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THE MECHANICAL COMPOSITION, TEXTURE, SPECIFIC SURFACE AREA AND THEIR AGRONOMIC IMPLICATIONS FOR PROFILES OF SOILS DEVELOPED FROM SANDSTONES IN CROSS RIVER STATE, NIGERIA

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ABSTRACT

The mechanical composition of soils, referred to as particle size distribution, used to determine the proportion of different sized particles in a soil, hence the textural class, was evaluated for soils of Ekureku in central Cross River State. Three profile pits were sunk on three landscape elements of crest, middleslope and valley bottom along a well defined and identified toposequence. The mean surface soil content of sand, silt and clay for the profiles were 69.0%, 26.0% and 5.0% while the mean subsoil content of same particles were 61.0 % (sand), 23.0 %(silt) and 16.05(clay) respectively. It was observed that sand was the dominant particle size fraction reflecting the sandstones from which the soils were derived. The textures of the crest, middleslope and valley bottom were loamy sands for crest and loams for middleslope and valley bottom. The loamy sands are coarse textured, very light and therefore subject to shearing, detachment and transportation, therefore prone to erosion and leaching. They are therefore very poor dry soils with low water holding capacity. The loams are medium textured, fairly retentive of moisture, good drainage, fertile and productive and good for irrigation. The soils on the crest are therefore poorly endowed but with good management are suited for arable crops like groundnuts, cocoyam, and plantation crops like cashew, oil palm, sugar cane, sod development and golf courses. The loams are prime agricultural land and good for many arable crops. Since the ability to change texture to suit desired crops is

limited, land use should be adjusted to fit existing physical conditions. Therefore the best management option is to use adapted crops.

KEYWORD: Mechanical composition, Texture, Specific Surface-area, Sandstones, Toposequence.

1. INTRODUCTION

The mechanical composition of soils or particle size distribution, texture, a relative proportion of the various soil separates or particles in a soil and soil specific surface, the sum of the surfaces of constituent dispersed soil particles referred to as unit mass or unit volume of soil are intimately related. Soil separates or particles are soil solid materials classified into three, based on sizes. They are sand, silt and clay. The materials are said to be ≤2.0mm in equivalent diameter. Based on the proportion of sand, silt and clay fractions in a soil sample, a soil can be placed in one of the twelve textural classes. Soil texture is almost a permanent property of soil if undisturbed (Savalia et al, 2016). The mechanical composition of soils is a basic aspect of their physical investigation. Land use capability classification (LUCC) is largely determined by texture. In the study of soil morphology, genesis, classification and mapping, accurate knowledge of texture is necessary. The texture of a mineral soil determines to a large extent the physical and chemical behavior as well as the biological potential of the soils. Soil texture is an indication of the type of management needed for good plant growth and for engineering purposes (Obi, 2000). Textures of the soil is intimately related to specific surface and for this reason the significance of both properties are always taken together in respect of soil behavior. As the texture tends towards the final range (clay) the specific surface increases exponentially. Most soil processes are surface phenomena. These processes include water retention, swelling and shrinking, nutrient retention and exchange, cohesion and strength. The magnitudes of these processes are determined by the surface area available, thus the larger the surface area, the greater the magnitude of this processes. The different textural fractions impact certain unique characteristics to the soil (Table 1, Fig 2A and Table 3). Sand for instance, because of its small specific surface contributes very little to the water and nutrient retention capacity of the soil. Also, because of the lack of cohesion the sand shearing is facilitated, therefore soils that are predominantly sandy tend to be highly erosive because of ease of detachment and transportation of the particles.

Sand however has some favorable effect on the soil. It will increase the total porosity because of its large pores and therefore are responsible for conduction of water and air in the soil. Silt has larger specific surface than sand and therefore a faster weathering rate and release of soluble nutrients for plant growth than sand. Silt also has larger capacity for holding water by virtue of larger specific surface. Clay has greatly increased specific surface compared with silt and sand. Therefore clay contributes a lot more to the physical reactivity of the soil than silt and sand combined (Brady and Weil, 2014). Sandstones are sedimentary rocks and soils derived from them termed "acid sands" are usually coarse to medium textured (Esu, 2010). These soils occur extensively in Central Cross River State. They have great potential for agricultural production. Their textures vis-à-vis their mechanical composition has not been adequately addressed. The mechanical composition of soils and hence their textures and specific surfaces determine to a large extent their physical and chemical behavior and biological potential. Their texture is also an indicator of the type of management needed for good plant growth and engineering purposes. Soils cannot be well managed and conserved unless its characteristics are measured and interpreted by skilled observers. The proper characterization of soils occupying any particular landscape is a pre-requisite to properly make recommendations for utilitarian purposes. The thrust of this study is therefore to determine the mechanical composition of the soils vis-à-vis their textures and specific surfaces in order to recommend best land use and management to meeting the land degradation and farming challenges in the 21st century.

2. MATERIALS AND METHODS

2.1. Location of study area

The area of study is at Ekureku in Cross River State of Nigeria. Cross River State is located between latitude 06^{0} 1'49.14"N and longitude 08^{0}02'27.8"E while Ekureku lies between latitude 05^{0}59'34.6"N and latitude 08^{0}02'27.8"E with an area of 30.4ha. (Fig 1) (Eyong and Akpa, 2018).

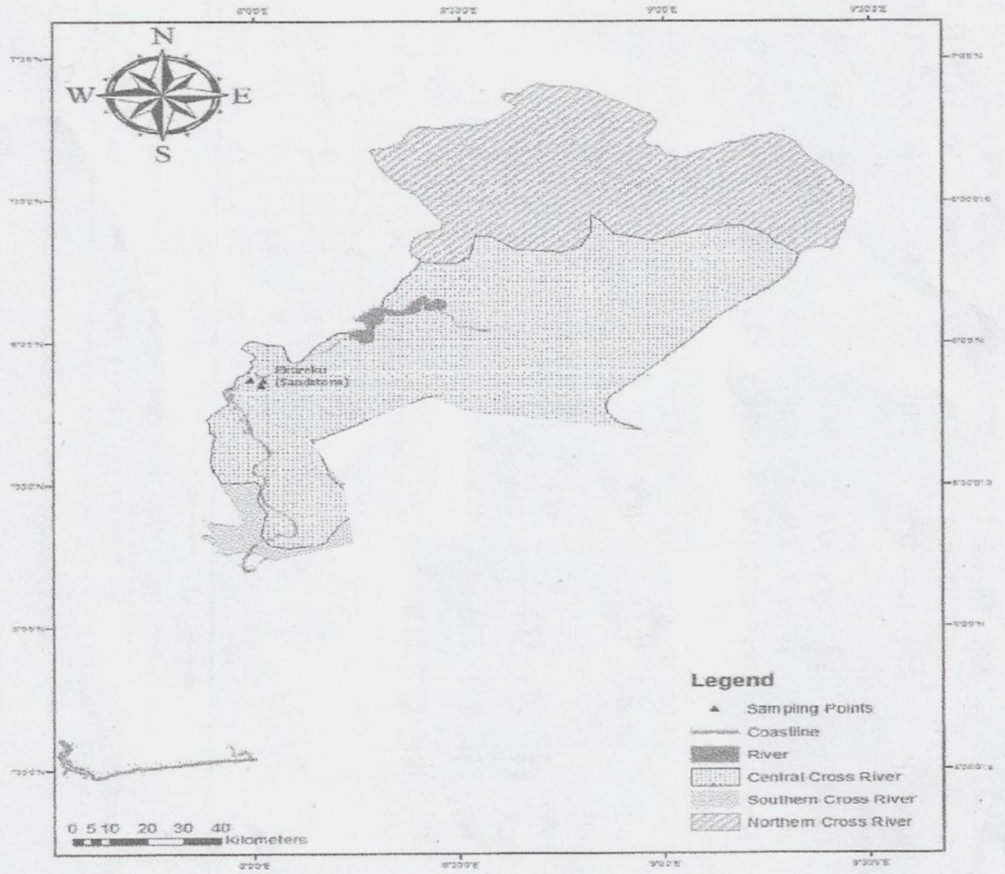

Fig.1: Map of the Cross River State showing the study areas with sampling points

Source: Geographic Information System (GIS), Department of Geography, University of Calabar (2017)

Fig 1: Showing the location study area in Cross River State.

2.2. Climate

The climate is tropical humid with distinct wet and dry season of four months between November and March. The mean annual rainfall range from 1800mm and 2500mm and the relative humidity is between 80% and 90%. The mean annual temperature is between 22^{0}C and 31.8^{0}C. The insulation is abundant and constant due to its location. The average sunshine hours are between 4.1 and 4.9 hours with a mean of 4.5 hours (Nwajubah and Oyeneke, 2010).

2.3. Geology and soil

The study area is underlain by the Precambrian cretaceous sandstones of Eze-aku group of South Eastern Benue through (Ekueme, 2003). The soils are termed acid sands. They are acidic and deep lateritic fertile soils. They have sandy surface soils while the sub soils are clayey and are heavily leached resulting from the prevailing high rainfall (Olatunji et. al., 2007). The soils are loose and have brownish, dark yellowish brown, very dark grayish brown, strong brown top soils over a great depth of largely non-differentiated, non-mottled, porous, stonny, and gravelly and non-gravely sub soils (Eyong and Akpa, 2018).

2.4. Vegetation and land use

The vegetation consists of a mosaic of farmlands and forest. The major crops are rice, cassava, yam, cocoyam, maize, okra, pepper, groundnut and beans (Effiong, 2011).

2.5. Field study

Three profile pits were sunk along a selected and well defined toposequence on the crest, middleslope and valley bottom. The profiles were dug 1.5m x 2.0m x2.0m deep or to impenetrable layer or water table or whichever was shallower. Each profile pit was described in the moist state following the guidelines of FAO (2006). The environmental properties inventorized included surface characteristics, local relief, slope, gradient and class, drainage, depth to water table, vegetation and land use. Soil morphological characteristics recorded included soil depth, color of matrix, mottles if present and texture by feel, structure and consistence. After the field descriptions, samples were collected from morphogenetic horizons of each profile pit into well labeled sample bags and taken to the laboratory.

3. Laboratory studies

In the laboratory, soils were air dried at room temperature for 48hrs. They were gently crushed with pestle & mortar & sieved through a 2mm sieve to obtain fine earth fraction for analysis. The mechanical composition analysis for determination of texture was done by the Bouyoucous hydrometer method using sodium hexametaphosphate (Calgon) as dispersant (Udo et. al., 2009). The soil texture was determined by use of the textural triangle (Soil Survey Staff, 2009). Bulk density (pb) was determined by the core method as elaborated by Blacke and Hartge (1986). Particles density was determined by calculation using the pycnometer method (Bolwes, 1962). The pH in water was determined in soil: water ratio of 1:2.5 using a glass electrode pH meter standardized with buffer solution of 4.0 and 6.85 as outlined by Udo et. al., (2009). Organic carbon was determined by the Walkley and Black method as elaborated by Nelson and Sommers (1996). Total nitrogen was determined by the macro-kjedhal method (Udo et. al., 2009). Available phosphorous was determined by Bray No 1 extraction method (Bray and Kurtz, 1945) and P in solution was determined colorimetrically by ascorbic acid method (Udo et. al. 2009). Exchangeable acidity (Al^{3+} and H^{+}) were determined by leaching the soil with INKCL solution and the extracts titrated with standard NaOH solution (Udo et. al. 2009). Exchangeable cations (Ca, Mg, K, and Na) were obtained by leaching the soil with NH_4OAC (pH 7.0) buffer. The Na^+ and K^+ were determined by flame photometer while Ca^+ and Mg^+ were determined using Atomic Absorption Spectrophotometer (Udo et. al. 2009). Cation exchange capacity (CEC) was determined using $IMNH_4OAc$ at pH 7.0 (Udo et. al. 2009). Base saturation was obtained by expressing the sum of exchangeable cations as percentage of the cation exchange capacity (IITA, 2000).

4. Data analysis

The data of the physical and chemical properties of the three profile pits were statistically processed using descriptive statistics.

5. RESULTS AND DISCUSSIONS

The mechanical composition (particle size distribution) of the soils are presented in Table 1 and Fig 2A, while the generalized influence of soil separates (sand, silt and clay) on some properties and behavior of soils are presented in Table 2.

Table 1: The mechanical composition and textural classes of soil developed on Ekureku sandstone parent materials.

Profile position	Horizon	Depth(cm)	Particle size (%)			Textural class
			Sand	Silt	Clay	
Crest	Ap	0-12	79.0	17.0	4.0	Loamy sand
	Bt1	12-39	78.0	16.0	6.0	Loamy sand
	Bt2	39-79	79.0	15.0	6.0	Loamy sand
	Ctr	79-145	66.0	9.0	23.0	Sandy clay loam
Middleslope	Ap	0-10	69.0	25.0	6.0	Sandy loam
	Bt1	10-50	65.0	13.0	22.0	Sandy loam
	Btq	50-95	56.0	12.0	28.0	Sandy clay loam
	Ctv	95-138	55.0	17.0	28.0	Sandy clay loam
Valley bottom	Ap	0-12	60.0	35.0	5.0	Sandy loam
	Bt1	12-39	49.0	40.0	11.0	Loam
	Bt2	39-74	49.0	40.0	11.0	Loam
	Ctr	74-145	49.0	40.0	11.0	Loam
Surface soils Range Mean			60-79 69.0	17-35 26.0	4-6 5.0	
Subsoil Rang Mean			49-79 61.0	9-40 23.0	6-28 16.0	

Table 2: Generalized influence of soil separates on some properties and behavior of soils.[a]

Property/behavior	Rating associated with soil separates		
	Sand	**Silt**	**Clay**
Water holding capacity	Low	Medium to high	High
Aeration	Good	Medium	Poor
Drainage rate	High	Slow to medium	Very slow
Soil organic matter level	Low	Medium to high	High to medium
Decomposition of organic matter	Rapid	Medium	Slow
Warm-up in spring	Rapid	Moderate	Slow
Compatibility	Low	Medium	High
Susceptibility to wind erosion	Moderate (high of fine sand)	High	Low
Susceptibility to water erosion	Low(unless fine sand)	High	Low if aggregated, high if not
Shrink-swell potential	Very low	Low	Moderate to very high
Sealing of ponds, dams, and landfills	Poor	Poor	Good
Suitability for tillage after rain	Good	Medium	Poor
Pollutant leaching potential	High	Medium	Low(unless cracked)
Ability to store plant nutrients	Poor	Medium to high	High
Resistance to pH change	Low	Medium	High

[a]Exceptions to these generalizations do occur, especially as a result of soil structure and clay mineralogy. Adapted from Brady and Weil (2016).

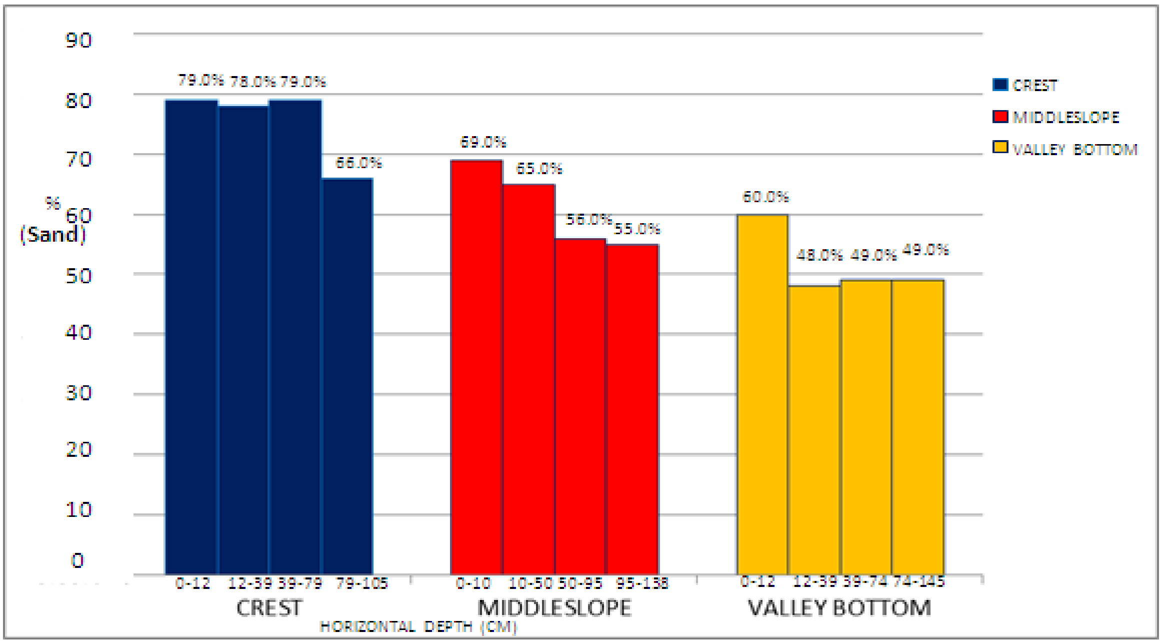

Fig 2A: Percent Sand in Crest, Middle Slope and Valley Bottom.

6. Mechanical composition of the soils

6.1. Sand

Sand was the dominant particle size fraction of the soils reflecting the sandstone parent material from which the soils were formed. The surface soils sand fraction ranged between 60.0% and 75.0% (mean, 69.0%) while subsoil sand content ranged from 49.0-79.0% (mean, 61.0%) (Table 1 and Fig 2A). Sand particles are smaller than 2.0mm in equivalent diameter but larger than 0.05mm and consist of a single mineral usually quartz (SiO_2) or other primary silicates. Quartz dominance indicates low plant nutrient content and large particles of sand means nutrient present will not likely be released for plant uptake (Brady and Weil, 2016). Large particles of sand mean low specific surface areas of the soil. Sand because of its small specific surface area will contribute very little to water and nutrient retention capacity of the soil. Its lack of cohesion will facilitate soil shearing. The soils will therefore tend to be highly erosive because of ease of detachment and transport of the particles. Sand, though will increase the total porosity because of its large pore size but particularly with the proportion of the large pores which enhance conduction of water and air in the soil (Obi, 2000).

6.2. Silt

The surface soil silt content ranged between 17.0% and 35.0% (mean, 26.0%) while subsoil silt content ranged from 9.0-40.0% (mean, 22.0%) (Table 1 and Fig 2B). Silts are particles smaller than 0.05mm but larger than 0.002mmm in equivalent diameter. Silt is composed of weatherable minerals and the relatively small size and therefore large surface area of the particles allows rapid weathering leading to release of significant amounts of plant nutrients (Savalia et. al., 2016) because the pores between particles of silt are much smaller and numerous than those in sand, silt will retain more water and reduce drain-through. Silt has low stickiness and plasticity, therefore soils high in silt and fine sand can be highly susceptible to erosion by wind and water. Silty soils are easily washed away by flowing water in a process called piping (Obi, 2000).

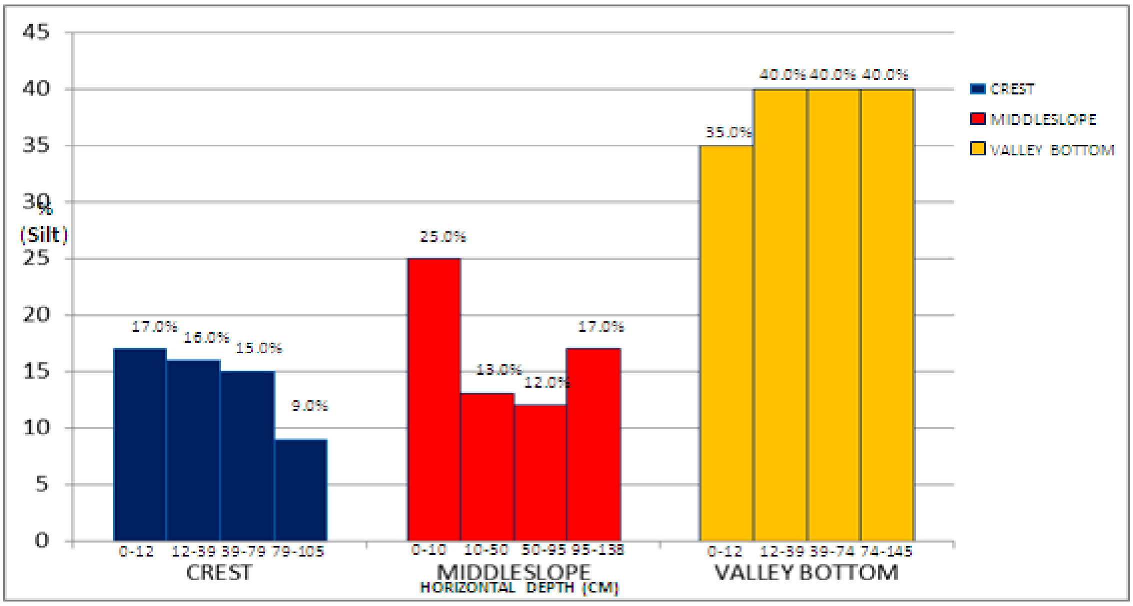

Fig. 2B: Percent Silt In Crest, Middle Slope and Valley Bottom.

6.3. Clay

Surface soil clay content of the soils ranged from 4-6.0% (mean, 5.0%) and the subsoil content ranged between 6% and 28.0% (mean, 16.0%). Clay particles are smaller than 0.002mm and consequently have very large specific surface areas. They thus have a tremendous capacity to absorb water and other substances; clay contributes a lot to the physical reactivity of the soil than silt and sand combined. (Table 1 and Fig 2C).

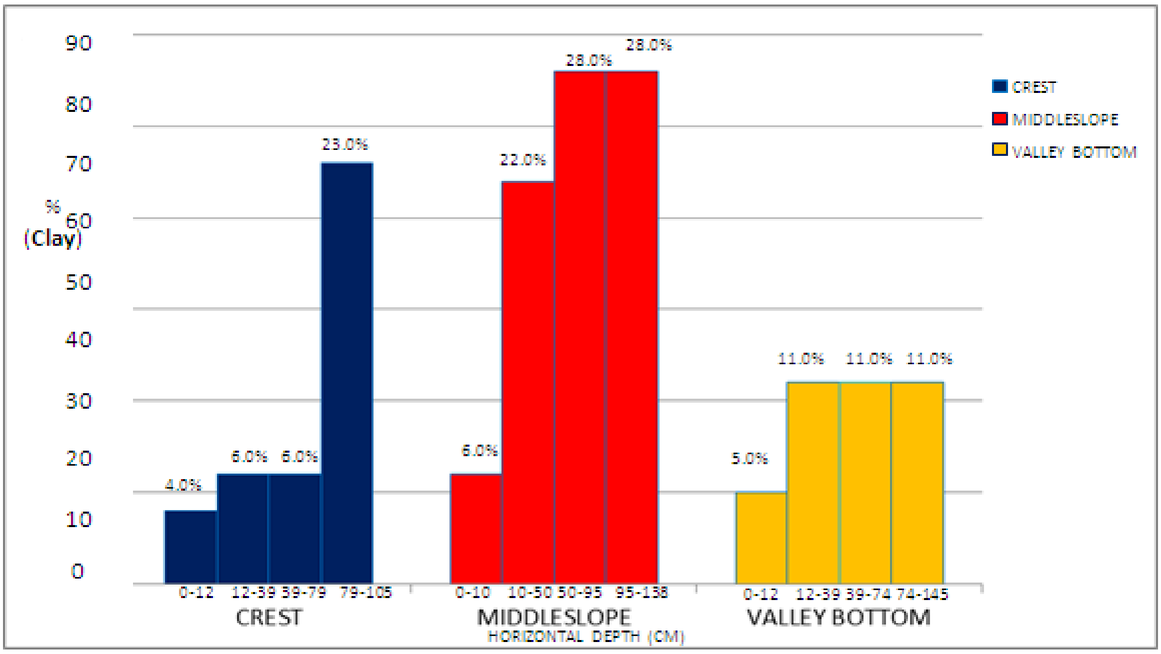

Fig. 2C: Percent Clay In Crest, Middle Slope And Valley Bottom.

6.4. Soil texture

The data on texture of the soils and soil textural classes are presented in Table 1. The textures were determined from the mechanical composition or particle size distribution of the soils. The classification or general terms used to describe soil texture in relation to the basic soil textural class name in U.S Department of Agriculture Classification System is shown in Table 3.

Table 3: General terms used to describe Soil Texture relation to the basic soil texture class names in U.S Department of Agriculture Classification System.

Sands Loamy Sands	**Sandy loam Fine sandy loam**	**Very fine Loam Silt Silt Sandy loam loam**	**Sandy Clay Silty clay Clay Loam loam**	**Sand Silty Clay clay clay**
General texture terms				
……Coarse…….	….Moderately……. coarse	……………..Medium………………..	…….Moderately fine…….	………...Fine……………
Sandy soils	……………………..……………………..Loamy soils……………………...………………………………			…….Clayey soils……

Brady and Weil (2014). The nature and property of soils.

6.5. Crest

The morphogenic horizons of the profile on the crest were mostly loamy sands. Loamy sands are soil materials that contain at the upper limit 85% to 90% sand and the percentage silt plus 1½ times the percentage of clay is not less than 15%. At the lower limit it contains not less than 70% to 85% sand and the percentage of clay does not exceed 30% (Esu, 2010). Based on classification in Table 4 the soils of the crest (loamy sands) are classed as coarse sands.

Table 4: Textural and Agricultural class of the soils developed on Ekureku sandstone parent materials.

Textural class	**Proportion of:**			**Agricultural class**	**General characteristics**
	Sand (%)	**Silt (%)**	**Clay (%)**		
Loamy sand	80	10-20	10-15	Very light	Very poor dry soil and low water holding capacity
Sandy loam	50-80	variable	15-20	Light	Poorly retentive of moisture draughty and hungry
Loam	<50	30-50	10-30	Medium	Fairly retentive of moisture, good drainage, fertile and productive, good for irrigation
Sandy clay loam	>45	<30	20-30	Medium	Fairly retentive of moisture, good drainage, fertile and productive, good for irrigation

Adapted from Savalia et. al. (2016).

6.6. Loamy sands

These are coarse textured sandy soils. They are made of fragments of rocks as well as minerals. Quartz (SiO_2) is the dominant mineral in the finer grades of sand. There are also presence of various other minerals like feldspars, micas, gibbsite, hematite and limonite (Savalia, 2016). Since quartz is dominant, loamy sands are chemically inactive and contain insoluble nutrient elements and hence cannot supply nutrient to plants. They are therefore very light soils, very poor dry soils and low water holding capacity (Table 4). They are suited for with proper management, some arable crops like groundnuts, cocoyam, and plantation crops like cashew, palm trees, sugar cane, sod development and non-agricultural ventures like golf courses (Obi, 2000). These loamy sands have the lowest ECEC values (Table 5).

Table 5: Physico-chemical properties of soil developed on Ekureku sandstone parent material.

Profile No	Horizon	Depth(cm)	Particle size Sand Silt Clay ← % →			TC	Silt/clay ratio	Bulk density g/cm³	Particle density g/cm³	pH (H_2O)	OC TN g/kg	AV.P Exh. Cations Exch Acidity (mg/kg) Ca^{2+} Mg^{2+} K^{+} Na^{+} Al^{3+} H^{+} ← cmol/kg →								ECEC	BS %
			Sand	Silt	Clay																
Crest	Ap	…	79	17	4	LS	4.3	1.4	2.3	5.5	13	11	5.5	2.6	0.4	0.1	0.08	1.2	0.36	4.74	67.09
	Bt1	12-39	78	16	6	LS	2.7	1.4	2.2	5.6	5.5	0.4	1.75	1.8	1.0	0.09	0.07	0.28	0.4	3.64	81.32
	Bt2	39-79	79	15	6	LS	2.5	1.5	2.2	5.8	2.3	0.1	2.13	2.0	0.6	0.1	0.07	0.64	3.68	7.9	39.07
	Ctr	79-145	68	9	23	SCL	0.4	1.26	2.1	5.8	1.0	0.1	2.25	1.4	1.6	0.8	0.07	0.86	4.36	8.37	46.24
Middleslope	Ap	0-10	69	25	6	SL	4.2	1.5	2.5	5.4	14.4	1.0	2.25	1.8	1.6	0.07	0.36	1.88	0.44	5.85	65.47
	Bt 1	10-50	65	13	22	SCL	0.6	1.6	2.3	5.1	9.4	0.7	4.5	2.4	0.8	0.09	0.07	2.24	1.08	6.68	50.30
	Bt 2	50-95	56	12	28	SCL	0.4	1.4	2.2	5.1	5.4	0.4	1.25	2.2	0.8	0.08	0.07	3.84	1.02	8.01	41.82
	Ctr	95-138	55	17	28	SCL	0.6	1.4		5.0	4.9	0.3	1.37	2.6	0.4	0.1	0.07	2.96	1.76	7.89	40.18
Valley bottom	Ap	0-10	60	35	5	SCL	7	1.2	2.3	5.0	15.9	1.1	2.88	3.8	1.0	0.11	0.09	0.16	0.8	5.96	83.89
	Bt 1	12-39	49	40	11	L	3.6	1.3	2.2	5.4	10	0.8	2.63	4.0	2.0	0.11	0.09	0.42	0.4	7.02	88.32
	Bt 2	39-79	49	40	11	L	3.6	1.3	2.2	5.4	10	0.8	2.63	4.0	2.0	0.11	0.09	0.42	0.4	7.02	88.32
	Ctr	74-145	49	40	11	L	3.6	1.3	2.2	5.4	13	0.1	2.76	3.9	1.5	0.11	0.09	0.29	0.6	6.49	86.29
Surface sample Mean			69.3	25.7	5.0		5.16	1.36	2.37	5.3	14.4	4.4	3.54	2.73	1.0	0.093	0.17	1.08	0.53	5.52	58.4
SD			9.5	9.01	1.0		1.59	0.153	0.11	0.26	1.4	5.7	1.72	1.01	0.6	0.021	0.15	0.87	0.23	0.67	19.3
CV (%)			13.7	35.1	20.0		30.7	11.2	4.9	5.0	100	131	48.6	36.8	60	22.0	89.9	80.2	43.9	12.2	33.1
Subsurface Sample Mean			60.88	22.4	16.2		2.0	2.64	2.2	5.4	6.8	0.5	2.35	2.7	1.18	0.17	0.77	1.32	1.52	6.91	49.4
SD			12.09	13.4	8.99		1.47	3.74	0.05	1.34	3.9	0.3	0.97	1.01	0.6	0.23	0.01	1.34	1.49	1.38	11.6
CV (%)			19.9	59.6	55.5		73.9	141.2	23	26.9	5.8	62.6	41.1	37.4	50.5	13.2	13	100.8	98.1	20	23.4

TC= Textural class; OC= Organic carbon; TN=Total nitrogen; Av. P=Available phosphorus; Ca=calcium; Mg=magnesium; K=potassium; Na=sodium; Al=aluminum; H=hydrogen; ECEC=effective cation exchange capacity; BS=base saturation; L=loam; SL=sandy loam; SCL=sandy clay loam; LS=loamy sand; SD=standard deviation; CV=coefficient of variation.

6.7.Middle slope

The horizons of the middleslope profile are predominantly sandy loams surface soils underlain by sandy clay loams subsoil's (Table 1).

6.8.Sandy loams

This are soil materials that contain either 20% clay or less and the percentage of silt plus twice the percentage of clay exceeds 30% and 52% or more sand; or less than 7% clay, less than 50% silt and between 43% and 52% sand. (Esu, 2010).

6.9.Sandy Clay loams

They are soil materials that contain 20% to 35% clay, less than 28% silt and 45% or more sand. (Esu, 2010).

Sandy loams are moderately coarse while sandy clay loams are moderately fine and they are both termed loamy soils (Table 3) (Brady and Weil, 2016).

6.10. Loams

Soil material that contains 7.0 to 27% clay, 28.0-50.0% silt and less than 52.0% sand. The central concept for loams is that they are a mixture of sand, silt and clay particles that exhibit the properties of those separates in about equal proportions. The concept does not mean that the three separates are present in equal amounts (Brady and Weil, 2016). They exhibit light and heavy properties in about equal proportions. The soils are fairly retentive of moisture, have good drainage, fertile and productive and good for irrigation (Table 4) (Savalia et. al., 2016).

6.11. Valley bottom

Profile horizons are dominantly loamy soils. Loams are medium textured loamy soils. They have soil materials that contain 7.0% to 27% clay, 28.0% to 50.0% silt and less than 52.0% sand (Esu, 2010). Loams are easier to cultivate lacking the excessive looseness and fragility of sandy soils or the compactness and stickiness of clay soils (Udoh and Ndom, 2016) they are fairly retentive of moisture have good drainage are fertile and productive and good for irrigation (Table 4).

7. CONCLUSION AND RECOMMENDATION

Mechanical composition of soils also referred to as particle size distribution used to determine the proportion of different sized particles in a soil hence their textural classes was evaluated for soils at Ekureku in Central Cross River State. It was observed that the soils of the crest were dominantly sandy soils (loamy sands) while those of the middleslope and valley bottom were loamy soils (sandy clay loams and loams). Based on these textures, the sandy soils will be suited for, with proper management, some arable crops like groundnut, and cocoyam etc, and plantation crops like cashews, palm trees, sugar cane, sod development and non-agricultural ventures like golf courses. The loams can be used for many arable crops and are usually the most productive soil. The ability to change soil physical conditions like texture to suit desired crop is limited. Therefore land use is often adjusted to fit existing physical conditions. The best management option is to use adapted crops.

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