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CHARACTERIZATION OF SOILS DERIVED FROM SANDSTONE IN EFFRAYA - ETUNG LOCAL GOVERNMENT AREA OF CROSS RIVER STATE, NIGERIA

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ABSTRACT

Pedological characterization of soils derived from sandstone in Effraya - Etung Local Government Area of Cross River State, Nigeria was studied with the view to suggesting appropriate management strategies. Three representative profile pits were dug in the summit, middle slope and valley bottom positions and the location of each profile was recorded with the aid of German Etrax 2000 GPS meter. The profile pits were described according to Soil Survey Staff. The soils were well drained in the summit and middle slope to poorly drained at the valley bottom and the soil color varied from very dark grayish brown to dark brown and also from yellowish brown to dark yellowish brown within the different horizons. Mean values of 65%, 23% and 12% were obtained in the surface soils for sand, silt and clay respectively while the textural class ranged from loamy sand to sandy loam in the surface and predominantly sandy clay loam in the subsurface soils. Bulk density and particle density had mean values of **1.2g/cm3** and **2.45g/cm3** with total porosity mean value of 48.5% for surface soils respectively. The strongly acidic soils were low in total nitrogen, organic carbon, available phosphorus, and exchangeable bases. CEC in the soils was moderately high with low ECEC while base saturation was below 50%. These results show that the soils are low in fertility and thus will require management practices such as liming, mulching, return of crop residues, and also planting of acid tolerant crops may be recommended for improved crop production.

KEYWORDS: Soil characterization; classification; toposequence; suitability

1.0 INTRODUCTION

Pedological characterization provides valuable information and knowledge on soil characteristics and gives clear understanding of soil genesis, morphology, classification and spatial distribution of soils in an area (Karuma et al., 2015; Kebeney et al., 2014). The information gathered through pedological characterization is needed by soil fertility specialists to carry out fertilizer trials and establish meaningful fertilizer recommendations (Msanya et al., 2003). Structural equation models indicate that micronutrients positively contribute to the ecosystem productivity, both directly (micronutrient availability to plants) and, to a lesser extent, indirectly via affecting the microbiome (Zhongmin, 2023).

The cementing agents present in matrix abundant which may afford sandstones greater structural integrity and resistance to weathering (Evans, 2021).Proper understanding and interpretation of data obtained through the study of soil morphological, physical and chemical characteristics is a sine qua non to good understanding of the use and management of soils as a whole. Data obtained from these studies are often associated with pedological characterization studies (Esu, 2010).

Parent material has a major influence on the physical and chemical properties of soils and it is one of the five traditionally recognized factors of soil formation, the others being climate, topography, organic material and time. Parent material is considered to provide the

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primary raw material upon which the other influencing factors will serve to modify (Gray and Murphy, 2002). The nature of parent material is probably more important than any other single factor in determining the characteristics and productivity of a soil as it is said to profoundly influence the development and characteristics of soils. Soil is a natural body arranged in layers (horizon) consisting of mineral constituents (Maniyunda et al., 2014). Soils vary in their morphological, physical and chemical characteristics. As the landscape is Undulating, soil characteristics at different topographic positions differ (Amhakhian and Achimugu, 2011). Hilly terrains formed on consolidated parent materials such as sandstone, usually have a restricted effective rooting depth as the soils are often eroded and shallow. Sandstones which are parent materials on which the soils are formed are clastic and formed from cemented grains of sand that may either be fragments of pre-existing rocks or be mono-minerallic crystals (Fitchter, 2000). Most sandstone is composed of quartz and/or feldspar which constitute the most common minerals on the earth crust. Sandstone may be any colour, but the most common colors are tan, brown, yellow, red, grey, pink, white and black, depending on the cementing agents (Udo and Sobulo, 1981). According to Ezomo and Aiyohuyin, (2012), sandstone is a very porous rock and is the ideal rock for ground water. Hence sandstone will house substantial aquifers and is also best oil reservoir because petroleum is a fluid that primarily flows through sandstone. Sandstone has a high mechanical strength and is resistant to air, saline water, acids, alkali, corrosion and weathering (Ezomo and Aiyohuyin, 2012). The chemical constitution of sandstone is the same as that of sand; the rock breaks, the cement is fractured and the individual grains remain whole, thus giving the surfaces a granular appearance (Amalu, 2006, 2009). Topsoil Soil Organic Carbon stocks and Soil Organic Carbon Concentration was reported to have the greatest values in limestone-derived soils and the lowest in tertiary red sandstone–derived soils (Xiali Mao et al., 2020). Clay mineral composition is related to the parent material, climate, and micro-topography, and that it can serve as an indicator of pedogenesis and soil type in subtropical China. (Ningxiang et al., 2021). To date, many scientific studies on geogenic heavy metal pollution are mainly focused on soil developed on argillaceous sedimentary rocks, such as shales, slates and mudstones (Althaus et al., 2018; Afuet al., 2020)) ultramafic rocks (Wen et al., 2020), black shale (Afu et al., 2020) and limestone (Wen et al., 2020).

Soils developed on sandstone parent material are usually shallow-depth, well-drained, dark, grayish brown, sandy loam in textures and coarse in nature. They are slightly acidic, having low base saturation and cation exchange capacity (CEC) with faint mottling in the subsoil which can be used for arable and tree crops cultivation. Sandstones can be used as material for construction of buildings and roads (Achukwu et al., 2013). A lot of research has been carried out on soils that are developed on these sandstones and with the present emphasis on the development of agriculture, this study seeks to determine the pedological characterization of soils derived from sandstones in Etung Local Government Area of Cross River State, Nigeria.

2.0 MATERIALS AND METHODS

2.1 Environment of study area

The study was carried out on soils derived from sandstone in Effraya, Etung Local Government Area, Cross River State of Nigeria. Etung Local Government Area is in the central Senatorial District of Cross River State and lies within Latitude 50 49' 12" N and Longitude 80 42' 35"E having Effraya as it headquarters. It has a land mass of 833.07 square kilometers, and shares an international boundary with the Republic of Cameroon to the East. It is bounded in the North by the Ikom LGA, in the South by Obubra and Akamkpa Local Government Areas of Cross River State, Nigeria (Ekwueme, 2004), (as shown in fig 1). The climate within Etung LGA in Cross River State is humid tropical with distinct wet and dry seasons. Wet season ranged between March and October while dry season ranged between November and March. The study area has a mean annual rainfall that varies between 3000 — 3500mm and an average temperature range between 25% and 27% and relative humidity range between 70 — 85% (Ekwueme, 2004). The study area is a sedimentary basin that occurs in diverse geological settings usually associated with plate tectonic activities. The parent materials are mainly limestone, sandstone, basalt and shale intercalation except at the valley bottom positions where alluvial materials have been deposited by the streams. The geology of Etung Local Government Area falls within the Precambrian basement rocks in the Calabar Flank (Ekwueme, 2004).

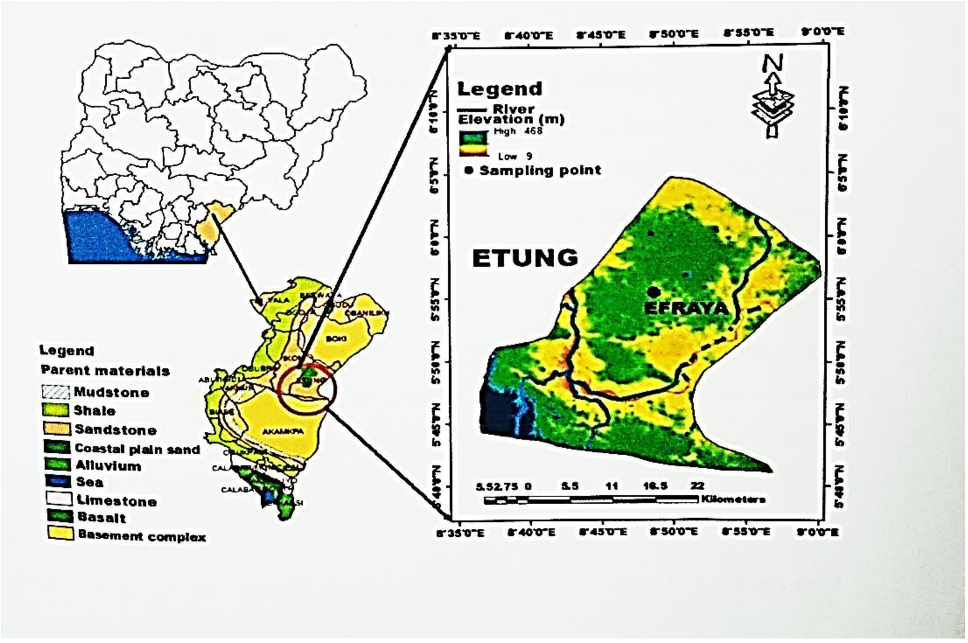

Figure 1**: Geological Map of the Study Area**

Field Studies

Field reconnaissance visit was carried out to areas of Effraya in Etung LGA whose underlying geology has been mapped and identified as sedimentary basin and parent material identified as sandstone by the Nigerian Geological Survey Agency. A topo sequence was identified within the area and three profile pits were dug at the crest, middle slope and valley bottom positions. The location of each of the profiles was taken with the aid of a German Etrex 2000 Geographical Positioning System (GPS), the data generated from the use of this interpretation are presented in figures 2, 3 and 4The profiles were described using a soil description sheet. The long hand description is presented in appendix 1. Soil samples were then collected from pedogenic horizons and stored in labeled black polyethene's and then transported to the laboratory for processing and analyses. The soil samples were air-dried under shade according to their labels for about 4-5 days and a wooden pestle was used to crush the sample to obtain a homogenous sample and the soil samples were then sieved through a 2mm mesh sieve. Particles larger than 2mm were discarded while those less than 2 mm were subjected to laboratory analyses.

Figure 2: profile pit 1-Crest.

Figure 3: Profile Pit 2 –Middle Slope.

Figure 4: Profile pit 3 – Valley Bottom

Laboratory Analysis

Particle-size distribution was determined by Bouyoucos hydrometer method using sodium hexametaphosphate (calgon) as the dispersant (Udo et al., 2009). The percent sand, silt and clay were used to confirm the soil texture using a soil textural triangle. Bulk density was determined by the undisturbed core cylinder method. At the experimental site, core cylinders were driven into the soil using a flat wood and hammer. Hand trowel was used to remove the core samples from the soil, both ends of the core were sliced using the knife, and labels were tagged on the cores. Core samples were weighed immediately and brought into the laboratory to get the wet (fresh) weight. The core samples were put into an oven at a temperature of 105^0C for 24 hours until a constant weight was reached and then the samples were cold in a desiccator and later weighed to get the dried weight after which the soil samples were emptied from the core cylinders and the cores were weighed to get the core weight length and diameter of the core for calculation as described by Grossman and Reinsch (2002).

Particle density was determined with the use of a pycnometer as described by Udo et al. (2009). Particle density was obtained using the expression

Where;

$$PD = \frac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)}$$

PD = Particle density

M_l = weight of empty container

M_2 = weight of empty container + soil sample

M_3 weight of empty container + soil sample + water

M4 = weight of empty container + water only.

Total porosity was calculated from the relation:

$$\text{Total Porosity} = I - \frac{\text{Bulk density}}{\text{Particle density}} \times \frac{100}{1}$$

Soil pH was determined potentiometrically in a soil to water ratio of 1:2.5 using a glass electrode pH meter (Udo et al., 2009). This was done after standardization with a buffer of pH 7.0. Organic carbon of the soil was determined by Walkley and Black wet oxidation method using diphenol amine as indicator and potassium dichromate as the oxidizing agent as outlined by Udo et al., (2009).

It was calculated, thus:

$$\text{Meq blank} = \frac{\text{meq sample} \times 0.5 \times 0.3 \times 1.3}{\text{Weight of sample.}}$$

Where Meq = Milliequivalent of samples

The macro Kjeldahl method was used in the determination of total nitrogen as outlined by Udo et al. (2009). Ten (10) g of the processed samples was digested using Na_2SO_4, and $CuSO_4$ was added to convert the N_2 in soil to $(NH_4)_2SO_4$ during digestion. Boric acid was added to the digest with Bromocresol methyl red acting as an indicator, here the digest $(NH_4)SO_4$ is converted to NH_3 solution. The distillate (NH_3 solution) was titrated with HCl and readings were taken.

Available phosphorus was determined with the use of Bray 1 solution as extractant. The extractant phosphorus was measured calorimetrically by the blue color method of Udo et al. (2009). Two (2) ml of the extract was made up to 50 ml with distilled water and then kept for time for color development before taking readings in a spectrophotometer.

The exchangeable bases (Ca^{2+}, Mg^{2+}, K^+& Na^+) were determined by leaching the soil sample with neutral NH_4OAC as the extractant solution at pH 7.0 (Udo et al., 2009), after which, it was titrated with KOH so as to determine Ca and Mg; this is the versenate EDTA titration method, while K and Na were determined by flame photometry**.** Exchangeable acidity was determined by titration as outlined by Udo et al. (2009). 1M KCl was used as an extractant after adding 5 drops of Phenolphthalein indicator and titrated with 0.01 M NaOH until a permanent pink coloration was obtained. The solution was titrated against 0.01 M HCI until a colorless solution was obtained. 10ml of NaF was then added and titrated to a colorless state.

The effective cation exchange capacity (ECEC) was obtained by the summation method of Udo et al. (2009), which is the summation of the exchangeable bases (Ca^{2+} + Mg^{2+} + $K^{2\,+}$+Na^+) and exchangeable acidity ($A1^{3+}$ and H^+).

Base saturation was determined by dividing the total exchangeable bases (Ca, Mg, K& Na) by the effective cation exchange capacity.

$$BS = \frac{(Ca^{2+} + Mg^{2+} + K^+ + Na^+)}{ECE} \times 100$$

The result of the physicochemical properties was statistically analyzed using means and ranges.

RESULTS AND DISCUSSION

Morphological Properties of the studied Soil

The Soil morphological properties of the studied Soil are presented in Table I. The texture of the surface soils varied between sandy loam in the summit as well as in the valley bottom and sandy clay loam in the middle slope while the subsurface soils were dominated by sandy clay loam. The soils are coarse textured. The coarse nature of these soils could be attributed to their parent material (Achukwu et al., 2013). Soil texture is likely to encourage good drainage and leaching (Shaw et al., 1994). Soil texture effects on agricultural drought varies significantly. Under similar climate, sandy soil is more prone to cause agricultural drought than clay soils while loam, loamy sand and sandy loam falls between these two soils. Sand, loam and loamy sand has the highest percentage of extremely agricultural drought, while clay showed the highest resistance to severe and extremely agricultural drought with high air temperature and low precipitation (Meixiu et al.,2023).

The surface soils ranged from weak medium granular in the summit, middle slopes as weak moderate medium coarse sub angular blocky structure and weak medium granular in the valley bottom (Amalu, 2006). The subsurface soils on the other hand ranged between moderate medium coarse sub angular blocky structures in the summit and weak moderate medium coarse sub angular surface structural type is mainly a reflection of the sandstone material that overly the soils and low organic matter content that would have otherwise acted as cementing agents. In addition, soil structure and soil texture assessed together, lead to a stronger predictability of soils’ infiltration characteristics (Christelle et al., 2023).

The surface soil consistency ranged between non-sticky and slightly sticky when wet and friable to firm when moist while the subsurface soils were sticky when wet. At moist condition, consistency was friable and mostly firm in the subsurface soils (Osedeke et al., 2002). Consistencies may probably be as a result of high clay and low sand dominated nature of the underlying parent material. In moist soil, the friable or firm consistency does not occur near the slightly moist condition. Friable or firm consistency are observed at moisture closer to field capacity. In dry soil, the clods/aggregates reach hard, very hard, or extremely hard consistency before the soil reaches the air-dried condition. Defining the range of moisture in which consistency should be evaluated is necessary for soil taxonomy in order to evaluate the purpose of detecting cohesive character in moist soil conditions (Alexandre et al., 2023).

Munsell soil colour in the surface soils ranged from very dark grayish brown (10YR 3/2) to dark brown (10YR 3/3). In the subsurface soils, soil colour ranged from yellowish brown 4/6) to dark yellowish brown (10YR 4/4) and yellowish brown at 10YR 5/4 for that of the valley bottom. Also, soil colour ranged from yellowish red (5YR 4/6) or (5YR 5/8) to strong brown (7.5YR 4/6) for the subsurface horizon in Pedon I as well to light grey (10YR 7/1) for the subsurface horizon in Pedon II. However, the reddish colours in the subsurface soils indicate that they are well drained and iron-enriched (Agbede, 2009; Esu, 2005), whereas brownish colour indicate relatively higher organic matter content. Also, the light grey colour in the subsurface soil indicates that the soil is either waterlogged at times or fairly dry at other times. The darker the soil color, the higher the Soil organic matter content. Soil color also holds the potential to serve as a surrogate for assessing cropland quality, particularly in evaluating Soil organic matter (Yang et al. 2023).

Many medium pores, many coarse pores (Blocher et al., 2013), many medium coarse roots and many medium roots were observed in the surface and subsurface (Esu, 2010) along with common few roots including ants and worms’ activities. Few moderate clay cutans were obtained in pores in the subsurface soils of the middle slope as a result of the accumulation of alluvial clay according to Scheonebeger, (1998). Horizon boundaries in the three pedons were mostly clear smooth by its distinctness (Ibanga, 2006).

Table 1: Morphological properties of Soils Developed on Sandstone in Effraya, Etung Local Government Area of Cross River State.

Horizon	Depth (cm)	Munsell colour (Moist)	Mottling	Texture	Structure	Consistence	Boundary
Soils in the summit: Pedon I (N05º51''43.3' E008º43''61.1' 117m ASL)							
Ap	0-23	10YR 5/2 (Very Dark Brown)	-	sl	1mgr	wnsnp, mfr	Cs
Bt_1	23-64	10YR 4/6 (Yellowish Brown)	-	scl	2mcsbk	ws, mfrfi	cs
Bt_2	64-99		-	scl	2mcsbk	ws, fi	cs
Bc	99-140		-	scl	2mcsbk	ws, fi	cs
Soils in the middle slope: Pedon II (N05º55''42.6' E008º43''45.9' 111m ASL)							
Ap	0-16	10YR 3/3 (Dark Brown)	-	scl	1, 2mcsbk	wss, mfri	cs
Bt_1	16-50	10YR 4/4 (Dark Yellow Brown)	-	scl	1, 2mcsbk	ws, mfi	gs
Bt_2	50-72	7.5YR 4/6 (Strong Brown)	-	scl	1, 2mcsbk	ws, mfi	cs
Crt	72-145	10YR 7/1 (Light Grey)	-	scl	2mcsbk	ws, mfi	cs
Soils in the valley bottom: Pedon III **(N05º51''41.7' E008º43''45.1' 102m ASL)**							
Ap	0-20	10YR 3/3 (Dark Brown)	-	sl	1mgr	wnsnp, mfr	cs
Bt_1	20-40	10YR 5/4 (Yellow Brown)	-	scl	1fsbk	ws, mfrfi	cs

Texture: S = Sand, L = Loam, C = Clay, Scl = Sandy Clay, SCL = Sandy Clay Loam, SL= Sandy Loam
Structure: 1, 2, 3= Weak, Moderate, Strong; FMC = Fine, Medium, Coarse, gr = granular, Sbk = Subangular blocky structure
Consistence: W = Wet, M = Moist, Ss = slightly sticky, np = non plastic, fr = friable, fi = firm, vf = very friable, L = Lose
ASL: Above Sea Level

PHYSICAL PROPERTIES OF THE STUDIED SOIL

The soil physical properties are presented in Table.2. The sand fraction of soils developed on sandstone in Etung Local Government Area of Cross River State, Nigeria ranged from 55 to 75 % with mean value of 65 % in the surface horizon and 44 to 69 % with mean value of 56. 5% in the subsurface horizon. The total sand is high as most values obtained were greater than 50 % and decreased with an increase in soil depth as reported by Esu, (2005). The high sand content is an indication of the sandstone parent material and is often responsible for low soil CEC and low basic cations mainly as a result of high leaching rate in the soils as well as little water and nutrient retention capacity as reported by Nnaji et al. (2002).In addition Helen et al. (2022) stated that C:N ratios in bulk soil were most strongly correlated with sand contents ($r = 0.52$; $p < 0.001$), consistent with the high Carbon :Nitrogen of sand-sized Soil Organic Matter (median 16.7) .

The silt fraction of soils ranged from 19 to 27 % with mean value of 23 % in the surface horizon and 15 to 32 % with mean value 23.5 % in the subsurface horizon and decrease regularly with depth in the three pedon studied. Being far lesser than percent sand, it tends to have a larger surface area with a fast-weathering rate than sand thus releases more soluble nutrients for plant growth than sand as reported by Vine, (1995). Also, organic matter associated with fine particles (clay and silt) is considered one of the essential aspects in its physical protection against biological and chemical decomposition in the soil and thus improving soil health and sustainability. (Thabit et al., 2023).

The clay fraction of ranged from 6 to 18 % with mean value of 12 % in the surface horizon and 14 to 32 % with mean value of 23 % in the subsurface horizon as reported by Osedeke et al., (2002). Being lower in percent than the sand and silt in the surface horizon indicate that it contributes a lot of chemical reactivity of the soil than sand and silt due to its greatest specific surface area as reported by Vine, (1995).The composition and relative content of clay minerals in clay fraction of soils can also efficiently indicate soil types with a high development degree (Ferrosols, Ultisols, and Acrisols), those with a low development degree (Primosols, Entisols, and Leptosols), and those with a strong redox status (Plinthic Ali-Udic Cambosols, Plinthudults, and Plinthosols) (Ouyang et al.,2021).

The silt/clay Ratio ranged from 1.5 to 3.5 with mean value of 2.5 in the surface soils and 0.5 to 1.4 with mean value of 0.95 in the subsurface soils as shown in Table. 2. This result indicate that there was a very low degree of weathering in the surface horizon to a low degree downward in the subsurface according to the findings of Ogunwale and Ashaye (1975) who reported that silt/silt+clay ratios less than 0.25 indicate high degree of weathering.

The bulk density of soils developed on sandstone in Etung Local Government Area of Cross River State, Nigeria ranged from 1.0 to **1.4 g/cm -3** with mean value of 1.2 **g/cm -3** in the surface horizon and 1.2 to 1.6 **g/cm-3** with mean value of 1.4 g/cm- in the subsurface horizon and increased with soil depth as shown in Table 2. This result indicates that the soil has no mechanical impedance for plant root and this is similar to the findings of Esu, (2010) who reported that the bulk density higher than **1.6g/cm-3** tend to restrict root growth.

The particle density ranged from 2.3 to 2.6 g'cm-3 with mean value of 2.45 g/cm-3 in the surface horizon and 2.2 to 2.6 g/cm-3 with mean value of 2.4 g/cm-3 in the subsurface horizon and decrease with soil depth as shown in Table. 2. This result is not in line with the findings of (Nsor 2011) who reported that the particle density of soils developed on sandstone in Central Cross River State, Nigeria ranged from 2.87 to 3.05 g/cm-3 with mean value of 2.96 g/cm-3 and increase with an increase in soil depth. This may be due to different mineral particles and the parent material intercalation with shale. Another reason for low particle density as seen in this study may be as a result of moderate amount of organic matter as corresponded by the findings of Gee and Or. (2002).

The total porosity of soils ranged from 41 to 56 % with mean value of 48.5 % in the surface horizon and 38 to 47 % with mean value of 42.5 % and decrease with soil depth as shown in Table. 2. This result is similar to the findings of Ogbodo and Chukwu (2012) who reported that the total porosity of soils developed on sandstone in Ebonyi State, Southeastern Nigeria ranged from 44.6 to 54.0 % and decreased with soil depth. However, this implies that the soils in Etung Local Government Area have pores spaces that can hold water and oxygen for plant absorption.

TABLE 2: Physical properties of Soils Developed on Sandstone in Effraya in Etung Local Government Area, Cross River State, Nigeria

Profile	Location & Elevation	Horizon Depth Designation	Depth (cm)	% Sand	PSD % Silt	Clay %	Silt/Clay Ratio	Textural Class	B.D (g/cm³)	P.D (g/cm³)	Total Porosity (%)
		Crest	**Pedon 1**								
1	05⁰ 51''43.3'N	Ap	0-23	74	20	6	3.5	ls	1.3	2.3	41
		Bt_1	23-64	56	15	29	0.5	scl	1.6	2.4	41
	008⁰43''61 .1'E	Bt_2	64-99	53	15	32	0.5	scl	1.4	2.6	47
	117m	Bc	99-140	53	17	30	0.6	scl	1.5	2.4	38
		Middle Slope	**Pedon 2**								
	05⁰55''42. 6'N	Ap	0-16	55	27	18	1.5	sl	1.4	2.6	47
2		Bt_1	16-50	52	26	22	1.2	scl	1.2	2.2	45
	008ᵒ43''45 .9'E	Bt_2	50-72	46	20	27	0.7	scl	1.5	2.5	40
	111m	Crt	72-145	44	32	24	1.4	1	1.3	2.2	41
		Valley Bottom	**Pedon 3**								
	05⁰51''41. 7'N	Ap	0-20	75	19	6	3.3	ls	1.0	2.3	56
3	008ᵒ43''45 .1E	Bt_1	20-40	69	18	14	1.3	ls	1.2	2.2	46
	102										
		SurfaceRange:	55-75	19-27	6-18	1.5-3.5			1.0-1.4	2.3-2.6	41-56
		Subsurface Range	44-69	15-32	14-32	0.5-1.4			1.2-1.6	2.2-2.6	38-47
		Surface Mean	65	12	12	2.5			12	2.45	48.5
		Subsurface Mean	56.5	23	23	0.95			1.4	2.4	42.5

Legend: SD = Particle size distribution; BD = Bulk Density; P. D= Particle density.

CHEMICAL PROPERTIES OF THE STUDIED SOIL

The soil chemical properties are presented inTable.3. The pH of the soils from 4.9 to 5.4 with mean value of 5.2 in the surface horizon and 4.8 to 5.2 with mean value of 5.0 in the subsurface horizon as shown in Table. 3. This result indicates that the soils developed on sandstone are strongly acidic according to the pH rating of Udo et al. (2009). This result is in agreement with the findings of Onwuka et al., (2016) who reported that soils developed on sandstone in Southeastern Nigeria had a pH range of 4.82 to 5.31 with mean value of 5.1. This may be due to high rainfall in the area causing leaching of the basic cations or porous sandy soils in the area.

The organic carbon of soils ranged from 0.82 to 1.81 with mean value of 1.3 g/kg in the surface horizon and 0.60 to 2.57 with mean value of 1.6 g/kg in the subsurface horizon and decrease with soil depth as shown in Table. 3. This result indicates that the organic carbon in the surface horizon was low due to continuous cropping system practiced in the area without incorporation of plant residues into the soils. The result is similar with the findings of Abah and Petia (2016) who reported that the organic carbon content of soils developed on sandstone in Southeastern Nigeria ranges from 0.44 to 1.04 g/kg with mean value of 0.7 g/kg in the surface horizon and 0.46 to 0.93 g/kg with mean value of 0.72 g/kg in the Subsurface horizon and decrease down the profile with depth. The values are far below the critical limit for tropical soils and may adversely affect the growth and yield of arable crops.

The total nitrogen content in the soils ranged from 0.07 to 0.16 with a mean value of 0.1 g/kg in the surface horizon and 0.05 to 0.22 with a mean value of 0.1 g/kg in the subsurface horizon as shown in Table. 3. This result indicates that the total nitrogen for both the surface and subsurface soils is low and is in-line to the findings of Afu et al., (2019) who reported that the total nitrogen content of sandstone derived soils in both surface and subsurface layers were low.

The C/N ratio in the soils ranged from 11.3 to 11.7 with mean value of 11.5 in the surface horizon and 11.7 to 12.8 with mean value of 12.3 in the subsurface horizon as shown in Table. 3. This result indicate high organic matter content in the soils thus the result is in-line with the findings of Agbede (2009) who reported that the C/N ratio of organic matter in arable surface soils ranged from 8 to 15 the median being near 12.

The available phosphorus content of the soils ranged from 0.05 to 2.0 mg/kg with mean value of 1.0 mg/kg in the surface horizon and 0.37 to 3.50 mg/kg with mean value of 1.9 mg/kg in the subsurface horizon as shown in Table. 3. This result indicates that the available phosphorus in both surface and subsurface soils is low. These low values of available phosphorus in the surface and subsurface soils are attributed to continuous cultivation, bush burning, high rate of mineralization and crop removal without incorporating back to soils (Nsor and Akamigbo, 2015).

The exchangeable calcium of the soils ranged from 1.8 to 5.2 with mean value of 3.5 cmol/kg in the surface horizon and 1.6 to 5.6 with mean value of 3.6 cmol/kg in the subsurface horizon as shown in Table. 3. This result indicates that the exchangeable calcium in the surface and subsurface horizon is low according to the exchangeable calcium rating by Jahn et al. (2006). The low value of exchangeable calcium in the surface and subsurface horizon might be due to leaching caused by high rainfall. This result is in agreement with the findings of Abah and Petja (2016) who reported that the exchangeable calcium of soils developed on sandstone were moderate with mean values of 3.3 cmol/kg in the surface horizon and 3.28 cmol/kg in the subsurface horizon.

The exchangeable magnesium of the soils ranged from 0.6 to 2.4 with mean value of 1.5 cmol/kg in the surface horizon and 0.8 to 4.0 with mean value of 2.4 cmol/kg in the subsurface horizon as shown in Table. 3. This result indicates that the exchangeable magnesium in the surface and subsurface horizon is low according to the exchangeable magnesium rating by Jahn et al. (2006). This result is in agreement with the findings of Abah and Petja (2016) who reported that the exchangeable magnesium of soils developed on sandstone were moderate with mean values of 2.0 c mol/kg in the surface horizon and 1.96 cmol/kg in the subsurface horizon.

The exchangeable potassium of the soils ranged from 0.6 to 2.4 cmol/kg with mean value of 1.5 cmol/kg in the surface horizon and 0.08 to 0.1 1 cmol/kg with mean value of 0.1 cmol/kg in the subsurface horizon as shown in Table. 3. This result indicates that the exchangeable potassium in the surface soils is low that of the subsurface soil is very low according to the rating by Jahn et al. (2006). This result is similar with the findings of Abah and Petja (2016) who reported that the exchangeable potassium of soils developed on sandstone in Southeastern Nigeria has a mean value of 0.09 cmol/kg in the surface and subsurface horizon.

TABLE 3: CHEMICAL PROPERTIES OF SOILS DEVELOPED ON SANDSTONE IN EFFRAYA IN ETUNG LOCAL GOVERNMENT AREA, CROSS RIVER STATE, NIGERIA

H. D	Depth (cm)	pH ($H_2$0)	O.G (g/kg)	T.N (g/kg)	C/N Ratio	Avail. P (mg/kg)	Ca^{2+}	Mg^{2+}	K+	Na+(cmo l\ /kg)	Al^{3+}	H^+	CEC	ECEC	BS (%)	Ca/Mg Ratio	k/Mg Ratio
Ap	0 – 23	5.4	0.82	0.07	11.7	0.05	5.2	1.0	0.12	0.10	0.44	1.48	4.0	8.34	77	5.2	0.12
Bt_1	23 – 64	5.2	0.84	0.07	12.0	1.00	5.0	3.4	0.11	0.09	1.56	1.84	4.0	12.0	72	1.5	0.03
Bt_2	64 – 99	4.9	0.64	0.05	12.8	0.62	5.6	4.0	0.09	0.07	2.72	3.28	5.4	15.76	62	1.4	0.02
Bc	99–140	4.9	0.64	0.05	12.8	0.37	1.6	2.8	0.09	0.07	3.52	4.0	7.2	12.08	38	0.6	0.03
	Pedon 2																
Ap	0 – 16	5.0	1.29	0.11	11.7	2.0	3.6	2.4	0.10	0.08	1.16	2.84	7.4	10.18	61		0.04
Bt_1	16 – 50	4.7	0.76	0.06	12.7	2.50	3.6	1.0	0.08	0.06	5.20	4.24	7.6	14.14	33	3.6	0.08
Bt_2	50 – 72	4.6	0.76	0.06	12.7	3.50	2.6	1.0	0.08	0.06	5.04	3.84	7.0	12.62	30	2.6	0.08
Crt	72– 145	4.6	2.57	0.22	11.7	0.37	2.2	0.8	0.09	0.06	5.52	6.96	6.0	15.63	20	2.8	0.11
	Pedon 3																
Ap	0 – 20	4.9	1.81	0.16	11.3	1.12	1.8	0.6	0.08	0.07	5.10	2.44	4.0	10.09	25	3.0	0.13
Bt_1	20 – 40	4.9	0.60	0.05	12.0	0.37	2.0	0.8	0.08	0.06	4.90	1.90	6.0	9.74	30	2.5	0.10
	Surface Range	4.9-5.4	0.82-1.81	0.07-0.16	11.3–11.7	0.05-2.0	1.8-5.2	0.6-2.4	0.6-2.4	0.07-0.10	0.44-5.10	1.48-2.84	4.0-7.4	8.34-10.18	25-77	1.5-5.2	0.04-0.13
	Sub surface Range	4.8-5.2	0.60-2.57	0.05-0.22	11.7-12.8	0.37-3.50	1.6-5.6	0.8-4.0	0.08-0.11	0.06-0.09	1.56-5.52	1.84-6.96	4.0-7.6	9.74-15.76	20-72	0.6-3.6	0.02-0.11
	Surface Mean	5.2	1.3	0.1	11.5	1.0	3.5	1.5	1.5	0.1	2.8	2.2	5.7	9.3	51	3.4	0.1
	SFF Mean	5.0	1.6	0.1	12.3	1.9	3.6	2.4	0.1	0.1	3.5	4.4	5.8	12.8	46	2.5	0.1

Legend: T.N = Total Nitrogen, Avail. P = Available Phosphorous; BS = Base Saturation; SFF = Subsurface.

The exchangeable sodium ranged from 0.07 to 0.10 cmol/kg with mean value of 0.1 cmol/kg in the surface horizon and 0.06 to 0.09 cmol/kg with mean value of 0.1c mol/kg in the subsurface horizon as shown in Table. 3. The results show a very low exchangeable Na+ content in the surface and subsurface soils based on the rating by Jahn et al., (2006). This result is similar with the findings of Abah and Petja (2016) who reported that the exchangeable sodium of soils developed on sandstone in Southeastern Nigeria has a mean value of 0.09 cmol/kg in the surface and subsurface horizons.

The Ca/Mg ratio of the soils ranged from 1.5 to 5.2 with mean value of 3.4 in the surface horizon and from 0.6 to 3.6 with mean value of 2.1 in the subsurface horizon as shown in Table. 3. This result indicate that the Ca/Mg ratio is an optimum approximate range for most arable crops and indicate that phosphorus uptake may be inhibited as reported by Havlin et al. (2016).

The K/Mg ratio of the soils ranged from 0.04 to 0.13 with mean value of 0.1 in the surface horizon and from 0.02 to 0.11 with mean value of 0.1 in the subsurface horizon as shown in Table. 3. From the above values, it has a clear indication that there's an inhibition of potassium (K) uptake in these soils. This result is similar to the findings of Stevens et al. (2005) who reported that the K/Mg ratio was generally higher than 2.0 in Central Southeastern Nigeria, resulting in the inhibition of Mg uptake in these soils. Thus, according to Doll and Lucas (1973), K/Mg ratio with value less than 1.1 is suitable for vegetables.

The exchangeable aluminum of the soils ranged from 0.44 to 5.10 cmol/kg with mean value of 2.8 cmol/kg in the surface horizon and 1.56 to 5.52 cmol/kg with mean value of 3.5 cmol/kg in the subsurface horizon; the exchangeable hydrogen of the soils ranged from 1.48 to 2.84 cmol/kg with mean value of 2.2 cmol/kg in the surface horizon and 1.84 to 6.96 cmol/kg with mean value of 4.4 cmol/kg in the subsurface horizon as shown in Table. 3. This result indicates that the exchangeable aluminum and hydrogen is high rating by Udo et al. (2009). The high value of exchangeable acidity in the surface and subsurface horizon implies that the soils of the study area is very toxic to plant roots and this might also be as a result of high rainfall in the study area (Nsor and Akamigbo, 2015).

The cation exchange capacity (CEC) of the soils ranged from 4.0 to 7.4 cmol/kg with mean value of 5.7 in the surface horizon and 4.0 to 7.6 cmol/kg with mean value of 7.6 in the subsurface horizon and increase with depth as shown in Table. 3. This result indicates that the cation exchange capacity (CEC) in the surface and subsurface is moderately high which is in line with the findings of Nsor and Akamigbo (2015) who reported that the cation exchange capacity of soils developed on sandstone in Central Cross River State, Nigeria ranged from 1 .9 to cmol/kg with mean value of 4.05 cmol/kg in the surface soils and 1.3 to 23.9 cmol/kg with mean value of 1 1.3 cmol/kg in the subsurface horizon. Thus, medium CEC from the results is due to the possession medium level of organic matter. The effective cation exchange capacity (ECEC) of the soils ranged from 8.34 to 10.18 cmol/kg with mean value of 9.3 cmol/kg in the surface horizon and 9.74 to 15.76 C mol/kg with mean value of 12.8 cmol/kg in the subsurface horizon as shown in Table. 3.

This result indicates that effective cation exchange capacity is high. Thus, high ECEC from the results is due to the possession of medium level of organic matter which is not in line with Onyekwere et al. (2012) who reported that the ECEC of soils developed on sandstone in Umuahia, Abia State, Nigeria ranged from 1.88 to 8.86 cmol/kg with mean value of 5.4 cmol/kg showing that the ECEC of the soils is low.

The base saturation of the soils ranged from 25 to 77 % with mean value of 51 % in the surface horizon and 20 to 72 % with mean value of 46 % in the subsurface horizon as shown in Table. 3. This result indicates that the percentage base saturation in the surface and Subsurface is medium which is in line with Holland et al. (1989) who reported that Percentage base saturation with value 20 — 60 % is medium and thus agrees with the fact that Sandstone soils are classified as low base status soils by Enwezor et al. (1991).

CONCLUSION

The productivity of any soil depends on the management systems employed and also the inherent fertility of the soil. This study was designed to determine the morphological, physical and chemical characteristics of soils overlying sandstone and to suggest the possible soil management techniques for improved crop production. Morphologically; the soils were poorly drained at the valley bottom to well drained in the summit and middle slope and the soil colour varied from very dark grayish brown to dark brown in the summit and middle slope and from yellowish brown to dark yellowish brown for that of the valley bottom. The soil is dominated by sandy loam, sandy clay and sandy clay loam irrespective of soil depth. They also have weak, fine to medium granular and sub angular blocky structures. Bulk and densities are less than 1.6 g/cm and 2.8 g/cm respectively. Thus, there will therefore easy root penetration and good drainage. The soils were acidic in reaction, low in organic C, low in total N and low exchangeable bases with moderate CEC while ECEC and per cent base saturation was low in the soils.

The determination of morphological, physical and chemical properties of soils developed on sandstone formation in Effraya, Etung Local Government Area of Cross River State, Nigeria showed that the soils with

the above determined properties may be suitable for cultivation of tuber crops at the Crest and Middle slope while vegetable and staple crops like rice are also encourage to be cultivated at the valley bottom.
From the understanding of the above stated crops requirement, it is therefore recommended the Crest and Middle slope should carry out the following management practices; returning to land of plant residues after harvesting, applications of organic manure, planting of leguminous crops and making of ridges across the slope while minimal/zero tillage operation is advisable at the valley bottom. The above stated management practices help to reduce incidents of surface compaction, improve soil structures, ameliorate (enhance) soil infiltration rate and bind sandy and silty soils together. As a preventive measure, unhealthy practices such as overgrazing, uncontrolled logging and bush burning, maximum tillage, continuous cropping and uncontrolled use of agro-chemicals which have resulted in the buildup of chemical substances that are detrimental to soil health should be reduced or abolished. Uncontrolled use of chemical fertilizers may have contributed to the acidic condition of the soil as most farmers in the area do not carry out proper soil test before cultivation. According to Havlin et al., (2016), when the Ca: Mg is around 3:1 to 4:1 which is the optimum approximate range for most crops, a mixture of calcitic and dolomitic lime at is recommended. These materials should be applied at a depth of 30cm.

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