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# PEDOLOGICAL STUDY OF SOILS DEVELOPED ON GRANODIORITE IN BIASE LOCAL GOVERNMENT AREA OF CROSS RIVER STATE, NIGERIA

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## ABSTRACT

Morphological, physico-chemical and mineralogical properties of soils derived from Granodiorite of Biase, Cross River State, Nigeria were studied with a view to classifying the soil taxonomically, assessing their potentials and suggesting appropriate management strategies. Three profiles were dug on the landscapes of Ikot-Okpara, Betem and Ehom. The micro-morphological properties of soil colour, soil structure, soil consistence, drainage and root abundance were determined in the field. The soils were characterized as follows: deep profiles (>100 cm) with texture of gravelly sandy clay loam to sandy clay; hues of 10YR – 2.5YR; structure of subangular peds with sticky consistence (wet); bulk density values of 1.3 – 1.6 mgm$^{-3}$; total porosity of 40 .0 – 52.8 %; silt-clay ratios of 0.1 – 1. Others were soil reaction (pH 4.6 – 5.3) $H_20$; organic carbon (1.6 – 23.84 gkg$^{-1}$); Total nitrogen (0.42 – 1.54 gkg$^{-1}$) ECEC (2.39 – 5.20 cmolkg$^{-1}$); CEC (4.20 – 6.60 cmolkg$^{-1}$); available P (2.12 – 11.17 mg/kg); base saturation (35 – 79 %) and minerals such as quartz (80.0 %), kaolinite (12.7 %), microcline (5.80 %) and Sepiolite (0.99 %). According to the criteria of the USDA Soil Taxonomy, the soils were classified as Loamy Skeletal, Mixed IsohyperthermicTypic Kandiudults. Equivalent FAO-World Reference Base for Soil Resources of the soils is Dystric Acrisols. Pedogenetic process of eluviation-illuviation reflecting the weathering process has been occurring in the soils under the humid tropical influence. The soils can be managed by planting acid tolerant crops liming and adopting appropriate cultural practices.

**Key Words:** Pedological Study, Granodiorite, Typic Kandiudults, Dystric Acrisols, Elluviation and Illuviation.

## INTRODUCTION

The soils of Biase Local Government Area are developed from Basement complex rocks consisting of Granodiorite in Cross River State, Nigeria. The Basement Complex rocks cover Oban landscape and is geologically referred to as Oban massif as well as Obudu landscape in Northern Cross River State of Nigeria (Ekwueme, 2003). The locations namely Ikot Okpora, Betem and Ehom all in Biase Local Government Area are underlain by Basement complex rocks characterized as Granodiorite (Ekwueme, 2003). Granodiorite is an igneous rock, rich in Sodium and Calcium plagioclase, potassium feldspar and quartz with minor amounts of mica-muscovite (Ekweme, 2003). Also associated with Granodiorite is hornblende mineral consisting of biotite and amphiboles which gives it a more distinctive toned or overall dark appearance. Granodiorite is crystalline and weathered easily and deeply under humid conditions to form deep soils (> 100 cm) profiles (Mustapha and Alhassan, 2012; Olaniyan *et al*., 2010). Many studies have shown that Granodiorite undergoing weathering under humid tropical condition can influence the morphological, physical, and chemical as well as mineralogical properties of the soils (Koppi and Williams, 1980; Aki *et al*., 2014).

A typical soil profile developed from Granodiorite in Southeastern Queensland was reported to have a thin A- horizon and a hue range of 2.5YR to 10YR in most layers depicting in-situ accumulation of Fe and Al which weathered through a dominant pedogenic process that persist below 50cm depth (Koppi and Williams, 1980; Mustapha and Alhassan, 2012). Soils formed on Granodiorite rocks in Sierra Nevada and Southeastern New Hampshire were observed to have dark reddish brown (5YR 3/2) fine sandy loam with moderate crumb structure on the surface over brown to dark brown (7.5YR 4/2 to 4/6) fine sandy loam with weak subangular blocky structure in the subsurface soils (Wilson, 1970); The soils were also observed to have a thin A horizon, with firmly developed B2 horizon, and the reddish weathered subsoils of Granodiorite persist below 50 cm depth with low total C, N, Available P, low $SO_4^{2-}$ and acidity (Koppi and Williams 1980). Also, soils derived from Granodiorite in Biase are characterized by deep profiles, depending on the topography, coarse to fine sand texture, low base status, acidic in reaction and have low activity clays probably due to high amount of rainfall (>2500-3500 mm) and high soil temperature (>26-320C) (Koppi and Williams, 1980).

The soils derived from Granodiorite in Biase support a lot of agricultural crops such as tree crop plantations (oil palm and rubber trees) and food crop production such as cassava, yam, cocoyam, plantain and vegetables. Many agricultural plantations have been established in the study area for the production of oil palm for the local and foreign industrial uses (Bulk trade and Investment Company Limited, 1989). With the wide spread of intensive cultivation of the soils and the associated land degradation problems, a pedological study consisting of morphological, physico-chemical and mineralogical properties as well as soil classification was carried out with a view to suggesting appropriate land use management measures for the soils formed from Granodiorite in Biase Local Government Area, Cross River State, Nigeria.

## MATERIALS AND METHODS

### Description of the Study Area

Biase Local Government Area (Latitudes $5^0$ 00' and $5^0$ 47' N; Longitudes $8^0$ 06' and $8^0$ 11' E) is located in southern ecological zone of Cross River State, Nigeria (Fig. 1). The climate of the area is characterized by tropical humid conditions with a mean annual rainfall of 2500- 3000 mm, mean annual temperature of 26- 27 $^0$C and a mean humidity of 80- 90 % at the peak of the rainy season (Akpan-Idiok, 2012).

The soils of the area are derived from the Basement Complex rocks which consist of Granodiorite, gabbro and dolerite as well as gneisses and precambrian schists (Ekwueme, 2004; Esu, 1999) The present study locations at Ikot-Okpora, Betem and Ehom are underlain by Granodiorite (Ekwueme, 2004). The landscape is gently to strongly undulating in some places. The original rainforest in the area has been tampered with by human activities.

**Soil Sampling**

Three representative soil profile pits of depths 0- 194 cm, 0- 191cm and 0- 140 cm were dug at Ikot Okpora ($05^0$ 26'. 37"N; $008^0$ 08' 06"E); Betem ($05^0$ 30'. 43"N; $008^0$ 09' 29"E); and Ehom ($05^0$ 27' 60"N; $008^0$ 08' 79"E) at elevations of 106 m, 124m and 108m respectively above a mean sea level. The coordinates and the altitudes of the three profile sites were obtained using Garmin Etrex 2000 GPS meter. Description of the profiles was carried out and the soil samples obtained from the pedogenic horizons from the base of the profiles to avoid contamination; the samples were preserved in polythene bags and were taken to the Soil Science laboratory for physico-chemical analyses at Ahmadu Bello University, Zaria, Nigeria.

**Laboratory Analysis**

Soil samples were air-dried and sieved through a 2 mm mesh. Particle size analysis was carried out by hydrometer method (Juo, 1979) using Sodium hexametaphosphate (calgon) as the dispersant. Soil pH was determined in soil water ratio 1:25 using a glass electrode pH. Organic Carbon was determined by the Walkley and Black method (Juo, 1979) while total nitrogen was by the Micro- kjedahl digestion method (Juo, 1976). Available phosphorus was determined by the Bray and Kurtz (1945) No.1 Method. Exchangeable bases (Ca, Mg, K, and Na) were extracted with 1N $NH_4OAc$ at pH 7. Exchangeable potassium and sodium were determined with a flame photometer while Ca and Mg were determined by the EDTA titration method (Black and Evans, 1965). Exchangeable acidity was determined by titration method using 1N KCl extract (Mclean, 1965). Effective cations exchange capacity was estimated by summing the exchangeable bases (Ca, Mg, K and Na) and exchangeable acidity $Al^{3+} + H^+$. Percentage base saturation was obtained by dividing the total exchangeable bases (Ca, Mg, K and Na) by effective cations exchange capacity. For x- ray analysis, particle size analysis was carried out on each sample to separate and prepare the clay fraction for the analysis. The sample was prepared for XRD analysis using a back loading preparation method. 10 % internal standard (flourite) was added and the sample micronized. The micronized material was analyzed by XRD utilizing a PAN analytical Empyrean Diffractometer with Pixcel detector and fixed slits with Fe filtered Co- k radiation. The phases were identified using X'pert High score plus softwave. The XRD analysis was used to determine the crystalline mineral phases present in the sample. The abundance of each phase (weight %) was determined by the Rietveld Refinement method. An orientation specimen was prepared from each of the samples, the head and the clay (< 2 um) fraction. The glass slide was analyzed by XRD to determine the mineralogy of the samples, the head and clay (<2 um) fraction. The slide was then glycolated and reanalyzed, heat treated and reanalyzed. The process of glycolation and heat treatment made it possible to identify, and quantify, the various phyllosilicates that occur in the clay fraction.

## RESULTS AND DISCUSSION

**Morphological Characteristics**

The morphological characteristics of the three profiles representing soils derived from Granodiorite at Ikot-Okpora, Betem, and Ehom were studied (Table 1). The morphological features showed a range of hues – 10YR to 7.5YR

Table 1: Morphological properties of soils developed on Granodiorite in Biase Local Government Area, Cross River State

| Location | Horizon Designation | Depth (cm) | Munsell Colour | Mottling | Texture | Structure | Consistence | Boundary | Other Features |
|---|---|---|---|---|---|---|---|---|---|
| 05°26'.369''N | Pedon 1(Ikot Okpora) | | | | | | | | |
| 008°08'.062''E | AP | 0 - 20 | 10 YR 3/4 ( Dark yellowish brown) | - | gscl | 1msbk | sssp | cs | Termite, many mica flakes, worm cast; many medium roots; macro and micro pores |
| | $Bt_1$ | 20 - 41 | 7.5 YR 5/6 (Strong brown) | - | gscl | 2msbk | sssp | gs | Common fine mica flakes; common fine and medium roots; clay skins in the peds |
| | BC | 41 - 62 | 7.5 YR 5/8 (Strong brown) | - | gsc | 2msbk | sp | gs | Decay dioritic materials and iron concretions; common medium and fine roots; common macro and fine pores |
| | Crt | 62 - 90 | 7.5 YR 5/8 (Strong brown) | 10 R 4/8 (Red) | gsc | 2msbk | sp | as | Decay dioritic dark weathered rocks; common fine roots and reddish iron concretions |
| | $Crt_2$ | 90 - 174 | 7.5YR5/8 (Strong brown) | 10 R 4/8 (Red) | gsc | 2mcsbk | sp | | Decay, dioritic dark weathered rocks; common fine roots and reddish iron concretions |
| 05°30'.430''N | Pedon 2 (Betem) | | | | | | | | |
| 008°09'.269''E | AP | 0 - 23 | 10 YR 4/4 ( Dark yellowish brown) | - | gscl | 1msbk | sssp | sc | Earthworms cast, Termite and ant activities; many fine roots; macro and micro pores. |
| | $Bt_1$ | 23 - 40 | 10 YR 7/8 (Reddish yellow) | - | gscl | 2msbk | sssp | cw | Many common mica flakes, termite activities; clay skins in the peds |
| | $Bt_2$ | 40 - 87 | 10 YR 6/6 (Reddish yellow) | - | gscl | 2msbk | sp | gs | Many fine mica flakes, many meddium weathered diorite rocks, fragments of quartzite; clay skins in the peds |
| | $Cr_1$ | 87 - 180 | YR 5/6 (Yellowish brown) | 2.5 YR 4/8 (Red) | gscl | 3mcsbk | sp | as | Many mica, Haemtite, termite activities |
| | $Cr_2$ | 180 - 191 | 5 YR 5/6 (Yellowish brown) | 2.5 YR 4/8 (Red) | gscl | 3mcsbk | sp | | Many mica, Haemtite, termite activities |

Texture: gls = gravelly loamy sand; gsl = gravelly sandy loam; gscl = gravelly sandy clay loam; gsc = gravelly sandy clay
Structure: 1 = Weak, 2 = Moderate, 3 = Strong, f = fine, m = medium, c = coarse, sbk = subangular blocky, gr = granular
Consistency :sssp = slightly sticky slightly plastic; sp = sticky and plastic
Boundary: cs = Clear smooth; gs = gradual smooth; gd = gradual diffuse, cw = clear wavy; as = abrupt smooth.

**Table 1: Morphological properties of soils developed on Granodiorite in Biase Local Government Area, Cross River State contd.**

| Location | Horizon Designation | Depth (cm) | Munsell Colour | Mottling | Texture | Structure | Consistence | Boundary | Other Features |
|---|---|---|---|---|---|---|---|---|---|
| 05°27'.603''N | Pedon 3 (Ehom) | | | | | | | | |
| 008°08'.788''E | AP | 0 - 14 | 10 YR 3/6 (Dark yellowish brown) | - | gsl | 1msbk | sssp | cs | Termite, Worm casts, Human activities; many fine and medium roots; many macro and micro pores |
| | $Bt_1$ | 14 - 42 | 7.5 YR 6/8 (Strong brown) | - | gscl | 2msbk | sssp | gs | Common fine roots; common macro and micro pores; many micas flakes; clay skins in the peds |
| | $Bt_2$ | 42 - 64 | 7.5 YR 6/8 (Strong brown) | - | gscl | 2msbk | sp | gs | Common fine roots;many micro pores; many mica flakes; clay skins in the peds |
| | Brt | 64 - 98 | 10 YR 6/8 (Brown yellow) | 2.5YR 3/6 Dark red | gsc | 2msbk | sp | as | Large quartzite, and weathered; common micro pores, many micas flakes. |
| | Cr | 98 - 140 | 10 YR 7/8 (Reddish yellow) | 10 YR 7/8 (Reddish yellow) | gsc | 2mcsbk | sp | | Decay diorite weathered rocks, many micas and iron concretions. |

**Texture: gls = gravelly loamy sand; gsl = gravelly sandy loam; gscl = gravelly sandy clay loam; gsc = gravelly sandy clay**
**Structure: 1 = Weak, 2 = Moderate, 3 = Strong, f = fine, m = medium, c = coarse, sbk = subangular blocky, gr = granular**
**Consistency :sssp = slightly sticky slightly plastic; sp = sticky and plastic**
**Boundary: cs = Clear smooth; gs = gradual smooth; gd = gradual diffuse, cw = clear wavy; as = abrupt smooth.**

which showed the soils with variation of colour such as dark yellowish brown, strong brown and reddish yellow. This range of colours is associated with minerals such as goethite (alpha-FeOOH), maghemite (gama- $Fe_2O_3$), Hematite (algha- $Fe_2O_3$) and Gibbsite [Al $(OH_3)$] (Akpan-Idiok *et al.*, 2013; Aki *et al.,* 2014). The hue of 10YR and chroma of 4 in the surface (Pedons 1 to 3) and the red mottles (10R4/8) and dark red (2.5YR3/6) at the Bt horizon and the bottom (pedons 1, 2 and 3), indicated that the soils were either imperfectly drained or poorly drained during the rainy season in the study locations. The soils are well developed with deep (> 100 cm) profiles and are characterized by gravelly loamy or sandy clay loam subsurface; weak medium subangular blocky structure; slightly sticky or sticky and slightly plastics or plastic under wet condition consistency; argillic or kandic horizons with clay skins in the peds at the depth of 20 to 191 cm; abundance of macro and micro pores; many fine and medium roots

Table 2: Physical properties of soils developed on Granodioritein Biase Local Government Area, Cross River State

| | | | Particle Size | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Location | Horizon / Designations | Horizon Depth | Sand | Silt | Clay | Gravel Content | Textural Classes | Bulk Density | Total Porosity | Silt/Clay Ratio |
| | | (cm) | gkg-1 | $gkg^{-1}$ | $gkg^{-1}$ | % | | $mgm^3$ | (%) | |
| 05°26'.369''N | Pedon 1 (IkotOkpora) | | | | | | | | | |
| 008°08.062''E | Ap | 0-20 | 570 | 280 | 250 | 9.2 | gscl | 1.3 | 52.8 | 1 |
| | $Bt_1$ | 20-41 | 470 | 140 | 290 | 13.9 | gscl | 1.4 | 48.0 | 0.5 |
| | $Bt_2$ | 41-62 | 530 | 80 | 390 | 57.1 | gsc | 1.4 | 47.8 | 0.2 |
| | $Crt_1$ | 62-90 | 510 | 60 | 430 | 39.2 | gsc | | | 0.1 |
| | $Crt_2$ | 90 – 194 | 470 | 120 | 410 | 47.5 | gsc | | | 0.3 |
| 05°30'.430''N | Pedon 2 (Betem) | | | | | | | | | |
| 008°09'.269''E | Ap | 0-23 | 570 | 100 | 330 | 10.8 | gscl | 1.6 | 40.3 | 0.2 |
| | Bt | 23-40 | 690 | 40 | 270 | 44.0 | gscl | 1.4 | 49.7 | 0.1 |
| | Btr | 40-87 | 710 | 60 | 230 | 44.0 | gscl | 1.6 | 39.2. | 0.2 |
| | Crt | 87-180 | 670 | 80 | 250 | 39.7 | gscl | | | 0.3 |
| | $Cr_2$ | 180 - 191 | 570 | 100 | 330 | 53.5 | gscl | | | 0.3 |
| 05°27'.603''N | Pedon 3 (Ehom) | | | | | | | | | |
| 008°08'.788''E | Ap | 0-14 | 850 | 20 | 130 | 29.2 | gsl | 1.5 | 43.2 | 0.1 |
| | Bt1 | 14-42 | 770 | 60 | 170 | 68.7 | gscl | 1.4 | 47.8 | 0.4 |
| | Bt2 | 42-64 | 670 | 60 | 270 | 52.0 | gscl | 1.5 | 44.2 | 0.2 |
| | Brt | 64-98 | 590 | 60 | 350 | 37.5 | gsc | | | 0.2 |
| | Cr | 98 - 140 | 550 | 100 | 350 | 56.9 | gsc | | | 0.3 |
| Range | | | 470 - 850 | 20 – 280 | 170 -4 30 | 9.2 - 68.7 | | 1.3 - 1.6 | 39.6 - 52.8 | 0.1 – 1.0 |
| Surface Mean | | | 653 | 107 | 240 | 29.4 | | 1.5 | 45.4 | 0.4 |
| Sub surface Mean | | | 418 | 69 | 334 | 47.0 | | 1.5 | 46.0 | 0.3 |

as well as animal activities with the presence of many termites, ants earthworms, many fine mica flakes and fragments of quartz, muscovites, biotites, schistose and weathered rocks; horizon delineation of clear smooth occur in the surface to gradual smooth or diffuse smooth in the subsurface. Similar observations were reported for forest soils of Biase (Bulktrade and Investment Company Limited, 1989; Aki *et al*., 2014).

## Physical characteristics

Particle size distribution data in the surface of the three profiles are sandy (> 653 $gkg^{-1}$) with an overall texture of loamy sand overlying sandy clay loam texture with sand fraction greater than 418 $gkg^{-1}$ in the subsurface (Table 2). Clay fractions (profiles 1 to 3) on the average are 240 $gkg^{-1}$ and 334 $gkg^{-1}$ for surface and subsurface soils respectively. The soils are free draining but with the clay content exceeding 200 gkg-1 in the subsurface horizons, the soils can retain considerable amount of water for crop production and that the clay accumulation in the subsurface indicates the dominant pedogenic process of eluviation-illuviation in layers coded as the Bt horizons in the three profiles (Aki *et al.,* 2014; Akpan-Idiok, 2012).

Bulk density values increase with soil depth with overall value of 1.50 $mgm^{-3}$surface and subsurface soils; that falls within the typical range of (1.00 to 1.60 $mgm^{-3}$) for mineral soils (Wild, 1963; Obi, 2000; Akpan-Idiok *et al.,* 2012). The soils therefore have no mechanical impedance for plant roots and also have adequate aeration. The mean total porosity varies from 39.6 to 52.8 % with overall mean values of 45.4 % and 46.0 % in surface and subsurface soils of the three profiles. This range of values shows that the soils contain greater percentage of sand fractions which may enable easy movement of water in the soils. Soils with 45 to 50 % total porosity are porous, well granulated and may have good moisture retention for crop plants (Akpan-Idiok *et al.,* 2012; Esu, 2010). Using silt/clay ratio of 0.15 (Van Wambeka, 1962) or 0.25 (Asomoa, 1973), the considerable silt/clay ratios averaging 0.4 and 0.3 in the surface and subsurface soils respectively indicate the parent material (granodiorite) as being under advanced level of weathering (Akpan-Idiok and Opuwaribo, 1992).

## Chemical characteristics

The soils are generally very strongly acid in reaction with average mean pH ($H_2O$) values of 4.3 and 4.9 in surface and subsurface soil respectively (Table 3). The exchangeable acidity values (sum of $Al^{3+}$ + $H^+$) in the surface (0.4 –

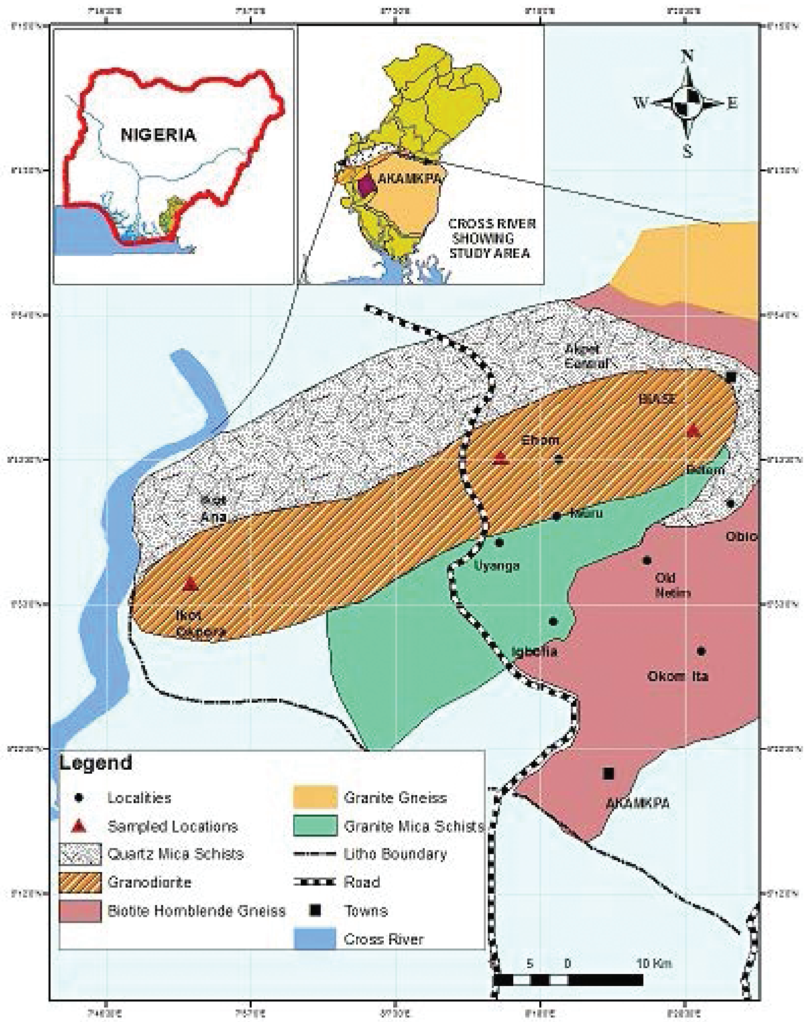


Fig 1: Map of Biase showing sampling points at IkotOkpora, Betem and Ehom

2.80 $cmolkg^{-1}$) are considerable when compared with the threshold value of 0.5 – 2 $cmolkg^{-1}$ for productive soils (Holland et al., 1989). The ΔpH values (pH in KCl – pH in $H_2O$) are negative with mean values of -0.8 and -1.0 for surface and subsurface soils. This is an indication that the soils possess net negative charge for all horizons. The soils with net negative charge can retain basic cations and heavy metal pollutants (Akpan-Idiok, 2002; Landon, 1991). The drop in pH in the KCl solution arises from the hydrolysis of $Al^{3+}$ displaced by the K (Mekaru and Uehara, 1972) and being strongly acidic soils, the dominant cation on the exchange complex might be exchangeable $Al^{3+}$ (Esu *et al,* 2008).

Organic carbon content decreases with soil depth in the three profiles (Table 3) with a mean value of 10.92g $kg^{-1}$ in the surface soils. Correspondingly, the surface total nitrogen (0.42 to 1.54g $kg^{-1}$) was rated moderate with a mean value of 2.66g $kg^{-1}$ while available P was generally low in the three profiles. Exchangeable Ca (1.00 to 2.4 $cmolkg^{-1}$), Mg (0.20 to 0.70 $cmokkg^{-1}$), K (0.04 to 0.27 $cmolkg^{-1}$) and Na (0.01 to 0.08 cmolkg-1) are low when compared with the critical values of 5, 10.3 and 0.3 $cmolkg^{-1}$ (Holland *et al*., 1989; Landon, 1991; Udo *et al,* 2009) for each of the cations. This indicates that the nutrients are removed from the soils due to leaching caused by high rainfall in the area and under

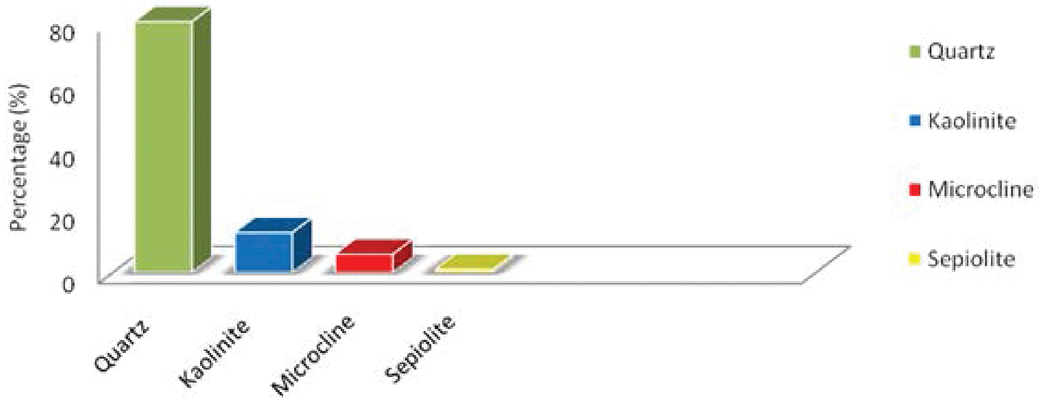


**Fig. 2: Distribution of minerals in clay fraction of soils (depth 23 – 191 cm) developed on Granodiorite in Biase Local Government Area, Cross River State, Nigeria**

advanced level of weathering. The removal of basic cations has been reported for soils derived from Granodiorite in South Western Nigeria (Mustapha and Alhassan, 2012). The effective cation exchange capacity (ECEC) (2.39 – 5.2 cmolkg$^{-1}$) and cation exchange capacity (CEC – $NH_4OAc$ – pH7) (4.2 – 6.6 cmolkg$^{-1}$) are rated low as most values are less than 7.00 cmolkg$^{-1}$ and 16 cmolkg$^{-1}$ respectively in most horizons (Table 3). With the mean percentage saturation of 41 to 61%, basic nutrients occur in available forms in soil solution for plant uptake in-spite of the low cations reserve in the soils (Aki *et al,* 2014).

## MINERALOGICALCHARACTERISTICS

### Quartz

Quartz is one of the common minerals that occur in highly weathered soils of humid tropical regions. It is an intrinsic part of sand sized grains and can persist in soil because it is chemically inert (Akpan-Idiok and Ukwang, 2012; Akpan-Idiok *et al.,* 2013). The x-ray diffraction analysis shows that quartz accounts for 80.0 % in the clay fraction of the soils derived from Granodiorite (Fig. 2). The high percentage (80.0 %) of quartz suggests that the soils are at advanced stage of weathering with low percentage (<10 %) of weatherable minerals such as feldspars (Microcline) (Chikezie *et al.,* 2010; Miranda-Trevino and Coles, 2003; Akpan-Idiok and Ukwang, 2012). The findings are consistent with the earlier work by Hannu *et al.,* (1999) who reported quartz as a dominant mineral in clay fraction of soils derived from granodiorite in Finland. Chemically, quartz mineral can hardly contribute to soil fertility or plant nutrition but its interaction with other soil elements improves structural stability, water permeability, biomass productivity, resistance to erosion, aeration among others (Akpan-Idiok and Ukwang, 2012). The x-ray diffractograms of the mineral are shown in Fig. 3.

### Kaolinite

Kaolinite has been recognized as a natural weathering product of Granodiorite (Gidigasu *et al.,* 1987). The x-ray diffraction data show that kaolinite constitutes about 12.70 % in the soils formed on granodiorite in Biase, Cross River State, Nigeria (Fig. 2). In the present study, kaolinite is one of the end products of weathering sequence of granodiorite. The implications of the identified minerals, quartz and kaolinite suggest that the soils have undergone advanced stage of weathering with low activity clay, low charged surface area, low cation reserve and low fertility status (Akpan-Idiok and Ukwang, 2012). Fig. 3 presents the x-ray diffractogramms of the minerals.

## Microcline

Microcline ($KAlSi_30_8$) is one of the important igneous rock-forming tectosilicate minerals such as feldspars, biotite among others. Its formation arises from cooling of orthoclase and more stable at lower temperature than orthoclase; it can be transformed to sanidine as a polymorph of alkali feldspar under higher temperature. It is a common mineral in metamorphic regions such as Eastern Alps in Germany (Bernotat and Morteani, 1982). The x-ray diffraction data show microcline constitutes about 5.80 % (Fig. 2) in the clay fraction of soils derived from granodiorite of Biase, Cross River State, Nigeria. Microcline is of agricultural importance because it releases the essential nutrient, potassium into soil solution for crop plant uptake. The x-ray diffractograms of the mineral are presented in Fig.3

## Sepiolite

Sepiolite is a naturally occurring clay mineral of sedimentary origin, a complex magnesium silicate with a typical formular ($Mg_4Si_6O_{15}$ $(OH)_2$. $(6H_2O)$, a non-swelling, light weight, porous clay due to aggregate and has density of 2.0 to 2.2 g/cm$^3$(Garcia-Romero *et al.,* 2010). The X- ray diffraction data shows that Sepiolite constitutes about 0.09 % of the minerals obtained from soils developed on granodiorite (Fig. 2 and 3). Sepiolite is one of the end products of weathering sequence of Granodiorite and the implication of the identified mineral is that Sepiolite is of crop nutritional importance because it releases the essential nutrient, magnesium into the soils solution for crop plant uptake. It increases total available water fraction and decreases suc-

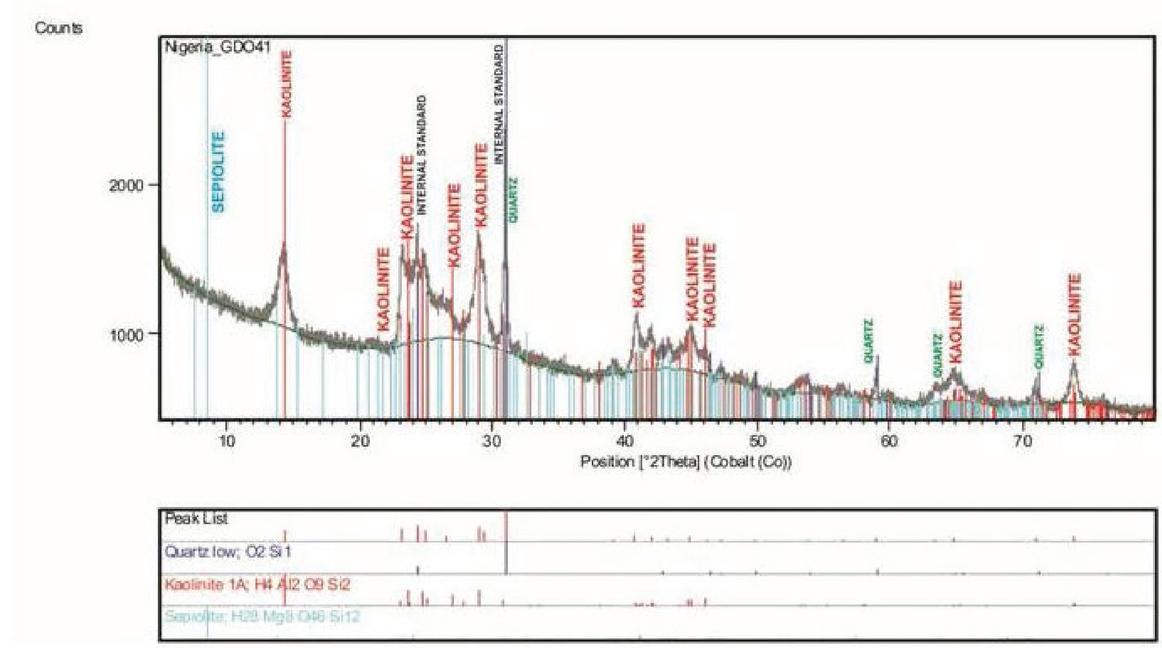


Fig. 3: X-ray diffractogram of clay fractions of soils developed on Granodiorite in Biase Local Government Area, Cross River State, Nigeria

tion pressure from the soils which therefore increases water availability for plants (Post *et al.*, 2007). Also, it modifies soils structure decreasing the excess of compacting of original soils aggregates (Giustetto *et al.*, 2011) as shown in Fig. 3.

## Classification

On the basis of morphological, physico-chemical and mineralogical properties, the soils are classified under USDA Soil Taxonomy and FAO-World Reference Base for Soil Resources. The three profiles have low base saturation (by summation of cations) of less than 35 %, kandic horizons (ECEC < 12 cmolkg$^{-1}$ of clay or less), Ochric epipedon (value of 3 and 4 or less, moist) for Ikot Okpora; Ehom and Betem epipedon are therefore fit into the ultisols order of the USDA Soil Taxonomy (Soil Survey Staff, 2010). The profiles have udic soil moisture regime and brown/brownish yellow argillic or kandic horizons in humid tropical conditions and are therefore fit into the suborder of Udults. With kandic horizon, increase in clay content with depth of 150 cm from the mineral soil surface, and irregular decrease of organic carbon with depth, the three profiles are placed in the Great group Kandiudults and Typic Kandiudults at the subgroup level. With less than 35 % of clay and rock fragments as well as mixed mineralogy of quartz, kaolinite and microcline (K-feldspars), the soils qualify as Loamy Skeletal, Mixed Isohyperthermic TypicKandiudults.

## Management strategies of the soils

The soils formed from Granodiorite are very strongly acid in reaction and are also characterized by medium high contents of organic carbon, total nitrogen and low effective cation exchange capacity. The soils are mostly sandy loam in the surface and sandy clay loam soils in the subsurface and also are rated low in fertility status. Some management strategies suggested for cultivation of the soils for increased crop production include the following:

*Liming of the soils*: Application of liming materials can neutralize the strong acidity of the soils. Liming supplies Ca and Mg and eliminates $Al^{3+}$ in soil solution. Most tropical crops such as cassava, yam, maize etc. grow well at pH range of 5.6 – 6.5 at which most soil nutrients occur in ionic forms in soil solutions for crop uptake. About 0.5 to 1.0 tonne per hectare of lime can be applied to the plough layer of 15 cm depth for

**Table 3: Chemical properties of soils developed on Granodiorite in Biase Local Government Area, Cross River State**

| Location | Horizon Designations | Horizon Depth | pH(1:1) | | pH | Organic Carbon | T:N | Avail P. | Ca | Mg | K | Na | TEB | H + Al | CEC | ECEC | Base Saturation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (cm) | KCl | $H_2O$ | | | (gkg$^{-1}$) | (mgkg) | ← | | | (cmolKg$^{-1}$) | | | | → | (%) |
| 05°26'.369''N | Pedon 1 (Ikot Okpora) | | | | | | | | | | | | | | | | |
| 008°08'.062''E | Ap | 0-20 | 4.2 | 4.9 | -0.7 | 23.84 | 1.54 | 7.89 | 1.2 | 0.6 | 0.27 | 0.02 | 2.09 | 1.4 | 6.6 | 3.49 | 60 |
| | Bt1 | 20-41 | 4.0 | 5.2 | -1.2 | 11.57 | 1.12 | 5.58 | 1.4 | 0.5 | 0.15 | 0.02 | 2.07 | 1.6 | 6.0 | 3.67 | 56 |
| | Bt2 | 41-62 | 4.0 | 5.1 | -1.1 | 8.78 | - | - | 1.0 | 0.3 | 0.25 | 0.06 | 1.61 | 2.4 | 5.1 | 4.01 | 40 |
| | Crt1 | 62-90 | 3.5 | 4.7 | -1.2 | 5.39 | - | - | 1.8 | 0.4 | 0.26 | 0.04 | 2.40 | 2.8 | 4.7 | 5.20 | 48 |
| | Crt2 | 90 - 194 | 4.2 | 5.0 | -0.8 | 3.99 | | | 1.0 | 0.3 | 0.07 | 0.03 | 1.40 | 2.6 | 5.4 | 4.00 | 35 |
| 05°30'.430''N | Pedon 2 (Betem) | | | | | | | | | | | | | | | | |
| 008°09'.269''E | Ap | 0-23 | 3.8 | 4.7 | -0.9 | 3.79 | 0.7 | 4.48 | 1.0 | 0.4 | 0.04 | 0.04 | 1.48 | 2.4 | 6.0 | 4.24 | 35 |
| | Btr1 | 23-40 | 4.0 | 5.0 | -1.0 | 5.59 | 0.42 | 2.19 | 1.0 | 0.3 | 0.05 | 0.03 | 1.38 | 1.2 | 4.7 | 2.58 | 61 |
| | Btr2 | 40-87 | 3.7 | 4.8 | -0.9 | 4.39 | - | - | 1.0 | 0.2 | 0.11 | 0.03 | 1.34 | 2.2 | 5.3 | 3.54 | 38 |
| | Crt1 | 87-180 | 3.6 | 4.6 | -1.0 | 3.19 | - | - | 1.2 | 0.3 | 0.04 | 0.01 | 1.55 | 2.8 | 5.0 | 4.35 | 36 |
| | Crt2 | 180-191 | 3.8 | 4.9 | -1.1 | 1.80 | | | 1.2 | 0.3 | 0.07 | 0.03 | 1.60 | 2.0 | 5.8 | 3.60 | 44 |
| 05°27'.603''N | Pedon 3 (Ehom) | | | | | | | | | | | | | | | | |
| 008°08'.788''E | Ap | 0-14 | 4.4 | 5.2 | -0.8 | 13.97 | 1.26 | 11.17 | 1.2 | 0.4 | 0.17 | 0.02 | 1.79 | 0.6 | 4.2 | 2.39 | 75 |
| | Bt1 | 14-42 | 4.6 | 5.3 | -0.7 | 6.78 | 0.56 | 6.78 | 2.4 | 0.4 | 0.09 | 0.07 | 2.96 | 0.8 | 6.2 | 3.76 | 79 |
| | Bt2 | 42-64 | 4.0 | 5.0 | -1.0 | 3.19 | - | - | 1.6 | 0.3 | 0.08 | 0.06 | 2.04 | 2.6 | 6.1 | 4.67 | 44 |
| | Brt | 64-98 | 4.1 | 4.9 | -0.8 | 2.59 | - | - | 1.4 | 0.7 | 0.04 | 0.08 | 2.22 | 1.4 | 5.1 | 3.62 | 61 |
| | Cr | 98-140 | 4.1 | 5.3 | -1.2 | 1.60 | | | 1.8 | 0.5 | 0.04 | 0.02 | 2.36 | 0.4 | 4.7 | 2.76 | 86 |
| Range | | | 3.6 - 4.6 | 4.6 - 5.3 | -(0.7) - (1.2) | 1.6 - 23.84 | 0.42- 1.54 | 2.12-11.17 | 1.0 - 2.4 | 0.2 - 0.7 | 0.04 - 0.27 | 0.01 - 0.08 | 1.34- 2.96 | 0.40- 2.80 | 4.20- 6.60 | 2.39- 5.20 | 25 - 79 |
| Surface Mean | | | 4.2 | 4.3 | -0.8 | 10.92 | 2.66 | 7.85 | 1.36 | 0.33 | 0.13 | 0.03 | 1.79 | 1.33 | 5.61 | 3.26 | 61 |
| Sub surface Mean | | | 3.9 | 4.9 | -1.0 | 3.90 | 1.03 | 4.83 | 1.33 | 0.37 | 0.11 | 0.04 | 1.91 | 2.09 | 5.28 | 3.97 | 41 |

alleviation of the acidic condition of soils in the ecological zone (FPDD, 1989).

*Planting of acid tolerant crops*: Most of the indigenous crops grown in the area are acid tolerant species. Among them include oil palm, rubber, cocoa, plantain, maize, yam, cassava, melon and sugar cane. For increase yield, acid tolerant crop species should be planted.

*Maintenance of soil fertility:* With the low fertility status of the soils, appropriate soil fertility management measures such as spreading of crop residues on the soils after harvesting, inclusion of legumes during fallow and timely application of soil nutrient additives (fertilizers) should be adopted. For crop mixtures (yam, maize/cassava) about 174 kg or 3.5 bags of urea, 333 kg or 6.7 bags of $P_2O_5$ and 100 kg or 2 bags of $K_2O$ fertilizer materials per hectare are recommended (FPDD, 1989; Akpan-Idiok, 2012).

Soil conservation practices: The area is characterized by gently to strongly undulating landscape, so soil erosion causes serious land degradation. Anthropogenic activities such as destruction of vegetation, bush burning accelerate soil erosion in the area. The soils are coarse-textured (loaming sand) so the surface is light and fragile and should be protected against erosion by cultural techniques such as cultivation of legumes, rotational cropping, bush fallow, incorporation of organic matter into the soils and zero tillage. Legumes such as *Pueraria phaseoloides, Calopogonium mucunoides and Centrosema pubescens* are recommended for the soils.

## CONCLUSION

The investigation highlights the morphological, physicochemical and mineralogical properties of soils derived from Granodiorite in Biase, Cross River State, Nigeria. The soils are well-developed, well-drained with coarse textured materials. The soils are characterized by very strongly acid in reaction, moderate organic carbon and nitrogen as well as low available P and basic cations. The soils have mixed mineralogy of quartz, kaolinite, microcline (K-feldspars) and sepiolite under the same geologic and climatic conditions and undergoing the same rate of weathering. Therefore, the soil fertility management should focus on reducing the leaching of basic nutrients from the soils through mulching, planting of cover crops, crop rotation, adoption of zero tillage as well as application of liming materials to reduce/ameliorate the strong acidity of the soils.

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