | 2.6 | 39 | 14   | 47   | C              | 1.25          | 52.67           | 0.3       | 0.23           |  |
| B                                      | 89-130  | 44.8           | 12.8 | 7.4  | 6.6  | 9.1  | 2.1 | 38 | 15   | 47   | C              | 1.39          | 47.36           | 0.32      | 0.24           |  |
| BC                                     | 130-200 | 46.2           | 10.2 | 6.2  | 6.9  | 12.6 | 3.0 | 39 | 16   | 45   | C              | 1.27          | 51.98           | 0.36      | 0.26           |  |
| Profile 8: Jago series (valley bottom) |         |                |      |      |      |      |     |    |      |      |                |               |                 |           |                |  |
| Ap                                     | 0-7     | 12.7           | 16.7 | 18.7 | 18.9 | 23   | 2.8 | 80 | 12   | 8    | LS             | 1.22          | 54.01           | 1.5       | 0.6            |  |
| BCg1                                   | 7-24    | 18.6           | 15.4 | 15.6 | 19.3 | 28.6 | 3.1 | 82 | 12   | 6    | LS             | 1.66          | 37.38           | 2         | 0.67           |  |
| BCg2                                   | 24-67   | 10.8           | 15.3 | 15.7 | 20.9 | 23.4 | 2.7 | 78 | 10   | 12   | SL             | 1.81          | 31.88           | 0.83      | 0.45           |  |

TS= Total Sand; VCS= very coarse sand; CS= Coarse sand; MS= Medium sand; FS= Fine sand; VFS= Very fine sand; BD= Bulk Density

### Chemical properties of the soils

The acidity of the soil varies from slightly acidic to strongly acidic (Table 3a and 3b) with pH range of 5.10 to 6.50 in water and 4.10 to 5.60 in 1 M KCl. The surface horizons of the soils are slightly acidic in reaction while the subsoil is strongly acidic in reaction. This could be as a result of high rainfall in the area which made the soils fragile and susceptible to erosion and leaching (Udo et al., 2009). The values of pH measured in 1M KCl suspension were lower than those pH values measured in distilled water. However, the value for both pH in H<sub>2</sub>O and KCl showed that there was no definite pattern of change in pH down the slope in all the soil profiles studied. The values were higher at the surface horizons of most of the soil profiles. Phytocycling and upward movement of bases due to intense evapotranspiration during the dry season in the humid tropics were suggested to have accounted for the relatively higher pH of the surface horizons (Amusan, 1991). The delta pH (i.e. pH KCl - pH H<sub>2</sub>O) was negative in all the soil horizons and this suggests that silicate clay mineralogy is dominant over oxidic mineralogy as suggested (van Raij and Peech, 1972) or that there is presence of negatively charged colloidal particles (Soil Survey Staff, 2009). All the soil profiles irrespective of their physiographic position revealed low electrical conductivity values ranging from 0.02 to 0.34 dS/m, indicating non-saline nature of the soils. The low electrical conductivity may be due to free drainage condition which favoured the removal of released bases by percolation and drainage. The total exchangeable acidity values for the surface soils ranged from 0.30 to 1.10 cmol/kg in the soils. The values showed low exchangeable acidity indicating that the level of exchangeable aluminum is still below the toxic range (Ajiboye et al., 2011). The soil organic matter (SOM) content was low to high. The soils of organic matter content ranged from 0.20 to 4.5%. The soil organic matter content decreased with depth in all the soil profiles except profile 04 which showed irregular trend with depth. The higher organic matter content at the surface (0.70- 4.5 %) of most of the soil profiles could be added to more decomposable plant materials on the surface soil (Ashok Kumar and Jagdish, 2010). The total nitrogen content varied from low to high (0.1 to 0.6 %) in the entire soils profile pit. The values decreased with increasing depth in all the soil profiles. The relatively higher values in the surface horizon of the profiles could be attributed to higher organic carbon contents, which were enhanced by nutrient cycling through litter fall (Onyekwere et al., 2001). All the values were above the critical value of 0.2 % where response is unlikely and fertilizer application may not be necessary (FPDD, 1989). The available P ranged from 2.20 – 19.20 ppm in the soils. The highest value recorded at the surface horizons is an indication that soil organic matter contributes significantly to

the available phosphorus content of the soils. Most of the soil available P values except profile 2 and profile 8 were considered high for the surface horizon because they were greater than 10 ppm and above the critical limit recommended for most commonly cultivated crops in southwestern Nigeria (Obigbesan, 2009). The values were also above the critical value of 8.5 ppm soil available P suggested for the soils in the derived savanna and places the soils in the medium P fertility class when compared with the soil test criteria and fertility map developed for Nigeria (FMANR, 1990). The lower available phosphorus content in the sub-surface horizon as compared to surface horizon may be due to fixation of the released phosphorus by clay minerals and oxides of iron and aluminum (Jubrin et al., 2000). Like in most tropical soils, the exchangeable sites of the soils studied were dominated by exchangeable calcium. The exchangeable calcium for the soils varied from 0.56 to 4.21 cmol/kg. The calcium content decreased irregularly with soil depth in most of the soil profiles except 3 and 5 which fluctuated irregularly with soil depth. The values showed that the calcium content of the surface horizon decreased across the slope for most of the profiles while it increased in soil profile 2. However, the values fluctuated irregularly across the slope for B horizons. The exchangeable magnesium content ranged from 0.28 to 0.65 cmol(+)/kg. The values fluctuated irregularly with profile depth and across the slope for both surface and subsurface horizons. The soils were rated moderately high considering the critical values of 0.4 Mg cmol(+)/kg soil for most crops (Fasina et al., 2005). Exchangeable K<sup>+</sup> varied from 0.14 to 0.53 cmol(+)/kg in the soils. The K<sup>+</sup> content was low to moderate considering the critical values of 0.20 K<sup>+</sup> cmol(+)/kg (Unamba-Opara, 1985) and adequate based on critical value of 0.15 K<sup>+</sup> cmol(+)/kg soil for most crops (Fasina et al., 2005). The values increased irregularly with soil depth in some soil profiles while others showed irregular distribution. With 0.16 cmol(+)/kg of K<sup>+</sup> and 0.28 cmol(+)/kg soil of Mg<sup>2+</sup> by Agboola and Ayodele (1985) as critical limit for exchangeable K and Mg, respectively, 10.0% of the soils would probably respond to K fertilizer application while only 5.0% of the soils may be deficient in Mg. The exchangeable Na<sup>+</sup> ranged from 0.1 to 0.65 cmol(+)/kg. The values decreased with soil depth in most of the soil profiles except profiles 2 and 07 which had no definite pattern. The cations occur in the order: Ca> Mg >K >Na at the exchangeable site. The low values of exchangeable bases of the soils may be attributed to high rainfall intensity, intensity of weathering, leaching and lateral translocation of bases (Solarin, 2000). Amhakhian and Osemwota (2011) showed that exchangeable cations were lost from the exchange site complex in the following order Ca<Mg<K<Na. The results showed that ECEC ranges between 1.68 and 5.67

cmol/kg for all the soils an indication that the ECEC values of the soils are low. The ECEC values decreased down the soil profiles in most of the soils. The low ECEC content indicated that the soils had low potential for retaining plant nutrients hence the need for adequate soil management. Generally, the values were low and this is similar to the findings of Agboola and Unamma (1991) who asserted that forest soils in the tropics were subjected to intensive weathering and leaching, which had resulted in a high proportion of kaolinitic clays with low cation exchange capacity of 3 – 15 cmol(+)/kg. The low ECEC content of the soils could also be attributed to the high rate of weathering and leaching of the basic cations in these soils as a result of high temperature and rainfall associated with a humid tropical climate. Cation exchange capacity (CEC - pH 8.2) values were generally higher than the corresponding ECEC values. This is attributed to the increase in negative charges due to the high pH of the extractant.

#### Relationship between the soils' physical and chemical properties

Results from the correlation analyses of the physical and chemical properties of the soils (Table 4) showed that the sand content of the soils had negative and significant relationship with the silt and clay content; positive relationship with pH (H<sub>2</sub>O) and soil organic matter ( $r = -0.40^{**}$ ;  $-0.98^{**}$ ;  $0.40^{**}$  and  $0.45^{**}$  respectively) implying that the sandier the soil is, the lower the silt and clay content of the soil but the higher the pH (H<sub>2</sub>O) and soil organic matter. The clay content showed a negative and significant relationship with the soil's pH (H<sub>2</sub>O) and organic matter ( $r = -0.41^{**}$ ;  $-0.46^{**}$ ). The SOM showed a positive and significant relationship with AP, TEB, ECEC, and BS ( $r = 0.44^{**}$ ;  $0.56^{**}$ ;  $0.54^{**}$  and  $0.47^{**}$ ). These are indicative of the fact that most of these mineral nutrients are present in SOM and they will be released upon mineralization. It also implies that loss of SOM would lead to a corresponding depletion of these nutrients.

Table 3a: Chemical properties of the soil3s

| Horizon                                                       | Depth<br>(cm) | pH<br>H <sub>2</sub> O | pH<br>KCl | Δ<br>pH | EC<br>dS/m | OM               | TN               | AP<br>(ppm)    | Exchangeable Bases |      |                             |                | TEA  |      |      | TA  | ECEC | CEC  | BS    |
|---------------------------------------------------------------|---------------|------------------------|-----------|---------|------------|------------------|------------------|----------------|--------------------|------|-----------------------------|----------------|------|------|------|-----|------|------|-------|
|                                                               |               | ← 1:1 →                |           | ← % →   |            | Ca <sup>2+</sup> | Mg <sup>2+</sup> | K <sup>+</sup> | Na <sup>+</sup>    | TEB  | Al <sup>3+</sup><br>Cmol/Kg | H <sup>+</sup> |      |      |      |     |      |      |       |
|                                                               |               |                        |           |         |            |                  |                  |                |                    |      |                             |                |      |      |      |     |      |      |       |
| ← % →                                                         |               |                        |           |         |            |                  |                  |                |                    |      |                             |                |      |      |      |     |      |      |       |
| Profile 1 (upper slope): typical isohyperthermic paleustults  |               |                        |           |         |            |                  |                  |                |                    |      |                             |                |      |      |      |     |      |      |       |
| A                                                             | 0-15          | 5.7                    | 4.7       | -1      | 0.08       | 2.1              | 0.6              | 14.1           | 2.42               | 0.37 | 0.22                        | 0.26           | 3.27 | 0.1  | 0.5  | 0.6 | 3.87 | 14.0 | 23.40 |
| AB                                                            | 15-35         | 5.8                    | 4.6       | -1.2    | 0.03       | 0.9              | 0.5              | 9.2            | 1.82               | 0.36 | 0.19                        | 0.21           | 2.57 | 0.1  | 0.2  | 0.3 | 2.87 | 12.0 | 21.50 |
| B1                                                            | 35-53         | 5.8                    | 4.6       | -1.2    | 0.02       | 0.9              | 0.5              | 6.5            | 1.33               | 0.35 | 0.19                        | 0.16           | 2.03 | 0.1  | 0.3  | 0.4 | 2.43 | 5.2  | 39.00 |
| B2                                                            | 53-65         | 5.7                    | 4.7       | -1      | 0.02       | 0.8              | 0.2              | 5.1            | 0.86               | 0.33 | 0.18                        | 0.17           | 1.54 | 0.1  | 0.3  | 0.4 | 1.94 | 7.0  | 22.00 |
| BC1                                                           | 65-140        | 5.6                    | 4.5       | -1.1    | 0.11       | 0.5              | 0.1              | 8.4            | 0.71               | 0.29 | 0.15                        | 0.14           | 1.29 | 0.3  | 0.2  | 0.5 | 1.79 | 11.4 | 11.32 |
| BC2                                                           | 140-200       | 5.5                    | 5.2       | -0.3    | 0.02       | 0.2              | 0.1              | 6.9            | 0.79               | 0.34 | 0.16                        | 0.11           | 1.39 | 0.1  | 0.4  | 0.5 | 1.89 | 5.2  | 26.73 |
| Profile 2 (mid slope): typical isohyperthermic paleustults    |               |                        |           |         |            |                  |                  |                |                    |      |                             |                |      |      |      |     |      |      |       |
| Ap                                                            | 0-9           | 6.4                    | 5.4       | -1      | 0.03       | 2.8              | 0.6              | 6.3            | 1.74               | 0.31 | 0.18                        | 0.2            | 2.43 | 0.1  | 0.4  | 0.5 | 2.93 | 16.0 | 15.19 |
| AB                                                            | 9-18          | 6.5                    | 5.4       | -1.1    | 0.08       | 1.1              | 0.4              | 9.8            | 1.02               | 0.37 | 0.2                         | 0.12           | 1.71 | 0.1  | 0.3  | 0.4 | 2.11 | 18.4 | 9.29  |
| Bt1                                                           | 18-57         | 5.6                    | 4.3       | -1.3    | 0.03       | 0.9              | 0.5              | 7.1            | 0.64               | 0.31 | 0.35                        | 0.18           | 1.48 | 0.2  | 0.4  | 0.6 | 2.08 | 15.6 | 9.49  |
| Bt2                                                           | 57-140        | 5.5                    | 4.3       | -0.2    | 0.03       | 0.5              | 0.3              | 3.9            | 0.56               | 0.3  | 0.4                         | 0.17           | 1.43 | 0.2  | 0.4  | 0.6 | 2.03 | 20.8 | 6.90  |
| BCm                                                           | 140-182       | 5.6                    | 4.3       | -1.3    | 0.03       | 0.1              | 0.1              | 3.3            | 0.94               | 0.38 | 0.31                        | 0.12           | 1.75 | 0.2  | 0.3  | 0.5 | 2.25 | 23.0 | 7.60  |
| Profile 3 (lower slope): plinthic isohyperthermic paleustults |               |                        |           |         |            |                  |                  |                |                    |      |                             |                |      |      |      |     |      |      |       |
| A                                                             | 0-20          | 6.5                    | 5.4       | -1.1    | 0.11       | 1.7              | 0.5              | 13.3           | 1.25               | 0.35 | 0.2                         | 0.23           | 2.03 | 0.1  | 0.3  | 0.4 | 2.13 | 14.8 | 13.72 |
| Bt                                                            | 20-56         | 6.1                    | 5.2       | -0.9    | 0.11       | 0.7              | 0.3              | 11.8           | 3.13               | 0.37 | 0.2                         | 0.21           | 3.91 | 0.1  | 0.3  | 0.4 | 4.31 | 12.0 | 32.58 |
| Bv1                                                           | 56-110        | 5.9                    | 4.7       | -1.2    | 0.03       | 0.9              | 0.3              | 2              | 1.33               | 0.32 | 0.3                         | 0.14           | 2.09 | 0.2  | 0.3  | 0.4 | 2.49 | 14.0 | 14.92 |
| Bv2                                                           | 110-160       | 5.5                    | 4.5       | -1.0    | 0.03       | 0.8              | 0.1              | 2.7            | 1.09               | 0.35 | 0.25                        | 0.12           | 1.81 | 0.2  | 0.1  | 0.4 | 2.21 | 15.6 | 11.60 |
| Profile 4 (lower slope): typical isohyperthermic paleustults  |               |                        |           |         |            |                  |                  |                |                    |      |                             |                |      |      |      |     |      |      |       |
| A                                                             | 0-20          | 5.8                    | 5.1       | -0.7    | 0.12       | 0.7              | 0.1              | 11.4           | 1.99               | 0.38 | 0.18                        | 0.2            | 2.75 | 0.2  | 0.3  | 0.5 | 3.25 | 12.0 | 22.92 |
| AB                                                            | 20-35         | 5.4                    | 4.3       | -1.1    | 0.03       | 1.2              | 0.3              | 10.8           | 0.86               | 0.36 | 0.14                        | 0.2            | 1.56 | 0.15 | 0.45 | 0.6 | 2.16 | 10.0 | 15.60 |
| Bt1                                                           | 35-67         | 5.5                    | 4.5       | -1      | 0.03       | 1.3              | 0.3              | 8.4            | 0.94               | 0.38 | 0.16                        | 0.17           | 1.64 | 0.05 | 0.45 | 0.5 | 2.14 | 13.0 | 12.62 |
| Bt2                                                           | 67-97         | 5.8                    | 4.8       | -1      | 0.03       | 0.7              | 0.3              | 3.7            | 1.91               | 0.37 | 0.21                        | 0.19           | 2.67 | 0.05 | 0.35 | 0.4 | 3.07 | 15.0 | 17.80 |
| 2BC1                                                          | 97-130        | 5.3                    | 4.2       | -1.1    | 0.13       | 0.9              | 0.1              | 6.3            | 0.71               | 0.38 | 0.17                        | 0.11           | 1.36 | 0.15 | 0.35 | 0.5 | 1.86 | 12.8 | 10.63 |
| 2BC2                                                          | 130           | 5.1                    | 4.2       | -0.9    | 0.03       | 0.7              | 0.5              | 5.5            | 0.69               | 0.34 | 0.14                        | 0.11           | 1.28 | 0.1  | 0.3  | 0.4 | 1.68 | 12.8 | 10.00 |

OM= Organic Matter; TN= Total Nitrogen; AP= Available P; TEB= Total Exchangeable Bases; TEA= Total Exchangeable Acidity; EC= Electrical Conductivity; ECEC= Effective Cation Exchange Capacity; BS = Basa Saturation

Table 3b: Chemical properties of the soils

| Horizon | Depth<br>(cm) | pH<br>H <sub>2</sub> O | pH<br>KCl | Δ<br>pH | EC<br>dS/m | OM | TN | AP<br>(ppm) | Exchangeable Bases |   |   |   | TEA |  | TA | ECEC | CEC | BS |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |    |
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OM= Organic Matter; TN= Total Nitrogen; AP= Available P; TEB= Total Exchangeable Bases; TEA= Total Exchangeable Acidity; EC= Electrical Conductivity; ECEC= Effective Cation Exchange Capacity; BS = Basa Saturation

Table 4: Pearson correlation coefficients of the soils' physical and chemical properties

|      | Sand    | Silt  | Clay    | pH (H <sub>2</sub> O) | OM     | TN    | AP     | TEB    | ECEC   | CEC   | BS |
|------|---------|-------|---------|-----------------------|--------|-------|--------|--------|--------|-------|----|
| Sand |         |       |         |                       |        |       |        |        |        |       |    |
| Silt | -0.40** |       |         |                       |        |       |        |        |        |       |    |
| Clay | -0.98** | 0.2   |         |                       |        |       |        |        |        |       |    |
| pHw  | 0.40**  | -0.09 | -0.41** |                       |        |       |        |        |        |       |    |
| OM   | 0.45**  | -0.11 | -0.46** | 0.45**                |        |       |        |        |        |       |    |
| TN   | 0.07    | 0.17  | -0.11   | 0.25                  | 0.03   |       |        |        |        |       |    |
| AP   | 0.14    | 0.04  | -0.15   | 0.01                  | 0.44** | 0.04  |        |        |        |       |    |
| TEB  | 0.08    | 0.08  | -0.1    | 0.18                  | 0.56** | 0.19  | 0.54** |        |        |       |    |
| ECEC | 0.03    | 0.12  | -0.07   | 0.15                  | 0.54** | 0.18  | 0.55** | 0.99** |        |       |    |
| CEC  | -0.23   | 0.04  | 0.24    | 0.11                  | 0.07   | -0.11 | 0.02   | 0.08   | 0.08   |       |    |
| BS   | 0.13    | 0     | -0.14   | 0.2                   | 0.47** | 0.18  | 0.46** | 0.71** | 0.70** | -0.27 |    |

\* Significant at  $P \leq 0.05$ \*\* Significant at  $P \leq 0.01$ 

OM = Organic matter; TN = Total Nitrogen, AP = Available phosphorus, TEB = Total exchangeable bases, ECEC = Effective Cation Exchange Capacity; CEC = Cation Exchange Capacity, BS = Base saturation.

### Classification of the soils

According to Smyth and Montgomery (1962), the key criteria utilized in dividing soils into series levels were parent rock type, drainage, profile morphology, and mechanism of formation. The soils along the two toposequences at the mid-slope positions (soil profiles 1, 2, 5, and 6) were categorized as Iwo, Gambari (profile 3: break of slope), and Oba (profiles 4 and 7 at the lower slope), whereas profile 8 was classed as Jago at the valley bottom. Except for 8, all of the soil profiles were classed as Ultisols based on CEC and significant clay content. The soils have been dried for more than 90 days but less than 180. The moisture regime of southern Nigerian upland soils has been classed as ustic (Okusami and Oyediran, 1985), putting the soils in the Ustults suborder. In southwestern Nigeria, the soil temperature regime is isohyperthermic (Amusan and Ashaye, 1991). The landscape is old and has remained geologically stable; it is pale and typical of the pedons. Pedons 01, 02, 04, 05, 06, and 07 are thus categorized as Typic isohyperthermic paleustults in the USDA Soil Taxonomy, however pedons 03 with petroplinthite material within 100 cm of the soil surface qualified as Plinthic isohyperthermic paleustults. However, due to the existence of an argillic B horizon, low ECEC, and low base saturation, soil profiles 1, 2, 4, 5, 6, and 7 were categorized as Lixisol in the FAO/UNESCO system of soil classification. Plinthic Lixisol was assigned to soil profile 03 with petroplinthite material, but soil profile 8 (Jago series) exhibited little or no evidence of the development of pedogenic layers, with the horizons appearing to have evolved as a result of successive alluvial deposition. Because of its high sand concentration of 78 to 82%, it fits into Entisols at the order and suborder levels. It is aquicpsament at the great group due to the aquic moisture regime and water table at 67 cm depth. As a result, it was classed as Typic aquicpsament and associated with Fluvisol. (FAO/UNESCO, 2006).

### CONCLUSION

The study investigated the morphological, physical, and chemical properties of soils across varying topographic positions within the study area. Soils were generally deep and well-drained, except at the valley bottom, where shallow, poorly drained profiles dominated. Surface horizons exhibited colors ranging from dark reddish brown (5YR3/4) to dark yellowish brown (10YR3/4), while subsurface horizons ranged from yellowish red (7.5YR5/6) to yellowish brown (10YR5/8). Textural classes ranged from loamy sand to highly gravelly sandy clay at the surface and from sandy loam to clay in the subsoil, with moderate, medium, sub-angular blocky structures. Gravel content ranged from 8.5–67.1%, bulk density from 1.17–1.81 g/cm<sup>3</sup>, and porosity from 38.07–54.63% at the surface and 31.88–55.63% in the subsurface. The soils were slightly to moderately acidic, with low to moderate levels of total exchangeable bases, organic matter, nitrogen, and available phosphorus. Organic matter was identified as a key determinant of nutrient availability. Taxonomically, upper and mid-slope soils were classified as Typic isohyperthermic paleustults, lower-slope soils as Plinthic isohyperthermic paleustults, and valley-bottom soils as Aquic psamment under USDA Soil Taxonomy, corresponding to Lixisol, Plinthic Lixisol, and Fluvisol in FAO/UNESCO classification. Overall, the soils exhibited low to medium fertility, emphasizing the need for sustainable soil management. Adoption of practices such as fertilizer application, crop residue incorporation, and organic manure utilization is recommended to enhance productivity and ensure the long-term sustainability of soil resources in the region.

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