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Characterization and fertility capability classification of some soils in the rain forest zone of Edo state, Nigeria

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ABSTRACT: Characterization and Fertility capability classification was carried out on some soils in the rainforest zone of Edo state to assess the native fertility status of the soil. Different soil types were identified through rigid grid soil survey procedure that produced two mapping units in each of the site studied (Sites A and B). Each mapping unit was represented by a modal class profile, which was sunk, described, sampled and analyzed using standard laboratory methods. The results revealed that the entire study area had a sandy top soil (0 - 20cm) with sand fraction of particle size ranging from 660 to 960 gkg^{-1}, silt ranged from 10 to 44 gkg^{-1} and clay had values ranging from 30 to 320 gkg^{-1}. Soil pH ranged from very strongly acidic (4.86) to slightly acidic (6.38); nutrient reserve was equally low as expressed by the low potassium values (K <0.2 $cmolkg^{-1}$) which ranged from 0.01 to 0.29 $cmolkg^{-1}$; and low Organic Carbon values (1.30 to 23.13 gkg^{-1}). The mean values ranged from 787gkg^{-1}- 886gkg^{-1} for sand, 15 gkg^{-1} – 26.8$gkg^{-1}$for silt and 88gkg^{-1}- 190$gkg^{-1}$for clay. The result of Fertility capability classification (FCC) showed that mapping units 1A (site A) and 1B (site B) were classified as FCC unit SSa$^-$n$^-$Kem; mapping units 2A (site A) and 2B (site B) were classified as SLa$^-$n$^-$Kem. This indicates that the soils of the study area are quite fertile and application of soil amendments, such as Organic fertilizers would enhance cation exchange capacity; biochar application would help to prevent high leaching rate of nutrients prevalent in the area and improve the inherent soil fertility.

Key words: Fertility capability classification, soil characterization, taxonomic classification, udic moisture regime

The characteristics of any soil and its ability to supply nutrients are determined by the dominant soil forming factor in the area under consideration, land use and management (Kefas *et al.*, 2022). Soil characterization refers to the in-depth study of soil characteristics which will provide baseline information on relevant soil properties for optimum use, while preserving the soil as a natural resource for the future (Okunsebor, 2023). The ever-increasing demand for food in third world countries like Nigeria, where most land use choices are based on discretion, rather than soil characteristics, requires that information on soil characteristics be made available to the average land user. Characterization provides the necessary basic information needed to create functional soil classification schemes, and assess soil fertility in order to reveal inherent limitations to crop production (Sharu *et al.,* 2013).

Fertility capability classification (FCC) is a technical system for grouping soils according to the kinds of problems they present for agronomic management (Adisa *et al.*, 2016). FCC-classes indicate the main fertility-related soil constraints, which can be interpreted in relation to specific farming systems or land utilization types (Sanchez *et al.*, 2003; Udoh and Ibia., 2022). Fertility capability classification studies help to identify soil constraints that limit crop production (Adisa *et al.*, 2016; Fasusi *et al.*, 2019). This system also bridges the gap between natural soil classification systems and groups soils according to the specific kinds of problems that they present for managing their chemical and physical properties in a particular location (Udoh *et al.*, 2013).

Soils of the humid tropics are known to generally possess a low fertility status as a result of high mean temperatures and rainfall intensities (Osujieke *et al.,* 2018; Oko-oboh *et al.,* 2018). Moreover, they are known to suffer multiple deficiencies of nutrients due to high intensity of land cultivation and by implication have low productivity. Through knowledge of soil characteristics and FCC classes, farmers and land users can identify fertility, rooting and moisture limitations of land to specific crops and plan their activities to circumvent the drawbacks (Sanchez *et al.,* 2003; Orimoloye, 2016). Thus, it is crucial to understand the state of soil fertility in order to make the right recommendations for managing soil nutrients, which defines specific soil conditions that affect plant growth. Therefore, this study was conducted to characterize some soils of the study area and establish their fertility capability classes.

MATERIALS AND METHODS

The study was conducted at Iguzama Community in Ovia North East Local Government area of Edo State, Nigeria. As shown in figures 1 and 3, the study area consists of two sites; Site A is a 4 hectare land lying within Latitude 6°24’40' N and 6°24’45"N; and Longitude 5°28’25"E and 5°28’35"E. Site B is a 12 hectare land which lies within latitude 6°24’30"N and 6°25’0"N; and Longitude 5°28’30"E and 5°29’0"E. The region is distinguished by a tropical climate with an annual average rainfall amount of 1900 mm, mean annual temperatures ranging from 23°C to 37°C and mean annual relative humidity ranging from 89% in the morning (10.00 am) to 75% in the evening (4 pm), recorded over a period of 18 years (NIFOR, 2018).

The soils were developed from coastal plain sand parent material, a derivative of sedimentary rock that has undergone intense weathering process arising from high rainfall and temperature (Nigeria

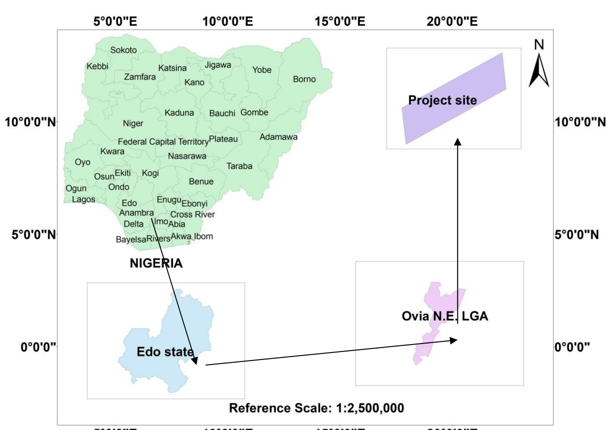

Fig. 1: Map of Site A

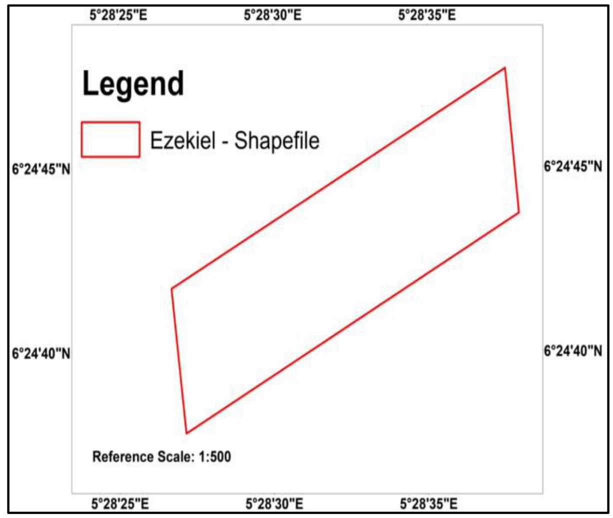

Fig.2: Shape file of Site A

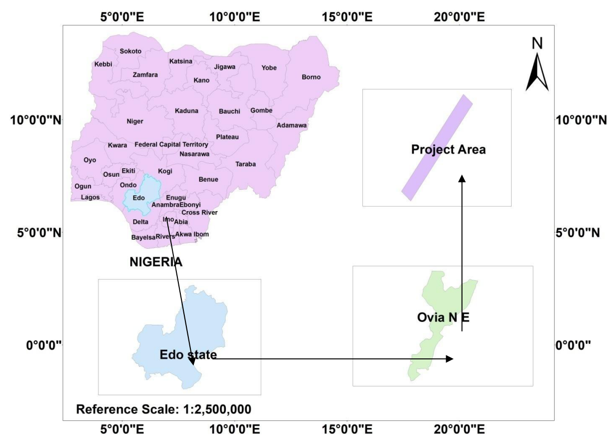

Fig. 3: Map of Site B

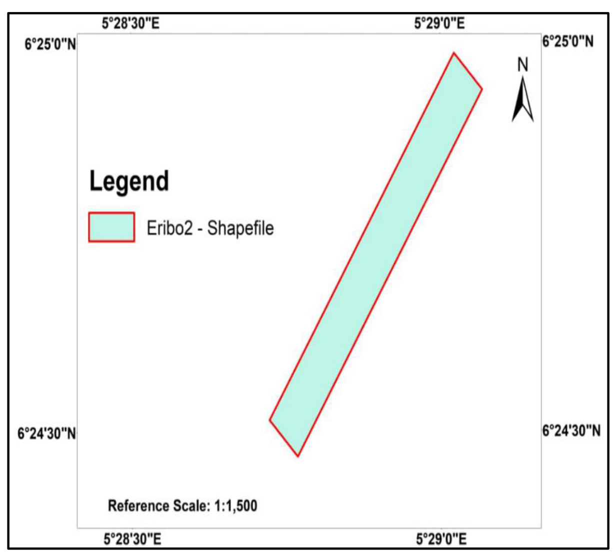

Fig.4: Shape file of Site B

Geological Survey Agency, 2008). The topography is a terrace, with a slope range of 2.59 - 6.09% in Site A; and 0.2 - 5.9% in Site B.

Field Studies

Soil survey was conducted on site A (4ha) and site B (12 ha) using the rigid grid systematic survey method at a detailed scale (Dent and Young, 1981). Traverses were cut at intervals of 100m apart; along the traverses, observation points (50 m apart for site A and 100 m apart for site B) were located using a GPS (global position system), Site A had eight observation points while Site B had twelve. Soil samples were examined at depth intervals of 30cm, 60cm, 90cm and 120cm respectively using a soil auger. The morphological properties which include texture by feel, colour, vegetation and slope position, were studied on the field and recorded on their respective proforma sheet. Mapping units were delineated based on similarities in properties and characteristics; two mapping units were delineated in each study site. Pedons measuring 2 m x 2 m x 2 m in dimension were sunk at representative points in each mapping unit, and described appropriately according to the guidelines of FAO (2006). The observed horizons were sampled from below to the top, collected in polythene bags and labeled properly for laboratory analysis.

Laboratory Analysis

The soil samples from each horizon were air-dried and passed through a 2mm sieve. The sieved samples were analysed for some physical and chemical properties. Particle size distribution was determined by the hydrometer method (Gee and Or, 2002) after the removal of organic matter content with hydrogen peroxide and dispersion with sodium hexametaphosphate (International Institute for Tropical Agriculture - IITA, 1979). Available P was determined by Bray-1 method (Olsen and Sommers, 1982). The pH was determined with glass electrode pH meter in soil: soil and water at ratio 1:1 (Maclean, 1982). Exchangeable Bases (Na, K, Ca and Mg) were extracted with neutral normal ammonium acetate (NH_4OAC at pH 7.0); Na and K were determined by flame photometer while Ca and Mg were determined by atomic absorption spectro photometer (Thomas, 1982). Total N was determined by Macro Kjedhal method (Bremner, 1996). Exchangeable Acidity was determined by titration method (Anderson and Ingram, 1993). Organic Carbon was determined by Walkley Black method (Page, 1982). Effective Cation Exchange Capacity (ECEC) was obtained by the summation of Exchangeable Bases and Exchangeable Acidity (Tan, 1996). Base Saturation was calculated by dividing the sum of Exchangeable Bases (Na, K, Ca and Mg) by the ECEC and multiplying the quotient by 100.

Aluminum saturation of the exchange complex was calculated using the formula

% Al Saturation = Al content (cmolkg^{-1}) / ECEC*100

Sodium saturation of the exchange complex was calculated using the formula

%Na Saturation = Na content (cmolkg^{-1}) /ECEC*100

Statistical Analysis

Data generated was analyzed statistically with Genstat (8.1 version). Variability of soil properties of horizons within the pedons was determined using coefficient of variation (cv). Coefficient of variation was ranked according to the procedure of Wilding *et al.* (1994) where:

CV <15%	=	Low Variation (LV)
15% ≥ CV ≤ 35%	=	Moderate Variation (MV)
CV > 35%	=	High Variation (HV)

Soil Map

Based on the field and laboratory results, a soil map was produced at a scale of 1: 1,500 for site A and 1 :< 5000 for site B.

Fertility capability classification

FCC version 4 (Sanchez *et al.*, 2003) was used to classify the soils on the basis of surface and sub-surface properties obtained from field studies and laboratory analysis.

RESULTS AND DISCUSSION

Morphological properties

Generally, the soils were deep, well drained and exhibited no sign of flooding. Soil colour varied from dark reddish brown (2.5YR3/3) to red (2.5YR4/6, 2.5YR4/8) in pedon 1A; dusky red (2.5YR5/2), dark red (2.5YR3/6) to red (2.5YR4/6, 2.5YR4/8) in pedon 2A; very dusky red (2.5YR2.5/2), dark reddish brown (2.5YR3/4) to red (2.5YR4/6 2.5YR4/6) in pedon 1B; dusky red (2.5YR3/2) to red (2.5YR4/6, 2.5YR4/8) in pedon 2B (Munsell, 1994). The prevalence of red colour (2.5YR) in the study area could be attributed to good drainage condition and parent material of the soils; (Okunsebor and Umweni 2021; Okunsebor *et al.*, 2021). The soils had Sandy texture in Ap horizon; but ranged from Loamy Sand (pedons1A and 2A) to Sandy Loam (pedons 2A and 1B) and Sandy Clay Loam (pedons 2A and 2B) in B horizon. The dominance of Sand fraction of particle size in all the pedons could be attributed to the nature of parent material (coastal plain sand), high rate of leaching and slope position of the soils (Osujieke *et al.*, 2018). Structure ranged from single grain crumb in Ap to fine/ Medium sub-angular blocky in B horizon. The prevalence of sub-angular blocky structure could be attributed to high rate of argilluviation in the study area. Root abundance in surface horizon was many but varied from many to very few in B horizon in all the pedons. Variation in root abundance across the soil profiles may suggest the degree of microbial activity in the soils. Boundary form ranged from smooth clear (Ap) to Smooth diffuse (B horizon) in all the pedons.

Some Physical and Chemical Properties

The physical and chemical properties of the soils (Table 2) showed that pH ranged from very strongly acidic (4.86) to slightly acidic (6.22) in pedon 1A; strongly acidic (5.18-5.26) to slightly acidic (6.14 – 6.38) in pedons 2A and 1B; and strongly acidic (5.26) to moderately acidic in pedon 2B according to the ratings of Chude *et al.*(2011), with mean values of 5.24, 5.58, 5.53 and 5.40 in pedons 1A, 2A, 1B and 2B respectively. The acidic pH of these soils could be attributed to the acidic nature of the parent material (coastal plain sands) from which the soils were derived, organic matter content of the soils, climatic condition of the study area and slope position (Weil and Brady, 2017; Abua, 2010; Osujieke *et al.*, 2018). Generally, organic carbon had high variation (≥59.70% to ≤110.10%) in all the pedons. This buttresses the fact that acid sands are low in organic matter content; the amount of plant litter fall and differences in soil biodiversity across the mapping units could be responsible for high variability of Organic matter in soils. Total Nitrogen was deficient in all the pedons according to the rating of Chude *et al.* (2011), with means values of 0.66, 0.48, 0.40 and 0.58 gkg^{-1} in pedons 1A 2A, 1B and 2B respectively; variation was high (≥58.60% to ≤113.00%) in all the pedons. Low total Nitrogen may be attributed to crop harvest, bush and residue burning which increases the rate of volatilization of Nitrogen (Osujieke *et al.*, 2018).

Available Phosphorous ranged from 1.72 – 44.47 mgkg^{-1} in pedon 1A, 1.30-13.14 mgkg^{-1} in pedon 2A, 2.46 – 5.61 mgkg^{-1} in pedon 1B and 1.72 – 6.48 mgkg^{-1} in pedon 2B; which indicates that Phosphorus

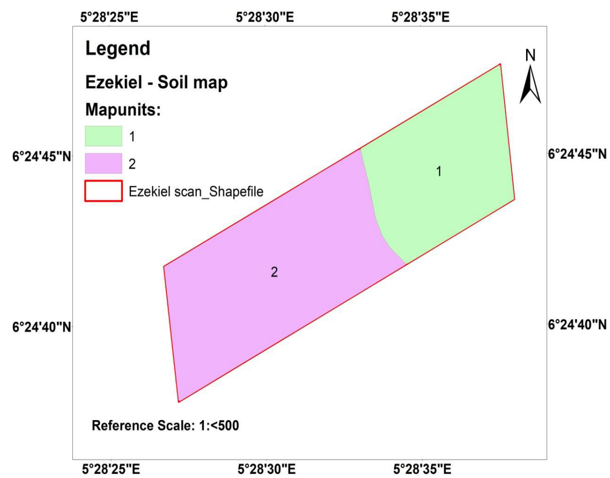

Fig. 5: Soil Map for Site A

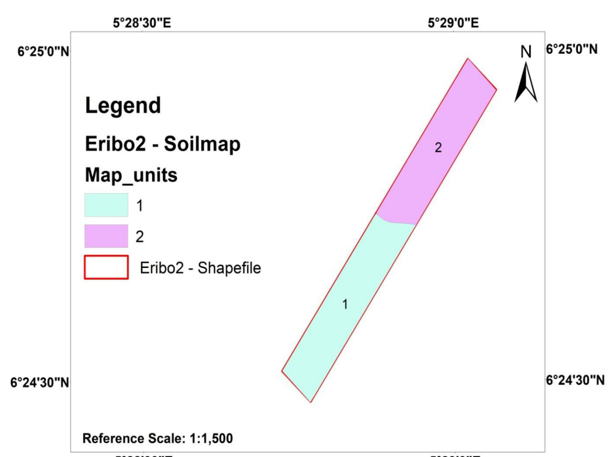

Fig. 6: Soil Map for Site B

Table 1: Some Morphological Properties of the Study Area

Pedon	Horizon Desig.	Depth (cm)	Colour (moist)	Texture	Roots Abundance	Structure	Boundary form
SITE A							
1A	Ap	0-13	2.5YR3/3	Sand	Fine many	Very fine Single grain crumb	Smooth-Clear
	AB	13-33	2.5YR4/8	Loamy Sand	Medium many	Fine/Medium Sub-Angular blocky	Smooth-Diffuse
	BA	33-69	2.5YR4/6	Sandy Loam	Coarse very few	Medium Sub-Angular blocky	Smooth-Diffuse
	B1	69-121	2.5YR4/6	Sandy Clay Loam	Fine very few	Medium Sub-Angular blocky	Smooth-Clear
	B2	121-180	2.5YR4/6	Sandy Clay Loam	Fine very few	Medium Sub-Angular blocky	-
2A	Ap	0-15	2.5YR3/2	Sand	Fine many	fine Single grain crumb	Smooth-Clear
	Bt1	15-39	2.5YR3/6	Sandy Loam	Fine/Medium many	Fine Sub-Angular blocky	Smooth-Diffuse
	Bt2	39-76	2.5YR4/6	Sandy Clay Loam	Coarse few	Fine Sub-Angular blocky	Smooth-Diffuse
	Bt3	76-127	2.5YR4/8	Sandy Clay	Medium very few	Medium Sub-Angular blocky	Smooth-Diffuse
	Bt4	127-169	2.5YR4/8	Sandy Clay	-	Medium Sub-Angular blocky	-
1B	Ap	0-11	2.5YR2.5/2	Sand	Medium many	fine Single grain crumb	Smooth-Clear
	Bw1	11-27	2.5YR3/4	Loamy Sand	Medium many	Fine Sub-Angular blocky	Smooth-Diffuse
	Bw2	27-59	2.5YR4/6	Loamy Sand	Medium few	Medium Sub-Angular blocky	Smooth-Diffuse
	Bw3	59-101	2.5YR4/6	Sandy Clay Loam	Medium very few	Medium Sub-Angular blocky	Smooth-Diffuse
	Bw4	101-175	2.5YR4/8	Sandy Clay Loam	-	Medium Sub-Angular blocky	-
2B	Ap	0-17	2.5YR3/2	Loamy Sand	Medium many	Very fine Single grain crumb	Smooth-Clear
	Bt1	17-34	2.5YR4/8	Sandy Clay Loam	Medium many	Fine Sub-Angular blocky	Smooth-Diffuse
	Bt2	34-78	2.5YR4/6	Sandy Clay Loam	Medium few	Medium Sub-Angular blocky	Smooth-Diffuse
	Bt3	78-116	2.5YR4/6	Sandy Clay Loam	Fine few	Medium Sub-Angular blocky	Smooth-Diffuse
	Bt4	116-183	2.5YR4/6	Sandy Clay	Fine very few	Medium Sub-Angular blocky	-

was very low to high in pedon 1A, ranged from very low to moderate in pedon 2A; very low to low in pedons 1B and 2B according to the ratings of Chude *et al.* (2011), Landon (1991). Variation for available P was high (≥40.90% to ≤156.20%) in all the pedons; high variation of available P could be as a result of erosion of soil particles due to surface run-off water, removal of biomass through harvest and fixation.

Results for exchangeable bases revealed that Calcium (Ca) was the predominant basic cation in the soils of the study area. Ca content ranged from 0.36 – 2.58 cmolkg^{-1}; Mg content ranged from 0.08 – 0.50 cmolkg^{-1}; Na content ranged from 0.10 – 0.43 cmolkg^{-1}; K content ranged from 0.01 – 0.29 cmolkg^{-1} in all the pedons. Exchangeable bases were generally low in all the pedons according to the rating of Landon (1991) and Chude *et al* (2011). Variation for Ca (≥63.50% to ≤97.40%) and K (≥56% to ≤142%) was high in all the pedons; variation for Mg was moderate in pedon 1B but high in other pedons (≥19.80% to ≤68.40%); variation for Na was moderate in pedons 1A and 1B, but high in pedons 2A and 2B (≥26.10% to ≤47.50%). Low content of exchangeable bases in the study area could be attributed to the parent material of the soils (coastal plain sands) and the high rainfall amount prevalent in the study area (Eze, 2015). It was also observed that exchangeable bases had an irregular trend with increase in depth; this could be as a result of translocation of materials down the profile.

Results for Exchangeable acidity (Table 2) showed that values for Hydrogen ranged from 0.04 - 0.26 cmolkg^{-1} in all the pedons, with variation ranging from Moderate (≥23.50% to ≤ 34.10%) in pedons 1A, 2A and 2B, to high (45.05%) in pedon 1B. Aluminum had values ranging from 0.00 - 1.2 cmolkg^{-1} in all the pedons. Variation for Al was high (≥51.89 to ≤59.40%) in all the pedons. Cation Exchange Capacity (CEC) had values ranging

Table 2: Some Physical and Chemical Properties of the Soils

Pedon ID	Horizon Design	Horizon Depth (cm)	Ph H20	EC µS/cm	Org. C gkg^{-1}	Org. matter	Total N. gkg^{-1}	Avail P $mgkg^{1}$	Ca	Mg	Na	K	H	Al	ECEC	CEC	ECEC CLAY	BS	BS-CEC %	SAND	SILT	CLAY	TC
									←				$cmolkg^{-1}$			→				←	gkg^{-1}	→	
		06.41313°N, 005.47692°E; 49 m ASL																					
1A	Ap	0-13	6.22	109.70	23.13	39.87	1.93	44.47	2.58	0.38	0.34	0.19	0.1	0.00	3.58	9.40	119.33	97.21	37.00	960.00	10.00	30.00	S
	AB	13-33	5.1	70.00	7.98	13.76	0.66	7.18	0.60	0.15	0.19	0.08	0.24	1.06	2.33	3.60	38.83	44.09	28.61	920.00	20.00	60.00	S
	BA	33-69	4.86	95.70	4.23	7.30	0.35	3.05	0.43	0.23	0.19	0.05	0.26	1.20	2.35	6.02	26.11	37.93	14.78	870.00	40.00	90.00	S
	B1	69-121	5.02	46.30	3.09	5.33	0.24	2.46	0.55	0.08	0.24	0.07	0.18	0.92	2.03	7.07	16.91	45.87	13.15	850.00	30.00	120.00	LS
	B2	121-180	5.02	65.10	1.30	2.25	0.10	1.72	0.55	0.08	0.29	0.17	0.16	0.82	2.06	7.45	14.71	52.52	14.49	830.00	30.00	140.00	LS
		MEAN	5.24	77.36	7.90	13.70	0.66	11.80	0.94	0.18	0.25	0.11	0.19	0.80	2.47	6.71	43.00	56.00	21.6	886.00	26.00	88.00	
		CV	10.50	32.60	111.20	111.10	113.00	156.20	97.40	68.40	26.10	56.60	34.10	58.70	25.80	21.30	101.00	43.00	49.20	6.00	43.90	50.40	
		RANKING	LV	MV	HV	HV	HV	HV	HV	HV	MV	HV	MV	HV	MV	MV	HV	HV	HV	LV	HV	HV	
		06.41168°N, 005.47450°E; 60 m ASL																					
2A	Ap	0-15	6.14	97.80	14.01	24.15	1.17	13.14	1.70	0.25	0.43	0.29	0.1	0.00	2.78	6.40	86.88	75.68	41.87	924.00	44.00	32.00	S
	Bt1	15-39	5.5	46.20	5.86	10.11	0.49	2.63	0.60	0.10	0.24	0.11	0.18	0.86	2.09	10.00	13.06	89.32	10.50	800.00	40.00	160.00	SL
	Bt2	39-76	5.34	34.80	3.58	6.18	0.30	1.30	0.50	0.10	0.14	0.02	0.18	1.00	1.94	10.74	10.21	84.22	7.08	790.00	20.00	190.00	SL
	Bt3	76-127	5.26	32.50	2.93	5.05	0.24	1.80	0.40	0.15	0.19	0.01	0.2	1.00	1.95	13.01	8.13	75.66	5.76	700.00	20.00	240.00	SCL
	Bt4	127-169	5.66	25.50	2.44	4.21	0.19	2.38	0.97	0.18	0.19	0.01	0.16	0.70	2.21	16.34	7.13	61.09	8.26	680.00	10.00	310.00	SCL
		MEAN	5.58	47.00	5.80	9.90	0.48	4.20	0.83	0.16	0.24	0.09	0.16	0.71	2.19	11.30	25.00	77.20	14.7	787.00	26.80	186.00	
		CV	6.20	61.60	833.10	83.10	84.40	117.60	63.50	40.20	47.50	136.90	23.50	58.50	15.80	32.60	138.00	13.90	103.9	11.50	54.20	55.40	
		RANKING	LV	HV	HV	HV	HV	HV	HV	HV	HV	HV	MV	HV	MV	MV	HV	LV	HV	LV	HV	HV	
		06.41097°N, 005.47964°E; 58m ASL																					
1B	Ap	0-11	6.38	61.90	9.12	15.72	0.76	5.61	1.60	0.20	0.24	0.08	0.04	0.08	2.24	7.14	28.00	94.64	29.70	900.00	20.00	80.00	S
	Bw1	11-27	5.58	47.70	5.86	10.11	0.49	2.55	0.75	0.30	0.14	0.03	0.16	0.52	1.90	8.00	15.83	64.25	15.25	860.00	20.00	120.00	LS
	Bw2	27-59	5.26	41.20	4.15	7.16	0.35	3.05	0.46	0.19	0.19	0.02	0.19	1.10	2.16	8.43	15.43	40.14	10.32	850.00	20.00	140.00	LS
	Bw3	59-101	5.18	39.10	3.09	5.33	0.26	2.63	0.42	0.28	0.10	0.02	0.23	1.00	2.04	10.32	11.03	39.79	7.85	800.00	15.00	185.00	SL
	Bw4	101-175	5.26	33.80	1.71	2.95	0.15	2.46	0.50	0.25	0.19	0.01	0.16	1.12	2.23	10.09	11.74	42.71	9.42	800.00	10.00	190.00	SL
		MEAN	5.53	44.70	4.80	8.30	0.40	3.26	0.75	0.24	0.17	0.03	0.16	0.76	2.11	8.80	16.40	56.00	14.5	842.00	15.00	143.00	
		CV	9.00	24.20	59.70	59.70	58.60	40.90	66.30	19.80	31.10	86.70	45.50	59.40	6.80	15.50	41.60	42.10	61.50	5.10	33.30	32.20	
		RANKING	LV	MV	HV	HV	HV	HV	HV	MV	MV	HV	HV	HV	LV	MV	HV		HV	LV	MV	MV	
		06.41547°N, 005.48365°E; 96 m ASL																					
2B	Ap	0-17	5.82	63.20	19.22	33.13	1.64	6.48	1.50	0.50	0.24	0.12	0.08	0.10	2.54	10.13	36.28	92.92	23.30	900.00	30.00	70.00	S
	Bt1	17-34	5.26	36.50	5.70	9.83	0.47	2.71	0.46	0.19	0.10	0.02	0.22	0.98	1.96	8.47	15.08	38.87	8.97	850.00	20.00	130.00	SL
	Bt2	34-78	5.34	34.30	4.23	7.30	0.35	5.00	0.43	0.27	0.10	0.01	0.19	1.11	2.10	11.46	10.50	38.16	6.98	790.00	10.00	200.00	SCL
	Bt3	78-116	5.26	32.00	3.09	5.33	0.26	2.71	0.42	0.18	0.10	0.01	0.17	1.25	2.12	12.56	9.22	33.08	5.57	760.00	10.00	230.00	SCL
	Bt4	116-183	5.34	29.10	2.04	3.51	0.17	1.72	0.36	0.19	0.14	0.01	0.19	0.90	1.79	16.70	5.59	39.12	4.19	660.00	20.00	320.00	SCL
		MEAN	5.40	39.00	6.90	11.80	0.58	3.72	0.63	0.27	0.14	0.03	0.17	0.87	2.10	11.90	15.30	48.00	9.80	792.00	18.00	190.00	
		CV	4.40	35.30	102.70	102.70	104.50	52.50	76.60	51.00	44.60	142.00	31.40	51.80	13.20	26.20	79.50	51.60	78.80	11.60	46.50	50.30	
		RANKING	LV	MV	HV	HV	HV	HV	HV	HV	HV	HV	MV	HV	LV	MV	HV		HV	LV	HV	HV	

from 3.60 - 16.70 cmolkg^{-1} in all the pedons. Variation was moderate (≥15.50% ≤32.60%) in all the pedons. Effective Cation Exchange Capacity (ECEC) ranged from 1.39 - 3.58 cmolkg^{-1} in all the pedons; and was below the critical value (12 cmolkg^{-1}) regarded to be suitable for crop production (Ekong and Uduak, 2015). Variation for ECEC ranged from low (≥6.80 to ≤25.80%) to moderate (15.80 to 25.80%).

Sand fraction was highest among particle size components, with mean values of 886, 787, 842 and 792 gkg^{-1} respectively for all the pedons. Variation was low (≥5.10% to ≤11.60%), which could be as a result of homogeneity of parent material (coastal plain sand) in the study area (Osujieke, *et al.*, 2018; Okunsebor and Umweni, 2021). Silt fraction had means of 26, 26, 15 and 18 gkg^{-1} respectively for all the pedons; the low silt content suggests high rate if eluviation in the study area; variation ranged from Moderate (33.30% - pedon 1B) to high (≥43.90% to ≤54.20% - pedons 1A, 1B and 2B). Clay fraction had means ranging from (≥88.00 to ≤190.00 gkg^{-1}). Clay content increased with depth, which suggests the presence of an argillic / Cambic horizons in some of the pedons. Higher clay content in subsurface soils confirms active pedogenesis and argilluviation in the study area. Variation of clay ranged from moderate (32.20% - pedon 1B) to high (≥50.30 to ≤55.40%).

Taxonomic classification

Taxonomic Classification of the soils was according USDA Soil Taxonomy (Soil Survey Staff, 2014). The pedons were designated as 1A, 2A, 1B and 2B. Generally, the study area is characterized by an udic moisture regime and an isohyperthermic soil temperature regime. Pedons 2A and 2B had argillic horizon and a Base saturation value less than 35% at the appropriate depth, thus, they qualified as the order Ultisols; the presence of cambic B horizon in pedon 1B qualified the pedon as the order Inceptisols. However, Pedon 1A did not exhibit any genetic horizon nor morphological feature except colour; therefore, it was classified as Entisols.

At sub-order level, pedons 2A and 2B were classified as udults because of the presence an udic moisture regime. At great group level, they qualified as Kandiudults, because of the presence of a kandic horizon at the appropriate depth in both pedons. They were classified as Rhodic kandiudults at subgroup level because they had a hue of 2.5YR.

Pedon 1A qualified as Psamments at the sub-order level because it had less than 35% (by volume) rock fragments and texture of Sand – Loamy sand in all the layers. At great group level, pedon 1A was classified as Udipsamments due to the presence of an udic moisture regime in the study area; and Typic Udipsamments at subgroup level, which indicates that there is no lithic contact, redox depletion, plaggen epipedon, and the pedon is not saturated with water. The soil classification results are in line with findings of Okunsebor and Umweni, (2021).

Fertility Capability Classification for Soils of the Study Area

Fertility Capability Classification (FCC) of the soils was according to the version IV (Sanchez, *et al.*, 2003). Pedons 1A (1.65 ha and 34% of site A) and 1B (6.4 ha and 53.3% of site B) were classified as SSa^{-}n^{-}kem; this implies that the pedons (1A and 1B) had Sandy texture in both top soil (within the top 0-20cm of the soil) and sub-strata (within 50cm). Pedons 2A (2.64 ha; 66% of site A) and 2B (5.69 ha; 47.4%) were classified as SLa^{-}n^{-}kem, indicating that the pedons had Sandy top soil (S) but Loamy (L) sub-strata.

Generally, fertility capability classification provides information on soil constraints that limit crop production (Moundjeu *et al.*, 2021). All the pedons had constraints of Aluminum toxicity (a^{-}), because Al saturation of ECEC in the top 50 cm of the soil was within 10 - 60%. Al toxicity of the soils could be attributed to the high rate of leaching associated with the soils of rain forest zone (Osujieke, *et al.*,

Table 3: Summary of Taxonomic Classification

Pedon	USDA Soil Taxonomy	Size (ha)
1A	Typic Udipsamments	1.65ha
2A	Rhodic kandiudults	2.64ha
1B	Typic Dystrudepts	6.4ha
2B	Rhodic kandiudults	5.69ha

Table 4: Summary of Fertility Capability classification for all the Pedons

Land characteristics	Pedon 1A	Pedon 2A	Pedon 1B	Pedon 2B
Type; Texture for top soil	S	S	S	S
Substrata type	S	L	S	L
Condition	**Modifer**			
Modifer related to soil physical properties				
Slope	2.59- 6.09%	0.79 - 2.6%	0.2 - 2.1%	2-5.9%
Modifer related to soil reactionAltoxicity	a^-	a^-	a^-	a^-
Alkalinity	n^-	n^-	n^-	n^-
Modifer related to soil mineralogy				
Low nutrient capital reserve (Potassium deficiency)	K	K	K	K
High leaching potential (low buffering capacity, low ECEC)	e	e	e	E
Modifer related to biological properties				
Low soil organic carbon saturation	m	M	M	M
FCC CLASS/UNIT	SSa^-n^-Kem	SLa^-n^-Kem	SLa^-n^-Kem	SLa^-n^-Kem
Area extent of land	1.65ha	2.64ha	6.4ha	5.69ha
%Coverage	34%	66%	53.3%	47.4%

Fertility Capability Soil Classification System (Version IV)

FCC class and short description	Symbol	Definition and Interpretations
Type:	S	Sandy topsoil >35% sand, loamy sands and sands
Texture is the average of plow layer 0-20cm depth or which is shallower	L	Loamy topsoil <35% clay but not loamy sand or sand
	C	Clayey topsoil >35% clay
	O	organic soil >I2% organic C lo a depth of 50 cm or more (histosol and histic group)
Subtype: used if textural change is encountered within 50cm	S	Sandy Subsoil - texture as in type
	L	Loamy subsoil - texture as in type
	C	Clayey subsoil - texture as in type
	R	Rock or other hard root restrictions layer within 50cm
	R^-	As in above, but layer can be plowed to increase rooting depth

Condition modifiers: in plowed layer or top 20 cm, whichever is shallower, unless otherwise specified; grouped into modifiers related to soil physical properties, soil reaction (pH), soil mineralogy and soil biological properties.

Condition	Modifier	Identifying criteria (if more than one, they are listed in decreasing desirability)
Modifiers related to soil physical properties Waterlogging (gley): anaerobic condition, chemical reduction, denitrification; N_2O and CH_4 emissions	*G*	aquic soil moisture regime, mottles <2 chroma within 50 cm for surface and below all A horizon or soil saturated with water for >60 days in most years
	g^+	prolonged waterlogging: soil saturated with water either naturally or by irrigation for >200 days/year with no evidence of mottles indicative of Fe3+ compounds in the top 50 cm; includes paddy rice soils in which an anaerobic crop cannot be grown without drainage; continuous chemical reduction can result in slower soil N mineralization and Zn deficient in rice
Strong dry season (dry): limits year-round cropping, interrupts pest cycles. Birch effect	*D*	ustic or xeric soil moisture regim dry >60 consecutive days/ year but moist >I80 cumulative days/year within 20-60 cm deapth
	d^+	aridic or torric soil moisture regime; too dry to grow a crop without irrigation
Low soil temperatures	T	cryic and frigid (<8^{o}C mean annual), non-iso soil temperature regimes, where management practices can help warm top soils for short-term cereal production

	t^{+}	permafrost within 50 cm gelisols; no cropping possible
*Modifier related to soil physical properties*Gravel	r^{+}	r^{+} = 10-35%
	r^{++} r^{+++}	r^{++}> 35% (by volume) of gravel size coarse fragments (2 - 25 cm in diameter) anywhere in the top 50 cm of the soilmore than 15% rock outcroppings
Slope	%	where desirable place range in % slope (i.e., 0 - 15%; 15 - 30%; >30%)
High risk erosion	SC, LC CR, LR, SR, >30%	soils with high erodibility due to sharp textural contrasts (SC, LC), shallow depth (R) or steep (>30%) slope
	C	pH < 3.5 after drying; jarosite mottles with hues, 2.5Y or yellower and chromas 6 or more within 60 cm sulfaquents, sulfaquepts, sulfudepts.
Aluminum toxicity for most common crops	a	>60% Al saturation within 50 cm, or < 33% base saturation of CEC (BS_7) determined by sum of cations at pH 7 within 50 cm, or < 14% base saturation of CEC ($BS_{8.2}$) by sum of cations at pH 8.2 within 50 cm, or pH < 5.5 except in organic soils (O)
	a^{-}	10 - 60% Al saturation within 50 cm for extremely acid-sensitive crops such as cotton and alfalfa
No major chemical limitations (includes former *h* modifier)	no symbol	< 60% Al saturation of ECEC within 50 cm and pH between 5.5 and 7.2
Calcareous (basic reaction): common Fe and Zn deficiencies	B	free CaCO3 within 50 cm (fizzing with HCl), or pH>7.3
Salinity	S	>0.4 S m^{-1} of saturated extract at 25^{o}C within 1 m; salids and salic groups; salonchaks
	s^{-}	0.2 - 0.4 S m^{-1} of saturated extract at 25^{o}C within 1 m (incipient salinity)
Alkalinity	N	>15% Na saturation of ECEC within most solonet
	n^{-}	6 - 15% Na saturation of ECEC within 50 cm (incipient alkalinity)
Modifiers related to soil mineralogy Low nutrient capital reserves (K deficiencies)	K	< 10% weatherable minerals in silt and sand fraction within 50 cm, or siliceous , mineralogy or exchangeable K < 0.20 cmolc kg^{-1} soil, or exchangeable K < 2% of sum of base,if sum of bases is < 10 cmolc kg 1 soil
High P fixation by Fe and Al oxides(>100 mg kg 1 P added to achieve adequate soil test levels); Ci soils have excellent structures but low water Ci subsoils retain nitrate holding capacity	I	dithionite-extractable free R2O3: clay ratio >0.2 or >4% citrate dithionite-extractable Fe in of topsoil, or oxisols and oxic groups with C type, or hues redder than 5YR and granular structure
Modifier related to soil mineralogy	i^{-}	as above, but soils have been recapitalized with P fertilizers to supply long-term P to crop soil test >10 mg kg^{-1} P by Olsen method
	i^{+}	as above; potential Fe toxicity if soils waterlogged for long time (g^{+}) or adjacent uplands have i modifier
Amorphous volcanic (X-ray amorphous); high P fixation by allophane(>200 mg kg 1 P added to achieveadequate soil test levels); low N mineralization rates	x	within 50 cm pH>10 (in 1 M NaF), or positive to field NaF test, or andisols and andic subgroup, except vitrands and vitric great groups and subgroups; other indirect evidences of allophane dominance in the clay size fraction or >90%
	x-	P retention (Blakemore *et al.*,1981 method)
	x^{-}	P retention between 30% and 90%; medium P fixers
Cracking clays (vertic properties): (low buffering capacity, low ECEC)	e	< 4 cmolc kg^{-1} soil as ECEC, or < 7 cmolc kg^{-1} soil by sum of cations at pH 7, or < 10 cmolc kg^{-1} soil by sum cations + Al_3^+ + H^+ at pH 8.2
Modifier related to soil biological properties (new) Low organic carbon saturation (soil organic matter depletion, C sequestration potential)	M	< 80% total organic C saturation in the topsoil (Van Noordwijk *et al.*, 1998) compared with a nearby undisturbed or productive site the same soil, which is equal to 100% or < 80% $KMnO_4$ extractable topsoil organic carbon saturation (Blair *et al.*, 1997) compared with a nearby undisturbed or productive site of the same soil, which is equal to 100%

Source: Sanchez *et al.* (2003)

2018). It was observed that sodium saturation of ECEC in the top 50 cm of the soils fell within the range of 6 - 15%, indicating that the soils had limitations in Alkalinity (n^-), although this condition is rare in the rain forest zone, application of sodium based fertilizers in the study area over time may be responsible. The soils had low nutrient reserve (k), as expressed by the low values of exchangeable bases, especially exchangeable K (0.08 – 0.19 $cmolkg^{-1}$) < 0.20 $cmolkg^{-1}$. The soils had high leaching potential as revealed by low values of ECEC (< 4 $cmolkg^{-1}$); soils of rain forest zone are low in soil nutrient reserve as a result of the high rainfall amount in this zone, thus resulting to high rate of leaching. Total Organic Carbon saturation was less than 80% in the soils, indicating that organic matter content was low (e). Acid sands are generally low in organic matter content and exchangeable bases (Okunsebor and Umweni, 2021).

Fertility Capability classification assesses the land on a general basis, however, information obtained from such assessment (fertility capability classes) provides insight on the native fertility status of soils and serves as a guide to fertilizer application and use.

CONCLUSION

Fertility limitations of the soils were assessed using Fertility Capability Classification (FCC). The study revealed that the agronomic constraints of the soils were sandy topsoil (S), slightly alkaline (potentially sodic), low nutrient reserve, high leaching potential and low organic carbon content and thus low organic matter content. These constraints could be managed by application of adding organic matter (soil amendment). Biochar can also be used to solve the problem of leaching of nutrients prevalent in the area to improve the inherent soil fertility.

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