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Analysis of Morphological and Physical Parameters of the Upland Soils in Southwestern Nigeria

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Abstract

Morphological and physical characteristics are important determinant factors and indicators of soil nutrient availability, sustainability and consequently soil productivity part of which contribute significantly to food security. This study characterized the upland soils in Akure North, Southwestern Nigeria in order to determine their capacity to support food production with the ultimate focus to ensure food security. Contour and topographic maps of the study communities were used to site profile pits under free survey technique. Soil depth was moderate to very deep (52 - 170 cm) with predominantly black (5YR and 7.5YR) and brownish black (2.5YR and 5YR) colours at the 'A/Ap' horizons and mottles of (10YR) in the subsoils were recorded. Soil structure varied widely from friable to moderately angular blocky. Soil consistency (moist) varied from loose to firm. The textures of the soils were predominantly loamy sand and sandy loam. The topsoils had lower bulk density, higher total porosity and higher hydraulic conductivity compared to the subsoils. The soils were classified as Udalfs at the Suborder level of Soil Taxonomy (USDA). Application of organic materials will help to maximize the potential of these soils for sustainable agricultural productivity. Specifically, the application of organic residues would generally lower the bulk densities and regulate the hydraulic conductivity of the soils. It is recommended that the soils of the study area be improved by addition of organic matter which will inturn, enhance the soil morphological and physical properties.

Keywords: Food Security, Upland, Soil Morphology, Soil Physical Characteristics, Soil Colour

Introduction

The upland soils are important landscape for achieving food security in the tropics as they occupy a large proportion of the landmass compared to the lowland soils. The upland soils are however known to have such limitations as poor water holding capacity, erosion hazards and low organic carbon content due to rapid mineralization. This is attributed to the report by Singh and Mishra (1995) that soil properties vary due to the factor of topographic influence on soil erosion, radiation intensity, and amount of water that enters the soil, material movement and distribution. In Nigeria, upland crop production is restricted to the rain fed cropping seasons and such upland soils are being rapidly degraded with attendant decline in productivity (Alasiri, 2001). This rapid degradation is not unconnected with the slash-and-burn agriculture, which is now being practiced with shortened fallow period because of high population growth rate (Onyekwere *et al.,* 2001). However, depending on the hydrology, rainfall pattern and availability of irrigation, soils at the higher topographic elevations (upland) could also be good grounds for crop production (Tuong *et al.,* 1991; Selbut, 2003; Ya'u *et al.,* 2014). Thus, the upland soils cannot be ignored in our attempt to achieve food security in Nigeria.

Processes directly related to topography often influenced the rate of soil property removal from the upland through erosion and deposition at the lowlands. Consequently, differences in topographic position lead to differentiation in soil properties and hydrological conditions (Tsubo *et al.,* 2006). Krasilnikov *et al.* (2005) corroborated that soil properties along a topographic sequence may differ due to degree of erosion, transport and deposition of chemical and particulate constituents of the soil. Irespective of the landscape however, certain soil characteristics which determine productivity may be used as a criteria to guide the farmers in the choice of crops and for general agricultural practices. Morphological and physical characteristics are some of the important determinant factors and indicators that influence soil nutrient availability.

There exist significant relationship between parent material and some soil morphological, physical and chemical properties (Young, 1976; Akamigbo and Asadu, 1983). However, soils derived from the same parent material under the same geographic and climatic conditions may vary extensively in their characteristics (Kolo *et al.,* 2009a; Ezeaku and Iwuanyanwu, 2013; Feng-bo *et al.,* 2015). These vertical/ lateral variations may be noticed within soil profile depth, along vegetation gradient and/ or across a topograhic sequence. It was observed that soils are morphologically composed of horizons which differ in appearance, thickness and properties influenced by the parent material, climate, organisms and topography interacting over a period of time (Kang and Tripathi, 1992; Rhoades, 2006; Ritter, 2009). According to Kang and Tripathi (1992) and Sharu *et al.,* (2013), soil classification is meant to group soils of similar properties in one class in order to organize knowledge, compare soil properties and facilitate exchange of information on soils found in different areas. Environments that share comparable soil forming factors will often produce similar types of soil (Pidwirny, 2006). Each soil, based on its physical and morphological characteristic has a predictable response to management or any kind of manipulation (Chikezie *et al.,* 2010). A good knowledge of the strength(s) and limitation(s) of any soil based on its morphological characteristics and physical stability is desirable for its best use and/ or appropriate management practices for profitable production. Generally, consistent investigation of the morphological and physical characteristics of the soils will provide the necessary information for suitable use and proper management of soils with a focus that the lands support crop production profitably towards food security in Nigeria. The main objective of this study was to examine the morphological and physical characteristics of the soils in Akure North Southwestern Nigeria and to relate its significance to agricultural productivity and food security.

Materials and Methods: Study Area: Akure North Local Government Area is located in the humid tropics at ($7^0$25'30"N, $5^0$10'0"E) and ($7^0$5'35"N, $5^0$28'30"E) of Ondo State in Southwestern Nigeria (Figure 1). The mean annual total precipitation of the area exceeds 2000 mm (Anifowose, 1989; Ajayi *et al.,* 2012). The monthly temperature averages about 24°C with the mean monthly relative humidity of about 75%. The area is characterized by rolling topography (Anifowose, 1989). The most outstanding characteristics of the upland landscape of the study area is the proliferation of many rock outcrops (Plate 1). The parent material of the soils of the study area is the Precambrian basement complex rock (Mogaji *et al.,* 2011). The predominant mineral constituents of the soils around the study area are essentially feldspars, quartz and biotic mica (Adepelumi *et al.,* 2006).

The study area is highly forested. The rainfall pattern which is well distributed in addition to high humidity keeps the vegetation green almost all the year round. Over the years however, there has been some ecological damage by human activities through clearing of forests, cultivation and bush burning (Anifowose, 1989). As a result, the original forest is now restricted to forest reserves. An important economic aspect of the vegetation of the study area is the prevalence of tree crops which include cocoa (*Theobroma cacao*), kola (*Cola acuminata*), oil palms (*Elaeis guineensis*) and citrus (*Citrus sinensis*). The natural and the reserved forests in this area are characterized by the following tree species: *Melicia excelsa, Antaris africana, Terminalia superba, Lophira procera, Symphonia globulifera, Blighia sapida, Parkia biglobosa, Gmelina arborea* and *Tectona grandis*. The land use of the study area is mainly cultivation of rain fed crops which includes cocoa, maize, plantain, banana, melon, water melon, sweet potatoes, yam and cassava at the upland. At the lowland areas, rice, cocoyam and cassava are cultivated in alternate seasons.

Field and Analytical Procedure: Four non-contiguous communities (Ita-Ogbolu, Igoba, Eleowo, Ilu-Abo) were identified as guiding locations for studies within Akure North Local Government Area of Ondo State, Southwestern Nigeria (Figure 2). A total of eight profile pits; two at each community were dug (Figure 2). The study profiles (Plate 2) were designated Profiles 1 and 2 for each study community respectively. Contour/topographic satellite map imageries (Figure 2) were used as a guide to delineate the upland from the lowland topographic positions of the study area under free survey technique. Specific information on the profile pit locations relating to the coordinates, elevations above sea level and names of host local communities were generated/ obtained in the field with the aid of a hand-held E Trex high sensitivity model Geographic Positioning System (GPS) and interaction with the 'locals' (Table 1). Pedons were described for their morphological characteristics in the field according to FAO's (2006) guidelines and the procedure described by Akamigbo (2010). The descriptions included soil colour patterns using Munsell soil colour charts; soil textural variations; soil structure; soil consistence; presence of clay coatings; presence and abundance of cutans, roots, pores and concretions; horizon thickness and boundary; drainage conditions, and rooting depth.

Following pedon morphological description, core and corresponding auger samples were collected from each identified genetic horizon in well labeled-polythene bags. Soil samples were collected from the bottom of the horizon upwards to avoid contaminations. The first set of soil samples that were collected with core samplers from the pit at the surface and subsurface horizons were used to determine some soil physical properties. The soil samples were air dried, ground using a porcelain pestle and mortar and passed through a 2-mm sieve. Sieved samples were stored in polythene bags and used for laboratory analyses using standard procedures. Particle size distribution was determined by the hydrometer method after dispersion in 5% calgon (sodium hexametaphosphate) solution as described by Day (1965). Bulk density was determined by the core method using a core sampler (Blake and Hartge, 1986). Total porosity of the soil was calculated mathematically from the results of bulk density and assumed particle density of 2.65 g cm^{-3} using the relation:

$$F = 100\left(1 - \rho_b \big/ \rho_p\right)$$

Where; F = total porosity (%)

ρ_b = bulk density g cm^{-3}

ρ_ρ = particle density 2.65 g cm^{-3}

Saturated hydraulic conductivity (Ksat) was calculated based on Klute and Dirksen (1986) method using the transposed Darcy's equation for vertical flows of liquids.

Results: The summary of the morphological and physical characteristics for the four study locations namely Ita-Ogbolu, Igoba, Eleowo and Ilu-Abo are respectively presented in Tables 2a and 2b to 5a and 5b.

Ita-Ogbolu: The depth of the soil profile at Ita-Ogbolu was 107 cm and 115 cm in profiles 1 and 2 respectively (Table 2a and 2b). Profiles in this syudy location were less than 200 cm deep. The 'A/Ap' horizons of the soils were brownish black (5YR 3/1) and dark reddish brown (5YR 3/2) colours underlain by brown, bright brown and dark/ dull reddish brown colours. Mottling was observed at 55 to 72 cm depth at Profile 2. Textural characteristics of the 'A/Ap' horizons were loam with the subsoil texture varying from sandy loam to gravelly sandy clay loam. Profile units were moderately well drained with weak and moderately developed fine granular soil structure (Table 2a). Soil consistency (wet) varied from non-sticky/non-plastic to sticky/slightly plastic and (moist) consistency varied from loose to firm in all horizons (Table 2a). Slightly hard consistency (dry) was only observed in the subsoil horizons under the prevailing field conditions. Roots and pores were observed in all horizons. In terms of relative abundance, roots varied from few to many and from very fine to moderate in size. Pores were few and common in abundance and very fine and fine in size.

Horizon boundaries varied from gradual and wavy, clear and wavy, diffuse and wavy, and gradual and irregular (Table 2a).
Bulk density and clay contents respectively had the lowest (7%) and highest (42%) coefficient of variation in this study location (Table 2b). The particle size distribution shows sandy loam textural class at the topsoils in the profiles with lower horizons having loamy sand and sandy loam (Table 2b). Clay ranged from 70 to 170 g kg^{-1} at the upland, decreased and increased respectively with depth in profiles 1 and 2. Silt ranged from 110 to 190 g/kg showing a decreasing pattern with depth. Fine sand showed an inconsistent distribution trend in Profile 2 and decreased with depth in profile 1. Coarse sand increased with depth in profiles 1 and irregularly distributed in Profile 2. Bulk density (BD) values increased with depth in all profiles and ranged from 1.20 g cm^{-3} in the 'Ap' horizon of profile 1 to 1.51 g cm^{-3} in the 'C' horizon of profile 2 (Table 2b). Total porosity was lowest (32.83%) in the 'B' horizon of profile 2 and highest (55.58%) in the 'A' horizon of profile 1 but also varied irregularly with depth in the two profiles. Hydraulic conductivity (Ksat) generally varied irregularly with depth in the two profiles with the lowest value (14.55 cm h^{-1}) recorded in the 'B' horizon in profile 2 and highest value (40.91 cm h^{-1}) in the 'C' horizon in profile 1.

Igoba: Soil depth at Igoba was 150 cm in the two profiles. The depth of 200 cm could not be reached due to bedrock contact (Table 3a and 3b). The 'Ap' horizons were all black (5YR 2/1) and (7.5YR 2/1) colour underlain by predominantly hue of (2.5YR). Textural characteristics were sandy loam and moderately well drained. The soils were weakly and moderately structured in all profiles. Soil consistency (moist) was loose and very friable all through the profiles. In terms of relative abundance, roots were few and common with predominant fine size in all profiles. Pores were mainly common and fine in size. Horizon boundaries were clear and wavy, diffuse and smooth, clear and smooth, diffuse and wavy (Table 3a). The coefficient of variation ranged from 0 to 68% for the soil physical properties in the two profiles (Table 3b). The particle size distribution shows loamy sand texture (Table 3b). Clay content was uniformly distributed (70 g/kg) in all horizons except in the B2 horizon of profile 2 where it was 110 g/kg. Silt ranged from 70 to 130 g/kg in all profiles with irregular increasing distribution pattern with depth. Fine sand and coarse sand generally showed irregular decreasing trend with depth in all profiles. Bulk density ranged from 1.05 to 1.68 g cm^{-3} in all profiles with lower values recorded at the top than in the lower horizons. Total porosity ranging from 36.60 to 60.38% in all profiles had higher values at the top. Ksat ranged from 7.27 cm h^{-1} in the B2 horizon of profile 2 to 50.00 cm h^{-1} in profile 1. Ksat was higher in the 'Ap' horizons than in the lower horizons.
Eleowo: The depth of the soil was 52 cm to 105 cm in profile 2 and 1 respectively (Table 4a and 4b). The moderately well-drained topsoils had a dark reddish brown (2.5YR 3/2) colour with a gravelly sandy loam texture in profile 1 and brownish black (5YR 3/1) colour with loamy texture in profile 2. The subsoils were brown, bright reddish brown and dull orange with gravelly sandy clay and gravelly sandy loam. The soils were weakly and moderately structured with slightly sticky and slightly plastic consistency (wet). In terms of relative abundance, roots were observed to be common at the topsoils and few in the lower horizons. Predominantly few and fine pores were observed in all profiles. Horizon boundaries were clear and wavy, diffuse and smooth, clear and broken. Table (4b) shows that the soil physical properties had a coefficient of variation ranging from 6 to 52% in the two profiles. Particle size analysis showed predominantly sandy loam, loamy sand and sandy clay loam texture in all horizons. Clay generally increased with depth with the highest content (370 g/kg) recorded in a 'C' horizon in profile 1. Silt content was higher at the top than in the lower horizons in the profiles. Fine sand varied irregularly with depth in profile 1 and decreased somewhat consistently with depth in profile 2. Coarse sand which showed inconsistent distribution pattern with depth was highest (530 g/kg) in the 'C' horizon in profile 2. Bulk density (BD) was lowest (1.45 g cm^{-3}) and highest (1.81 g cm^{-3}) in the 'Ap' and 'B' horizons respectively in profile 2. Bulk density was higher (1.69 g cm^{-3}) at the surface in profile 1 than in the lower horizons. The values of total porosity varied irregularly with depth in the profiles. Ksat was generally slower at the top in the profiles than in the lower horizons.
Ilu-Abo: Soil depth in this syudy location was 130cm and 170 cm in profiles 2 and 1 respectively (Table 5a&b). The 'A' horizons were all brownish black colour. The subsoil colours were brown, dark brown, dull reddish brown, bright reddish brown, yellowish brown and dull yellow (Table 5a). Mottle colours with hue (10YR) were observed in the subsoils of profile 2. Soil texture was loam and sandy loam underlain by sandy loam, sandy clay loam and sandy clay. The soils were moderately well drained. Structural aggregates were weak and moderate. Consistency (wet) was non sticky and non plastic at the top. Moist consistency ranged from loose to firm in all profiles while dry consistency was slightly hard and hard (Table 5a). In terms of relative abundance, roots and pores were few and common and varied from very fine to coarse in sizes in all profiles. Horizon boundaries were gradual and wavy, clear and smooth, diffuse and smooth, diffuse and wavy, abrupt and wavy. The soil physical properties generally had a coeffient of variation ranging from 0 to 77% in all profiles (Table 5b). Soil texture in the profiles was predominantly sandy loam and sandy clay loam in the horizons (Table 5b). Clay content showed an increasing pattern of distribution with depth in the profiles. Silt was uniformly 150 g/kg in all horizons in profile 2 and decreased irregularly in profile 1. Fine sand consistently decreased with depth in the profiles. Coarse sand ranged from 300 to 430 g/kg and varied irregularly with depth in the profiles. Bulk density values ranged from 1.45 to 1.76 g cm^{-3} and were lower at the top in all profiles (Table 5b). Total porosity ranged from 36.60 to 53.96% in the profiles and generally decreased, though irregularly with depth. Ksat ranged from 1.73 cm h^{-1} in the 'Btv2' in profile 1 to 50.00 cm h^{-1} in profile 2. Generally, Ksat decreased sharply to slower rates with depth in the profiles.
Discussion: Morphological Characteristics of the Soil Profiles in Four study Locations: Soil depth is a very important characteristic of pedons. In all study locations, the range of soil depth (52 to 170 cm) was rated moderately deep to very deep. Atofarati *et al.* (2012) earlier reported that soils developed on the Precambrian basement complex rocks of Southwestern Nigeria are generally moderately to very deep. The black, dark brown and brownish colour observed in the 'A/Ap' horizons indicates that the surface soils are rich in organic matter which is the main colouring agent in topsoils (Nuhu, 1983; ISC, 2017). Ajayi *et al.* (2012) also reported dark brown colours for the soils of Southwestern Nigeria. The dark and brown colours found in some lower horizons at Eleowo study locations (Table 4a) is probably an indication of translocation of organic matter from the surface to the deeper horizons. Hard layer or semi-permeable zone with attendant drainage problems may be responsible for mottling observed in the profiles 2 at Ita-Ogbolu (Table 2a) and Ilu-Abo (Table 5a) study locations. That the profile depth was less than 200 cm depth in all profiles at all study locations was attributed to bedrock contact. Variations in soil texture which ranged from sandy loam to sndy clay loam may be attributed to variations in selective removal of soil particles from one location/ horizon to another by agents of soil erosion and variations in weathering intensity under the influence of high rainfall and fluctuating temperature regimes. Sharu *et al.* (2013) related high clay contents to high weathering intensity. Variations recorded in soil structure may be due to variations observed in biological

activities and in textural characteristics (Heck and Mermut, 1992; Saskatchewan, 2002).

Variations in soil consistency (moist) from loose and very friable on the topsoils to very firm recorded in some lower horizons may be attributed to variations in soil texture and organic C within the profiles. The hard soil consistency (dry) in the lower horizons in profile 1 at Ilu-Abo (Table 5a) was attributed to the plinthite forming a continuous phase from 50 to 170 cm depth. The presence of iron and manganese concretions observed in these horizons may be responsible for the hard soil consistency and plinthite formation. High rates of Fe accumulation leading to the formation of plinthite upon alternate wetting and drying has been reported (Mustapha and Singh, 2003). Plinthite restricts the rooting zone of plants and causes drainage problems which affects nutrient uptake and consequently lower the productivity of such soils. Varying horizontal bands of particle size and soil colours defined the specific soil horizons in all profiles at the four study locations studied in the field (Heck and Mermut, 1992; Sheshagiri *et al.*, 1992; RaghuMohan and Bhonsle, 1993; Brady and Weil, 2006).

Generally, the absence of prismatic and platy structures in addition to the absence of sticky and plastic soil consistency (wet) in all the four study locations will facilitate good soil tillage, and unhindered plant root penetration. This good soil structure attribute is an essential quality that could be leveraged on to boost apricultural production towards ensuring food security in Nigeria. The generally moderately well drained soils in all study locations was attributed to higher elevation of the landscape studied with the tendency to cause lateral flow of water into the adjoining lowland (Osanato (1975 and Nsokpo and Ibanga (2001). This will therefore greatly influence the choice of crops based on water requirement.

Physical Characteristics of the Soil Profiles in Four Study Locations: The coefficient of variation for soil physical properties in all land use types within profiles (range, 0 to 77%) was rated low to high variation (Wilding, 1985). The wide variations in the soil physical properties within the profiles was attributed to elluviation/ iluviation processes as well as to the influence of erosion which might have eroded some soil physical materials from the surface. The results obtained for particle size distribution in all study locations showed variations ranging from predominantly sandy loam at the topsoils to sandy clay loam at the subsoil horizons. Ajayi *et al.* (2012) had reported that soils of Southwestern Nigeria are predominantly sandy. Variations in textural classes in the study locations might have resulted from the differential impact of rainfall, temperature and organisms. Increase in clay and silt content with depth generally observed in the study locations and a corresponding decrease in coarse sand may be attributed to selective transport of fine soil particles into the lower horizons along with the vertically moving water by eluviation/ illuviation processes (Akamigbo *et al.*, 2001; Mustapha *et al.*, 2003; Obalum *et al.*, 2011; Atofarati *et al.*, 2012; Osuaku *et al.*, 2014; Amuyuo and Kotingo, 2015). The uniformly distributed clay content at Igoba study location (Table 3b) is an indication of immobility of the clay fractions into the lower horizons. The decrease in clay content with corresponding increase in coarse sand with depth in profile 1 at Ita-Ogbolu (Table 2b) indicates non transport of finer soil materials into the lower horizons. The inconsistent distribution of coarse sand with profile depth in Ilu-Abo study location (Table 5b) might have been influenced by pedogenic factors, responsible for irregular removal, transportation and redepositing of soil materials (Babalola *et al.*, 2007; Sharu *et al.*, 2013). Bulk density which ranged from 1.05 to 1.81 g cm^{-3} in all study loations was found increasing with profile depth. Similar increases in bulk density with depth were reported for some tropical soils (Ahn, 1993; Essoka and Esu, 2001). The results are also consistent with the reports of Jewitt (1979) and (Igwe 2001) who related bulk density distribution pattern with organic carbon contents which in most cases decreases with depth in tropical soils. The generally higher bulk density in the subsoils was attributed to the weight of the overlying soil layers and lower organic carbon contents in the lower horizons than at the topsoils (Brady and Weil, 1999; Igwe, 2001). The higher bulk density (1.69 g cm^{-3}) value at the topsoil in profile 1 at Eleowo (Table 4b) may be due to soil surface compaction resulting from cultivation (Shaver *et al.*, 2002; Igwe, 2003; Blanco-conqui and Lal, 2009). The higher bulk density with a corresponding higher clay contents in the lower horizons in the profiles of the study location did not however, reflect the relationship that associates the two parameters as reported by Babalola and Ogbam (2003). Generally, bulk density values at the topsoils in all study locations were below the critical limit of 1.60 g cm^{-3} which defines low aeration and water movement for optimum root growth (NSSC, 1995). The results for total porosity which generally showed lower values in the underlying horizons and higher at the surface horizons agrees with Okenmuo (2015) who reported similar observation for the soils at Ogbaru, Anambra State, Southeastern Nigeria. A sequence of downward pedotransfer of fine earth materials might have been responsible for reducing the porosity in the lower horizons (Nimmo, 2004; Obalum *et al.*, 2011). Variations in total porosity and hydraulic conductivity with depth at all the study locations were also attributed to variations in particle size distribution, moisture content, organic C and CEC with depth (Messing and Jarvis, 1993; Obi, 1989; Shelton, 2003; Nimmo, 2004; Obalum *et al.*, 2011).

Conclusion: The sustainability of human environment depends largely, not only on the availability of land resources but also on the morphological and physical characteristics that defines the useability of such lands for agricultural production. The determination of morphological and physical characteristics of a soil will help to provide guide on the necessary amendments and/ or improvements that may be required to ensure that the land yields optimum productivity. The soils of the study area have high potential to support rainfed agricultural crops such as cassava, potatoes, tomatoes, plantain, rice and maize. However, considering the moisture regime of the soils, irrigation facilities or artificial rain may be required to enable the soils support rice production. However, if rice is planted early into the rainy season in a normal year, the potential for good yields will be high with or without irrigation. Generally, when these soils are properly managed, their capacity to contribute to food security will be very high.

To maximize the potential of these soils for sustainable use, an integrated nutrient management system involving a combined use of organic materials and inorganic fertilizers will ensure profitable productivity. Organic residues such as animal manures, grasses and crop residues which are usually readily available to farmers should be applied in large quantities. The application of organic residues would generally keep the bulk densities low and regulate the hydraulic conductivity of the soils.

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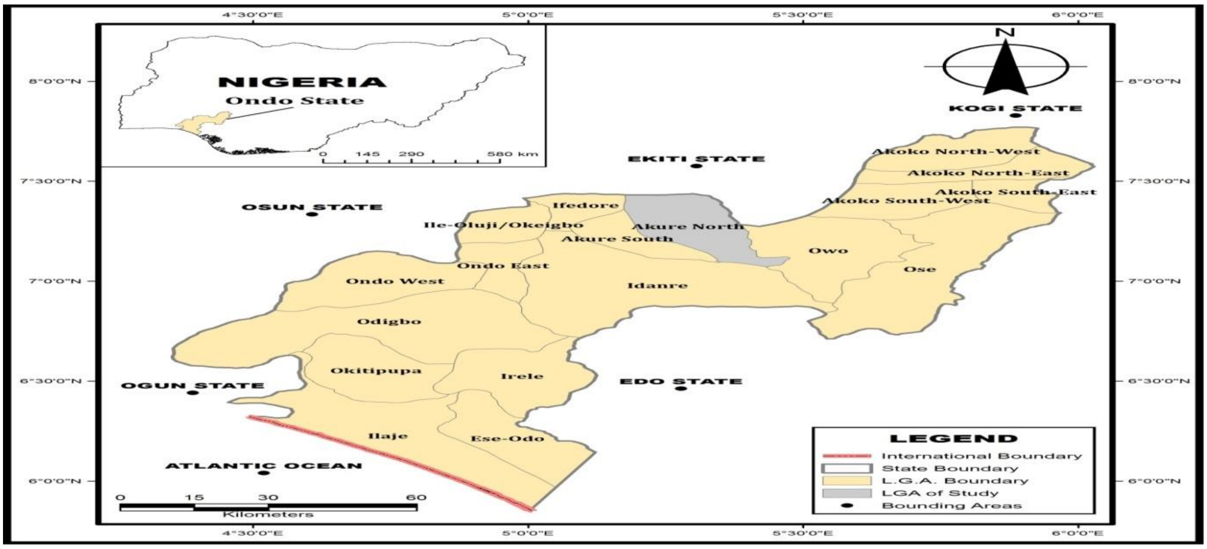

Figure 1: Map of Ondo State showing the local government area of study (Inset: Map of Nigeria)

Plate 1: A geologic characteristic of the landscape showing a rock outcrop in the study area

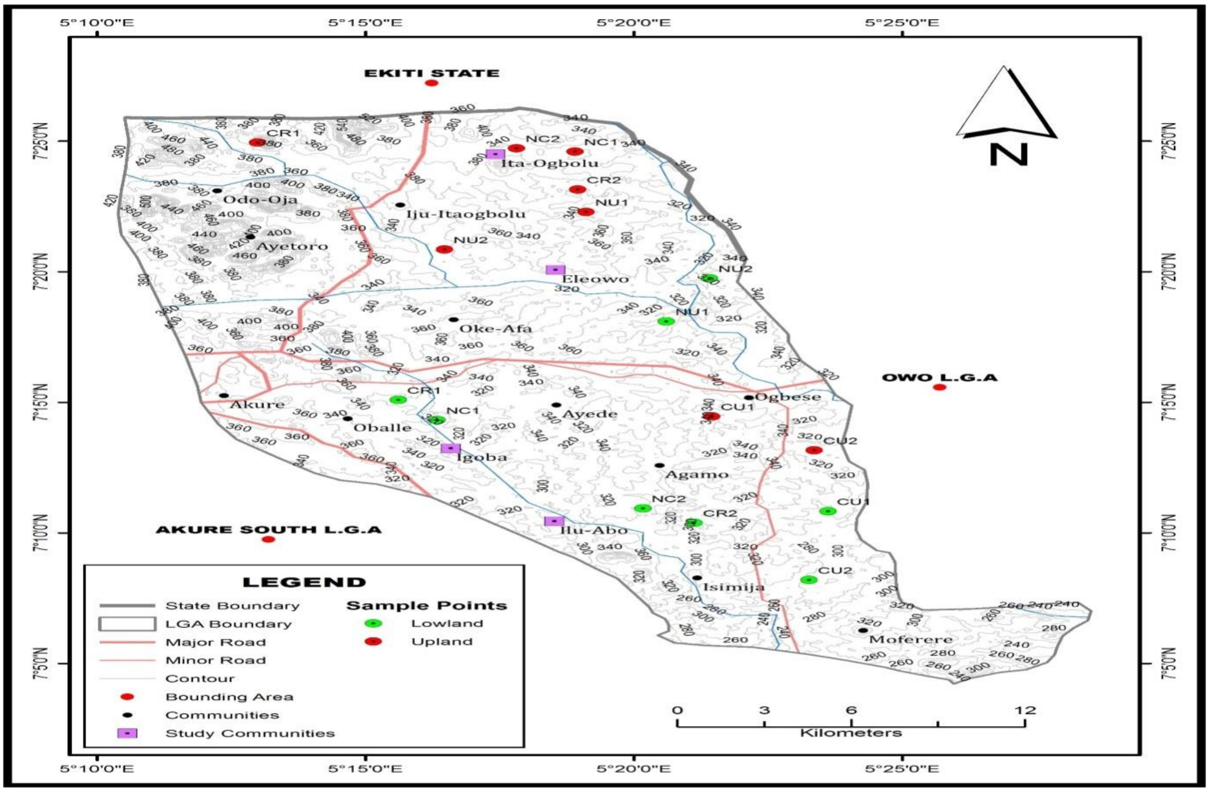

Fig. 2: Topographic map of Akure North local government area, Ondo State showing local communities and sample points

Table 1: Field locations, communities, profile names, elevations and coordinates of the study farms

Profile Name	Community	Topographic Position	Elevation a.s.l.	Coordinate
Profile 1	Ita-Ogbolu	Upland	366	(7^{0}22’46.7”N, 5^{0}19’03.2”E)
Profile 2	Ita-Ogbolu	Upland	372	(7^{0}21’23.4”N, 5^{0}16’38.9”E)
Profile 1	Igoba	Upland	340	(7^{0}14’13.5”N, 5^{0}21’26”E)
Profile 2	Igoba	Upland	345	(7^{0}13’25.6”N, 5^{0}23’43.7”E)
Profile 1	Eleowo	Upland	400	(7^{0}25’28.8”N, 5^{0}13’34.2”E)
Profile 2	Eleowo	Upland	370	(7^{0}23’38.7”N, 5^{0}18’53.9”E)
Profile 1	Ilu-Abo	Upland	380	(7^{0}24’36.1”N, 5^{0}18’54.4”E)
Profile 2	Ilu-Abo	Upland	377	(7^{0}24’32.5”N, 5^{0}18.48’2”E)

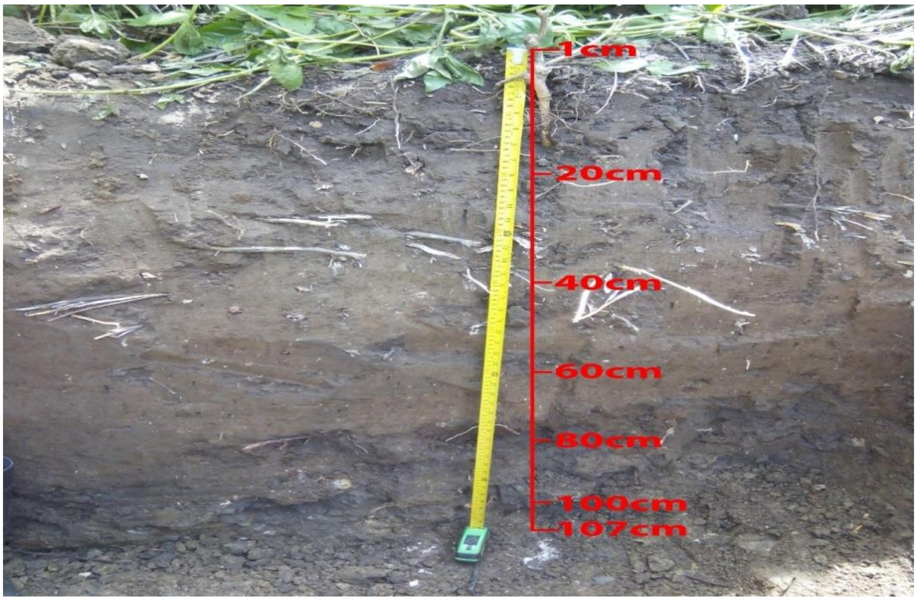

Plate 2: A representative profile pit in an upland topographic position showing evidence of bedrock contact

Table 2a: Some morphological characteristics of the soil profiles at Ita-Ogbolu in Akure North LGA, Ondo State, Nigeria

Horizon	Depth (cm)	Colour (moist)	Colour (mottles)	Texture	Structure	Consistency	Boundary	Other features
Profile 1								
A	0-15	5YR 3/1	-	L	1fgr	wnsnp,ml	GW	1fcr,1fp
B	15-50	7.5YR 4/4	-	GSL	1fgr	wslsslp,mvfr	CW	1fr,1fp
C	50-107	7.5YR 5/8	-	GSC	1fgr	wslsslp,mvfr		1vfr,1vfp
Profile 2								
Ap	0-15	5YR 3/2	-	L	2fgr	wnsnp,ml,	CW	2fr,1fp
AB	15-37	5YR 3/2	-	SL	2mcr	wnsnp,mfr,dslh	DW	1fr,1fp
B	37-55	5YR 4/3	-	GSL	2mcr	wnsnp,mfr,dslh	GI	1vfr,1fp
C	55-115	5YR 6/3	10YR 5/8	GSCL	2mcr	wslsslp,mfr,dslh		1vfr,1fp

Texture: L - loam, SL - sandy loam, SC - sandy clay, GSL - gravelly sandy loam, GSC - gravelly sandy clay, GSCL - gravelly sandy clay loam, Structure: 0 - structure less, 1 - weak, 2 - moderate, 3 - strong, sg - single grained; f - fine, m - medium, c - coarse; cr - crumb, gr - granular, sbk - subangular blocky, abk - angular blocky; Consistency: w - wet, ns - non sticky, sls - slightly sticky, S - sticky, np - non plastic, slp - slightly plastic, p - plastic; m - moist, L - loose, vfr - very friable, fr - friable, F - firm vf - very firm; d - dry, l - loose, s - soft, slh - slightly hard, h - hard, vh - very hard; Roots/pores: r - roots, p - pores; 1 - few, 2 - common, 3 - many; vf - very fine, f - fine, m - moderate, c – coarse; Boundary: C - clear, G - gradual, D - diffuse, W - wavy, I - irregular.

Table 2b: Some physical characteristics of soil profiles at Ita-Ogbolu in Akure North LGA, Ondo State, Nigeria

Horizon	Depth (cm)	Textural Class	Clay	Silt	F. Sand	C. Sand	BD ($g\ cm^{-3}$)	TP (%)	Ksat ($cm\ h^{-1}$)
			(g/kg)						
Profile 1									
A	0-15	SL	90	190	400	320	1.23	55.58	29.09
B	15-50	LS	70	150	270	510	1.36	33.58	34.55
C	50-107	LS	70	150	230	550	1.20	43.40	40.91
Mean		LS	77	163	300	460	1.26	43.38	34.85
CV (%)			15	14	30	27	7	25	17
Profile 2									
Ap	0-15	SL	70	170	290	470	1.25	33.96	30.91
AB	15-37	SL	90	150	330	430	1.32	38.87	31.82
B	37-55	SL	90	150	210	550	1.38	32.83	14.55
C	55-115	SL	170	110	220	500	1.51	43.02	31.82
Mean		LS	105	145	262	488	1.37	37.17	27.27
CV (%)			42	17	22	10	8	13	31

SL - Sandy loam, SCL - Sandy clay loam, LS - Loamy sand, F - Fine, C – Coarse; BD - Bulk density; TP - Total porosity; Ksat - Saturated hydraulic conductivity

Table 3a: Some morphological characteristics of the soil profiles at Igoba in Akure North LGA, Ondo State, Nigeria

Horizon	Depth (cm)	Colour (moist)	Colour (mottles)	Texture	Structure	Consistency	Boundary	Other features
Profile 1								
Ap	0-30	5YR 2/1	-	SL	2mgr	wnsnp,mvfr	CW	2fmr,3fp
B1	30-80	2.5YR 6/2	-	SL	2mgr	wnsnp,mvfr	DS	1fr,2fp
B2	80-150	5YR 7/4	-	SCL	2msbk	wnsnp,mfr		1vfr,2fp
Profile 2								
Ap1	0-16	7.5YR 2/1	-	SL	1fgr	wnsnp,ml	CS	2fr,2fp
A2	16-35	7.5YR 6/2	-	SL	1fgr	wnsnp,ml	DS	1fr,2fp
B1	35-90	2.5YR 7/3	-	SCL	1fgr	wnsnp,ml	DW	1fr,2fp
B2	90-150	2.5YR 7/3	-	SCL	1fsbk	wnsnp,mvfr		1vfr,2fp

Texture: L - loam, SL - sandy loam, SC - sandy clay, SCL - sandy clay loam, SIC - silty clay, CL - clay loam, GSL - gravelly sandy loam, GSC - gravelly sandy clay, GSCL - gravelly sandy clay loam, STC - Stony clay; Structure: 0 - structure less, 1 - weak, 2 - moderate, 3 - strong, sg - single grained; f - fine, m - medium, c - coarse; cr - crumb, gr - granular, sbk - subangular blocky, abk - angular blocky; Consistency: w - wet, ns - non sticky, sls - slightly sticky, s - sticky, np - non plastic, slp - slightly plastic, p - plastic; m - moist, l - loose, vfr - very friable, fr - friable, f - firm vf - very firm; d - dry, l - loose, s - soft, slh - slightly hard, h - hard, vh - very hard; Roots/Pores: r - roots, p - pores; 1 - few, 2 - common, 3 - many; vf - very fine, f - fine, m - moderate, c - coarse; Boundary: A - abrupt, C - clear, D - diffuse, S - smooth, W - wavy.

Table 3b: Some physical characteristics of the soil profiles at Igoba in Akure North LGA, Ondo State, Nigeria

Horizon	Depth (cm)	Textural Class	Clay	Silt	F. Sand	C. Sand	BD (g cm^{-3})	TP (%)	Ksat (cm h^{-1})
			(g/kg)						
Profile 1									
Ap	0-30	LS	70	70	300	560	1.05	60.38	50.00
B1	30-80	LS	70	90	300	540	1.49	43.77	43.66
B2	80-150	LS	70	110	250	570	1.68	36.60	10.91
Mean		LS	70	90	283	557	1.40	46.91	19.85
CV (%)			0	22	10	3	23	60	35
Profile 2									
Ap1	0-16	LS	70	90	270	570	1.32	50.19	45.45
A2	16-35	LS	70	70	330	530	1.46	44.91	38.18
B1	35-90	LS	70	70	280	580	1.40	47.16	15.45
B2	90-150	LS	110	130	190	570	1.51	43.02	7.27
Mean		LS	80	90	268	562	1.42	46.32	26.58
CV (%)			25	31	22	4	6	7	68

SL - Sandy loam, SCL - Sandy clay loam, LS - Loamy sand, F - Fine, C - Coarse, BD - Bulk density, TP - Total porosity, Ksat - Saturated hydraulic conductivity

Table 4a: Some morphological characteristics of the soil profiles at Eleowo in Akure North LGA, Ondo State, Nigeria

Horizon	Depth (cm)	Colour (moist)	Colour (mottles)	Texture	Structure	Consistency	Boundary	Other features
Profile 1								
Ap	0-30	2.5YR 3/2	-	GSL	2fcr	wslsslp,mvfr,	CW	2fr,1fp
Bt	30-60	5YR 5/6	-	GSC	1mgr	wslsslp,mfi	DS	1vfr,2fp
C	60-105	2.5YR 6/4	-	GSC	1mgr	wsslp,mfi		1vfr,1fp
Profile 2								
Ap	0-23	5YR 3/1	-	L	2fgr	wslsslp,mvfr	CW	2fmr,2fp
B	23-37	7.5YR 4/4	-	GSL	1fcr	wslsslp,mfr,dslh	CB	1fr,1fp
C	37-52	7.5YR 4/6	-	GSC	1fsbk	wslsslp,mfr,dslh		1vfr,1fp

Texture: L - loam, SL - sandy loam, SC - sandy clay, SCL - sandy clay loam, SIC - silty clay, CL - clay loam, GSL - gravelly sandy loam, GSC - gravelly sandy clay, GSCL - gravelly sandy clay loam, STC - Stony clay; Structure: 0 - structure less, 1 - weak, 2 - moderate, 3 - strong, sg - single grained; f - fine, m - medium, c - coarse; cr - crumb, gr - granular, sbk - subangular blocky, abk - angular blocky; Consistency: w - wet, ns - non sticky, sls - slightly sticky, s - sticky, np - non plastic, slp - slightly plastic, p - plastic; m - moist, l - loose, vfr - very friable, f r - friable, f - firm vf - very firm; d - dry, l - loose, s - soft, slh - slightly hard, h - hard, vh - very hard; Roots/Pores: r - roots, p - pores; 1 - few, 2 - common, 3 - many; vf - very fine, f - fine, m - moderate, c – coarse; Boundary: A - abrupt, C - clear, G - gradual, D - diffuse, S - smooth, W - wavy, I - Irregular, B – broken

Table 4b: Some physical characteristics of the soil profiles at Eleowo in Akure North LGA, Ondo State, Nigeria

Horizon	Depth (cm)	Textural Class	Clay	Silt	F. Sand	C. Sand	BD (g cm^{-3})	TP (%)	Ksat (cm h^{-1})
			(g/kg)						

Profile 1									
Ap	0-30	SL	110	200	250	440	1.69	36.23	13.64
Bt	30-60	SCL	330	110	150	410	1.57	40.75	30.91
C	60-105	SC	370	130	170	330	1.51	43-02	36.36
Mean		SCL	270	150	190	390	1.59	40.00	26.97
CV (%)			52	32	28	15	6	9	44
Profile 2									
Ap	0-23	SL	70	190	400	340	1.45	45.28	3.64
B	23-37	SL	90	130	320	460	1.81	31.40	6.36
C	37-52	LS	70	150	250	530	1.80	32.08	2.36
Mean		LS	80	160	320	440	1.68	36.25	4.12
CV (%)			15	19	23	22	12	22	50

SL - Sandy loam, SCL - Sandy clay loam, SC - Sandy clay, LS - Loamy sand, F - Fine, C - Coarse, BD - Bulk density, TP - Total porosity, Ksat - Saturated hydraulic conductivity

Table 5a: Some morphological characteristics of the soil profiles at Ilu-Abo in Akure North LGA, Ondo State, Nigeria

Horizon	Depth (cm)	Colour (moist)	Colour (mottles)	Texture	Structure	Consistency	Boundary	Other features
Profile 1								
A1	0-29	5YR 3/1	-	SL	2mgr	wnsnp,ml,dslh	GW	2fmr,2mp
A2	29-50	5YR 4/3	-	SL	2msbk	wnsnp,ml,dslh	CS	2mcr,2fmp
Btv1	50-80	5YR 5/4	-	SCL	2msbk	wslsslp,mvfr,dh	DS	1fmr,1fp
Btv2	80-125	5YR 5/8	-	SC	2csbk	wslsslp,mfr,dh	DS	1vfr,1vfp
C	125-170	5YR 6/6	-	SC	2csbk	wsslp,mfr,dh		1vfr,1vfp
Profile 2								
A1	0-25	10YR 2/3	-	L	1mgr	wnsnp,ml,ds	DS	2fmr,2fp
A2	25-53	10YR 3/3	-	SL	2mgr	wnsnp,mvfr	DW	2mr,1fmp
AB	53-86	7.5YR 4/6	-	SC	1msbk	wnsnp,mvfr	AW	1cr,1fcp
Bt	86-130	2.5YR 5/6	10YR 6/6	SCL	1fsbk	wslsslp,mfr		1vfr,1vfp

Texture: L - loam, SL - sandy loam, SC - sandy clay, SCL - sandy clay loam, SIC - silty clay, CL - clay loam, GSL - gravelly sandy loam, GSC - gravelly sandy clay, GSCL - gravelly sandy clay loam, STC - Stony clay; Structure: 0 - structure less, 1 - weak, 2 - moderate, 3 - strong, sg - single grained; f - fine, m - medium, c - coarse; cr - crumb, gr - granular, sbk - subangular blocky, abk - angular blocky; Consistency: w - wet, ns - non sticky, sls - slightly sticky, s - sticky, np - non plastic, slp - slightly plastic, p - plastic; m - moist, l - loose, vfr - very friable, fr - friable, f - firm vf - very firm; d - dry, l - loose, s - soft, slh - slightly hard, h - hard, vh - very hard; Roots/Pores: r - roots, p - pores; 1 - few, 2 - common, 3 - many; vf - very fine, f - fine, m - moderate, c – coarse; Boundary: A - a brupt, C - clear, G - gradual, D - diffuse, S - smooth, W - wavy

Table 5b: Some physical characteristics of the soil profiles in Ilu-Abo in Akure North LGA, Ondo State, Nigeria

Horizon	Depth (cm)	Textural Class	Clay (g/kg)	Silt	F. Sand	C. Sand	BD (g cm^{-3})	TP (%)	Ksat (cm h^{-1})
Profile 1									
A1	0-29	SL	90	170	380	360	1.45	53.21	20.91
A2	29-50	SL	110	130	330	430	1.60	43.40	20.00
Btv1	50-80	SCL	250	70	300	380	1.71	39.25	3.03
Btv2	80-125	SCL	330	110	220	340	1.65	41.51	1.73
C	125-170	SCL	350	110	240	300	1.59	47.55	13.64
Mean		LS	230	120	290	360	1.60	44.98	11.86
CV (%)			54	31	22	13	6	12	77
Profile 2									
A1	0-25	SL	110	150	410	330	1.52	53.96	50.00
A2	25-53	SL	110	150	370	370	1.60	47.16	49.09
AB	53-86	SCL	250	150	250	350	1.68	36.60	7.27
Bt	86-130	SCL	270	150	230	350	1.76	52.45	27.27
Mean		SL	185	150	315	350	1.64	47.54	33.40
CV (%)			47	0	28	5	6	17	61

SL - Sandy loam, SCL - Sandy clay loam, LS - Loamy sand, F - Fine, C - Coarse, BD - Bulk density, TP - Total porosity, Ksat - Saturated hydraulic conductivity