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Evaluation of soils on a toposequence formed from the coastal plain sands of the Imo river basin, Southeastern Nigeria

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ABSTRACT

Due to the increasing land degradation in southeastern Nigeria – with particular reference to the ubiquitous gully network in the region – selected soils formed from the Coastal Plain Sands of the Imo River Basin were evaluated and characterized to determine their potentials and capabilities. , Three profile pits were consequently dug on the upper slope (Umuariam), -mid-slope (Umulogho), and foot slope (Umungwa) of three towns on the Imo River Basin underlain by the coastal plain sands. The soil color ranged from greyish brown (5 YR 5/2) to dull brown (7.5 YR 5/3) in the topsoil and from dull orange (5 YR 6/4) to orange (5 YR 6/7) in the subsoil. The soils had sandy topsoil and relatively more clayey subsoil. The pH (in KCl) ranged from very strongly acidic (4.5 – 5.0) to moderately acidic (5.1 – 6.0). They had low organic matter, low total nitrogen, low ECEC, low Al saturation, and moderate base saturation. The soils of Umuariam (Upper Slope) and Umulogho (Mid Slope) were classified as Typic Hapludults (Chromic Acrisols), while that of Umungwa (Foot Slope) was classified as Typic Udipsamments (Rubic Arenosols). Umuariam had a USDA land capability class of IIes and a USBR land capability class of 2v/C. Umulogho and Umungwa both had a USDA and USBR capability class of IVs and 3v/C respectively. Though moderately to marginally irrigable, the soils can still produce increased and sustainable agricultural yield if the appropriate land use and husbandry practices are adopted, with particular reference to erosion control, organic manure, lime, and fertilizer application.

1.0. Introduction

Coastal Plain Sands underlie up to 50 % of the Imo River Basin of Southeastern Nigeria. It consists of unconsolidated yellow and white sand materials which are sometimes cross-bedded with clays, sandy clays, and pebbles (Orajaka, 1975). Soils on Coastal Plain Sands are deep, highly weathered, strongly acidic, coarse-textured, easily eroded, and generally of low total nitrogen, organic matter, ECEC, base saturation, and inherent chemical fertility (Osuji *et al.*, 2002; Obi, 2015; Osujieke *et al.*, 2018; Abam and Orji, 2019).

This inherent low fertility and poor structural stability necessitate the need for effective management and sustainable use. Unfortunately, due to inadequate soil information, uninformed land allocation, and land use planning, the soils of the region have become largely degraded. The extent and magnitude of the degradation areare immense, encompassing a multiplicity of aspects, some of which include soil erosion, pollution, deforestation, and loss of soil fertility and sustainability, to mention but a few. These problems are compounded by the very high annual rainfall amount and intensity recorded in the region.

All of these have collectively resulted in numerous social, economic, psychological, and environmental malaise in the region, fueling social and political unrest among the restive population. In the face of these disturbing realities, the importance of the soil survey and land use planning of the region cannot be overemphasized. It is indeed a prerequisite for the sustainable use and management of this limited resource (FAO, 2015). More so, Esu (2004) contended that as far as food security and environmental sustainability determinations are concerned, the 1985 reconnaissance soil map of Nigeria is of little or no value. Similarly, Fagbami and Ogunkunle (2000) stated that the soil map of

Nigeria has credibility problems and too small a scale to give satisfactory direction on project site selection, soil management, and land use planning.
As such, while the conduct of a detailed and/or semi-detailed soil survey of Nigeria is still strongly advocated as the panacea for effective and sustainable agricultural development, in the light of the extent of soil degradation in Southeastern Nigeria, interim measures must be taken to forestall further deterioration. Therefore, the major objective of this study is to evaluate the nature and properties of soils formed from the Coastal Plain Sands, which is one of the major geologic formations in Southeastern Nigeria. The specific objectives are to:

- characterize soils on the toposequence overlying th Coastal Plain Sands of the Imo River Basin
- classify the soils using the Soil Taxonomy and the World Reference Base for Soil Resources
- determine the USDA and USBR land capability classes of the soils
- make land use management recommendations.

2.0. Materials and methods

2.1 The Physical Environment of the Study Area
The area receives an average of 2134 mm of rainfall distributed to about 139 days of the year (Madueke, 2010). It is double maxima, with an August break occurring in July or August. The daily temperature ranges from a minimum of 21^{o}C to a maximum of 34^{o}C. The relative humidity reaches a minimum of 60 % in January (at the peak of the dry season) and rises to 80 - 90 % in July (at the peak of the rains) (Monanu, 1975). The original vegetation of the study area was the tropical rain forest (Igbozuruike, 1975). The rain forest has however been destroyed largely through human activities and supplanted with what is today referred to as the oil palm bush.

2.1.1 *Selection of Study Area*
Three profile pits were dug on three different physiographic positions on the portion of the Imo River Basin underlain by the Coastal Plain Sands. The geologic map of the Imo River Basin indicating the region underlain by the Coastal Plain sands is shown in Figure 1. The following were the study sites: Umuariam (Upper Slope), Umulogho (Mid Slope), and Umungwa (Foot Slope) (Figure 2, 3, 4, and 5). The geographic coordinates (latitude, longitude, and altitude) were measured using the global positioning system (GPS) (Garmin Ltd, Taiwan).

2.2 Soil Characterization
2.2.1 Fieldwork
Three profile pits were dug in three towns of Imo State, viz: Umuariam (upper slope), Umulogho (-mid-slope), and Umungwa (foot slope). The site and profile description aswas in accordance withthe method described by FAO (2006). Delineation of horizon boundaries was accomplished before actual sample collection for laboratory analysis. Soil samples were taken from each of the constituent horizons, starting from the bottom horizon. These samples were placed inappropriately labeled polythene bags and transported to the laboratory. The samples were then air-dried for three days, crushed, and passed through a 2 mm sieve before routine laboratory analysis. A small quantity (about 10 g) of each sample was finely ground and preserved for the determination of organic carbon and total nitrogen. Undisturbed soil samples for determination of saturated hydraulic conductivity and bulk density were collected in cylindrical metal canisters.

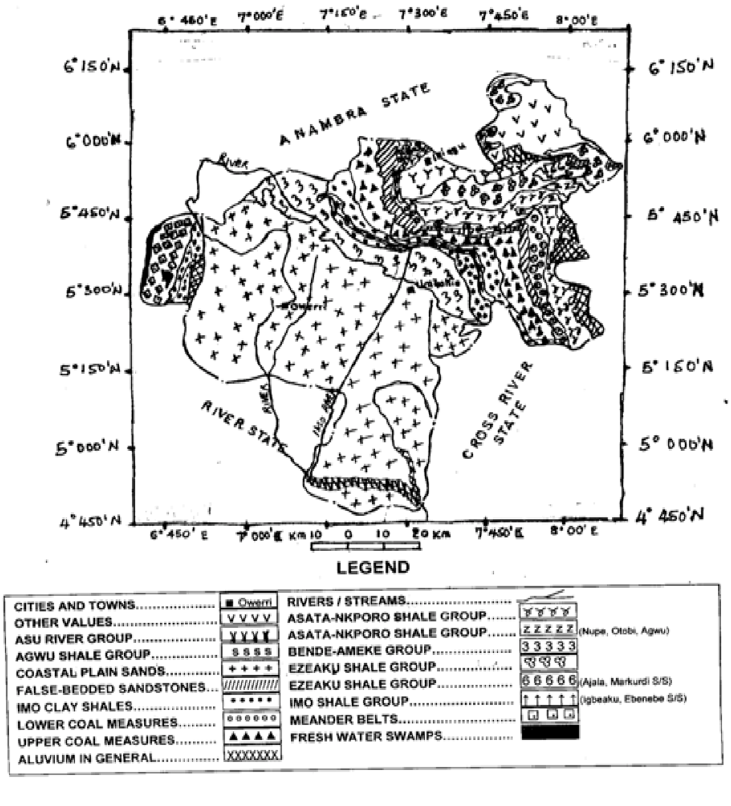

Figure 1: Geologic Map of Imo River Basin

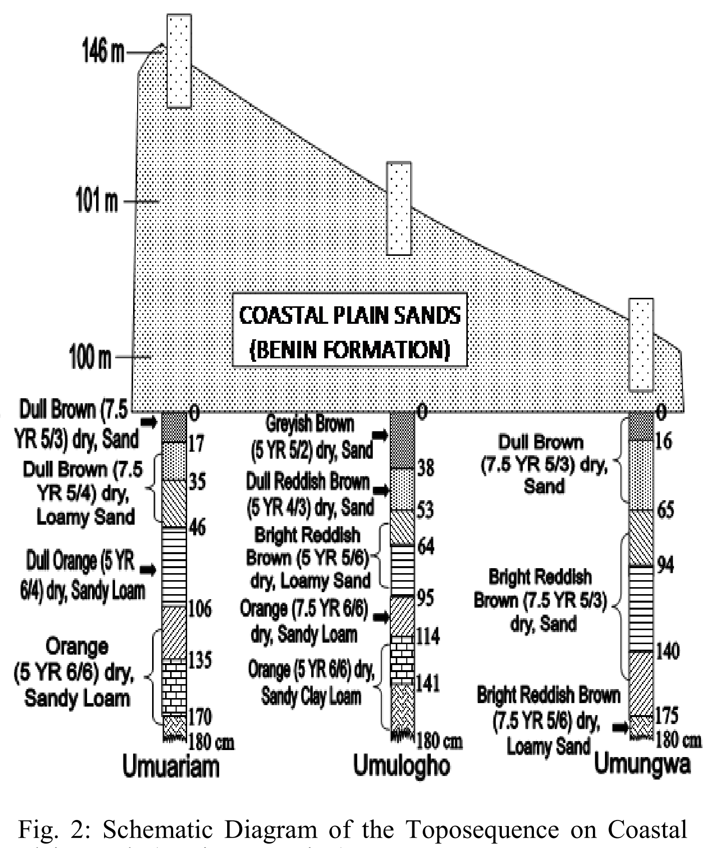

Fig. 2: Schematic Diagram of the Toposequence on Coastal Plain Sands (Benin Formation)

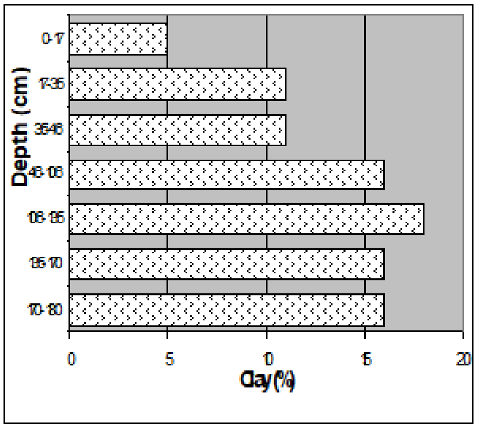

Fig. 3: Depth Function of Clay at Umuariam (Upper

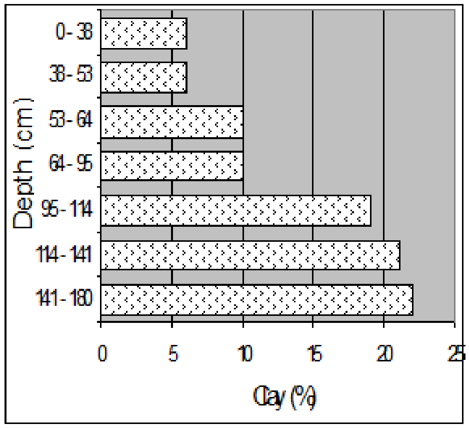

Fig. 4: Depth Function of Clay atUmulogho(Mid Slope)

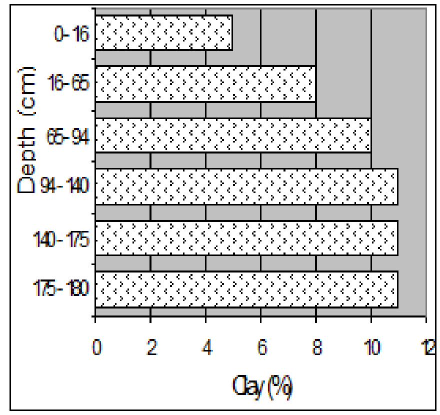

Fig. 5: Depth Function of Clay at Umungwa (Foot Slope)

2.3 Laboratory Soil Analysis

The physical and chemical properties of the soil samples were determined using routine analytical methods. The moisture content was determined gravimetrically. Particle size distribution was carried out by the hydrometer method (Gee and Bauder, 1986). Bulk density was determined using the procedure outlined by Arshad *et al.* (1996). Porosity was computed from bulk and particle density as described by Vomocil (1965). Saturated hydraulic conductivity was determined by the Falling Head Method, as reported by McWhorter and Sunda (1977). Soil pH was measured electrometrically by glass electrode in pH meter in both KCI (1 N) and distilled water suspension using a soil: liquid ratio of 1: 2.5 (International Institute for Tropical Agriculture, 1979). Electrical conductivity was determined electrometrically with the electrical conductivity meter using a soil: liquid ratio of 1: 2.5. Exchangeable basic cations were extracted with neutral ammonium acetate (NH_4OAC). Exchangeable calcium and magnesium were determined by the ethylene diamine-tetraacetic acid (EDTA) titration method while exchangeable potassium and sodium were estimated by flame photometry (Jackson, 1962). Exchangeable acidity was extracted with KCl (1 N) and measured titrimetrically according to the procedure of Mclean (1982). Effective Cation Exchange Capacity (ECEC) was computed as the sum of the exchangeable bases and the exchange acidity, while base saturation, aluminum saturation, exchangeable sodium percentage, and exchangeable potassium percentage were computed as the percentage of the ratios exchangeable bases, exchangeable aluminum, exchangeable sodium, and exchangeable potassium respectively to ECEC. Ca: Mg ratio and K: Mg ratios were calculated from the exchangeable basic cations. Soil organic carbon (SOC) was determined by Walkley and Black digestion method (Nelson and Sommers, 1982). Total Nitrogen was estimated by the micro-Kjeldahl digestion method (Bremner and Mulvaney, 1982) while available phosphorus was determined by Bray II Method (Olsen and Sommers, 1982).

2.4 Soil Classification and Land Use Planning

The soils were classified in accordance with the USDA Soil Taxonomy (Soil Survey Staff, 2003) and the World Reference Base for Soil Resources (FAO, 2001; IUSS, 2006). The soils were further classified based on the USDA (Klingbiel and Montgomery, 1961) and the USBR Land Capability Classification (USBR, 1953; Landon, 2013). The land use recommendations were then made with respect to these classifications and the Physicochemical properties of the soils.

3.0. Results and Discusion

3.1 The Geo-References of the Study Area

The geographic information of the soils isis shown in Table 1, while the schematic diagram of the toposequence is shown in Figure 2. The profile pits were sited as shown in Table 1.

Table 1: Geo-Information of the Study Area

Study area	Physiographic position	Latitude	Longitude	Altitude
Umuariam	Upper Slope	N 05° 33' 09.0"	E 007° 21' 05.8"	146 m
Umulogho	Mid Slope	N 05° 34' 21.0"	E 007° 22' 30.8"	101 m
Umungwa	Foot Slope	N 05° 33' 39.1"	E 007° 24' 19.7"	100 m

3.2 Physical Properties

The physical properties of the soils are shown in Table 2. Soil texture ranged from sand in the topsoil to sandy clay loam in the Bt_2 (114 – 141 cm) and Bt_3 (141 – 180 cm) horizons of Umulogho (Mid slope). They generally have sandy topsoil, with relatively more clayey subsoil (Figures 3, 4, and 5), a phenomenon that could be diagnostic of the existence of argillic horizons. Similar results were also reported by Chikezie *et al.* (2010).

Sand content ranged from 78 % in the Bt_3 horizon (141 – 180 cm) of Umulogho to 94 % in the Ap horizon (0 – 17 cm) of Umuariam, with an average value of 86.80 %. Silt content ranged from 1 – 2 % in the profiles under study, with a mean of 1.2 %. This generally low silt content as also reported by Chikezie *et al.* (2010), is in line with the assertion of Akamigbo (1984) that soils of Southeastern Nigeria are low in silt as a result of the high degree and extent of weathering and leaching they have undergone.

Clay content ranged from 5 % in the Ap horizon (0 – 17 cm) of Umuariam to 21 % in the Bt_3 horizon (141 – 180 cm) of Umulogho. Clay was generally higher in the subsoil of all the profiles studied. It was least in the topsoil, increasing down the profile, except at Umuariam where it attained a peak value in the Bt_1 horizon (106 – 135 cm) and started decreasing. The higher clay content in the subsurface horizon may be a result of illuviation, which is diagnostic of the existence of argillic horizons (Soil Survey Staff, 2014).

The bulk density ranged from 1.28 Mg/m^3 in the Ap horizon (0 – 17 cm) of Umuariam to 1.61 Mg/m^3 in the Bt_2 (114 – 141 cm) and Bt_3 horizons (170 – 180 cm) of Umulogho and

Umuariam respectively. In all the constituent horizons, bulk density was below the value quoted as the minimum bulk density at which root-restricting conditions will occur on sandy loam soils (1.75 – 1.80 Mg/m^3) (USDA-NRCS, 1996), sand (1.6 Mg/m^3), and clay (1.4 Mg/m^3) (Donahue *et al.,* 1990). The low bulk density showed that the soils were not compacted (Esu and Ojanuga, 1986).

Table 2: Physical Properties of Soils of the Study Area

Hor.	Depth (cm)	Moisture Content (%)	Particle Size Distribution				Bulk Density (Mg/m^3)	Porosity	S. H. C. (cm/s)
			Sand (%)	Silt (%)	Clay (%)	Textural Class			
Umuariam – Upper Slope									
Ap	0-17	0.96	94	1	5	Sand	1.28	51.55	2.38
A_2	17-35	0.93	88	1	11	Loamy Sand	1.33	49.89	2.27
A_3	35-46	0.93	87	2	11	Loamy Sand	1.36	48.60	1.62
AB	46-106	2.68	83	1	16	Sandy Loam	1.41	46.83	1.41
Bt_1	106-135	4.50	81	1	18	Sandy Loam	1.44	45.58	1.08
Bt_2	135-170	3.77	83	1	16	Sandy Loam	1.42	46.60	0.76
Bt_3	170-180	2.86	83	1	16	Sandy Loam	1.61	39.28	0.43
Umulogho – Mid Slope									
Ap	0-38	0.85	93	1	6	Sand	1.34	49.43	6.49
A_2	38-53	0.92	93	1	6	Sand	1.46	44.87	5.30
A_3	53-64	2.78	89	2	10	Loamy Sand	1.42	46.53	3.78
BA	64-95	2.65	88	2	10	Loamy Sand	1.44	45.70	2.49
Bt_1	95-114	6.86	80	2	19	Sandy Loam	1.42	46.53	0.32
Bt_2	114-141	7.55	79	1	20	Sandy Clay Loam	1.61	39.25	0.22
Bt_3	141-180	7.92	78	1	21	Sandy Clay Loam	1.59	39.85	0.05
Umungwa – Foot Slope									
Ap	0-16	0.85	91	1	8	Sand	1.49	43.66	4.00
A_2	16-65	0.89	92	1	8	Sand	1.51	42.87	2.59
BA	65-94	0.92	89	1	10	Loamy Sand	1.52	42.79	2.27
B_1	94-140	0.93	89	1	10	Loamy Sand	1.52	42.53	1.73
B_2	140-175	1.87	88	1	11	Loamy Sand	1.53	42.43	1.41
B_3	175-180	1.79	88	1	11	Loamy Sand	1.59	39.85	1.19

Hor. = Horizon, S.H.C. = Saturated Hydraulic Conductivity

Saturated hydraulic conductivity ranged from 0.05 cm/s in the Bt_3 (141 – 180 cm) horizon of Umulogho to 6.49 cm/s in the Ap horizon (0 – 38 cm) of Umulogho, with a mean value of 2.09 cm/s. It was generally highest in the topsoil, decreasing down the profile, as also reported by Igwe and Akamigbo (2001) and Oguike and Mbagwu (2009). This was generally due to the lower bulk density and clay content of topsoil.

3.3 Chemical Properties

The chemical properties of soils are shown in Table 3. The pH ranged from 4.19 (very strongly acidic) in the Bt_3 horizon (170 – 180 cm) of Umuariam to 6.51 (moderately acidic) in the Ap horizon (0 – 16 cm) of Umungwa. This relatively low soil pH, as also reported by Akpa *et al.* (2019), is characteristic of soils in Southeastern Nigeria and may be attributed to the acidic nature of the parent rocks, coupled with the influence of the leached profile under high annual rainfall condition. The soil organic matter content ranged from 0.69 % in the Bt_3 horizon (170 - 180 cm) of Umuariam to 5.15 % in the Ap horizon (0 - 38 cm) of Umulogho. Similarly, Brady and Weil (2016) reported that the topsoil of most cultivable soils contains 1 – 6 % organic matter. Total Nitrogen ranged from 0.04 % in the Bt_2 (135 – 170 cm) and Bt_3 horizon (170 – 180 cm) of Umuariam to 0.22 % in the Ap horizon (0 – 38 cm) of Umulogho. The low total nitrogen is a common phenomenon in the soils of Southeastern Nigeria and is a result of the high nitrogen losses sustained through the leaching of nitrates, as well as the rapid mineralization of organic matter in the humid tropics.

The soils were acutely deficient in available phosphorus (< 3.0 ppm), except for the topsoil where it was marginal (6.5 – 13.0 ppm). The moderate to low available phosphorus concentration is, however, a widespread phenomenon in the humid tropical soils of Southeastern Nigeria and can be attributed to the high phosphate fixation capacity of these soils. The ECEC of the soils ranged from 1.57 cmol/kg in the Ap horizon (0 - 38 cm) of Umulogho to 2.54 cmol/kg in the Bt_2 horizon (114 – 141 cm) of Umulogho**.** This low ECEC is in line with the assertion by Osuji *et al.* (2002) that soils formed on Coastal Plain Sands and sandstones are acidic, low in CEC, base saturation, and fertility levels.

Exchangeable Calcium was generally low (< 4 cmol/kg). Exchangeable magnesium was also low (< 0.5 cmol/kg). This low concentration is characteristic of the soils of Southeastern Nigeria. It can be attributed to the acidic nature of the parent rocks, coupled with the influence of the leached profile under the high annual rainfall condition of the region. Potassium concentration was low to moderate (< 0.6 cmol/kg). Similarly, Osemwota *et al.* (2005) reported low potassium reserve in soils formed from Coastal Plain Sands in Central Southern Nigeria. This low potassium concentration may be attributed to the fact that there is generally a low potassium reserve in acid sands. This is necessitated by the highly mobile nature of exchangeable potassium relative to calcium and magnesium and its consequent massive loss through leaching. Sodium concentration was generally low (< 1.0 cmol/kg). As such, none of the soils can be classified as sodic or alkaline soils.

Exchangeable aluminum was low in the topsoils. It ranged from 0.20 cmol/kg in the B_2 horizon (140 – 175 cm) of Umungwa to 1.25 cmol/kg in the Bt_2 horizon (114 – 141 cm) of Umulogho. Aluminum saturation ranged from 11 % in the B_3 horizon (175 – 180 cm) of Umungwa to 49 % in the A_3 horizon (35 – 46 cm) of Umuariam. Sanchez (1976) reported that there is less than 1.0 ppm aluminum in the soil solution when aluminum saturation is less than 60 % but rises sharply when aluminum saturation increases beyond 60 %. As such, due to the low aluminum saturation (< 60%) in the soils, there is little risk of aluminum concentration attaining toxic levels.

Base saturation generally ranged from as low as 24 % in the Bt_2 horizon (114 – 141 cm) of Umulogho to 51 % in the Ap horizon (0 – 16 cm) of Umungwa. Base saturation was generally highest in the topsoil. This may be attributed to the positive correlation that exists between pH and base saturation. As such, the decrease of base saturation with increasing depth is attributable to pH, which tended to decrease with increasing depth.

Table 3: Chemical Properties of the Study Area

Hor.	Depth	pH		Org. C (%)	Org. Mat. (%)	Tot. N (%)	C: N Ratio	Ava. P (ppm)	Ex. Bases (cmol/kg)				Ex. Acid. (cmol/kg)		ECEC (cmol/kg)	Clay Activity (cmol/kg)	Base Sat. (%)	Al Sat. (%)	ESP (%)	EPP (%)	K: Mg Ratio	Ca: Mg Ratio	EC (mmho/m x10^{-2})
		H_2O	KCl						Ca	Mg	K	Na	Al	H									
Umuariam – Coastal Plain Sands (Top Slope)																							
Ap	0-17	5.29	4.87	2.38	4.10	0.17	14:1	6.53	0.21	0.10	0.30	0.17	0.60	0.51	1.89	21.00	41	32	9	16	3: 1	2: 1	11.26
A2	17-35	5.38	4.90	1.70	2.93	0.13	13:1	3.73	0.18	0.10	0.44	0.12	0.90	0.35	2.09	19.00	40	43	6	21	9: 2	2: 1	9.84
A3	35-46	5.36	4.86	1.66	2.86	0.13	13:1	4.66	0.14	0.09	0.34	0.11	0.90	0.24	1.82	18.20	37	49	6	19	4: 1	3: 2	13.59
AB	46-106	5.36	4.77	1.55	2.67	0.12	13:1	1.87	0.13	0.09	0.43	0.13	0.72	0.84	2.34	14.63	33	31	6	18	5: 1	4: 3	8.52
Bt1	106-135	4.92	4.83	0.50	0.86	0.14	13:1	2.80	0.13	0.08	0.48	0.16	0.66	0.98	2.49	13.83	34	27	6	19	6: 1	3: 2	8.32
Bt2	135-170	4.92	4.83	0.45	0.78	0.04	11:1	1.87	0.12	0.08	0.28	0.08	0.30	1.02	1.88	11.75	30	16	4	15	7: 2	3: 2	5.55
Bt3	170-180	4.19	4.87	0.40	0.69	0.04	10:1	1.87	0.12	0.10	0.23	0.07	0.87	0.42	1.81	11.31	29	48	4	13	9: 4	6: 5	4.13
Umulogho (Mid Slope)																							
Ap	0-38	5.96	5.72	2.99	5.15	0.22	14:1	9.33	0.25	0.14	0.24	0.10	0.41	0.43	1.57	26.17	46	26	6	15	5: 3	2: 1	13.76
A2	38-53	5.65	5.16	2.20	3.79	0.14	9:1	4.66	0.25	0.10	0.30	0.13	0.50	0.62	1.90	31.67	41	26	7	16	3: 1	5: 2	6.04
A3	53-64	5.40	5.01	1.50	2.59	0.11	14:1	6.53	0.17	0.09	0.33	0.10	0.53	0.53	1.75	17.50	39	30	6	19	11: 3	2: 1	3.65
BA	64-95	5.20	4.83	1.30	2.24	0.10	13:1	1.87	0.17	0.10	0.27	0.09	0.83	0.53	1.99	19.90	32	42	5	14	8: 3	5: 3	3.37
Bt1	95-114	5.09	4.78	1.30	2.24	0.11	12:1	1.87	0.14	0.08	0.38	0.10	1.10	0.62	2.42	12.74	29	45	4	16	5: 1	2: 1	2.49
Bt2	114-141	4.90	4.78	0.72	1.24	0.06	12:1	1.87	0.10	0.07	0.36	0.09	1.25	0.67	2.54	12.10	24	49	4	14	5: 1	4: 3	2.96
Bt3	141-180	4.94	4.78	0.65	1.12	0.06	11:1	1.87	0.13	0.07	0.37	0.10	1.11	0.82	2.60	11.82	26	43	4	14	4: 1	2: 1	2.75
Umungwa (Foot Slope)																							
Ap	0-16	6.51	5.77	1.70	2.93	0.12	14:1	11.19	0.38	0.11	0.28	0.09	0.45	0.38	1.69	33.80	51	27	5	17	5: 2	7: 2	5.29
A2	16-65	5.60	5.00	1.40	2.41	0.10	14:1	4.66	0.28	0.10	0.30	0.10	0.45	0.68	1.91	23.88	41	24	5	16	3: 1	3: 1	2.19
BA	65-94	5.16	4.81	1.30	2.24	0.10	13:1	2.80	0.20	0.09	0.32	0.10	0.51	0.96	2.18	21.80	33	23	5	15	7: 2	11: 5	1.13
B1	94-140	5.17	4.81	1.20	2.07	0.10	12:1	2.80	0.17	0.08	0.28	0.08	0.57	0.90	2.08	18.91	29	27	4	13	7: 2	2: 1	1.33
B2	140-175	5.17	4.81	1.10	1.90	0.09	12:1	2.80	0.16	0.10	0.30	0.10	0.25	0.99	1.90	17.27	35	13	5	16	3: 1	3: 2	1.14
B3	175-180	5.09	4.81	0.55	0.95	0.05	11:1	2.80	0.13	0.07	0.39	0.10	0.20	0.90	1.79	16.27	39	11	6	22	11: 2	2: 1	1.66

Hor. = Horizon, ECEC = Effective Cation Exchange Capacity, Ex. Acid. = Exchange Acidity, ESP = Exchangeable Sodium Percentage, EPP = Exchangeable potassium Percentage, EC = Electrical Conductivity, Ca = Calcium, Mg = Magnesium, K = Potassium, Na = Sodium, KCl = Potassium Chloride, H_2O =Water, Org. C = Organic Carbon, Org. Mat. = Organic Matter, Tot. N = Total Nitrogen, Ava. P = Available Phosphorus

3.4 Soil Classification

3.4.1 Taxonomic and WRB Classification

The soils of Upper Slope (Umuariam) and Mid Slope (Umulogho) were classified as Typic Hapludults (Chromic Acrisols), while that of Foot Slope (Umungwa) was classified as Typic Udipsamments (Rubic Arenosols) (Table 4).

3.4.2 USDA Land Capability Classification

Soils on the Coastal Plain Sands (Mid Slope and Foot Slope) had moderate susceptibility to erosion and subsoil permeability but were generally classified as IVs due to their sandy topsoil texture. Umuariam, on the Upper Slope, was placed in class IIes due to its moderate susceptibility to erosion, subsoil permeability, and loamy sand topsoil texture.

3.4.3 USBR Land Capability Classification

The soils of Upper Slope (Umuariam), Mid Slope (Umulogho), and Foot Slope (Umungwa) all met the minimum soil, topographic, and drainage requirements to warrant placement in class 1 of irrigable lands, but for the textural limitation. Owing to the loamy sand topsoil texture recorded at Umuariam, it was placed in class 2 of irrigable lands, with the classification 2v/C. Umulogho and Umungwa, with sandy topsoil texture, were placed in class 3 (3v/C).

3.4.4 Land Use and Management Recommendations

The land use recommendations of the soils on the different physiographic positions are shown in Table 4. Brady and Weil (2016) reported that soils of capability classes I to IV are suitable for intense grazing, forestry, wildlife, water supply, aesthetic purposes, and different intensities of arable crop production. As such, being of classes II and IV the soils of the study area can be said to be suitable for the afore-mentioned land uses.

Also, since the soils all had an exchangeable sodium percentage of less than 15 % and electrical conductivity of less than 4000 Umho/cm, the soils are not at risk of becoming sodic or saline. Similarly, since the exchangeable potassium percentage (EPP) is less than 25 %, the soils are not potassium-rich enough to negatively affect crop growth and soil structural stability. They all also had EPP of more than 2 % - which is the minimum level to avoid potassium deficiency in the humid tropics.

- *Upper Slope (Umuariam):* This is a soil of USDA land capability class II. It is suitable for intense cultivation. As soils of USBR land capability class of 2v/C, it is moderately irrigable. Most arable crops are grown in Southeastern Nigeria (e.g., yam, cassava, maize, okra, and fluted pumpkins, etc.), can be sustainably grown here. The soil, however, requires moderate conservation measures geared towards improving subsoil porosity and permeability and curbing water erosion. As such, high organic manure input, contour ridging, and minimum tillage are recommended. This is in line with the assertion of Brady and Weil (2016) that though Acrisols (Ultisols) are not fertile soils, they respond to good management and can be quite productive where adequate levels of fertilizers and lime are applied. Furthermore, FAO (2001) recommended that undemanding, acid-tolerant cash crops such as oil palm, pineapple, cashew, or rubber can be grown on Acrisols. Umuariam had a K: Mg ratio of greater than 2: 1, which inhibits Mg uptake. They consequently require the increased application of Mg fertilizers, relative to K fertilizers. Due to topsoil Ca: Mg ratio of 3: 1 to 4: 1, Umuariam met the optimum approximate Ca: Mg ratio for most crops.
- *Mid Slope (Umulogho):* As soils of USDA land capability class IV, this soil is marginally suitable for arable crop production due to its sandy topsoil texture. The soils are of USBR land capability class 3v/C and are classified as marginally irrigable soils. There is a limited range of crops that can be substantially grown on these soils, though crops like yam, cassava, maize, okra, and fluted pumpkins can be grown on the soil with careful management. They require high organic matter input to improve soil available water holding capacity and curb erosion by water. Landon (2013) asserted that soils in this class (IV) are suited only for two or three common crops, or harvest produced may be low in relation to inputs over a long period. He suggested the growth of such crops as fruits, ornamentals, and shrubs. These soils (Class IV) are thus only suitable for limited cultivation. Similarly, FAO (2001) asserted that Acrisols are unproductive soils that must gulp down some capital investment on soil conservation and productivity improvement if they are to be used for intensive food production. Umulogho soils had K: Mg ratio of less than 2: 1, therefore Mg uptake will not be inhibited.
- *Foot Slope (Umungwa):* As soils of USDA land capability class IV, this soil is marginally suitable for arable crop production due to its sandy topsoil texture. The soils are of USBR land capability class 3v/C and are classified as marginally irrigable soils. Brady and Weil (2016) corroborated this when they stated that the productivity of Entisols is restricted by inadequate clay content and water availability. There is a limited range of crops that can be sustainably grown on these soils even with careful management. Similarly, FAO (2001) asserted that Arenosols in the humid tropics are best left under their natural vegetation. They, however, agreed that Arenosols can be planted for perennial crops such as rubber, pepper, coconut, cashew, and pine, especially where good quality groundwater is within reach of the root system. Due to the ease of cultivation, rooting and harvesting of root and tuber crops on these soils, FAO (2001) also recommended growing cassava and (Bambara) groundnuts on Arenosols. More so, Brady and Weil (2016) opined that some Entisols can be quite productive if properly managed. They require high organic matter input and minimum tillage to improve soil available water holding capacity and curb erosion by water. As class IV soils, like Umulogho on the -mid-slope, only a limited number and intensity of crops can be grown here, including fruits, ornamentals, and shrubs. It is consequently recommended that most crops grown in Southeastern Nigeria like cassava, maize, yam, and vegetables, can be grown at Umungwa but a lower intensity, and with greater organic matter and fertilizer input. Umungwa soil had a K: Mg ratio of greater than 2: 1, which inhibits Mg uptake. They consequently require an increase in the application of Mg fertilizers, relative to K fertilizers. With a Ca: Mg ratio of less than 3: 1, Umungwa soil is likely to have inhibited P uptake. They consequently require liming or the application of Calcium-based fertilizer supplements.

Table 4: Land Use Recommendations of Soils of the Study Area

Taxonomic Class	WRB/FAO Class	USDA Class	Land Use / Mgt. Recommendations	USBR Class	Land Use / Mgt. Recommendations
Upper Slope (Umuariam)					
Typic Hapludults	Chromic Acrisols	IIes	- Intense suitability for cultivation - Adapted to the cultivation of all the upland crops of the region - They require high organic matter input/minimum to no-tillage to improve soil porosity, reduce runoff and curb water erosion.	$\frac{2v}{C}$	- Moderately irrigable - Requires organic matter input and/or no / minimum tillage / green manuring to improve available water holding capacity (AWC).
Mid Slope (Umulogho)					
Typic Hapludults	Chromic Acrisols	IVs	- Limited suitability for cultivation - Limited choice of plants and careful management required - very high organic matter input/minimum to no-tillage isrequired to improve soil available water capacity, as well as reduce runoff and erosion	$\frac{3v}{C}$	- Marginally irrigable - Requires high input of organic matter/minimum to no-tillage to improve soil AWC - Adapted to use of drip irrigation system whereas much water to meet plant need are supplied at any particular moment in time, and not more - crops grown are reduced to those adapted to such conditions
Foot Slope (Umungwa)					
Typic Udi-psamments	Rubic Arenosols	IVs	- Being is Class IVs, it has limitations and land uses similar to those of Umulogho (ABOVE).	$\frac{3v}{C}$	- Being in the same class as Umulogho, they are both assumed to have similar limitations and land uses (SEE UMULOGHO).

4.0. Conclusion

The soils of the Upper Slope (Umuariam) and the Mid Slope (Umulogho) were classified as Typic Hapludults (Chromic Acrisols), while that of the Foot Slope (Umungwa) was classified as Typic Udipsamments (Rubic Arenosols). The Upper Slope (Umuariam) had a USDA land capability class of IIes and a USBR land capability class of 2v/C. The Upper Slope (Umuariam) and the Mid Slope (Umulogho) both had a USDA and USBR capability class of IVs and 3v/C respectively. These soils are suitable for such land uses as intense grazing, forestry, wildlife, water supply, aesthetic purposes, and different intensities of arable crop production. However, if the soils are to produce increased and sustainable agricultural yield, devoid of further environmental degradation, the appropriate land use, and husbandry practices should be adopted, with particular reference to erosion control, organic manure, lime, and fertilizer application.

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