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Characterization and Classification of Soils of Rigachikun- Kaduna, Northern Guinea Savanna, Nigeria

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Abstract
This research was carried out at Rigachikun, a Northern Guinea Savanna region of Nigeria and aimed at characterizing and classifying the soils of the region to generate soil information resources that will provide a guide in the utilization of the soils of the region. With the aid of a location map, soils were delineated into three locations A, B and C and three profile pits were dug in each location giving a total of nine (9) profile pits. The morphological properties of the studied soils show that the grade of structure ranged from weak at the surface to strong down the horizon in all studied locations A, B and C. Soil colours at location A ranged from 2.5 YR 6/3 (light reddish brown) to 2.5 YR 5/6 (red) in pedon 1, 2.5YR 4/4 (reddish brown) to 2.5YR4/8 (red) in pedon 2 and 2.5YR 4/2 (weak red) to 2.5YR 4/6 (red). Location B colour matrixes ranged thus, pedon 1; from 2.5YR ¾ (dark reddish brown) to 2.5YR 3/6 (dark red), pedon 2; 2.5YR 5/2 (weak red) - 2.5YR 3/6 (dark red) while Pedon 3; 2.5YR 3/2 (dusky red) to 2.5YR 3/6 (dark red). Textural properties show that in location A, clay increased in all pedons and silt decreased while sand showed no clear pattern although it ultimately decreased down the profile. In location B; clay also increased down the profile in all pedons investigated, silt decreased in pedons 1 and 3 while it has no clear distribution in pedon 2. Sand however decreased in all pedons of location B. In Location C; clay and silt increased while sand decreased in pedons 1 and 2. In pedon 3, clay increased, sand decreased while silt has no particular pattern of distribution. The coefficient of variation showed that clay and silt ranged mostly from moderate (CV>15≤ 35) to high variation (CV > 35) except in location A pedon 3, location B pedons 1 and 2; Location C pedons 1, 2 and 3 where silt had low variability (CV≤ 15). Location A pedons 1 and 2 were classified as Typic Durustepts while pedon 3 is Aridic Lithic Haplustepts. Location B pedons 1, 2 and 3 were classified as Arenic Aridic Kandiustults while location C pedons 1,2 and 3 were classified as Aridic Kandiustults.

Keywords: Soil characterization, soil classification, soil properties, northern Guinea savanna

Introduction

Agriculture is one the activities of great economic importance in Nigeria and seems to be attracting major attention now the country is faced with the high population increase and the dwindling state of other sources of economic sustenance. This is because, at a regular population growth rate of 3.2%, Nigeria's population was expected to have risen above 170 million by the year 2015 according to Obasi *et al*. (2015). The huge human population size will need food crops from agriculture for sustenance and livelihood in agroecology known to be fragile and highly sensitive (IITA 1994). This has necessitated agricultural development and increased demand for experimental data, leading to research on soil characterization. This provides the basic information necessary to create functional soil classification schemes, and assess soil fertility to unravel some unique soil problems in an ecosystem (Lekwa *et al*., 2004). Soil characterization gives us information on the physical, chemical, mineralogical and microbiological properties of the soils which enable us to grow crops and sustain forests and grasslands which serve as homes for wildlife. Soil classification, on the other hand, helps to organize our knowledge, facilitates the transfer of experience and technology from one place to another and helps to compare soil properties. However, in addition to soil characterization, soil classification and soil mapping provide powerful resources for the benefit of man especially in the area of food security, soil management and environmental sustainability (Obasi *et al*., 2017). Ahukaemere, (2015) noted that parent material may influence some soil properties such as drainage, nutrient content and distribution, soil colour, structure and even soil pH. It is therefore certain that variations in soil characteristics are primarily a result of changes in the pedogenetic origin of the soil and due to differences in land use as well as management practices prevalent in such locations. Esu, (2010) reported a significant relationship between parent material and soil texture, soil reaction, total exchangeable bases, total acidity, soil depth, colour, profile drainage and gravel content.

Eswaram (1977), stated that part of the uses of soil characterization data are to assist in the adequate classification of the soil and aid other scientists place the soils in their taxonomies or classification systems and provide the basis for a more detailed evaluation of the soil as well as give fundamental information on nutrient, physical or other limitations needed to produce a capability class. A soil characterization study, therefore, is foundational for understanding the soil, classifying it and getting the best understanding of the environment. Akamigbo (2001) opined that soil classification often refers to criteria based on soil morphology in addition to properties developed during soil pedogenesis. Criteria are designed to guide choices in land use and soil management. USDA soil taxonomy provides the core criteria for differentiating soil map units. Soil taxonomy-based soil map units are additionally sorted into classes based on technical classification systems. The major objective of this research work was therefore to characterize and classify soils of Rigachikun, Northern Guinea Savanna, Nigeria.

Materials and Methods

Location

The study area is located at Latitudes **10°36' and** 10° 60' N and Longitudes **7°25' and 7°** 40'E **respectively and in northwestern Nigeria.** It has been characterized as a region where the rainfall is unimodal in pattern and between 900 – 1300 mm per annum (Uyovbisere and Lombin 1991). The region has a wavelike to plain relief, with general elevation above sea level from about 450 to 700 m, having high sandy soils, which are usually very low in organic matter which further degrades speedily under conditions of high rainfall. The Northern Guinea Savanna region is known for high annual average temperature (28-32°C), short wet season and long dry season (6-9 months). Generally, soil moisture and temperature regimes in the area are inferred to be ustic and isohyperthemic respectively. During the rainy season however, mean temperature drops to 25°C – 28°C (June to September) and decreases to less than 20°C in the months between December and February (Gabasawa *et al*., 2017). The study location and altitudes of the study area are stated in Table 1. The different study locations. The altitude ranges are Location A (605 – 609 m), Location B (607 – 611 m) and Location C (609 – 615 m). These elevations clearly show that the studied area is located within the highlands of northern Nigeria. This region has a characteristic climate indicating Long-term annual rainfall averages of about 1050 mm having peaks of rainfall between June and September. The 1999 to 2002 mean rainfall amounts ranged from 952.6 to 1397 mm and could start in May, but often stops in September or early October. The duration of the Dry season starts in October and lasts into May (Odunze *et al*., 2004). Soil moisture and temperature regimes in the area are inferred to be ustic and isohyperthermic respectively (Ojanuga and Esu 1985). Uyovbisere and Lombin (1991) however noted that the region is characterized by a unimodal pattern of rainfall ranging between 900 – 1300 mm per annum. Rigachikum Kaduna is where the Demonstration/Research Farm of the National Open University of Nigeria, Kaduna is situated. This region has over 20 hectares of land where cereals like maize, guinea cone, upland/fadama rice and millets are grown. Tree crops such as grapes, oranges, grape vines, guavas and mangoes as well as the screen house crops such as tomatoes and peppers have been grown on a commercial basis in the recent past. This location has the potential to provide food for the sustenance of the teeming population of the people of Kaduna as well as the neighbouring states such as Kano, Katsina, Jigawa and Zamfara. Also, at the present, oil economy is seriously failing and much pressure is on the farmers, agricultural researchers and extension agents by the government and stakeholders to save the nation and world population by stepping up food production and farming generally. This region that has this great potential of saving the nation's population has not been studied as there is no information as concerns the classification and suitability of the soils of this region. This will give direction to indigenous farmers, prospective farmers and investors in the region. Information generated can as well arm the extension agents to give adequate information to soil users thereby enhancing proper management and productivity of the region. Currently, some farmlands around Rigachikun especially the research and commercial farmland of the National Open University of Nigeria, is experiencing severe crop failures, especially in the established Guava and grape plantation, grapevine orchard, some other tree crop development and some essential crops due to a lack of good soil information and management. This has contributed to the major agricultural and productivity problems of Rigachikum soils. This research, therefore will bridge the gap created by the lack of soil information in the faculty of Agricultural Sciences, National Open University of Nigeria, Kaduna thereby enhancing soil productivity and management of the farm. Students and researchers in the higher institutions within the North Western Zone of Nigeria will benefit immensely from this research work as it would provide resourceful information on the soil status of the region.

Field Work

A reconnaissance survey was carried out with the aid of the location's geological map sourced from the Geology Department of Ahmadu Bello University, Zaria. Soils of the region were delineated into mapping units. Depending on the identified soil groups, Pedons were sunk in each of the delineated mapping units. Three profile pits were dug in each of the identified three mapping units named Location A, B and C cutting across the uplands and lowlands in the area. A total of nine profile pits were dug with about 36 soil samples collected. Morphological properties were analyzed in situ. Core samplers were used to collect samples for bulk density while about 1kg samples were collected from the different horizons of each pedon, Samples were carefully packaged and labelled and transported to the standard laboratory of the Department of Soil, Ahmadu Bello University Zaria for analysis.

Laboratory Soil Analysis

Some physical and chemical properties of the soil were used as parameters for the study. Physical properties are Mechanical analysis (particle size distribution), while the chemical properties are; soil pH, exchangeable acidity (Al^{3+} and H^{+}), exchangeable bases (Ca^{2+} , Mg^{2+},K^{+}, Na^{+}), ECEC, percentage base saturation, total nitrogen, available phosphorus, organic carbon, organic matter and carbon /nitrogen ratio. Their methods of determination are as follows: Particle size distribution was determined by hydrometer method using the procedure of (Gee and Or, 2002), Soil pH was determined in 1:2.5 soil liquid ratios in water and 0.1N KCl (IITA, 1979). Organic Carbon was determined using the method described by (Nelson and Sommers, 1996). Total Nitrogen was determined using the modified micro Kjeldahl method (Bremner and Mulvaney 1982); Total available phosphorus was determined using the Bray II method (Olsen and Sommers, 1982); Cation exchange capacity (CEC) was measured by repeated saturation using 1M NH_4OAC followed by washing, distilling and titrating (Soil Survey Staff, 1996).

Statistical analysis

The coefficient of Variation (CV) was used to estimate the degree of variability existing among soil properties in the study site. Coefficient of variation (C.V.) ranked as follows; Low variation ≤15%, Moderate variation >15≤35%, High variation >35% was used as outlined by Wilding, (1985). The correlation was done using the SPSS software package.

Results and Discussion

Morphological properties

The morphological properties of the studied soils are displayed in Table 2. The grade of structure ranged from weak at the surface to strong down the horizon in all studied locations A, B and C. The forms of the structure were mostly crumbs (cr) at the surface to blocky (bk), angular blocky (abk) and sub-angular blocky (sbk) at the illuvial horizons. The structural size ranged from fine (f) to medium (m), coarse (c) and very coarse (vc) down the profiles in all study locations. Soil consistency showed that all investigated soils were hard (h) when the soils were dry. Pedon 1 of location A was particularly extremely hard (eh) at its Bt2 horizon when dry while pedons 1 and 2 of location B were visibly cemented at their Bt2 horizons when dry. Illuviation of clay down the horizons may have created an argillation (argillic horizon) leading to the cementation observed in this study location. Under the moist condition, soil consistency ranged from friable (fr) at the topmost horizons to firm (fi) and very firm (vf) progressively down the horizons in all locations A and B while extremely firm (efi) condition was observed at the Bt2 horizons of all pedons in location C. At wet conditions, pedons exhibited slightly sticky (ss) at their topmost horizons to very sticky (vs) and plastic (p) in their Bt1 – Bt2 horizons in all investigated locations. At pedon 3 of location A, a hard pan was encountered due to oxidized Fe^{3+} presence, with a markedly very reddish-brown colour and vary hard to dig further. Accumulation of sesquioxides (oxides of Fe and Al) and strong illuviation had led to the formation of this horizon whose consistency when wet was very plastic (vp). Soil colours at location A ranged from 2.5 YR 6/3 (light reddish brown) to 2.5 YR 5/6 (red) in pedon 1, 2.5YR 4/4 (reddish brown) to 2.5YR4/8 (red) in pedon 2 and 2.5YR 4/2 (weak red) to 2.5YR 4/6 (red). Location B colour matrixes ranged thus, pedon 1; from 2.5YR ¾ (dark reddish brown) to 2.5YR 3/6 (dark red), pedon 2; 2.5YR 5/2 (weak red) - 2.5YR 3/6 (dark red) while Pedon 3; 2.5YR 3/2 (dusky red) to 2.5YR 3/6 (dark red). At location C, Pedon 1 colours ranged from 7.5YR 6/1 (grey) - 7.5YR 6/8 (reddish yellow); Pedon 2 from 7.5YR 7/1 (light grey) - 7.5YR 5/4 (brown) while pedon 3 from 7.5YR 5/1 (grey) - 7.5YR 5/4 (brown).

Physical Properties of the Soil

The physical properties of the studied soils are shown in Table 3. In location A, clay increased in all pedons, silt decreased while sand showed no clear pattern although it ultimately decreased down the profile. Means of clay, silt and sand respectively in Location A are; 107.5, 132.5 and 760 g/kg for pedon 1; 80, 92.5 and 830 g/kg for pedon 2 and 80, 93.3 and 826.7 g/kg for pedon 3. In location B; clay also increased down the profile in all pedons investigated, silt decreased in pedons 1 and 3 while it had no clear distribution in pedon 2. Sand however decreased in all pedons of location B. The mean clay, the silt and sand distribution in the investigated pedons of location B are thus; pedon 1; 90, 65 and 845 g/kg; pedon 2; 82.5, 70 and 847.5 g/kg; pedon 3; 110, 72.5 and 817.5 g/kg respectively. In Location C; clay and silt increased while sand decreased in pedons 1 and 2. In pedon 3, clay increased, sand decreased while silt has no particular pattern of distribution. The coefficient of variation showed that clay and silt ranged mostly from moderate (CV>15≤ 35) to high variation (CV > 35) except in location A pedon 3, location B pedons 1 and 2; Location C pedons 1, 2 and 3 where silt had low variability (CV≤ 15). Sand however showed low variability in all investigated pedons. The textural class of all studied soils ranged from sand, loamy sand and sandy loam. Silt-clay ratios were mostly decreased down the profile but higher on the surface horizons. Means of silt-clay ratio are as shown thus; Location A; 1.536, 1.264 and 1.340; Location B; 0.812, 0.947 and 0.812, Location C; 0.802, 1.011 and 0.729 in their pedons 1, 2 and 3 respectively. It is worth noting that Location A where maize was previously grown had the highest silt-clay ratio values. This is followed by pedon 2 of Location C where cowpea was previously grown, while all other pedons had a silt-clay ratio of less than 1.0. The values of the silt–clay ratio of the soils in locations A, B and C are an indication that the soils are not old soils derived from old parent materials and are of intense degree of weathering; as old soils usually have silt–clay ratio less than 0.15, with a low degree of weathering (Obasi *et al*., 2017). This silt-clay ratio shows that the continual grazing on the soil by herders as well as erosion threat emanating from the regular overflowing of the Rigachikun River on the farmlands have caused some degradation of the studied soils. Igwe *et al*., (1995) documented that a higher silt-clay ratio denotes a younger soil and is associated with landscape devastation by erosion. Silt-clay ratio variability were high (CV > 35) in all investigated soils except in Location C pedon 1 where silt-clay was moderate (CV > 15 ≤ 35). Bulk Density (BD) were as shown in Table 3 and means ranged between 1.20 - 1.35 g/cm^3 and increased down the profile in all investigated soils. Means of bulk density followed thus; Location A; 1.29, 1.31 and 1.33 g/cm^3, Location B; 1.31, 1.35 and 1.22 g/cm^3, Location C; 1.24, 1.20 and 1.27 g/cm^3 in their respective pedons. The mean bulk density values of the soil groups fall within the range that is obtainable in most tropical soils (Landon, 1991). Therefore, bulk density will not be a hindrance to root penetration and tillage practices within the soil group, as lower bulk density promotes root penetration when compared to heavier bulk densities. However, (Brady and Weil, 2002), stated that soils with heavier bulk density will likely promote soil resistance to root penetration, poor aeration, slow movement of nutrients and water, and build-up of toxic gases and root exudates. The coefficient of variation showed that bulk density varied lowly (CV ≤ 15) across pedons in all locations.

Soil Chemical Properties

The results of the chemical properties as shown in Table 4, indicated that soil pH all had means above 6.0 in all investigated locations except location B pedon 1 and location C pedons 1 and 2 where mean pH was less than 6.0. The pH range of the studied location indicated that the soils are only slightly acidic which may not be a problem to soil productivity. At very low pH, most nutrient elements are likely to be fixed leading to the preponderance of H and Al ions in the soils. Ahukaemere and Obasi (2018) reported moderate and slight pH conditions in some Nigerian soils. Abua *et al.* (2010); related the acidity condition of a place to be connected to factors such as the parent material, climate of the region, organic matter, leaching of basic cations and topographic situations. Very high annual rainfall (usually above 2500 mm) experienced in Southern Nigeria has contributed immensely to the highly acidic condition (less than 5.5) Obasi *et al*. (2015) of soils of the region due to leaching of exchangeable cations leaving behind acidic cations such as H and Al in the soil complex. However, the soils under study in Northwestern (Rigachikun-Kaduna) Nigeria only experience about 900 – 1300 mm annual rainfall (Lombin, 1991) which may not be capable of causing leaching in the investigated soils, but serious cases of drought become a major challenge. The coefficient of variation indicated that soil pH varied lowly in all investigated locations. The organic carbon content of investigated soils was medium and means were recorded as follows; location A; 3.142, 3.193 and 2.926 g/kg; location B, 2.044, 2.493 and 3.940 g/kg, location C, 3.460, 3.940 and 3.03 g/kg in their pedons 1, 2 and 3 respectively. The organic carbon decreased down the horizon in all investigated pedons. This trend follows closely to organic matter which decreased in the same pattern with the values of organic carbon. Organic matter distribution took the following trends; Location A; 5.525, 5.505 and 5.044 g/kg; Location B; 3.525, 4.300 and 6.793 g/kg. Location C; 5.960, 6.800 and 5.221 g/kg all in their respective pedons 1, 2 and 3. The high concentration of organic substances such as twigs, litter and dead decayed organisms on the surface of soils may be largely responsible for the higher organic carbon and organic matter on or near the surface of the studied soils. (SOM) has been used in different ways to describe the organic constituents of soil. Baldock and Skjemstad (1999) stated that SOM includes "all organic materials found in soils irrespective of origin or state of decomposition". Soil organic matter contains C, H, O, N, P and S. Part of living organic matter are plants, microbial biomass and faunal biomass, dissolved organic matter, particulate organic matter, humus and inert or highly carbonized organic matter. Part of soil organic matter consists of carbohydrates, lipids and proteins that are abundant in fresh plant residues. These are rapidly metabolized, immobilized or decomposed (Adiaha 2017). Lombin *et al*. (1991) noted that although there is an appreciable variation in the nutrient makeup of organic manures depending basically on the source, handling and management, the main nutrients supplied are N, P, K, Mg, Ca and a host of micronutrients. The organic matter contents of locations A and B where rice and cowpea were previously grown were higher than those of Location B where maize was harvested although these differences do not entail much variation from the results. The huge litter deposits from rice husks and cowpea leaves may have contributed to these relatively higher values. Adiaha (2017) reported that when organic matter is added to the soil, it does not only reduce bulk density and increase water holding capacity of the soil, but also effectively increases soil aggregate stability. Kay and Anger (1999) reported that a minimum of 2% SOC was necessary to maintain structural stability. Boix-Fayos *et al*. (2001) showed that a threshold of 3-3.5% SOC had to be attained to achieve an increase in aggregate stability. However, all investigated pedons in the studied location had their organic matter content higher than (≥) 2% suggesting that organic matter could not possibly be a limiting factor in the nutritional composition of the studied soils. Nguemezi *et al*. (2020) who worked on South-west Cameroun soils noted that Organic matter content of ≥ 2% will not pose a limitation challenge to soil productivity. All the investigated locations showed high variability (CV ≥ 35) except pedons 1 and 2 of location C where the coefficient of variation was moderate (CV > 15 < 35) according to Wilding (1985). The available P distribution of the studied soils is shown in Table 3. Available P decreased down the horizon in most of the studied soils (Location A pedons 1 and 3; Locations B pedon 3). Available P rather increases in location A pedon 2 within their first three horizons and decreased consistently in Bt horizons. Location B recorded an increase in pedons 1 and 2. Mean available P distribution in respective locations are as follows; Location A; 2.70, 2.19 and 2.86 mg/kg; Location B; 2.83, 2.58 and 1.63 mg/kg; Location C; 2.32, 2.02 and 2.03 mg/kg in their pedons 1, 2 and 3 respectively. Nguemezi (2020) pointed out that available P of < 5 mg/kg will pose a very severe limitation to crop productivity. It is therefore evident that P availability is a major challenge of soils of Rigachikun in the Igabi area of Kaduna Northern Nigeria as all nine profile pits in three locations were very low in available phosphorus. Among the major challenge that surrounds the huge depletion of P include the fact that tropical forests with above-ground biomass which is supposed to be a net source of primary productivity nutrients which includes P (Houghton 2005) have been cleared for arable cropping and animal feeds (Lal, 1986). This ultimately results in critical nutrient limitation once biomass is removed leading to limited P availability and low total P. Other factors may include long periods of leaching and strong adsorption or occlusion of P with iron and aluminium oxides Baillie (1996). Exchangeable potassium (K) was next to lowest after Na in most of the profile pits investigated among all four exchangeable basic cations (Ca, Mg, Na and K) studied as shown in Table 3. K behaviour in the investigated soils does not follow a particular trend as it increased in location A pedons 1 and 2 while it had no specific pattern in pedon 3. Conversely, K rather decreased down the profile in location B pedons 1 and 2 (though partially). However, K had no pattern in pedon 3 of location B, and also no pattern in virtually all pedons of location C. The means K distributions in the studied soil are as follows: Location A; 0.17, 0.14 and 0.11 g/kg; Location B; 0.08, 0.08 and 0.06 g/kg, Location C; 0.06, 0.10 and 0.14 in their pedons 1, 2 and 3 respectively. From the results recorded, it can be seen that K is seriously limiting in all the investigated soils. All pedons in location A as well as location C pedons 2 and 3 had K content between 0.1 – 0.2 g/kg suggesting a severe limitation while all pedons in location B and pedon 1 in location C had their K content less than (<) 0.1 g/kg implying a very severe limitation according to Nguemezi (2020). The Sodium (Na) distribution of the studied soils are as shown on Table 4. There was a decrease down the horizons in most of the studied soils. Na decreased in Location A pedons 1 and 2 while it decreased in pedon 3. Location B had a decrease in all its pedons 1, 2 and 3 while in Location C, it increased in pedon 1 and decreased in pedons 2 and 3. Means of Na content are as follows; Location A; 0.11, 0.09 and 0.05 g/kg, Location B; 0.03, 0.05 and 0.05 g/kg, Location C; 0.06, 0.11 and 0.15 g/kg in pedons 1, 2 and 3 respectively of three studied locations. All Na results are within the range of 0.045 – 0.08 mg/kg which according to Quemada and Cabrera (1995) is the threshold Na content that poses average limitations for crop growth and productivity. Calcium (Ca) distribution in the studied soils is as shown in Table 4. appearing to have the highest value per pedon compared to other exchangeable cations. Ca increased in Location A pedon 1, decreased in pedon 2 and showed no particular trend in pedon 3. In location B, Ca decreased down the profile in pedon 1 while it decreased in pedons 2 and 3. There was also a consistent Ca increase in Pedon 1, 2 and 3 of location C although there was a sharp drop in Bt2 and Bt1 horizons of pedons 2 and 3 respectively. Means of Ca were recorded as follows, Location A; 5.80, 6.05, 7.25 g/kg, Location B; 5.80, 4.35, 4.25 g/kg and C; 4.20, 5.45, 3.65 g/kg in pedons 1, 2 and 3 respectively of the locations. The Ca requirement for plants varies widely with grasses having the lowest requirement, legumes intermediate, and fruit crops and cotton the highest. Calcium levels from 2.0 to 2.5 g/kg are quite adequate for pasture grasses and corn. Soybean and cowpea have a critical Ca concentration in the mature leaves of 5.0 g/kg, while the level for peanuts is 12.5 g/kg (Fageria, 2016). Total exchangeable bases (TEB) follow the trend of all other exchangeable cations put together. Means TEB as follows, Location A; 7.66, 7.96 and 9.73 g/kg; Location B; 7.48, 5.66 and 5.61 g/kg; Location C; 5.56, 5.92 and 4.97 g/kg in their pedons 1, 2 and 3 respectively. Percentage base saturations was all above 80% while Al saturations was all below 20% in all studied location pedons. Magnesium contents of the studied soils as shown in Table 4, indicated that Mg increased in Location A pedon 1 and decreased in pedons 2 and 3. In location B, Mg decreased pedon 1 and increased in pedons 2 and 3. There was, however increase in all pedons 1, 2 and 3 of Location C. This Mg horizon distribution almost took a similar trend when compared to those of Ca in the studied locations. Means of Mg follows as thus; Location A; 1.58, 1.68 and 2.03g/kg, Location B; 1.59, 1.18 and 1.25 g/kg, Location C; 1.24, 1.51 and 1.03 g/kg in pedons 1, 2 and 3 respectively of studied locations. Coefficient of Variation indicated that Ca and Mg varied from low (CV< 15) to moderate (CV ≥ 15 < 35) in all the investigated soils except pedon 1 of location B where Mg recorded high (CV≥35) variation according to Wilding (1985). However, most of the studied soils had their Ca^{+2} and Mg^{+2} levels higher than the critical levels of 2.00 and 1.20 g/kg respectively (Halvin *et al*., 2005), except locations B and C whose pedons 2 and 3 scored 1.18 and 1.03 g/kg Mg respectively, showing the potentials ability of the investigated soils to support crop production. The effective cation exchange capacity of the soil was dominated by the exchangeable bases showing the capacity of the soil to retain nutrient elements. Bruce (1999) as quoted by Hamza (2008) suggested that it is difficult to establish critical levels of exchangeable Ca for plant growth that apply across a range of dissimilar soils. Pierre (1931) emphasized the importance of exchangeable Ca in acid soils and suggested that base saturation was more important than the absolute amount of exchangeable Ca.

Soil Classification

The diagnostic criteria for the classification of studied soils were according to the USDA Soil Taxonomy (Soil Survey Staff, 2014), soil moisture and temperature regimes in the area are inferred to be ustic and isohyperthemic soil moisture regime is intermediate between the aridic regime and the udic regime. Its concept is one of moisture that is limited but is present at a time when conditions are suitable for plant growth. Van Wambeke (1962) reported that "old" parent materials usually have a silt/clay ratio below 0.15 while silt/clay ratios above 0.15 are indicative of "young" parent materials. Results of this study show that, all the soils have silt/clay ratios above 0.15 indicating that the soils are relatively young with a high degree of weathering potential. Silt/clay ratios are relatively higher in the surface horizons and decrease with increasing depth in the pedons. The decrease in silt/clay ratio with depth is an indication that subsoil horizons are more weathered than surface horizons. At location A, silt/ clay ratios were 1.536, 1.264 and 1.340 in their pedons 1, 2 and 3 respectively. Locations B and C had their silt/clay distributions thus, B; was 0.812, 0.947, 0.812; and location C; 0.802, 1.011, 0.729 in their pedons 1, 2 and 3 respectively. Location A soils clay content had no particular trend and soils could be said to qualify as Inceptisols. Pedons 1 and 2 had duripans that have their upper boundary within 100 cm of the mineral soil surface while pedon 3 had a lithic contact within their horizons within 50 cm depth. At locations B and C there was the presence or kandic and argillic horizons suggesting a consistent clay movement down the profile or an accumulation of clay at the Bt horizons suggesting that these soils could be Ultisols or Alfisols, however, the very high base saturation is indicative of Alfisols (base saturation >35%). Location A pedons 1 and 2 were classified as Typic Durustepts while pedon 3 is Aridic Lithic Haplustepts. Location B pedons 1, 2 and 3 were classified as Arenic Aridic Kandiustults while location C pedons 1,2 and 3 were classified as Aridic Kandiustults.

Conclusion

These elevations clearly shows that the studied area is located within the highlands of northern Nigeria. Means of clay, silt and sand respectively in Location A are; 107.5, 132.5 and 760 g/kg for pedon 1; 80, 92.5 and 830 g/kg for pedon 2 and 80, 93.3 and 826.7 g/kg for pedon 3. In location B; clay also increased down the profile in all pedons investigated and silt decreased in pedons 1 and 3 while it has no clear distribution in pedon 2. Sand however decreased in all pedons of location B. The mean clay, silt and sand distribution in the investigated pedons of location B are thus; pedon 1; 90, 65 and 845 g/kg; pedon 2; 82.5, 70 and 847.5 g/kg; pedon 3; 110, 72.5 and 817.5 g/kg respectively. Location A soils clay content had no particular trend and soils could be said to qualify as Inceptisols. There was however the presence of duripans in pedons 1 and 2 with upper boundaries lying within 100 cm of the mineral soil surface while there was a lithic contact within their horizons within the 50 cm depth of pedon 3. There was the presence of kandic and argillic horizons at locations B and C pedons suggesting a consistent clay movement down the profile or an accumulation of clay at the Bt horizons which are major characteristics of Ultisols or Alfisols, however, the very high base saturation is indicative of Alfisols (base saturation >35%). Location A pedons 1 and 2 were classified as Typic Durustepts while pedon 3 is Aridic Lithic Haplustepts. Location B pedons 1, 2 and 3 were classified as Arenic Aridic Kandiustults while location C pedons 1,2 and 3 were classified as Aridic Kandiustults.

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Table 1: Geographic Coordinates of Research Area in Igabi L. G. A. Kaduna

Location	Latitude	Longitude	Altitude (m)
1	10.614447	7.475940	609
2	10.614585	7.476755	609
3	10.613689	7.478127	605
1	10.614625	7.478230	607
2	10.615250	7.477857	611
3	10.716818	7.477228	610
1	10.615858	7.476001	612
2	10.615727	7.475068	615
3	10.613786	7.475203	609

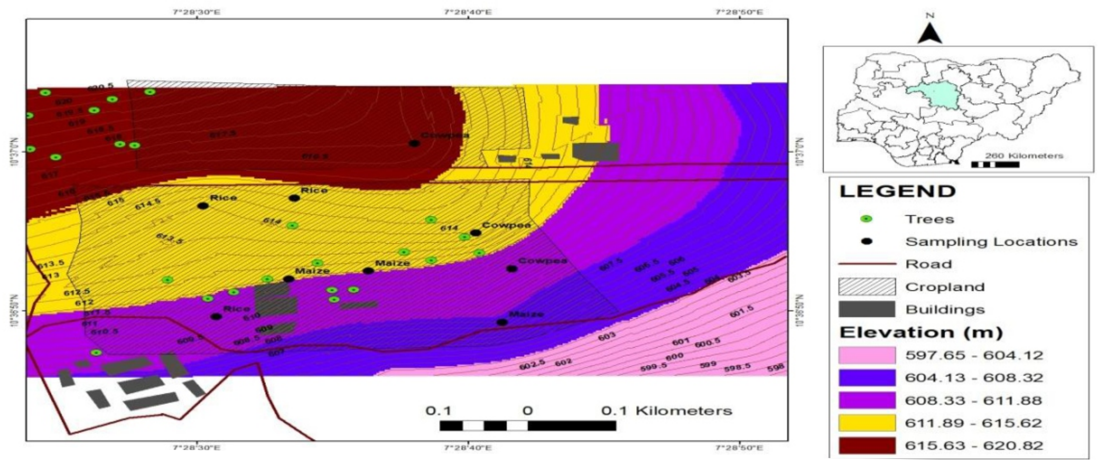

Fig. 1: 2D Map of Study Area Showing Sampling Points and Contour Lines

Table 2: Morphological Properties

Samples locations	Horizon Depth	Structure	Consistence			Colour (wet)
			Dry	Moist	Wet	
Loc. A						
Pedon 1						
A	0 - 18	1,cr,f	h	fr	Ss	2.5YR 6/3 (light reddish brown)
AB	18 - 45	2,bk,m	h	vfi	Vs	2.5YR 7/4 (light reddish brown)
Bt1	45 - 77	3,sbk,c	h	vfi	P	2.5YR 5/3 (reddish brown)
Bt2	77 - 130	3,sbk,vc	eh	vfi	Vp	2.5YR 5/6 (red)
Pedon 2						
A	0 - 9	1,cr,f	h	vfr	Ss	2.5YR 4/4 (reddish brown)
AB	9 - 30	2,bk,m	h	fr	S	2.5YR 5/3 (reddish brown)
Bt1	30 - 85	3,sbk,c	h	fi	Vs	2.5YR 5/8 (red)
Bt2	85 - 150	3,sbk,vc	h	vfi	P	2.5YR 4/8 (red)
Pedon 3						
A	0 – 16	1,cr,f	h	fr	Ss	2.5YR 4/2 (weak red)
AB	16 - 45	2,bk,m	h	fi	S	2.5YR 4/4 (reddish brown)
Bt1	45 – 78	3,sbk,c	h	vfi	Vp	2.5YR 4/6 (red)
Loc. B						
A	0 – 10	1,cr,f	h	fr	Ss	2.5YR 3/4 (dark reddish brown)
AB	10 – 34	2,bk,m	h	fi	S	2.5YR 3/3 (dark reddish brown)
Bt1	34 – 76	3,sbk,c	h	vfi	Vs	2.5YR 4/6 (red)
Bt2	76 – 145	3,sbk,vc	h	vfi	P	2.5YR 3/6 (dark red)
Pedon 2						
A	0 – 11	1,cr,f	h	fr	Ss	2.5YR 5/2 (weak red)
AB	11 – 27	2,bk,m	h	fi	S	2.5YR 4/4 (reddish brown)
Bt1	27 – 54	3,sbk,c	h	vfi	Vs	2.5YR 4/6 (red)
Bt2	54 – 120	3,sbk,vc	h	vfi	P	2.5YR 3/6 (dark red)
Pedon 3						
A	0 – 13	1,cr,f	h	fr	Ss	2.5YR 3/2 (dusky red)
AB	13 – 31	2,bk,m	h	fi	S	2.5YR 3/4 (dark reddish brown)
Bt1	31 – 66	3,sbk,c	h	vf	Vs	2.5YR 4/8 (red)
Bt2	66 – 153	3,sbk,vc	h	vf	P	2.5YR 3/6 (dark red)
Loc. C						
A	0 – 15	1,cr,f	h	fr	Ss	7.5YR 6/1 (gray)
AB	15 – 29	2,bk,m	h	fi	S	7.5YR 6/4 (light brown)
Bt1	29 – 63	3,sbk,c	h	vfi	Vs	7.5YR 6/3 (light brown)
Bt2	63 – 127	3,sbk,vc	cw	efi	P	7.5YR 6/8 (reddish yellow)
Pedon 2						
A	0 – 12	1,cr,f	h	fr	Ss	7.5YR 7/1 (light gray)
AB	12 – 26	2,bk,m	h	fi	S	7.5YR 5/1 (gray)
B	26 – 54	3,sbk,c	h	vfi	Vs	7.5YR 6/4 (light brown)
Bt	54 - 120	3,sbk,vc	cw	efi	Vp	7.5YR 5/4 (brown)
Pedon 3						
A	0 – 14	1,cr,f	h	fr	Ss	7.5YR 5/1 (gray)
AB	14 – 34	2,bk,m	h	fi	S	7.5YR 6/2 (pinkish gray)
B	34 – 56	3,sbk,c	h	Vfi	P	7.5YR 6/4 light brown)
Bt	56 – 98	3,sbk,vc	h	Efi	Vp	7.5YR 5/4 (brown)

Table 3: Some Physical Properties

Samples locations	Particle Size Analysis corrected to 20ºC (gkg^{-1})			Silt/Clay Ratio	Bulk Density (gcm^{-3})	Grav. Moisture C. (%)	Soil Texture (USDA Standard)
	Clay	Silt	Sand				
Loc. A							
Pedon 1							
Ap	70	150	780	2.142	1.27	0.79	LS
AB	170	120	710	0.706	1.29	3.22	SL
B	70	190	740	2.714	1.32	4.02	SL
Bt	120	70	810	0.583			SL
Mean	107.5	132.5	760	1.536	1.29	2.68	
CV	44.53	38.17	5.785	68.81	1.95	62.85	
Pedon 2							
Ap	50	110	840	2.200	1.29	0.79	LS
AB	100	110	800	1.100	1.32	6.95	LS
B1	100	90	810	0.900	1.33	7.08	LS
B2	70	60	870	0.857	1.30		LS
Mean	80	92.5	830	1.264	1.31	4.94	
CV	30.62	25.54	3.810	50.05	1.59	72.77	
Pedon 3							
Ap	40	80	880	2.000	1.32	0.89	S
AB	110	100	790	0.910	1.32	3.77	SL
B	90	100	810	1.110	1.35	8.90	LS
Mean	80	93.3	826.7	1.340	1.33	4.52	
CV	45.07	12.37	5.72	43.30	5.33	89.76	
Loc. B							
Pedon 1							
Ap	50	70	880	1.400	1.31	0.93	S
AB	100	70	830	0.700	1.39	4.38	LS
B1	110	60	830	0.546	1.25	10.39	LS
B2	100	60	840	0.600			LS
Mean	90	65	845	0.812	1.31	5.23	
CV	30.09	8.88	2.817	48.98	1.30	91.90	
Pedon 2							
Ap	40	60	900	1.500	1.43	0.45	S
AB	100	80	820	0.800	1.21	1.46	LS
B	90	80	830	0.880	1.40	3.23	LS
Bt	100	60	840	0.600			LS
Mean	82.5	70	847.5	0.947	1.35	1.71	
CV	34.82	16.50	4.24	41.09	8.85	82.1	
Pedon 3							
Ap	60	110	830	1.833	1.24	0.95	LS
AB	140	70	790	0.500	1.12	4.28	SL
B1	120	60	830	0.500	1.30	6.67	SL
B2	120	50	820	0.416			SL
Mean	110	72.5	817.5	0.812	1.22	3.97	
CV	31.49	36.28	2.32	83.92	7.51	72.43	
Loc. C							
Pedon 1							
Ap	50	60	890	1.200	1.52	0.43	S
AB	120	80	800	0.666	1.14	1.54	SL
Bt	130	80	790	0.615	1.05	7.49	SL
B	110	80	810	0.727			SL
Mean	102.5	75	822.5	0.802	1.24	3.15	
CV	35.06	13.33	5.56	33.57	20.17	120.4	
Pedon 2							
Ap	40	70	890	1.75	1.30	0.47	S
AB	120	100	780	0.833	1.21	0.40	SL
Bt1	110	90	800	0.818	1.08	7.81	SL
Bt2	140	90	770	0.643			SL
Mean	102.5	87.4	810	1.011	1.20	2.89	
CV	42.43	14.38	6.762	49.47	9.24	147.2	
Pedon 3							
Ap	70	90	840	1.286	1.32	0.49	LS
AB	150	90	760	0.600	1.28	3.27	SL
Bt1	160	80	760	0.500	1.21	7.14	SL
Bt2	170	90	740	0.529			SL
Mean	137.5	87.5	800	0.729	1.27	3.63	
CV	33.26	5.714	5.72	51.30	4.384	91.92	

Table 4: Chemical Properties of study area

Samples locations	Soil pH (KCl)	Organic C (gkg-1)	Organic M (gkg-1)	Total N (gkg^{-1})	C/N Ratio	Bray 1 Avail. P ($mgkg^{-1}$)	Exchangeable Bases (gkg^{-1})				Total Exch. Bases (gkg^{-1})	Base Saturation (%)	Exch. Acidity ($H+Al^{3+}$)	Acidity (%)
							K	Na	Ca	Mg				
Loc. A (RP)														
A	6.48	6.983	12.04	0.873	7.98	4.80	0.11	0.10	4.60	1.24	6.05	91.0	0.60	9.00
AB	6.50	2.793	4.815	0.379	7.36	2.57	0.12	0.09	4.80	1.30	6.31	86.3	1.00	13.7
Bt1	6.71	1.995	3.439	0.285	7.00	1.54	0.16	0.03	7.60	2.10	9.89	92.5	0.80	7.50
Bt2	6.33	0.798	1.376	0.114	7.00	1.89	0.29	0.21	6.20	1.67	8.37	91.3	0.80	8.70
Mean	6.51	3.142	5.418	0.412	7.34	2.70	0.17	0.11	5.80	1.58	7.66	90.3	0.8	9.70
CV	2.403	85.56	85.57	78.95		54.22	48.7	69.77	24.06	25.16	23.72	3.022	20.41	28.05
Pedon 2														
A	6.30	7.781	13.41	0.974	7.99	1.03	0.15	0.20	6.20	1.86	8.41	91.3	0.80	8.70
AB	6.30	2.594	4.472	0.371	6.99	3.60	0.11	0.03	7.00	1.89	9.03	83.3	1.80	16.7
Bt1	6.29	1.397	2.408	0.199	7.02	2.40	0.14	0.05	5.60	1.50	7.29	85.9	1.20	14.1
Bt2	6.18	0.998	1.721	0.143	6.97	1.72	0.17	0.09	5.40	1.46	7.12	78.0	2.00	22.0
Mean	6.27	3.193	5.503	0.421	7.24	2.19	0.14	0.09	6.05	1.68	7.96	84.6	1.45	15.4
CV	0.934	98.14	98.12	90.27		50.07	17.5	82.04	11.88	13.65	11.47	6.54	37.98	35.98
Pedon 3														
A	6.21	5.187	8.942	0.648	8.00	3.77	0.09	0.03	7.80	2.10	10.02	92.6	0.80	7.40
AB	6.16	1.995	3.439	0.285	7.00	2.57	0.13	0.05	8.20	2.21	10.59	93.0	0.80	7.00
Bt	6.06	1.596	2.752	0.228	7.00	2.23	0.12	0.06	6.60	1.79	8.57	95.5	0.40	4.50
Mean	6.14	2.926	5.044	0.387	7.33	2.86	0.11	0.05	7.53	2.03	9.73	93.5	0.67	6.50
CV	1.243	67.27	67.26	58.87		28.32	18.4	32.73	11.05	10.71	10.71	1.677	34.64	24.95
Loc. B (MP)														
A	6.00	5.586	9.630	0.698	8.00	4.97	0.09	0.04	7.80	2.20	10.13	91.0	1.00	9.00
AB	6.01	1.596	2.752	0.200	7.98	1.54	0.09	0.04	7.20	1.94	9.27	92.05	0.80	7.95
Bt1	5.96	0.798	1.376	0.114	7.00	1.03	0.07	0.02	4.40	1.20	5.69	85.05	1.00	14.95
Bt2	5.90	0.199	0.343	0.028	7.11	3.77	0.06	0.02	3.80	1.03	4.91	83.08	1.00	16.92
Mean	5.97	2,044	3.525	0.260	7.52	2.83	0.08	0.03	5.80	1.59	7.48	88.52	0.95	11.48
CV	0.836	118.8	118.8	115.5		65.75	19.3	38.49	34.37	35.53	34.46	5.01	10.53	36.07
Pedon 2														
A	6.30	4.589	7.911	0.656	7.00	2.06	0.10	0.08	3.60	1.00	4.78	85.7	0.80	14.30
AB	6.06	2.793	4.815	0.379	7.34	1.89	0.06	0.02	4.80	1.30	6.16	83.7	1.20	16.3
Bt1	5.90	1.596	2.752	0.199	8.02	1.72	0.07	0.06	5.40	1.46	6.99	89.7	0.80	10.3
Bt2	5.93	0.998	1.721	0.143	6.98	4.63	0.09	0.03	3.60	0.97	4.69	85.4	0.80	14.6
Mean	6.05	2.493	4.300	0.344	7.33	2.58	0.08	0.05	4.35	1.18	5.66	86.9	0.85	13.1
CV	3.011	63.48	63.48	67.08		53.48	22.8	57.97	20.69	20.09	19.73	2.95	22.22	18.31
Pedon 3														
A	5.53	9.576	16.509	1.197	8.00	1.89	0.06	0.09	3.40	1.02	4.57	87.4	0.80	12.6
AB	5.93	3.192	5.503	0.456	7.00	1.37	0.05	0.04	4.60	1.38	6.07	88.3	0.80	11.7
Bt1	6.00	1.796	3.096	0.256	7.02	1.37	0.05	0.03	4.40	1.19	5.67	90.4	0.60	9.60
Bt2	5.94	1.197	2.064	0.171	7.00	1.89	0.06	0.05	4.60	1.42	6.13	83.6	1.20	16.4

Mean	5.88	3.940	6.793	0.52	7.26	1.63	0.06	0.05	4.25	1.25	5.61	86.8	0.85	13.2
CV	3.69	97.68	97.68	98.78		18.42	10.5	50.09	13.52	14.74	12.88	3.25	29.61	22.61
Loc. C														
A	5.96	4.389	7.567	0.549	7.99	3.26	0.05	0.03	3.20	0.86	4.14	80.5	1.00	19.5
AB	6.24	3.990	6.879	0.488	8.18	1.89	0.07	0.03	3.80	1.14	5.04	75.9	1.60	24.1
Bt1	6.00	2.512	4.331	0.359	7.00	2.40	0.06	0.07	4.80	1.44	6.37	82.0	1.40	18.0
Bt2	5.96	2.937	5.063	0.419	7.01	1.72	0.07	0.12	5.00	1.50	6.69	89.3	0.80	10.7
Mean	6.04	3.46	5.96	0.454	7.54	2.32	0.06	0.06	4.20	1.24	5.56	82.2	1.20	17.8
CV	2.229	25.42	25.41	27.19		29.84	15.3	68.35	20.20	23.92	21.33	6.786	30.43	30.76
Pedon 2														
A	5.93	4.772	8.227	0.596	8.01	2.57	0.08	0.12	4.80	1.30	6.30	86.3	1.00	13.7
AB	6.20	4.589	7.911	0.574	7.99	2.23	0.12	0.12	6.00	1.62	7.86	90.8	0.80	9.20
Bt1	5.95	4.405	7.594	0.550	8.01	1.72	0.09	0.10	6.60	1.80	8.58	82.6	1.80	17.4
Bt2	5.90	2.019	3.481	0.288	7.01	1.54	0.10	0.10	4.40	1.32	5.92	78.7	1.60	21.3
Mean	6.00	3.946	6.80	0.502	7.76	2.02	0.10	0.11	5.45	1.51	7.17	86.5	1.12	13.5
CV	2.31	32.78	32.78	28.66		23.40	17.5	10.50	18.80	16.06	17.62	6.11	36.62	33.56
Pedon 3														
A	5.89	6.607	11.390	0.943	7.01	2.57	0.16	0.17	2.60	0.70	3.63	75.2	1.20	24.8
AB	6.24	2.937	5.063	0.367	8.00	1.89	0.14	0.13	4.00	1.10	5.37	81.7	1.20	18.3
Bt1	6.04	1.652	2.848	0.236	7.00	1.54	0.12	0.14	3.40	0.92	4.58	82.1	1.00	17.9
Bt2	6.10	0.918	1.583	0.130	6.90	2.06	0.15	0.14	4.60	1.38	6.27	88.7	0.80	11.3
Mean	6.07	3.029	5.221	0.419	7.48	2.02	0.14	0.15	3.65	1.03	4.97	82.6	1.05	17.3
CV	2.39	83.45	83.45	29.22		21.27	11.9	11.95	23.41	28.07	22.67	6.730	18.24	30.51