Soil Moisture Characteristics of Humid Tropical Soils of the Southern Part of Rivers State Nigeria

[1*]Orji, O. A. and [2]Iruene, T.
Soil Science Department, Faculty of Agriculture, Rivers State University Port Harcourt
P.M.B.5080 Port Harcourt

Corresponding Author: [1*]Orji O. A.

Abstract:- Soil moisture characteristics data are extremely valuable tools for describing and managing water storage and flow transport in soils, as well as informing climate-smart agricultural courses and practices. Saturated hydraulic conductivity (Ks), aggregate size distribution, mean weight diameter (MWD), soil moisture characteristic curve (SMCC) and other indices of soil structure were estimated for soils of the 8 Local Government Areas (Akuku-Toru, Degema, Gokhana, Khana, Ogu-Bolo, Okrika, Oyigbo and Tai) in the South of Rivers State Nigeria. Core samples were taken from across the 8 LGAs in triplicates at 0-5, 5-10, 10-15 and 15-20cm depths along with bulk samples at 0-10cm and 10-20cm depths. The high spatial variability of these soils of the same terrain, were evidenced in the high coefficient of variation (CV) values in all parameters measured; with the exception of % of sand across all areas sampled. The soils were generally sandy loam to sand. Bulk density values ranged between 1.17 to 1.74gcm^{-3} at the 0-10cm depth, with a CV of 12.8% across locations. Ks values were generally moderate (2.5x10^{-3} to 9.9 x 10^{-4} cmsec^{-1}) with a CV of 91.8 to 109.7% across locations and depth. Degema, Okrika and Tai soils had significantly higher aggregate stability as indicated by the MWD, with 43.5 to 46.1% of their aggregates being >3.5mm in diameter size; when compared with the other locations. SMCC showed that moisture content at the field capacity (50cm suction) varied significantly across both locations and depths, with CV values between 49.0 to 71.0%. At the 0.1bar suction, the volumetric moisture contents were in the order 0.030, 0.020, 0.020, 0.020, 0.012, 0.010, 0.010 and 0.002cm^{3}cm^{-3} for Gokhana, Degema, Oyigbo, Khana, Ogu-Bolo, Akuku-Toru, Tai and Okrika soils, respectively. Results obtained form a baseline data of the parameters measured, for management of water storage, climate smart and precision agriculture; in these parts of Rivers State.

Keywords:- *Soil Moisture Characteristics, Aggregate Stability, Saturated Hydraulic Conductivity, CV.*

I. INTRODUCTION

Soil moisture is the volumetric water content of soil held within the spaces of the soil particles or soil aggregates (Dorigo *et al*., 2011), while soil moisture characteristics basically refer to the water storage capacity of soils at various suction or negative water potential levels.

Soil moisture characteristics as well as other hydraulic properties of soils are essential in irrigation and drainage studies for closing water balance equations, predicting leaching of nutrients, and for other agronomical and environmental applications.

Soil moisture characterization is the systematic arrangement of soils into groups or categories based on their inherent properties; thus, soil moisture varies from one location to another.

Climate smart and precision farming depends extensively on the volumetric patterns and trends in the water content of the soil particularly in the root zone (Akpan *et al*, 2021). Soil moisture characteristics which give the available moisture content as affected by the soil water potential energy is a determinant factor in the infiltration of water into the soil, retention of water and availability of soil water to plants. (Orji and Ikechi 2018). The soil moisture characteristic curve (SMCC) describes the relationship between a soil's matric potential and its moisture content, it is a fundamental hydraulic property used to study transport flow in soils and in the calculation of plant available water (Seyedah *et al*, 2017).

These hydraulic properties of soils are largely influenced by various inherent soil properties such as texture, structure, bulk density, porosity, organic matter, and interactions of these properties with each other (Indoria *et al*., 2020).

Soil moisture is also an important climate variable for agricultural drought monitoring and research into land-atmosphere interactions. Droughts and floods are soil moisture extremes that are commonplace on our planet today, and they have both been exacerbated by climate change.

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With the aid of soil moisture constants data, environmental challenges such as these could be timely checked, and their effects ameliorated. Soil moisture characteristics are therefore important indices used by both environmentalists and agronomists in the prevention of moisture-stress, as well as flooding conditions in soils, and consequently in crops.

To this effect, moisture content, soil moisture related properties, matric potential, saturated hydraulic conductivity, and soil moisture characteristic curve (SMCC) were studied in 8 Local Government Areas (LGAs) in the Southern part of Rivers State. These include Akuku-toru, Degema, Gokhana, Khana, Okrika, Ogu-bolo, Oyigbo and Tai LGAs.

II. MATERIALS AND METHODS

A. *Study Area*

The study sites of this study were eight Local Government Areas (LGAs) in the Southern part of Rivers State. The entire Rivers State is in the Tropical Rainforest belt of Nigeria. The globe locations and the elevations above sea level of the 8 LGA studied are as indicated on Table 1. They are characterized by tropical climatic conditions with two seasons (wet and dry). The average temperature in these regions ranges between 23ºC and 30ºC, with a yearly mean rainfall of between 2000 and 3000mm. Rainfall is usually at its peak in the months of July and September. A sudden fall from this peak is common in August; consequently, this period is referred to as the “August break” (Chinago, 2020). The mean annual temperature is between 26-30°C and mean relative humidity is about 79%.

Table 1 The Geographic Coordinates of the Study Areas

Location	Geographic Coordinates	Elevation Above Sea Level (m)
Akuku-Toru	Between Latitude 4^0 33' 36"North, and Longitude: 6^0 44' 59" East,	5
Degema	Between Latitude 4^0 34' 27" North and Longitude 6^0 56' 17" East	54
Gokhana	Between Latitude 4^0 37' 56" North and Longitude 7^0 16' 16" East	21
Khana	Between Latitude 4^0 40' 18" North and Longitude 7^0 20' 38" East	26
Ogu-Bolo	Between Latitude 4º38'52" North and Longitude $7^0$11'11"East.	7
Okrika	Between Latitude $4^0$38'18"North and Longitude $7^0$4'54"East	9
Oyigbo	Between Latitude 4^0 52' 41"North and Longitude 7^0 7' 41"East	22
Tai	Between Latitude 4^0 43' 0"North and Longitude 7^0 18' 0"East	17

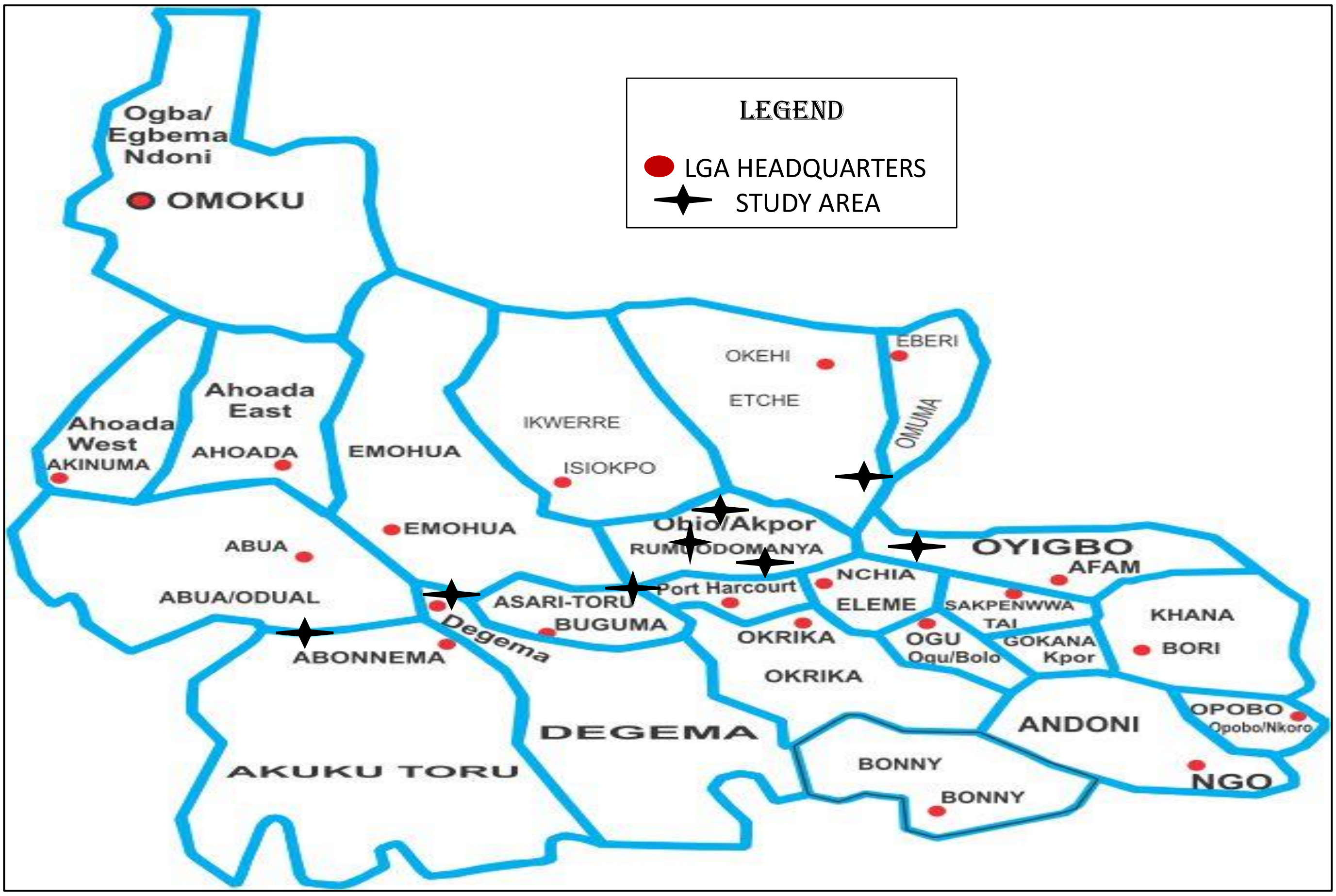

Fig 1 Map of Rivers State Indicating Study Areas
(Source: Youth wing Christian Council of Nigeria, Rivers State Chapter)

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B. Data Collection

Cylindrical metal cores with a dimension of 5cm internal diameter x 5cm height was used to collect undisturbed soil samples, in triplicates from the various locations. they were used to determine bulk density, total porosity, water holding capacity, saturated hydraulic conductivity and soil moisture characteristics of the soils.

Bulk density was determined using the procedure described by Blake and Hartage (1986), as a ratio of mass of oven-dried soil to column. The bulk density will be derived from the equation below:

$$\ell b = Ms/Vb \quad \ldots\ldots (1)$$

Where:

ℓb = Bulk density (gcm^3)

Ms = Mass of oven dried soil (g)

Vb = Bulk volume of the soil (cm^3)

Total porosity was calculated from the bulk density by assuming average particle density as 2.65kgm3 using the equation

$$P = (1 - \ell b/\ell s) \quad \ldots\ldots (2)$$

Where;

P = Total porosity

ℓb = Bulk density (gcm^{-3})

ℓs = particle size density (gcm^{-3})

The water holding capacity was determined by converting the saturation gravimetric moisture content to the volumetric moisture content using the following equations.

$$\theta m = Mw/Ms \quad \ldots\ldots (3)$$

$$\theta v = (\theta m \times \ell b) / \ell w \quad \ldots\ldots (4)$$

Where;

θm = Gravimetric moisture content

Mw = Mass of water (g)

Ms = Mass of solid particles (g)

θv = Volumetric moisture content (cm^3cm^{-3})

ℓb = Bulk density (gcm3)

ℓw = Particle density (gcm3)

Saturated hydraulic conductivity was determined using the constant head permeameter method as described by Klute and Dickson (1986). It was derived from an empirical relationship between the flux of water through saturated columns of soil and the hydraulic head loss expressed as follows:

$$q = Q^1 / At \ \alpha \ \Delta H/L \quad \ldots\ldots (5)$$

$$Q^1 / At = Ks \ \Delta H/L \quad \ldots\ldots (6)$$

$$Ks = Q^1 / AT \times L/\Delta H = Q^1L / \Delta HAT \quad \ldots\ldots (7)$$

Where,

q = flux density of water (cm sec-1)

Q^1 = equilibrium volume of water passing through the soil column (cm^3)

L = length of soil column (cm)

A = cross sectional area through which the flow takes place (cm^3)

ΔH = Change of hydraulic head

T = time (sec.)

h = pressure head (cm)

Ks = saturated hydraulic conductivity (cm sec^{-1})

Bulk samples were also collected from same locations at the 0-10 and 10-20cm depths. These were air dried and used to determine particle size distribution, aggregate size distribution, mean weight diameter and organic matter contents of the soils.

Particle size distribution was determined by Bouyoucos hydrometer method as described by Gee and Bauder (2002). The percentage of sand, silt and clay were used to assign the samples to a textural class based on the soil Textural Triangle. The dry aggregates distribution was determine using with a nest of sieves by the procedure of Kenper and Chepil as described by Nweke and Nnabude (2014), and mean weight diameter was calculated with the formula below.

$$MWD = \sum_{i=1}^{n} \bar{X}_1 W_1 \quad \ldots\ldots (8)$$

Where;

MWD = Mean weight diameter (mm)

X_I = Mean diameter size range of aggregates separated by a sieve (mm)

W1 = Weight of aggregates in that size range, as a function of the total dry weight of the sample analyzed (g).

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Organic carbon was determined by Walkey and Black method, as modified by Udo *et. al.,* 2009. Organic matter content was determined by multiplying with the factor 1.724

III. RESULTS AND DISCUSSION

A. Particle Size Distribution and Texture

The particle size distribution of the soils of the various locations at two depths (0-10 and 10-20cm) are as shown on Figs. 2a and 2b. At the 0-10cm depth, the percentage of sand ranged between 73,8 to 91.6% with a coefficient of variation (CV) of 7.4%, across the 8 LGAs.

Results showed higher CV values for the silt fraction (42.9%) and the clay fractions (35.5%). Higher values of percentage sand were recorded for the Ogu-bolo, Khana, Okrika and Tai LGAs. Oyigbo, Gokhana, Degema and Tai recorded higher clay contents, when compared with the other LGAs. This trend was similar at the 10-20cm depth (2b). the clay contents were generally higher at the 10-20cm depth, with a decrease value in the sand contents.

The soil texture at both depths were generally sandy loam to loamy sand for all the LGAs, except for Ogu-bolo LGA, which was sand (Table 2). There are similar reports on soils of these areas (Kamalu and Orji, 2018)

B. Bulk Density and Total Porosity

Bulk density values were generally moderate, at the 0-5cm depth, ranging from 1.17gcm^{-3} for Degema to 1.56 gcm^{-3} for Okrika (Table 3). The bulk density of Tai was significantly higher with a value of 1.74 gcm^{-3}, when compared with the other LGAs. The CV in the bulk density of the soils of the various LGAs was 12.8% at the 0-5cm depth. Results showed a decrease in the CV of bulk density with depth.

The total porosity values followed the same trend with the bulk density of the soils of the study areas; with a mean of 45.8, 44.0, 42.4 and 42.2% for the 0-5, 5-10. 10-15 and 15-20cm depths, respectively (Table 3). The CV was higher as depth increased with total porosity, than with bulk density.

Generally, inverse relationship existed between bulk density and total porosity as previously established in these areas (Orji and Oko-Jaja 2016; Kamalu and 2018; Orji and Ikechi 2018).

C. Saturated Hydraulic Conductivity

The saturated hydraulic conductivity (Ks) across the four depths measured for the various LGAs is as shown on Table 3. Ks was generally moderate, ranging between 6.2 x 10^{-4} (for Akuku-toru) to 8.23 x 10^{-3}cmsec^{-1} (for Ogu-bolo), at the 0-5 cm depth. The high sand content of Ogu-bolo soils may have enhanced the Ks, as also reported by Touma (2009). The Tai soils with significantly higher bulk density values ($P<0.05$) also has low Ks values. Results showed very wide CV with respect to Ks across all locations and across all depths of measurement. The CV values were 106.5, 95.2, 129.3 and 121.2% for the 0-5, 5-10, 10-15 and 15-20cm depths.

D. Water Holding Capacity

Oyigbo soils, with significantly higher clay but lower sand contents (Fig.2a had the highest water holding capacity (WHC) across all depths when compared with the other locations (Table 3). The CV with respect to WHC was 30.8, 25.7, 38.7 and 33.1% for the 0-5, 5-10, 10-15 and 15-20cm depths, respectively. This agrees with finding that finer particles tend to hold more water because of their larger surface areas (Kamalu and Orji 2018).

E. Aggregate Size Distribution

The aggregate size distribution of the soils of the various LGAs studied and their mean weight diameters (MWD) is as shown on Table 4.The soils had a greater percentage of their aggregates less than 1.8mm in diameter. Gokhana, Khana and Ogu-bolo had more than 80% of their aggregates in this range. This suggests a poor aggregate stability and therefore poor soil structure and higher erodibility for these LGAs (Azuka and Obi 2012).

Degema, Okrika and Tai had more than 40% of their aggregates greater than 3.5mm in diameter. Their MWD were also significantly higher at both depths measured, than those of the other LGAs; ranging between 2.15 and 2.85mm. The CV of the MWD was 20.9, and 27.1% at the 0-10 and 10-20cm depths respectively.

F. Soil Moisture Characteristics

The soil moisture characteristics curves (SMCC) for the various locations is as shown on Fig. 3. The moisture content at saturation generally increased with depth, across all the locations. However, the CV across the location was as already noted on Table 3. The moisture at the field capacity (50cm matric suction) varied widely across the 8 locations, with CV values ranging between 49.0 and 71.0%.

The moisture content at the field capacity was in the order 0.13 > 0.12 > 0.11 > 0.09 > 0.08 > 0.05 > 0.04 for Oyigbo, Gokhana, Khana, Tai, Ogu-bolo, Okrika/Degema and Akuku-toru, respectively.

Organic matter contents of the locations studied were moderate, ranging between 1.40 to 2.9% at the 0-10cm depth (Fig.4). The organic matter contents were also noted to be highest for the Oyigbo (2.9%), Gokhana (2.8%) and Tai (2.4%), but this did not reflect in both their aggregate size distribution and MWD; contrary to establishments that organic matter contents will did improve soil structure (Mbonu and Elenwo 2006; Deepagoda *et. al.* 2019). It was also noted that the CV of the organic matter contents varied widely across locations at the 0-10cm (30.2%) and 10-20cm (39.2%) depths.

IV. CONCLUSION

Spatial variability of soil physical and moisture related properties of the soils of the Local Government Areas in the Southern part of Rivers State were studied. Even with the same climatic conditions, soil parent materials (coastal plain sands), and soil order (ultisols), all the parameters measured varied widely, for all the various locations studied. This study shows the need for sampling at close ranges, in the estimation of these properties; particularly with the management of water storage in these parts of Rivers State and the challenges of climate change.

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TABLES AND FIGURES

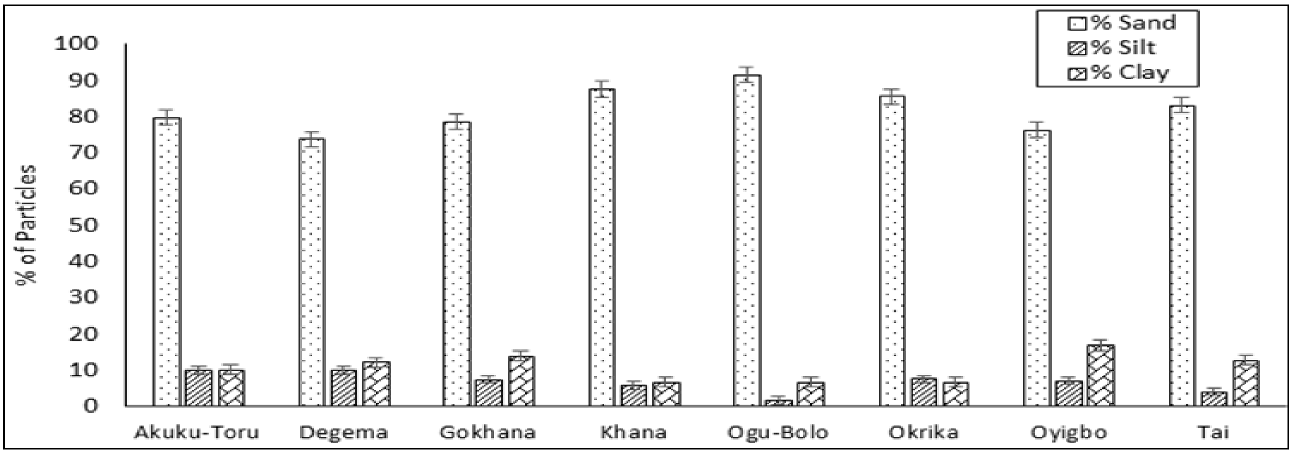

Fig 2a Particle Size Distribution for the Various Locations at the 0-10cm Depth

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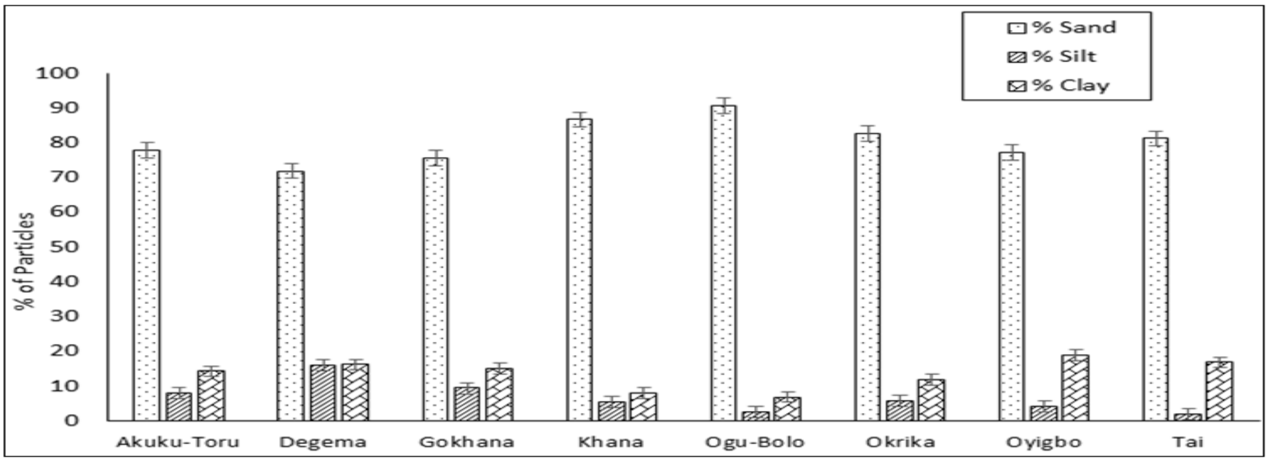

Fig 2b Particle Size Distribution for the Various Locations at the 10-20cm Depth

Table 2 Textural Classes of Soils of the Study Areas

Location	**0-10cm Depth**	**0-20cm Depth**
Akuku-Toru	Sandy Loam	Sandy loam
Degema	Sandy Loam	Sandy loam
Gokhana	Sandy Loam	Sandy loam
Khana	Loamy Sand	Loamy sand
Ogu-Bolo	Sand	Sand
Okrika	Loamy Sand	Loamy sand
Oyigbo	Sandy Loam	Sandy loam
Tai	Loamy Sand	Sandy loam

Table 3 Some Physical Properties of the Soils of the Study Areas

Depth (cm)	**Location**	**Bulk Density (gcm^{-3})**	**Total Porosity (%)**	**Saturated Hydraulic Conductivity (cmsec^{-1})**	**Water Holding Capacity (cm^{3}cm^{-3})**
0-5	Akuku-Toru	1.33	49.7	6.2×10^{-4}	0.39
	Degema	1.17	53.7	6.3×10^{-4}	0.41
	Gokhana	1.26	52.3	1.1×10^{-3}	0.64
	Khana	1.38	48.1	3.3×10^{-3}	0.54
	Ogu-Bolo	1.53	42.4	8.23×10^{-3}	0.50
	Okrika	1.56	41.0	1.12×10^{-3}	0.46
	Oyigbo	1.45	45.3	6.9×10^{-3}	0.91
	Tai	1.74	34.2	9.9×10^{-4}	0.71
	Mean	1.43	45.84	2.86×10^{-3}	0.57
	STD	0.18	6.49	3.05×10^{-3}	0.18
	CV (%)	12.8	14.2	106.5	30.8
5-10	Akuku-Toru	1.40	51.1	2.5×10^{-3}	0.39
	Degema	1.30	50.8	8.0×10^{-4}	0.35
	Gokhana	1.26	52.3	9.4×10^{-4}	0.59
	Khana	1.42	45.8	2.7×10^{-3}	0.53
	Ogu-Bolo	1.54	39.9	6.29×10^{-3}	0.48
	Okrika	1.62	39.0	1.99×10^{-4}	0.42
	Oyigbo	1.51	43.1	4.1×10^{-3}	0.72
	Tai	1.85	30.3	3.4×10^{-4}	0.67
	Mean	1.49	44.04	2.23×10^{-3}	0.52
	STD	0.19	7.55	2.13×10^{-3}	0.13
	CV (%)	12.7	17.1	95.2	25.7
10-15	Akuku-Toru	1.43	47.7	5.8×10^{-4}	0.32
	Degema	1.30	50.8	2.9×10^{-5}	0.30
	Gokhana	1.38	47.8	5.9×10^{-4}	0.66
	Khana	1.56	41.0	2.5×10^{-3}	0.57
	Ogu-Bolo	1.59	41.9	7.40×10^{-3}	0.49

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	Okrika	1.71	35.4	5.53×10^{-4}	0.44
	Oyigbo	1.56	41.3	6.6×10^{-3}	0.95
	Tai	1.78	33.0	2.7×10^{-4}	0.65
	Mean	1.54	42.36	2.32×10^{-3}	0.55
	STD	0.16	6.19	2.99×10^{-3}	0.21
	CV (%)	10.6	14.6	129.3	38.7
15-20	Akuku-Toru	1.53	46.0	1.0×10^{-4}	0.34
	Degema	1.37	48.2	7.4×10^{-5}	0.40
	Gokhana	1.32	50.0	2.9×10^{-4}	0.69
	Khana	1.61	40.1	2.4×10^{-3}	0.43
	Ogu-Bolo	1.62	38.9	4.44×10^{-3}	0.42
	Okrika	1.69	36.2	6.98×10^{-4}	0.43
	Oyigbo	1.54	42.0	5.0×10^{-3}	0.82
	Tai	1.69	36.1	3.9×10^{-4}	0.65
	Mean	1.55	42.19	1.7×10^{-3}	0.52
	STD	0.14	5.34	2.0×10^{-3}	0.17
	CV (%)	8.9	12.7	121.2	33.1

Table 4 Aggregate Size Distribution and Mean Weight Diameter of Soils of the Study Areas

Location	**Diameter Range**	**Depth**			
		0-10cm		**10-20cm**	
		% of Agg.	**MWD (mm)**	**% of Agg.**	**MWD (mm)**
Akuku-Toru	>3.5mm	39.7	2.04	23.4	1.66
	2.4-3.5	2.9		3.6	
	1.8-2.4	3.6		5.8	
	<1.8	53.8		67	
Degema	>3.5mm	46.1	2.17	40.1	2.10
	2.4-3.5	1.8		4.9	
	1.8-2.4	2.7		3.3	
	<1.8	49.4		51.7	
Gokhana	>3.5mm	18.0	1.52	17.7	1.53
	2.4-3.5	3.0		4.2	
	1.8-2.4	6.8		6.0	
	<1.8	72.2		72.1	
Khana	>3.5mm	5.2	1.24	17.5	
	2.4-3.5	2.8		2.7	1.54
	1.8-2.4	11.5		9.8	
	<1.8	80.7		70.0	
Ogu-Bolo	>3.5mm	12.2	1.34	10.5	1.27
	2.4-3.5	3.3		2.2	
	1.8-2.4	3.4		3.6	
	<1.8	81.2		83.6	
Okrika	>3.5mm	43.5	2.18	73.4	2.85
	2.4-3.5	3.9		1.0	
	1.8-2.4	4.7		1.6	
	<1.8	47.9		24.0	
Oyigbo	>3.5mm	29.6	1.82	45.7	2.15
	2.4-3.5	1.4		0.7	
	1.8-2.4	9.7		4.1	
	<1.8	59.3		49.5	
Tai	>3.5mm	43.5	1.99	53.1	2.34
	2.4-3.5	4.2		1.9	
	1.8-2.4	4.4		1.6	
	<1.8	47.9		43.4	
Mean			1.79		1.93
STD			0.37		0.52
CV (%)			20.9		27.1

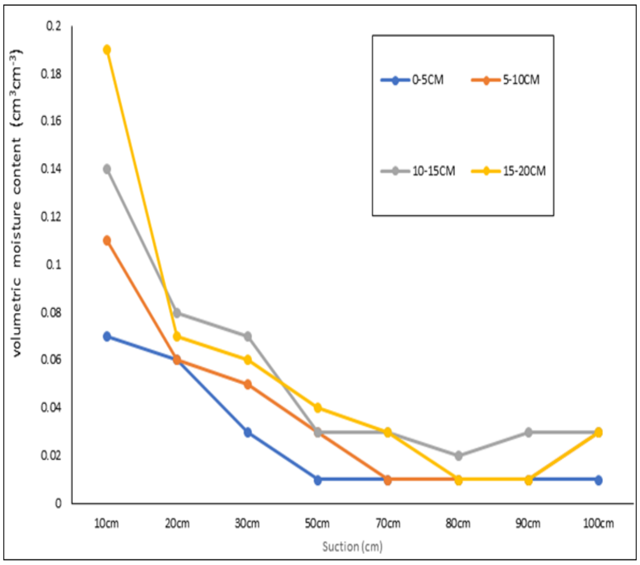

Fig 3a Soil Moisture Charateristic Curve of Akuku-Toru Soil

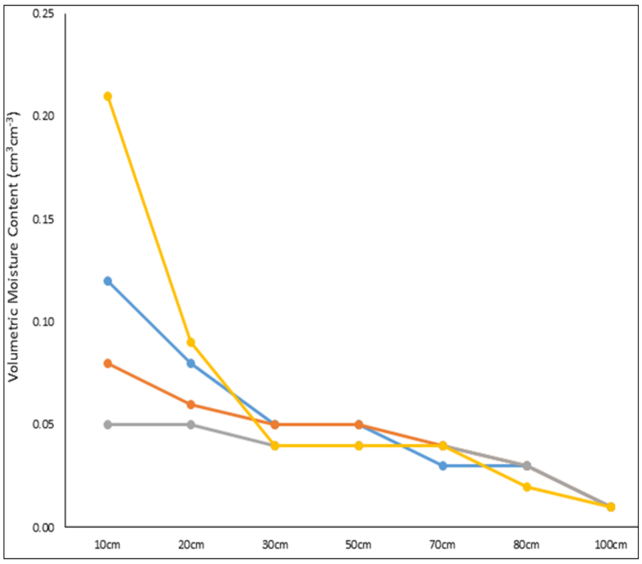

Fig 3d Soil Moisture Charateristic Curve of Gokhana Soil

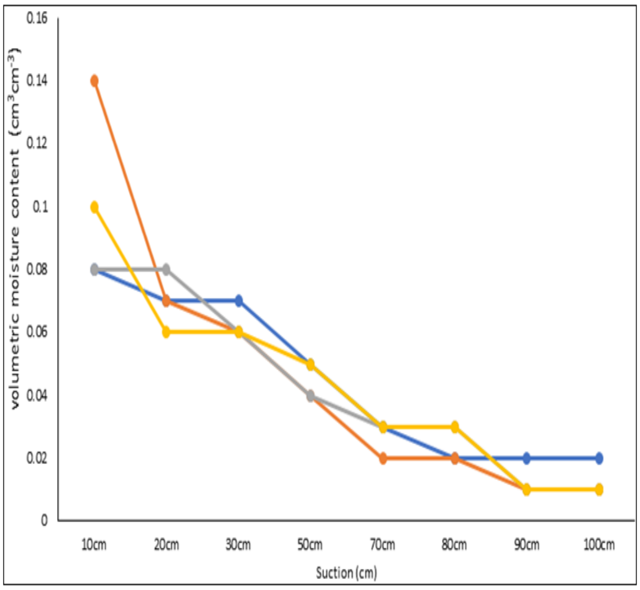

Fig 3b Soil Moisture Charateristic Curve of Degema Soil

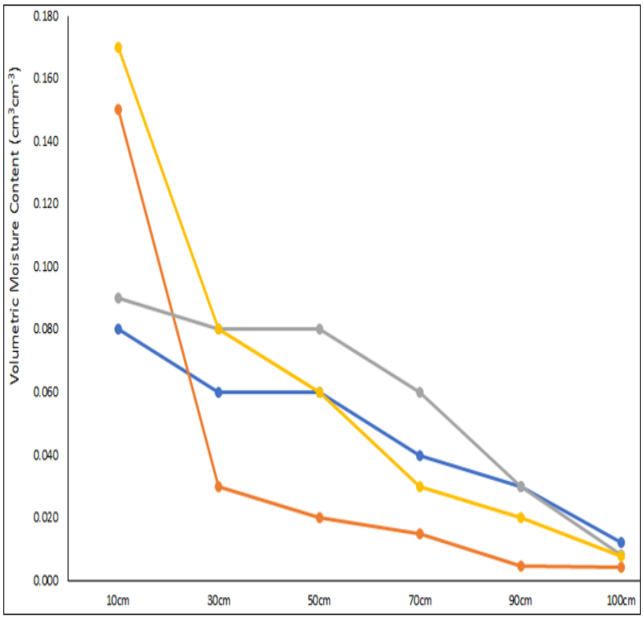

Fig 3e Soil Moisture Charateristic Curve of Ogu-Bolo Soil

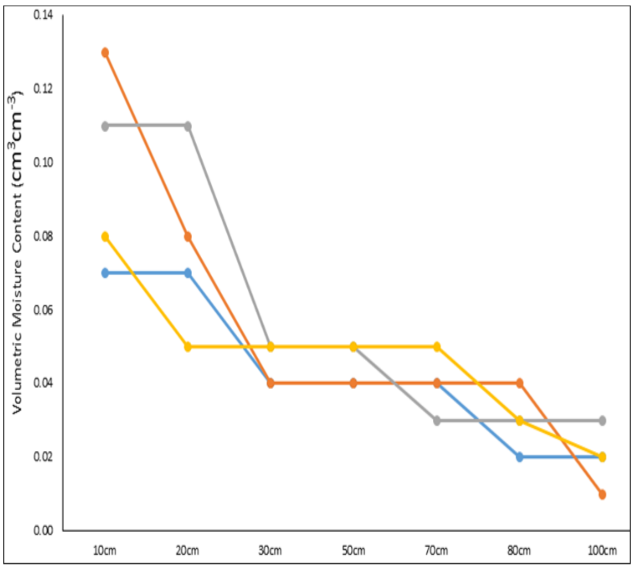

Fig 3c Soil Moisture Characteristics Curve of Khana Soil

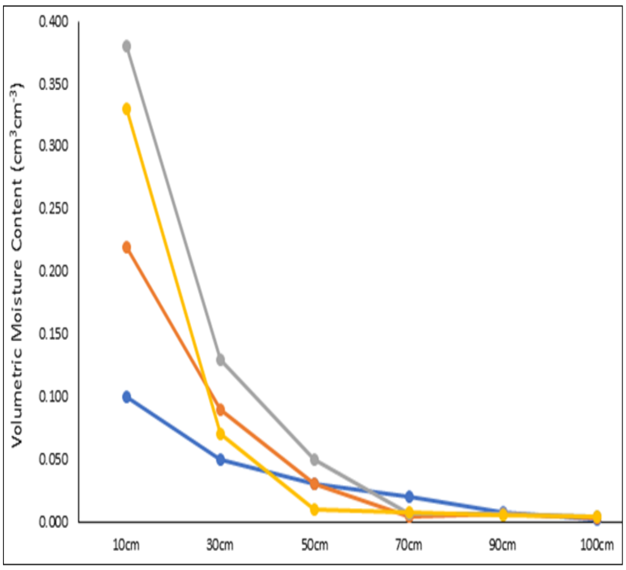

Fig 3f Soil Moisture Charateristic Curve of Okrika Soil

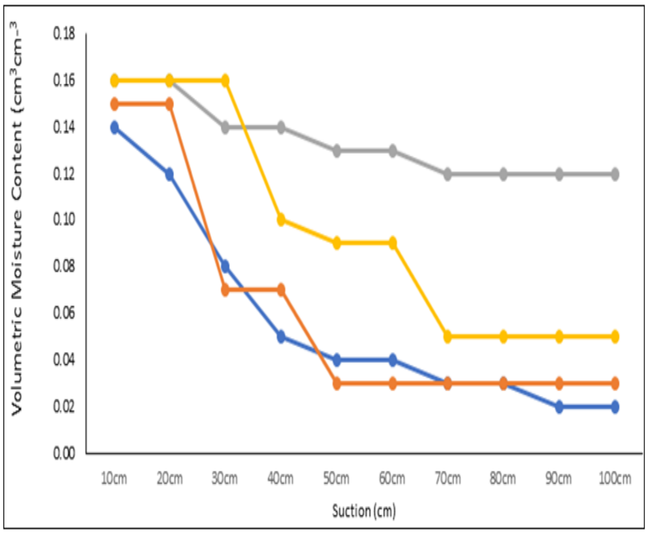

Fig 3g Soil Moisture Charateristic Curve of OYIGBO Soil

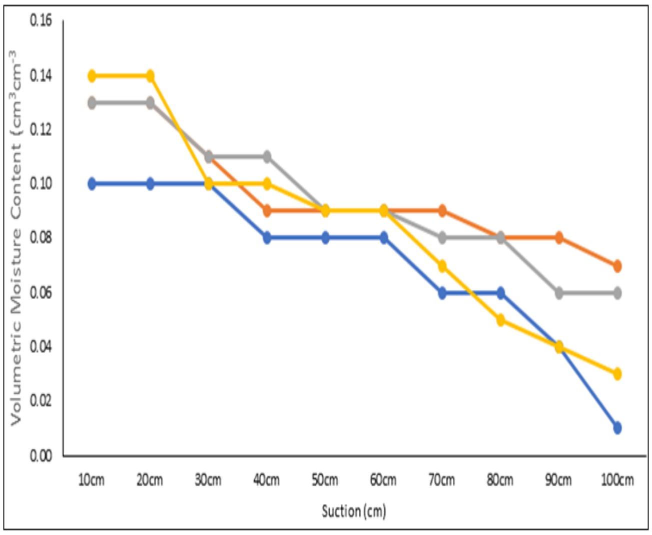

Fig 3h Soil Moisture Charateristic Curve of TAI Soil

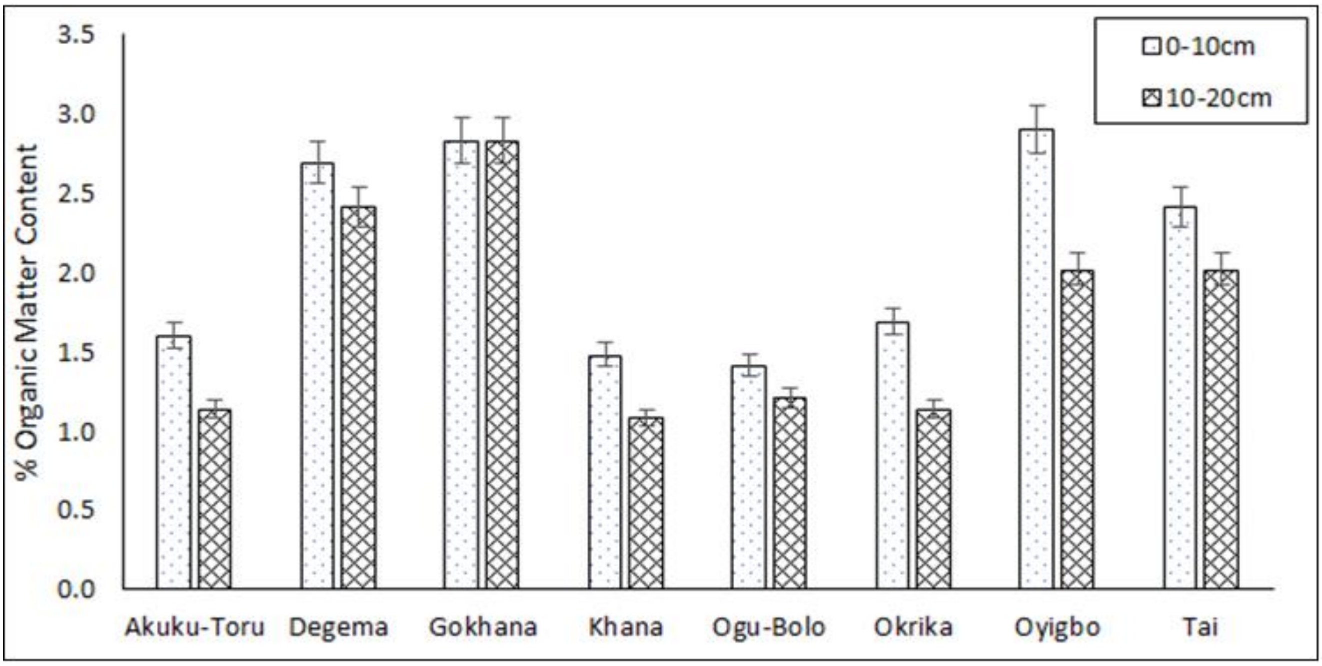

Fig 4 Varition of Organic Matter Contents of Study Areas