CHARACTERIZATION AND LAND EVALUATION OF THREE TROPICAL RAINFOREST SOILS DERIVED FROM THE COASTAL PLAIN SANDS OF SOUTHEASTERN NIGERIA

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ABSTRACT
Soils on coastal plain sands of southeastern Nigeria have hitherto been referred to as fragile sandy and acidic soils of low base saturation, cation exchange capacity (CEC) and fertility, as evidenced by the extensive land degradation evident in the region. This underscores the need for the characterization of the soils for sustainable use. Three profile pits were therefore dug on the upper, middle and bottom slopes of three towns in the rainforest belt underlain by the coastal plain sands. The results showed that the topsoil of the soils was generally sandy, with relatively more clayey subsoil. The pH ranged from extremely acidic (< 4.4) to slightly acidic (6.1-6.5). They had low organic matter, low total nitrogen, low effective CEC, low Al saturation and moderate base saturation. The soils of the upper and the middle slopes were classified as Arenic Kandiudult by the United States Department of Agriculture's (USDA) Soil Taxonomy or as Chromic Acrisols by the World Reference Base (WRB) for Soil Resources classification system, while that of the bottom slope was classified as a Typic Dystrudept (USDA Soil Taxonomy) / Dystric Cambisol (WRB classification system). The upper slope had a USDA land capability class of IIes and a United States Bureau for Reclamation (USBR) land capability class of 2v/C. The middle slope and the bottom slope both had 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.

Key words: Coastal plain sands, land use planning, soil characterization, toposequence, tropical rainforest

INTRODUCTION

Coastal plain sands cover over 25% of the tropical rainforest belt 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; Obi *et al.*, 2011; Madueke *et al.*, 2020, 2021). Soils derived from the coastal plain sands are deep, highly weathered, strongly acidic, coarse-textured, easily eroded and generally of low organic matter, total nitrogen, cation exchange capacity, base saturation and inherent chemical fertility (Osuji *et al.*, 2002; Obi, 2015; Osujieke *et al.*, 2018; Abam and Orji, 2019; Madueke *et al.*, 2020). This inherent low fertility and poor structural stability calls for their 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 is immense, encompassing a multiplicity of aspects, some of which include soil erosion, pollution, deforestation, and loss of soil fertility and quality, to mention but a few. These hazards, particularly the ubiquitous gully erosion that crisscross the entire region, are compounded by the very high annual rainfall amount and intensity recorded in the rainforest belt. The menace of gully erosion has taken its toll on the socioeconomic wellbeing of the people living in the rainforest belt, such that lands used for aesthetic, agricultural and industrial purposes, ancestral homes, crops, livestock and other infrastructure are lost at alarming rate (Obiadi *et al.*, 2011). In many communities, landmarks have been destroyed, ancestral burial sites washed away, economic trees felled, towns and villages balkanized, and lives lost (Jimoh, 2006; Umahi, 2011). The situation is so menacing that the World Bank (1990) put the annual cost of the damage caused by gully erosion in Southeastern Nigeria at $100,000,000.

All of these have collectively resulted in numerous social, economic, psychological and environmental malaises 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).

Moreover, 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 studies to assess the spatial dynamics of soils within the region is of fundamental importance. Therefore, the main objective of this study was to evaluate the nature and properties of rainforest soils formed from the coastal plain sands of Southeastern Nigeria. The specific objectives were to (i) characterize the soils on the coastal plain sands using their physical and chemical properties, (ii) classify the soil according to the United States Department of Agriculture (USDA) Soil Taxonomy and The World Reference Base for soil resources classification systems, (iii) determine the USDA and United States Bureau for Reclamation (USBR) land capability classes of the soils, and (iv) make land use and management recommendations.

MATERIALS AND METHODS
Physical Environment of the Study Area
The area receives an average of 2,134 mm of rainfall distributed over about 139 days of the year (Madueke, 2010). It is double maxima, with a break occurring in July or August. The daily temperature ranges from a minimum of 21°C to a maximum of 34°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 study area is located in 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.

Study Area
Three profile pits were dug on three different physiographic positions (Figures 1 and 2). The geo-information of the study sites is shown in Table 1.

Soil Sampling
Three profile pits were dug in Obowo Local Government Area (with an approximate area of 87.41 km^2) in the rainforest belt, viz: Umuariam (upper slope), Umulogho (middle slope) and Umungwa (bottom slope) (Table 1, Figure 1). The site and profile description were in accordance with the method described by (FAO, 2006). Soil samples were taken from horizons for laboratory analysis. These samples were placed in 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 prior to routine laboratory analysis. Undisturbed core samples were taken for the determination of saturated hydraulic conductivity and bulk density.

Soil Analysis
The physical and chemical properties of the soil samples were determined using routine analytical methods. Moisture content of the soils was determined gravimetrically. Particle size distribution was determined according to 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 & Sunda (1977). Soil pH was measured electrometrically with a pH meter using a soil-liquid ratio of 1:2.5 (International Institute for Tropical Agriculture [IITA], 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$_4$OAC). Exchangeable calcium and magnesium were determined by ethylene diaminetetra-acetic 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. Base saturation, aluminum saturation, exchangeable sodium percentage and exchangeable potassium percentage were computed as the respective percentages of exchangeable bases, aluminum, sodium and potassium to ECEC. Clay activity was computed as:

$$100 \times \frac{ECEC}{\% \, Clay}$$ (Young, 1980; Eshett, 1995).

Clay activity lower than 16 cmol kg^{-1} indicates the predominance of low activity clays, while higher values indicate high activity clays (Eshett, 1995).

Table 1: Geo-information of the study area

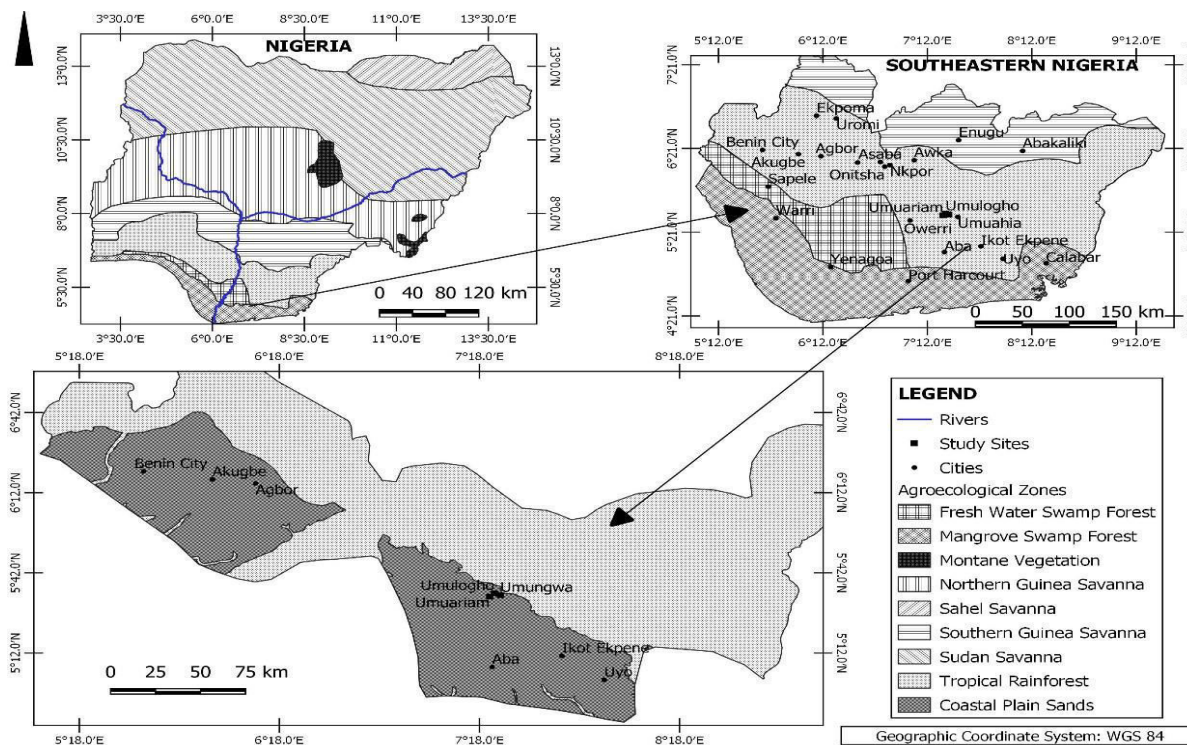| Study area	Position	Latitude	Longitude	Altitude	Slope	Depth
Umuariam	Upper slope	N 05º 33' 09.0"	E 007º 21' 05.8"	146 m	< 5%	>200 cm
Umulogho	Middle slope	N 05º 34' 21.0"	E 007º 22' 30.8"	101 m	< 5%	>200 cm
Umungwa	Bottom slope	N 05º 33' 39.1"	E 007º 24' 19.7"	100 m	< 5%	>200 cm

Figure 1: Map of the study area showing the region of the tropical rainforest underlain by the Coastal Plain Sands

Furthermore, Young (1980) also recommended that a clay activity of > 40 cmol kg^{-1} is indicative of substantial amounts of 2:1 lattice clay minerals while between 15 to 20 cmol kg^{-1} indicate dominance of kaolinite and free sesquioxides. Soil organic carbon (SOC) was determined by Walkley and Black digestion method (Nelson and Sommers, 1982). Total Nitrogen was estimated by micro-Kjeldahl digestion method (Bremner and Mulvaney, 1982) while available phosphorus was determined by Bray II Method (Olsen and Somers, 1982).

Data Analysis
Horizontal bar charts were used to depict the depth function of different soil properties. Linear correlation plots were used to depict the functional relationship between different physical and chemical properties of the soils.

Soil Classification and Land Use Planning
The soils were classified according to USDA soil taxonomy (Soil Survey Staff, 2014) and world reference base for soil resources (IUSS Working Group WRB, 2015). The soils were further classified based on the USDA (Klingebiel 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 physico-chemical properties of the soils.

RESULTS AND DISCUSSION
Physical Properties
The geographic information of the pedons is shown in Table 1, while the schematic diagram depicting the sampled physiographic positions is shown in Figure 2. The physical properties of the soils are shown in Table 2.

Soil textural class ranged from sand in the topsoil to sandy loam in the B horizons of the upper slope (Umuariam) and the middle slope (Umulogho). The bottom slope (Umungwa) had sandy topsoil and loamy sand subsoil. The distinctive textural class of the bottom slope is attributable to the influence of the Imo River on whose bank it is located. Nevertheless, the soils generally have sandy topsoil, with relatively more clayey subsoil, a phenomenon that could be diagnostic of the existence of argillic horizons, as also reported by Chikezie *et al.* (2010) and Madueke *et al.* (2011, 2020, 2021).

Sand content ranged from 81% in the subsoil to 94% in the topsoil of the upper slope (Umuariam), 78 to 93% on the middle slope (Umulogho) and 88 to 92% on the bottom slope (Umungwa). Sand tended to decrease from the upper slope to the bottom slope. This may be attributed to the preferential erosion and transportation of finer sediments down the slope, leaving behind the coarser sand particles. Clay ranged from 5% in the topsoil to 18% in the subsoil of Umuariam, 6 to 21% at Umulogho and 8 to 11% at Umungwa. This also

portrays a trend that is in line with the movement of clay-size particles down the slope. The lower clay content at Umungwa may be attributed to the deposition of coarse sediments by the Imo River on whose bank Umungwa is located.

Clay was generally moderately higher in the subsoil of all the profiles studied. It was least in the topsoil, increasing down the profile, except at the upper slope (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 as a result of illuviation, which is diagnostic of the existence of kandic or argillic horizons (Obalum et al., 2013; Soil Survey Staff, 2014). Nevertheless, though there is evidence of increasing clay content down the profile on the bottom slope (Umungwa), it was very infinitesimal, precluding the existence of a well-developed argillic or kandic horizon within the profile.

Silt content ranged from 1 to 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 observation by Akamigbo (1984) that most soils of Southeastern Nigeria are low in silt as a result of the high degree and extent of weathering and leaching they have undergone, an indicative of low silt-clay ratio.

Bulk density ranged from 1.28 Mg m^{-3} in the Ap horizon (0-17 cm) to 1.61 Mg m^{-3} in the Bt_3 horizons (170-200 cm) of the upper slope (Umuariam). It ranged from 1.34 mg m^{-3} in the Ap (0-33 cm) to 1.61 Mg m^{-3} in the Bt_2 (114-141 cm) horizon of the middle slope (Umulogho), and 1.49 to 1.59 Mg m^{-3} on the bottom slope (Umungwa). The relatively higher bulk density in the topsoil of the bottom slope may be attributed to lower organic matter content in the pedon. This is in line with the report of Chaudhari et al. (2013) that bulk density correlates negatively with organic matter. 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 Natural Resources Conservation Service, 2001) and sand (1.6 Mg m^{-3}) (Donahue et al., 1990). The low bulk density show that the soils were not compacted.
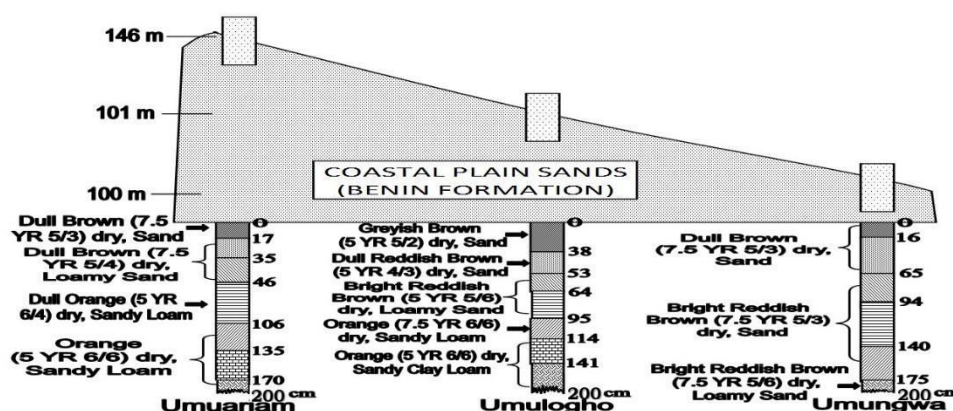

Figure 2: Schematic diagram of the toposequence on the Coastal Plain Sands

Table 2: Physical properties of the coastal plain soils of the tropical rainforest of Southeastern Nigeria

Hor.	Depth (cm)	Moist. Cont. (%)	Sand (%)	Silt (%)	Clay (%)	Textural Class	Bulk Dens. (Mg m^{-3})	Porosity (%)	Ksat (cm s^{-1})
					Upper slope – Umuariam				
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	170-200	2.86	83	1	16	Sandy Loam	1.61	39.28	0.43
					Middle slope – Umulogho				
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 Loam	1.61	39.25	0.22
Bt_3	141-200	7.92	78	1	21	Sandy Loam	1.59	39.85	0.05
					Bottom slope – Umungwa				
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	175-200	1.79	88	1	11	Loamy Sand	1.59	39.85	1.19

Hor. - Horizon, Moist. Cont. - Moisture Content, Dens. - Density, Ksat. - Saturated Hydraulic Conductivity

Saturated hydraulic conductivity ranged from 0.43 cm s^{-1} in the Bt$_3$ (170-200 cm) to 2.38 cm s^{-1} in the Ap horizon of the upper slope (Umuariam), 0.05 cm s^{-1} in the Bt$_3$ (141-200 cm) to 6.49 cm s^{-1} in the Ap horizon (0-38 cm) of the middle slope (Umulogho) and 1.19 cm s^{-1} in the B$_3$ (175-200 cm) to 4.0 cm s^{-1} in the Ap horizon (0-38 cm) of the bottom slope (Umungwa). It was generally highest in the topsoil, decreasing down the profile (Figure 3), as also reported by Igwe and Akamigbo (2001), Ogban and Babalola (2009) and Oguike and Mbagwu (2009). This may be linked to the negative correlation between saturated hydraulic conductivity and clay content (Figure 4a). This negative correlation is due mainly to the preponderance of micropores which, relative to macropores, reduces the ease of flow of fluids. As such, the greater hydraulic conductivity of the topsoil is due mainly to its greater macro-porosity (Obalum *et al.*, 2011).

Saturated hydraulic conductivity, however, correlates positively with pH (Figure 4b). This moderate correlation ($r^2 = 0.58$) is attributable to the fact that higher rate of water flow translates into lower residence time within which basic nutrients can be solubilized and subsequently leached out of the profile. This view is corroborated by the positive correlation existing between saturated hydraulic conductivity and base saturation (Figure 4c).

Chemical Properties
The chemical properties of soils are shown in Table 3. The pH ranged from 4.19 (extremely acidic) in the Bt$_3$ horizon (170-200 cm) to 5.38 (strongly acidic) in the A$_2$ (17-35 cm) horizon of the upper slope (Umulogho), 4.90 (very strongly acidic) to 5.96 (moderately acidic) in the middle slope (Umulogho) and 5.09 (strongly acidic) to 6.51 (slightly acidic) in the bottom slope (Umungwa). The higher pH of the bottom slope may be attributed to the riparian nature of the pedon. The generally low soil pH, as also reported by Akpa *et al.* (2019), is characteristic of soils in the rainforest belt of 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.

Soil organic matter ranged from 0.69% in the Bt$_3$ to 5.10% in the Ap horizon of the upper slope (Umuariam), 1.12 to 5.15% in the middle slope (Umulogho) and 0.95 to 2.93% in the bottom slope (Umungwa). The lower organic matter content of the bottom slope is attributable to the relatively lower vegetative cover of the banks of the Imo River. The topsoil concentration of organic matter ranging from 2.93 to 5.15% is, however, in line with the report of Brady and Weil (2016) that the topsoil of most cultivable soils contain 1.00-6.00% organic matter. Total nitrogen ranged from 0.04% in the subsoil to 0.17% in the topsoil of the Upper Slope (Umuariam), 0.06 to 0.22% in the middle slope (Umulogho) and 0.05 to 0.12% in the bottom slope

(Umungwa). The low total nitrogen is a common phenomenon in the soils of Southeastern Nigeria and is as 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. Soil organic matter and total nitrogen were generally highest in the topsoil, decreasing with depth. This buttresses the positive correlation existing between soil organic matter and total nitrogen (Figure 5a).

The soils were acutely deficient in available phosphorus (< 3.0 ppm), except for the topsoils of the upper slope (4.66-6.53 ppm), middle slope (4.66-9.33 ppm) and bottom slope (4.66-11.19 ppm). This depicts a trend of increasing available phosphorus content down the slope. This may be attributed to translocation labile phosphorus down the slope via overland flow, as reported by Gao *et al.* (2009). The marginal to low available phosphorus concentration is, however, a widespread phenomenon in the tropical rainforest belt of southeastern Nigeria and can be attributed to the high phosphate fixation capacity of tropical soils (Eshett *et al.*, 1990; Tening *et al.*, 2013).

The ECEC of the soils ranged from 1.81 cmol kg^{-1} in the Bt$_3$ to 2.49 cmol kg^{-1} in the Bt$_1$ horizon of the upper slope (Umuariam), 1.57 cmol kg^{-1} in the Ap to 2.60 cmol kg^{-1} in the Bt$_3$ horizon of the middle slope (Umulogho) and 1.69 cmol kg^{-1} in the Ap to 2.18 cmol kg^{-1} in the BA horizon of the bottom slope (Umuariam). This trend of ECEC across the physiographic positions is in line with that of clay, buttressing the positive correlation between ECEC and clay (Figure 5b). The ECEC and clay are often positively correlated (Obalum *et al.*, 2012), due to the relatively higher net negative charge on clay colloids. The generally 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 ranged from 0.12 cmol kg^{-1} in the subsoil to 0.21 cmol kg^{-1} in the topsoil of the upper slope (Umuariam), 0.10 to 0.25 cmol kg^{-1} in the middle slope (Umulogho) and 0.13 to 0.38 cmol kg^{-1} in the bottom slope (Umungwa). Increasing calcium content down the slope may be indicative of overland flow of soluble exchangeable calcium in runoff. Exchangeable calcium was generally low (< 4 cmol kg^{-1}). Exchangeable magnesium ranged from 0.08 to 0.10 cmol kg^{-1} in the upper slope (Umuariam), 0.07 to 0.14 cmol kg^{-1} in the middle slope (Umulogho) and 0.07 to 0.11 cmol kg^{-1} in the bottom slope (Umungwa). Exchangeable magnesium was also low (< 0.5 cmol kg^{-1}). This low concentration is characteristic of the soils of rainforest belt of Southeastern Nigeria. It can be attributed to the acidic nature of the parent rocks, coupled with the influence of the leached profile under high annual rainfall condition of the region.
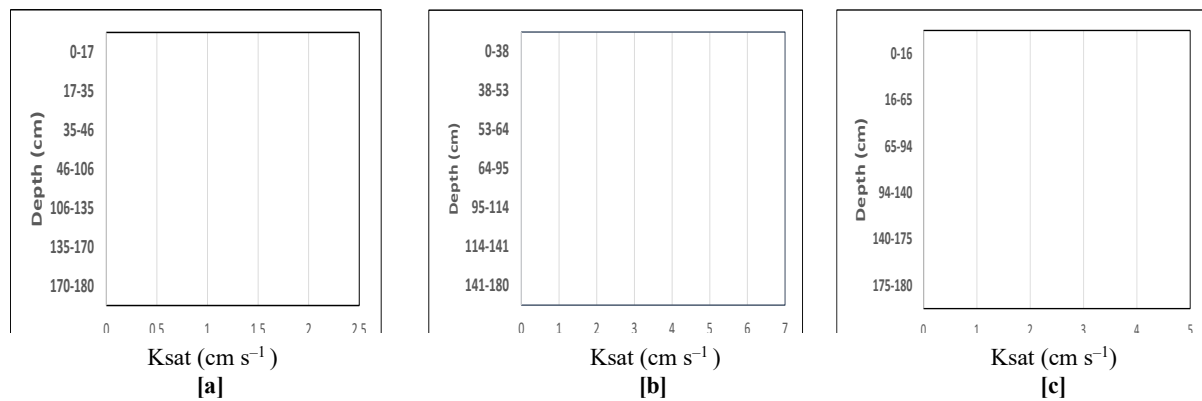
Figure 3: Depth function of Ksat (cm s^{-1}) on the upper slope (Umuariam) [a], middle slope (Umulogho) [b] and bottom slope (Umungwa) [c] in the coastal plain soils

Table 3: Chemical properties of the coastal plain soils of the tropical rainforest of Southeastern Nigeria

Hor.	Depth (cm)	pH	Org. Mat. (%)	Tot. N (%)	Ava. P (ppm)	Ex. Bases				Ex. Acid.		ECEC	CA	Base Sat. (%)	Al Sat. (%)	ESP (%)	EPP (%)	EC (10^{-1}) (S m^{-1})
						Ca	Mg	K	Na	Al	H							
						(cmol kg^{-1})												
Upper slope – Umuariam																		
Ap	0-17	5.29	4.10	0.17	6.53	0.21	0.10	0.30	0.17	0.60	0.51	1.89	21.00	41	32	9	16	0.011
A$_2$	17-35	5.38	2.93	0.13	3.73	0.18	0.10	0.44	0.12	0.90	0.35	2.09	19.00	40	43	6	21	0.010
A$_3$	35-46	5.36	2.86	0.13	4.66	0.14	0.09	0.34	0.11	0.90	0.24	1.82	18.20	37	49	6	19	0.014
AB	46-106	5.36	2.67	0.12	1.87	0.13	0.09	0.43	0.13	0.72	0.84	2.34	14.63	33	31	6	18	0.009
Bt$_1$	106-135	4.92	0.86	0.14	2.80	0.13	0.08	0.48	0.16	0.66	0.98	2.49	13.83	34	27	6	19	0.008
Bt$_2$	135-170	4.92	0.78	0.04	1.87	0.12	0.08	0.28	0.08	0.30	1.02	1.88	11.75	30	16	4	15	0.006
Bt$_3$	170-200	4.19	0.69	0.04	1.87	0.12	0.10	0.23	0.07	0.87	0.42	1.81	11.31	29	48	4	13	0.004
Mid slope – Umulogho																		
Ap	0-38	5.96	5.15	0.22	9.33	0.25	0.14	0.24	0.10	0.41	0.43	1.57	26.17	46	26	6	15	0.014
A$_2$	38-53	5.65	3.79	0.14	4.66	0.25	0.10	0.30	0.13	0.50	0.62	1.90	31.67	41	26	7	16	0.006
A$_3$	53-64	5.40	2.59	0.11	6.53	0.17	0.09	0.33	0.10	0.53	0.53	1.75	17.50	39	30	6	19	0.004
BA	64-95	5.20	2.24	0.10	1.87	0.17	0.10	0.27	0.09	0.83	0.53	1.99	19.90	32	42	5	14	0.003
Bt$_1$	95-114	5.09	2.24	0.11	1.87	0.14	0.08	0.38	0.10	1.10	0.62	2.42	12.74	29	45	4	16	0.002
Bt$_2$	114-141	4.90	1.24	0.06	1.87	0.10	0.07	0.36	0.09	1.25	0.67	2.54	12.10	24	49	4	14	0.003
Bt$_3$	141-200	4.94	1.12	0.06	1.87	0.13	0.07	0.37	0.10	1.11	0.82	2.60	11.82	26	43	4	14	0.003
Foot slope – Umungwa																		
Ap	0-16	6.51	2.93	0.12	11.19	0.38	0.11	0.28	0.09	0.45	0.38	1.69	33.80	51	27	5	17	0.014
A2	16-65	5.60	2.41	0.10	4.66	0.28	0.10	0.30	0.10	0.45	0.68	1.91	23.88	41	24	5	16	0.006
BA	65-94	5.16	2.24	0.10	2.80	0.20	0.09	0.32	0.10	0.51	0.96	2.18	21.80	33	23	5	15	0.004
B1	94-140	5.17	2.07	0.10	2.80	0.17	0.08	0.28	0.08	0.57	0.90	2.08	18.91	29	27	4	13	0.003
B2	140-175	5.17	1.90	0.09	2.80	0.16	0.10	0.30	0.10	0.25	0.99	1.90	17.27	35	13	5	16	0.002
B3	175-200	5.09	0.95	0.05	2.80	0.13	0.07	0.39	0.10	0.20	0.90	1.79	16.27	39	11	6	22	0.003

Hor. - Horizon, ECEC - Effective Cation Exchange Capacity, CA - Clay Activity, Ex. Acid. - Exchange Acidity,
ESP - Exchangeable Sodium Percentage, EPP - Exchangeable potassium Percentage, EC - Electrical Conductivity,
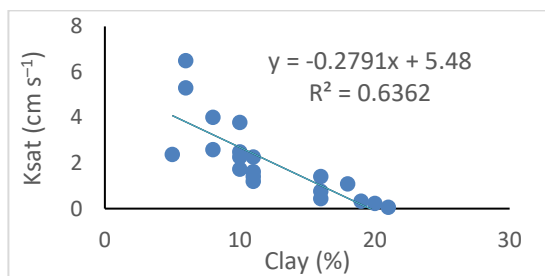Org. Mat. - Organic Matter, Tot. N - Total Nitrogen, Ava. P - Available Phosphorus

Exchangeable potassium ranges from 0.23 to 0.48 cmol kg^{-1} in the upper slope (Umuariam), 0.24 to 0.38 cmol kg^{-1} in the middle slope (Umulogho) and 0.28 to 0.39 cmol kg^{-1} in the bottom slope (Umungwa). Potassium concentration generally moderate (below 0.60 cmol kg^{-1}, but greater than 0.20 cmol kg^{-1}). Osemwota *et al*. (2005), however, reported low potassium reserve in soils derived from coastal plain sands. They attributed the low potassium concentration to a low potassium reserve in acid sands, which may have been necessitated by the highly mobile nature of exchangeable potassium and its consequent massive loss through leaching (Alfaro *et al*., 2017). The moderate concentration in the study are may be attributed to the ongoing farming activities, including possible use of organic and/or inorganic fertilizers.

Exchangeable sodium ranges from 0.07 to 0.17 cmol kg^{-1} in the upper slope (Umuariam), 0.09 to 0.13 cmol kg^{-1} in the middle slope (Umulogho) and 0.08 to 0.10 cmol kg^{-1} in the bottom slope (Umungwa). Topography did not seem to have any effect on the spatial distribution of exchangeable sodium due to the fact that the parent material (coastal plain sands) has inherently low sodium reserves. Sodium concentration was generally low (< 1.00 cmol kg^{-1}). As such, none of the soils can be classified as sodic, saline or alkaline soils.
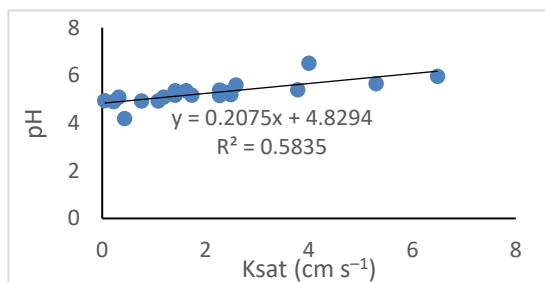
Exchangeable aluminum was low in the topsoil. It ranged from 0.60 cmol kg^{-1} in the upper slope (Umuariam), through 0.45 cmol kg^{-1}in the middle slope (Umungwa) to 0.41 cmol kg^{-1} in the bottom slope (Umulogho). Similarly, aluminum saturation in the topsoils amounted to 32%, 26% and 27% in the

upper slope, middle slope and bottom slope, respectively. While tending to decrease down the slope, the trend was not consistent, as also reported by Yasin and Yulnafatmawita (2018). Sanchez (1976) reported that there is less than 1.00 ppm aluminum in the soil solution when aluminum saturation is less than 60%, but rises sharply when it increases beyond 60%. Aluminum saturation was generally below 60%, mitigating the risk of aluminum concentration attaining toxic levels.
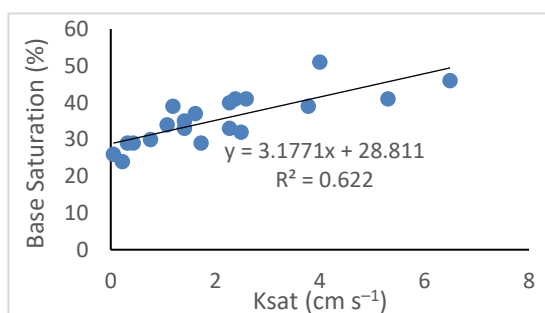
Base saturation ranged from 27% in the subsoil to 41% in the topsoil of the upper slope (Umuariam), 24 to 46% in the middle slope (Umulogho) and 29 to 51% in the bottom slope (Umungwa). This depicts a trend of increasing base saturation down the slope. This may be attributed to the dissolution and translocation of basic cations down the slope by runoff. More so, base saturation was generally higher in the topsoil. This, in turns, led to an increase in soil pH as there exists a positive correlation between pH and base saturation (Figure 5c). As such, the decrease of base saturation with increasing depth translates to a pH, which also tended to decrease with increasing depth.
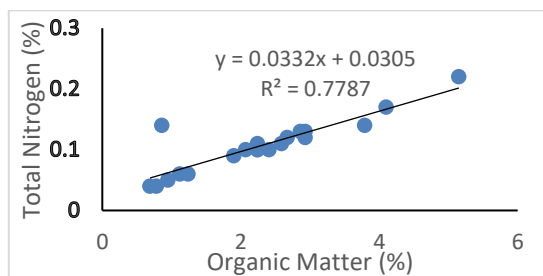
Soil Classification
The soils were classified according Soil Taxonomy and the World Reference Base for Soil Resources (WRB). Land capability classes of the soils were determined using the USDA and the USBR systems. The different soil classes are shown in Table 4.
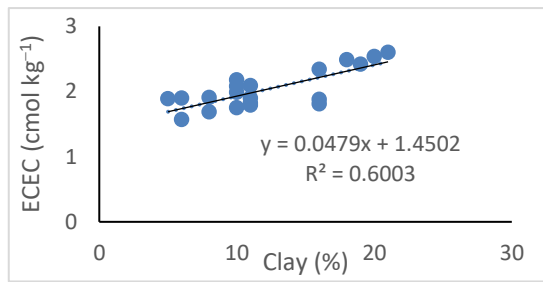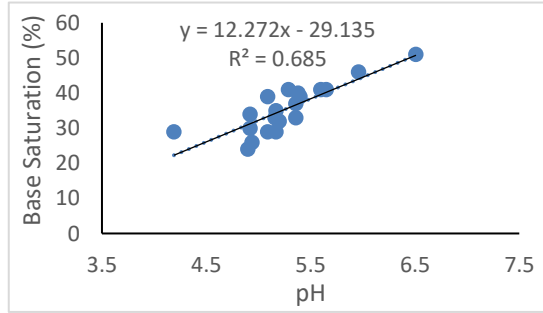
Soil Taxonomy
Order
Upper slope (Umuariam) and middle slope (Umulogho) may have been classified as Alfisols or Ultisols because of the existence of a kandic horizon as well as evidence of increasing clay content with increasing depth. They were however classified as Ultisols due to a base saturation that was < 35% at 125 cm below the upper boundary of the kandic horizon but not deeper than 180-200 cm below the mineral soil surface. The bottom slope (Umungwa) may have been classified as an Entisol due to the alluvial nature of the soil and a texture ranging from sand to loamy sand (Table 2). Nevertheless, with the existence of minimal diagnostic features like poor structural stability, minimal variation in soil colour and no evidence of illuviation, it was thus classified as an Inceptisol.

[a]

[b]

[c]

Figure 4: Correlations of saturated hydraulic conductivity [Ksat] (cm s^{-1}) with each of % clay [a], soil pH [b] and % base saturation [c] in the Coastal Plain Soils

[a]

[b]

[c]

Figure 5: Correlations between % total nitrogen and % organic matter [a], ECEC (cmol kg^{-1}) and % clay [b], and % base saturation and soil pH [c] in the Coastal Plain Soils

Table 4: Land use recommendations for the coastal plain soils of the tropical rainforest of Southeastern Nigeria

Taxonomic class	WRB class	USDA class	USBR class	Land use/management recommendations
				Upper slope (Umuariam)
Arenic Kandiudult	Ferralic Acrisol	IIes	$\dfrac{2v}{C}$	- Moderately irrigable - Intense suitability for cultivation - Adapted to the cultivation of all the upland crops of the region - They require high organic matter input / minimum tillage to improve Soil porosity, reduce runoff, curb water erosion and improve available water holding capacity (AWC).
				Middle slope (Umulogho)
Arenic Kandiudult	Ferralic Acrisol	IVs	$\dfrac{3v}{C}$	- Marginally irrigable - Limited suitability for cultivation - Limited choice of plants and careful management required - very high organic matter input / minimum tillage are required to improve soil available water capacity (AWC), as well as reduce runoff and erosion - Adapted to use of drip irrigation system where as much water to meet plant need are supplied at any particular moment in time, and not more
				Bottom slope (Umungwa)
Typic Dystrudept	Dystric Cambisol	IVs	$\dfrac{3v}{C}$	- Being in Class IVs and 3v/C, it has limitations and land uses similar to those of the Middle Slope (Umulogho) and is also marginally irrigable.

Sub-Order

Due to absence of redoximorphic features and relatively low organic carbon content, the upper slope (Umuariam) and the middle slope (Umulogho) could not be classified as Aquults or Humults. They were further classified as Udults because of the udic soil moisture regime reported by FDALR [Federal Department of Agricultural Land Resources] (1985) for soils in old Imo State. Similarly, the bottom slope (Umungwa) did not have aquic soil moisture regime, nor does it have gelic or cryic soil temperature regimes. It was therefore classified as an Udept due to the prevailing udic soil moisture regime.

Great Group

The upper slope (Umuariam) and the middle slope (Umulogho) did not have plinthite, fragipans, densic, lithic, paralithic or petroferric contact and could consequently not be classified as Plinthudults or Fragiudults. They were classified as Kandiudults due to the presence of kandic horizons and the absence of a clay decrease of 20% or more, with increasing depth, (relative) from the maximum clay content. The bottom slope (Umungwa) did not have a sulfuric, mollic or umbric horizon, nor did it have duripan or fragipan. Therefore, it could not be classified as Sulfudept, Durudept, Fragiudept or Humudept. It could also not be classified as Eutrudept due to a base saturation that was generally below 60%. It was thus classified as a Dystrudept due to an ECEC less than 15 cmol kg⁻¹ and a base saturation less than 60% in all horizons.

Sub-Group

Due to absence of aquic soil moisture regime, plinthite or horizons with hue of 2.50 YR or 10.00 R, the upper slope (Umuariam) and the middle slope (Umulogho) could not be classified as Arenic Plinthaquic, Aquic Arenic, Arenic Plinthic or Arenic Rhodic Kandiudults. They were classified as Arenic Kandiudults because the soil texture ranged from sandy to loamy sand in all horizons above the kandic horizon. Due to the absence of densic, lithic or paralithic contact, mollic or umbric epipedon, network of cracks, aquic moisture regime, andic soil properties, fragipans, argillic, kandic or natric horizon, human-transported materials or stratified alluvial sediments, the bottom slope (Umungwa) could not be classified as Humic, Lithic, Vertic, Aquic, Andic, Oxic, Alfic, Ultic, Fragic, Fluventic or Lamellic Dystrudept. It was therefore classified as a Typic Dystrudept.

WRB Classification

Soils of the upper slope (Umuariam) and those of the middle slope (Umulogho) may have been classified as Retisols due to the presence of argic horizons, but for the absence of retic properties (i.e., net-like intercalation of the elluvial horizon into the illuvial horizon). Though Acrisols, Lixisols, Alisols and Luvisols are equally characterized by the presence of argic horizons, the soils were classified as Acrisols due to:

1. the presence an argic horizon, which has a cation exchange capacity of < 24 cmol kg⁻¹ clay in some part (Table 3), starting within 100 cm from the soil surface;
2. their having < 50% base saturation in the major part between 25 and 100 cm (Table 3); and
3. their clay activity being < 16 cmol kg⁻¹ in the argic horizons (Table 3).

Due to absence of abrupt textural change, fragipans, continuous hard rock, plinthite, aquic properties, mottles, and other redoximorphic properties, Umuariam and Umulogho soils could not be classified as Abruptic, Fragic, Leptic, Plinthic, Anthraquic, Gleyic or Stagnic Acrisols. They were classified as Ferralic Acrisols due to a strongly weathered profile dominated by kaolinite and oxides. This is in line with the contention of Young (1980) that soils with clay activity between 15 and 20 cmol kg⁻¹, as seen in Table 3, are dominated by kaolinites and sesquioxides. Due to

absence of an argic horizon, irrespective of the minimal increase in clay down the profile (Table 2), the bottom slope (Umungwa) was not classified as either a Retisol, Acrisol, Lixisol, Alisol or Luvisol. It was classified as a Cambisol as a result of the existence of a cambic horizon as connoted by

1. soil texture ranging from sand or loamy sand;
2. absence of rock fragments or structures in the entire in profile;
3. evidence of pedogenetic alteration, such as poor structural stability and minimal variation in soil colour down the profile; and
4. a thickness of greater than 15 cm.

Furthermore, Umungwa soil met the requirement for classification as Eutric Cambisol, but for a base saturation of less than 50% in all horizons starting from a depth of 16 cm from the mineral soil surface (Table 3). It was therefore classified as a Dystric Cambisol.

USDA Land Capability Classification

The soils on the middle slope (Umulogho) and the bottom slope (Umungwa) had moderate susceptibility to erosion and subsoil permeability, but were generally classified as IVs due to their sandy topsoil texture. The soils on the upper slope (Umuariam), was placed in class IIes due to its moderate susceptibility to erosion, subsoil permeability and loamy sand topsoil texture.

USBR Land Capability Classification

The soils of upper slope (Umuariam), middle slope (Umulogho) and bottom slope (Umungwa) met the minimum soil, topographic and drainage requirements to warrant placement in class 1 of irrigable lands, but with textural limitation. Owing to the loamy sand topsoil texture recorded on the upper slope, it was placed in class 2 of irrigable lands, with the classification 2v/C. the middle slope and the bottom slope, with sandy topsoil texture were placed in class 3 (3v/C).

Land Use and Management Recommendations

The land use recommendations of the soils on the different physiographic positions are shown in Table 4. According to the contention of Brady and Weil (2016), 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. Similar findings were reported by Madueke *et al.* (2011).

Also, since the soils all had exchangeable sodium percentage of less than 15% and an electrical conductivity of less than 0.4 S m^{-1}, the soils are not at risk of becoming sodic or saline. Similarly, exchangeable potassium percentage (EPP) was generally less than 25%, and does not have a negative effect on soil structural stability. This is in accordance with the contention of

Landon (2013) that a soil with EPP greater than 25% is considered a potassium-rich soil, and like sodic soils, has detrimental effects not only on crop growth, but also on soil structure and stability. They all also had EPP of more than 2% – which, according to Landon (2013), 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 grown in Southeastern Nigeria (e.g., yam, cassava, maize, okra and fluted pumpkins, etc.), can be sustainably grown on the soil. The soil however, requires moderate conservation measures geared towards improving subsoil porosity and permeability and curbing water erosion. As such, high manure input, contour ridging and minimum tillage are recommended. Furthermore, though Brady & Weil (2016) reported that Ultisols (Acrisols) are not fertile soils, they contended that the soils respond to good management and can be quite productive where adequate doses of fertilizers and lime are applied. FAO (2001) recommended that undemanding, acid-tolerant cash crops such as oil palm, pineapple, cashew or rubber can be grown on Acrisols.

Middle Slope (Umulogho)

As soils of USDA land capability class IV, this soil is marginally suitable for arable crop production due to their 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 yields may be low in relation to inputs over a long period of time. He suggested the growth of such crops as fruits, ornamentals and shrubs. These soils (Class IV) are thus only suitable for limited cultivation. Similarly, Acrisols were reported to be unproductive soils that would require lots of capital investment in soil conservation and productivity improvement if they are to be used for intensive food production (FAO, 2001).

Bottom Slope (Umungwa)

The soil was classified as a Cambisol, which is reportedly suitable for intensive agricultural use (IUSS Working Group WRB, 2015), but the generally sandy nature of the bottom slope, warranting its placement in USDA and USBR land capability classes IV and 3v/C respectively, translates into its classification as marginally

cultivable / marginally irrigable. As such, there is a limited range of crops that can be sustainably grown on these soils even with careful management. However, it has been reported that although acidic Cambisols are less fertile, they can be used for mixed arable farming, grazing, farm plantations and forest land (IUSS Working Group WRB, 2015). Furthermore, due to the ease of cultivation, rooting and harvesting of root and tuber crops on these soils, with careful management, the soils can sustainably support the cultivation of crops like cassava, yam and (bambara) groundnuts. Finally, as class IV soils, like the soils of the middle slope (Umulogho), only a limited number and intensity of crops can be grown on the soil. It is consequently recommended that most crops grown in Southeastern Nigeria like cassava, maize, yam and vegetables, can be grown on the bottom slope, but at a lower intensity, and with improved and efficient fertilizer (organic and inorganic) use and other land husbandry practices.

CONCLUSION

The soils derived from the coastal plain sands of the study area are predominantly sandy, ranging from sandy to sandy loam in the upper slope (Umuariam) and middle slope (Umulogho) through sandy to loamy sand in the bottom slope (Umungwa). Soil pH ranged from extremely acidic (< 4.40) to slightly acidic (6.10-6.50). The soils generally had low organic matter, low total nitrogen, low Effective CEC, low Al saturation and moderate base saturation. The soils of the upper slope (Umuariam) and the middle slope (Umulogho) were classified as Arenic Kandiudults (Chromic Acrisols), while that of the bottom slope (Umungwa) was classified as Typic Dystrudept (Dystric Cambisol). The upper slope (Umuariam) had a USDA land capability class of IIes and a USBR land capability class of 2v/C. The middle slope (Umulogho) and the bottom slope (Umungwa) 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 and different intensities of arable crop production. The soils on the upper slope (Umuariam) are suitable for intense cultivation and can support most of the crops grown in the rainforest belt of Southeastern Nigeria. Due to their sandy topsoil texture, the soils on the middle slope (Umulogho) and the bottom slope (Umungwa) are only suitable for marginal cultivation. They can only support a limited range of crops and require management. As such, 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.

This buttresses the need for full understanding of the nature, properties and classifications of the rainforest soils of Southeastern Nigeria. The need for detailed or semi-detailed soil survey and land use planning of the region cannot be overemphasized. It should be an integral part of the agricultural sector of any economy that wishes to rise above mediocrity, as it is a prerequisite to efficient and sustainable agricultural production. In fact, the detailed or semi-detailed soil survey of the country may be the panacea that will engender increased food production, environmental sustainability and food security. This is more so because, with effective soil survey and land use planning, even the most marginal of soils can be put to productive and sustainable use.

Finally, given the fact that several studies have been conducted in Nigeria that link soil variability to the top sequence, if the spatial extent of the five physiographic positions (summit, upper slope, middle slope, bottom slope and valleys) can be delineated for the soils overlying the coastal plain sands, it may serve as a proxy for the semi-detailed soil survey of the region, when used alongside the other parameters and factors of soil formation.

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