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Original Article

Morphological characterization of soils on false-bedded sandstone for the production of cocoyam and bitter yam in Enugu Ezike, Nigeria

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ABSTRACT

The successful management of land for crop production depends on understanding soil variation and its suitability for specific crops. This study characterized soils developed on false bedded sandstone used for cocoyam and bitter yam production in Enugu Ezike, Nigeria. Soil profiles were excavated, described morphologically, and sampled for physical and chemical analyses. Morphologically, the pedons were deep (up to 200 cm), with a dull reddish brown Ap horizon (7.5R 3/3) and reddish-brown subsoil horizons. Soil structure was weak to moderate and platy in surface horizons, becoming firmer with depth. Texture ranged from sandy loam at the surface to sandy clay loam and sandy clay in the subsoil, with bulk density between 1.34 and 1.60 g cm^{-3} and total porosity of 40-50%. Soil pH ranged from 5.1 to 6.0 (strongly to moderately acid). Soil organic carbon (0.14-0.68 g kg^{-1}) and total nitrogen (0.04-0.07 g kg^{-1}) were generally low, decreasing with depth. Available phosphorus ranged from 3.38 to 21.98 mg kg^{-1} (low to high). Exchangeable calcium was the dominant base (0.40-1.40 cmol$_c$ kg^{-1}), and cation exchange capacity was low (4.40-6.00 cmol$_c$ kg^{-1}), indicating limited nutrient retention capacity. Land suitability evaluation classified the soils as not suitable (NS) for cocoyam and marginally suitable (S3) for bitter yam, with soil fertility as the primary constraint. Sustainable production of both crops requires improved fertilization and soil conservation practices to enhance nutrient supply and retention.

KEYWORDS: *Chemical properties, Colocasia esculenta, Physical properties, Sandstone, Soil suitability*

INTRODUCTION

Soil is a complex system comprised of minerals, soil organic matter (SOM), water, and air (Bashir *et al*., 2021), and it is an indispensable and finite natural resource for agriculture, playing a relevant role in enhancing crop production (Gehlot *et al*., 2019). As a fundamental component of the biosphere, soil supports plant growth, regulates water and nutrient cycles, modifies the Earth's atmosphere, and provides a habitat for countless organisms (Sharma *et al*., 2023). However, the heterogeneous nature of soils renders these functions contingent on factors relating to their composition and characteristics, and the capability of the different soil types to perform these functions also varies. It is imperative to acknowledge the significance of comprehending the characteristics and suitability of diverse soil types within a specific geographical area, as this fundamental understanding is crucial for effective decision-making processes concerning crop production and alternative land use strategies (Yitbarek *et al*., 2016).

Soil characterization has been reported as the major building block for classification and for better understanding of the environment (Akpan-Idiok *et al*., 2013). Esu (2010) reported that one of the strategies for achieving food security as well as

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a sustainable environment remains a detailed study of the soil resources through the processes of soil characterization and land evaluation for various land utilization types. Such study provides crucial insights into the physical, chemical, mineralogical, and microbiological properties of the soils, which are imperative for effective planning and utilization for various purposes, including crop cultivation, forest and grassland management, and infrastructure development (Ogunkunle, 2005). Of particular significance is the understanding of soil profile development and the formation of distinct horizons that overlie the parent material, as this is a pivotal factor in soil formation, determining soil type and contributing to soil variation.

False-bedded sandstone (FBS), alternatively termed Ajali Sandstone, is a type of sedimentary rock characterized by angled layers formed by ancient water or wind deposition (Miall, 2022). Schaetzl and Anderson (2005) posit that the weathering of layered sedimentary rocks results in the formation of soils that exhibit complex vertical differentiation. In the geographical area of Southeastern Nigeria, FSB is one of the most prevalent geological formations, in conjunction with shale, coastal plain sands, and alluvium (Akamigbo and Asadu, 1983). It is mainly characterized by medium to coarse-grained sub-angular to sub-rounded structures (Osujieke, 2017). The chemical properties of soils developed on FSB have been shown to have a significant impact on their fertility and overall suitability for various land uses (Okebalama *et al*., 2024). Sandstone-derived soils often have a low pH due to the predominance of quartz and the relative absence of base-rich minerals (Sumner and Noble, 2003). In the study of FBS soils in Southeastern Nigeria, Okebalama *et al*. (2024) identified that P and K were the most important potentially limiting nutrients in the soil. However, the soil exhibited superior drainage properties and leaching potential attributable to elevated saturated hydraulic conductivity.

Cocoyams (*Colocasia esculenta*) and new cocoyams (*Xanthosoma spp*.) commonly known as 'taro' and 'malanga', respectively, are herbaceous perennial plants in the family Araceae. They are tropical plants grown primarily for their edible roots, although all parts of the plant are edible. They are cultivated in areas with high rainfall and even in flooded conditions by farmers. In Nigeria, cocoyam is considered the third most important tuber crop after yam and cassava (Olayiwola *et al*., 2013). It is a rich source of carbohydrates and is considered a significant food crop. Notwithstanding the significance of taro as a staple crop in a number of regions, including the Pacific Islands, Asia and Africa, and its industrial, nutritional, and health benefits (Otekunrin *et al*., 2021), the study of the soil for increased cocoyam production remains inadequate.

Bitter yam (*Dioscorea dumetorum)*, also known as bitter yam, cluster yam, trifoliate yam, or three-leaved yam, belongs to the family Dioscoreaceae. Bitter yam is a yam species that is underutilised in Africa, including Nigeria. Bitter yam is underused because it is bitter and its tubers harden when stored (Afoakwa and Sefa-Dedeh, 2002). However, it has potential for better use due to its starch content. The bitter yam is believed to contain bioactive agents that contribute to its potency in traditional medicine (Salehi at al., 2019). According to Promise *et al*. (2025), *Dioscorea dumetorum* tuber extract may have utility in the treatment of liver cancer. Bitter yam can be cultivated or found in the wild, but reports of land suitability for increased production in soils overlaid by FBS are lacking.

The FBS soils primarily support arable crop production, plantation, grazing land, and forestry (Ezeaku *et al*., 2015), thus rendering them a tool for evaluating land suitability and managing soil fertility. Majority of the traditional areas for cocoyam and bitter yam cultivation in Nigeria have not been subject to evaluation with regard to their suitability and production potential. The evaluation of the soils for their suitability for the production of these crops would provide a logical plan that enables farmers to make judicious use of the soils for sustainable productivity. Moreover, the evaluation of the suitability of these soils for the selected crops had not been considered in the study area. The need for the generation of soil information on FBS soils, soil potentials and constraints for their production in the study area necessitated this study, with the aim of characterizing soils on false-bedded sandstone morphologically for the production of cocoyam and bitter yam in Enugu Ezike, Nigeria.

MATERIALS AND METHOD

Description of the Study Area

The study was conducted in Nkpamute-Ulo, Enugu-Ezike in Igbo-Eze North Local Government Area of Enugu State. The geographical location of Nkpamute-Ulo lies within longitude (7° 20' 0" E and 7° 32' 0" E), and latitude (6° 52' 0" N and 7° 8' 0" N), and an altitude of 384.97 m (Figure 1). The climate is classified as humid tropical, with distinct wet and dry seasons. The region has an average temperature in excess of 20 °C throughout the year and receives over 1,300 mm of precipitation annually. The annual rainfall variability for a 10-year climatic data set ranges from 1,537.28 to 1,757.61 mm (Figure 2). The minimum annual temperature ranges from 18.20 ºC to 23.40 ºC, while the maximum annual temperature ranges from 27.40 ºC to 32.94 ºC (Figure 2).

The predominant socio-economic activities of the inhabitants of the area under study were agriculture, with crops such as bitter yam (*Dioscorea dumetorum*), maize (*Zea mays*), groundnut (*Arachis hypogaea*), potatoes (*Solanum tuberosum*), cassava (*Manihot esculenta*) and vegetables (such as *Lactuca sativa*, *Telfairia occidentalis)* being cultivated. According to Nigeria Geological Survey Agency (2006), the study site was found to be predominantly composed of false bedded sandstone. The soils are categorized into two main types: hydromorphic soils and ferrallitic soils. The former soils are deep, porous red soils formed from sandstones and shales, while the latter soils are red and brown soils derived from sandy deposits. The vegetation at Nkpamute-Ulo is mainly derived savanna. The land use is characterized by small farmland areas where crops such as potatoes, and cassava, etc. are grown.

Field Studies

A reconnaissance survey was conducted to identify the geological formation in the location. It was determined that the geology of the study area was false-bedded sandstone. A profile pit was dug and described according to FAO (2006) guidelines for profile description. Soil samples (auger and core) were collected from identified horizons and labelled thoroughly prior to laboratory analysis. Soil colours were described using Munsell Soil Colour Charts (Munsell Color Company, 2009). In addition, soil samples were collected at four random points 200 m from the profile pit at 0-30 cm and 30-60 cm depth using an auger. A total of 13 loose soil samples (eight soil samples from four random points at two soil depths and five from diagnostic horizons). The samples were then placed in labeled polythene bags and transported to the laboratory, where they were air-dried and analyzed.

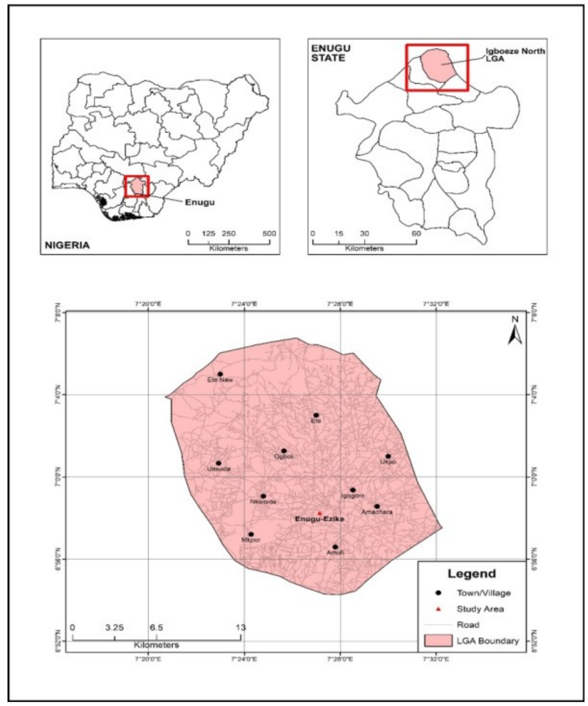

Figure 1: Map of Igbo-Eze North showing the study area.

Laboratory Analysis

The Bouyoucous hydrometer method, as modified by Gee and Or (2002), was used for the analysis of particle size, and the textural class identified through the use of a textural triangle. The bulk density (BD) of the soils was determined by core method, as described by Grossman and Reinsch (2002), and the core samples were also used to determine saturated hydraulic conductivity (Ksat) using the constant pressure head method (Klute and Dirksen, 1986). Total porosity was calculated using a mathematical relationship between bulk density and particle density, as outlined in equation (1):

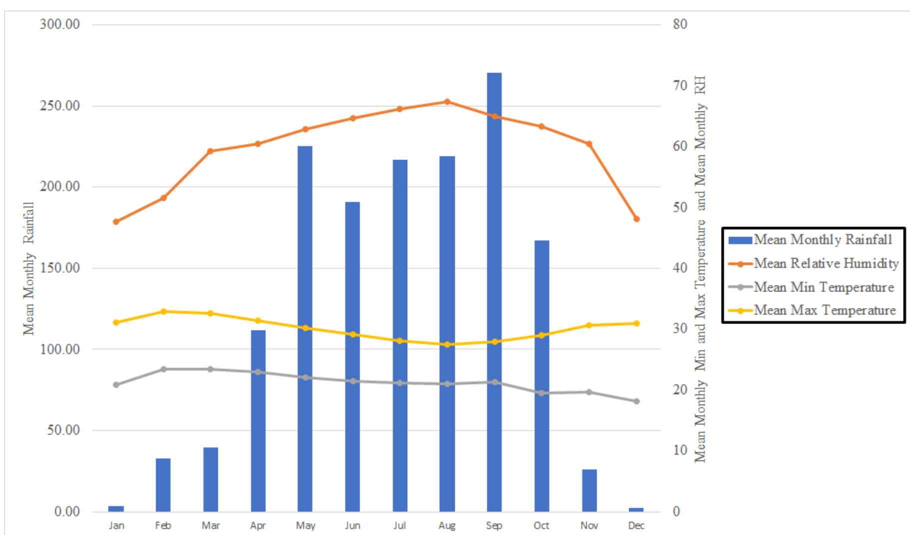

Figure 2: Graph showing the climatic distribution of Nsukka Local Government Area over the past decade.

Source: Umeugokwe *et al*. (2025)

$$\text{Total porosity (\%)} = \left(1 - \frac{Bulk\ density}{Particle\ density}\right) \times \frac{100}{1} \quad (1)$$

Soil pH was determined by means of an electrometer, with a soil-to-water ratio of 1:2:5 in both water and KCl solution. Soil organic carbon (SOC) was determined using the wet oxidation method as described by Nelson and Sommers (1996). The organic matter (OM) content was then calculated by multiplying organic carbon by 1.724 (van Bemmelen correction factor). Total nitrogen (TN) was determined by the Kjeldahl digestion and distillation method (Bremer, 1996), while available phosphorus (Av. P) was determined by the Bray's II method (Olsen and Sommers, 1982). Exchangeable base cations were extracted by leaching the soil samples using 1 ml neutral ammonium acetate (NH_4OAC). Exchangeable calcium and magnesium were determined by the ethylene diamine tetraacetic (EDTA) titration method, while sodium and potassium contents were ascertained using a flame photometry. The summation of the exchangeable Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} was used to compute the total exchangeable bases. Exchangeable acidity was determined by the titration technique outlined by Hendershot *et al*. (2008). Cation exchange capacity (CEC) was determined using the NH_4OAC method (Chapman, 1965). Percentage base saturation (BS) was determined as the ratio of the total exchangeable bases to the CEC of the soil.

Land Suitability Evaluation

A non-parametric method (the Principle of Limitation Method) was used to assess the suitability of the land for cocoyam and bitter yam production. This land suitability evaluation was conducted in accordance with the guidelines established by Naidu *et al*. (2006) and Chukwu *et al*. (2014) for bitter yam and cocoyam, respectively. The characteristics of the area were then compared to the land requirements for cocoyam and bitter yam, and a suitability class was assigned (Tables 1 and 2). The aggregate suitability class was determined by applying Liebig's Law of Minimum to the most restrictive characteristic within a class. Suitability classes were established as follows: highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (Ns).

Statistical Analysis

The variability in soil physiochemical properties was determined by descriptive statistics (mean, range, and coefficient of variance) of the soil data obtained from the profile pit. Microsoft Excel version 2016 was used for this purpose.

Table 1: Land use requirements for bitter yam production

Land Characteristics	Highly Suitable	Moderately Suitable	Marginally Suitable	Not Suitable
Climate (c)				
Temperature (°C)	20-30	30-34	34-35	<20, >35
Rainfall (mm/yr)	1000-2000	2000-3500	>3500	<1000
Humidity (%)	High	Mid	Low	
Chemical Properties (f)				
pH	5-7.4	7.4-7.8	5.1-5.6	<5.1
CEC (cmol/kg)	17-23	10-16	5-10	<5
SOC (g/kg)	>5	3-5	0-3	
Physical Properties (p)				
Slope (%)	0-4	4-8	8-20	>20

CEC = cation exchange capacity, SOC = soil organic carbon **Source:** Igbawua *et al*. (2022).

Table 2: Land use requirements for cocoyam production

Land Characteristics	Unit	Highly Suitable	Moderately Suitable	Marginally Suitable	Not Suitable
Climate (C)					
Temperature	°C	21-25	25-30	30-35	>35
Total rainfall	mm	>2000	1300-1299	1000-1299	<1000
Fertility (f): Nutrient Availability					
Total N	g kg^{-1}	>0.6	0-3-0.5	0.1-0.2	<0.1
Available P	g kg^{-1}	60-43	6-42	4-5	<4
Exchangeable K	cmol$_c$ kg^{-1}	>0.05	0.03-0.04	0.01-0.02	<0.01
Organic Matter	g kg^{-1}	>12.6	8-12.5	4-7	<4
pH		7.5-5.2	5.2-4.1	3.9-4.1	<3.9
Fertility (f): Nutrient Retention					
Base saturation	%	>60	40-60	20-39	<20
Soil Physical Characteristics (S)					
Top soil texture		C	CL	SL	S
Wetness (w)					
Drainage		Very poorly	Poorly	Imperfectly	Well drained
Topography (t)					
Slope	%	0-2	2-4	4-6	>6

Source: Chukwu *et al*. (2014). *N = nitrogen, P = phosphorus, K = potassium, C = clay, CL= clay loam, SL= sandy loam, S= sand*

RESULTS AND DISCUSSION

Morphological Properties of the Soils Underlain by False-bedded Sandstone

The morphological description of the soils of the study area (Table 3) shows a deep morphology, with depths reaching up to 200 cm across all pedons. This characteristic, coupled with the low to moderate excavation difficulty experienced, underscores the significance of soil depth in influencing water and nutrient retention, as well as root growth. It is therefore postulated that the increased soil depth observed in the study area will enhance its capacity for nutrient and moisture retention over extended periods, thereby fostering favourable conditions for robust root development (Oyetola, 2024).

The Ap horizon displayed a dull reddish-brown hue (7.5R 3/3), while the AB and B horizons exhibited reddish brown colours (10R 4/4) and (2.5YR 4/8), respectively. This observation suggests that organic matter (OM) exerted a strong influence on the colouration of the soils. In contrast, the Bt1 and Bt2 horizons exhibited orange (5YR 6/6) and bright brown (2.5 YR 5/8) hues, respectively. Overall, the observed colour variations are indicative of the occurrence of eluviation in virtually all pedons, a process where sesquioxides and/or clay minerals have been leached out (Oyetola, 2024). The redder colour of the soils at Ap, AB and B horizons may be due to the release of iron as a result of intense weathering, as previously observed by Dutta *et al*. (1999). The bright soil colour at Bt1 and Bt2 horizons is perhaps indicative of adequate internal drainage of the soil, as suggested by Amusan (1991).

The Ap, AB, and B horizons exhibited weak, medium, and platy structures, with consistency ranging from slightly sticky to very friable and slightly plastic, except for the B horizon, which demonstrated non-plastic consistency. For the Bt1 and Bt2 horizons, the soils exhibited medium, moderate, and platy structures, with consistency ranging from sticky to friable, firm to plastic. It is noteworthy that the strength of structure generally increases with depth due to an increase in clay content. This is similar to the report of Nkwopara (2018) on FBS soils. The boundary between the Ap, AB, and B horizons was distinct and smooth, while the Bt1 horizon exhibited a more abrupt and smooth boundary.

Physical Properties of the Soils Underlain by False-bedded Sandstone

As illustrated in Table 4, the profile distribution of soil physical properties within the study area exhibited a range of percentages from 17 to 37 % for clay, 3 to 21 % for silt, and 58 to 62 % for sand. The clay content increased with soil depth, while the silt content decreased with soil depth. The increase in clay content with depth can be attributed to illuviation processes, as well as to the contribution of weathering to the underlying geology (Idoga *et al*., 2005). The dominance of sand in the study area reflects the geological formations of the soils, and the decreased in silt content with depth is similar to the findings of Umeugokwe *et al*. (2023) of the soils of FBS. The textural class was determined as sandy loam over SCL in AB and B horizons, and SC in Bt horizon. This classification is indicative of the nature of the parent material from which the soil was formed. The CV of the clay, silt and sand content were 23.77, 74.13, and 2.70 %, respectively, implying moderate, high and low variability according to the rating of Wilding and Drees (1983).

Table 3: Morphological description of the study soil

Horizon	Depth (cm)	Colour (moist)	Texture	Structure	Consistency	Boundary
Ap1	0-14	7.5R 3/3	SCL	w, p, m	ss, vf, sp	d, s
AB	14-52	10R 4/4	SCL	w, p, m	ss, vf, sp	d, s
B	52-101	2.5YR 4/8	SCL	w, p, m	ss, vf, np	d, s
Bt1	101-152	5YR 6/6	CL	mod, p, m	s, ff, p	a, s
Bt2	152-200	2.5YR 5/8	CL	mod, p, m	s, ff, p	-

w = weak, p = platy, mod = moderate, m = medium, SCL = sandy clay loam, CL = clay loam, ss = slightly sticky, vf = very friable, sp = slightly plastic, np = non plastic, s = sticky, ff = friable firm, p = plastic, d = distinct, s = smooth, a = abrupt

Table 4: **Soil Particle Size Distribution of the various horizons of the study soil**

Horizon	Depth (cm)	Clay	Silt	Sand	TC	BD	TP	Ksat
		------------------%-----------------				g cm^{-3}	%	cm h^{-1}
Ap	0-14	17	21	62	SL	1.45	45.20	17.49
AB	14-52	35	7	58	SCL	1.41	46.98	30.86
B	52-101	35	7	58	SCL	1.60	39.45	27.26
Bt1	101-152	37	3	60	SC	1.55	41.58	17.49
Bt2	152-200	37	5	58	SC	1.34	49.58	36.01
Mean		32.20	8.60	59.20		1.47	44.56	25.82
CV		23.77	74.13	2.70		6.40	8.18	28.46

TC = textural class, SL = sandy loam, SCL = sandy clay loam, SC = sandy clay, BD = bulk density, TP = total porosity, Ksat = saturated hydraulic conductivity.

The bulk density ranged from 1.34 to 1.60 g cm^{-3}, with values generally falling below the threshold limit (1.85 g cm^{-3}). This is significant because root proliferation, air and water transport within the soil profile would not be impeded. This assertion is collaborated by the total porosity of the soil, which exhibited a high range of values between 40 and 50 %, a factor which may exert a significant influence on moisture retention for plants and the absence of risk of compaction (Nwaoba *et al*., 2021). The Ksat exhibited a range of values from 17.49 to 36.01 cm h^{-1}, which varied irregularly with soil depth, reaching higher levels in the Bt2 horizon. This rapid water permeability across the soil horizons could be related to the texture of the soils, which could influence its leaching potential and thus explain the low nutrient contents, particularly the exchangeable base cations (Tables 6 and 7).

Mean of the Particle Size Distribution of the Random Soil Samples

In Table 5, the mean proportion of clay and silt content was 18 % and 6 %, respectively, at the surface, and 26 % and 11 %, respectively, at the subsurface. It is evident that the sand content decreased with depth, lending credence to the aforementioned stronger structure with increasing depth. The textural class of the surface and subsurface soils was sandy clay loam.

Table 5: Mean effect of the particle size distribution

Depth (cm)	Clay	Silt	Sand	TC
	-----------%	--------------		
0-30	17	5	78	SCL
0-30	17	5	78	SCL
0-30	17	5	78	SCL
0-30	21	9	70	SCL
30-60	23	13	64	SCL
30-60	25	13	62	SCL
30-60	23	9	68	SCL
30-60	33	7	60	SCL
Mean (Topsoil)	18	6	76	SCL
Mean (Subsoil)	26	10	64	SCL

SCL = sandy clay loam

Chemical Properties of the Soils Underlain by False-bedded Sandstone

As presented in Table 6, the soil pH values ranged from 5.1 to 6.0, thus corroborating a result similar to that documented by Okebalama *et al*. (2024) in southeastern Nigerian soils. The soil reaction indicated strongly to moderately acidic reactions, suggesting an acidic nature due to heavy leaching promoted by the high rainfall in the area (Figure 2). Acidity of the soils may also be due to the effect of cultivation, erosion and leaching of nutrients or a combination of these (Malgwi *et al*., 2000).

The SOC was higher in the Ap Horizon and decreased with depth, with the values ranging from 0.14 to 0.68 g kg^{-1}. The high SOC content at the Ap Horizon is attributed to the accumulation of leaf litter, which subsequently decays and mineralizes to yield organic materials (Olayinka, 2009). Visual field observations indicated an accumulation of litter in the topsoil, which may account for the higher OM content observed in the FBS soils. The SOC in the study area was low according to the ratings of Chude *et al*. (2011), who characterized the soils of southeastern Nigeria. The environment in southeastern Nigeria is characterized by high temperatures and relative humidity, which favour rapid mineralization of OM (Chikezie *et al*., 2010).

The total nitrogen levels of the soils ranged from 0.04 to 0.07 g kg^{-1}, with a CV of 15.81 %, indicative of minimal variability, comparable to that observed in SOC content. In tropical soils, where organic matter constitutes the predominant portion of TN, Ezeaku & Iwuanyanwu (2013) documented a comparable trend with TN and ascribed it to the accelerated decomposition and oxidation of organic matter. The Av. P contents in the soil samples ranged from 3.38 to 21.98 mg kg^{-1}, with values decreasing with depth (Figure 3). The Av. P values fall within the low to high concentration range (Chude *et al*., 2011). The high concentration of Av. P in the Ap horizon may be attributed to its low solubility/mobility in soil (Adegbite *et al*., 2019). Furthermore, the low Av. P concentration in the subsoils may be due to the low OM content and the fixation of P by iron or aluminum oxide and hydroxides and clay (Orimoloye *et al*., 2019).

The exchangeable Ca^{2+} was the most dominant base, with values decreasing down the depth, ranging from 0.40 to 1.40 $cmol_c$ kg^{-1}. Exchangeable Mg^{2+} ranked next to Ca^{2+}, with values increasing with depth. The surface value was 0.2 $cmol_c$ kg^{-1}, which was dominant until it slightly increased at Bt1 and Bt2. The exchangeable Na^{+} and K^{+} were the least dominant, with values decreasing with depth. The dominance of exchangeable Ca^{2+} and Mg^{2+} can be attributed to leaching, which removes these cations from the exchange complex of soils (Okebalama *et al*., 2024). The total exchangeable bases are relatively low, signifying that the soil is strongly weathered and excessively leached (Chikezie *et al*., 2010). This finding is consistent with the observations reported by Ndukwu *et al*. (2012) and Umeugokwe *et al*. (2023) in the soils of southeastern Nigeria. The soil's CEC ranged from 4.40 to 6.00 $cmol_c$ kg^{-1}, indicating a low CEC with a notable prevalence of exchangeable acidity. This finding indicates that the soil possesses a limited capacity to retain essential nutrients (Ćirić *et al*., 2023).

Table 6: Soil chemical properties of the profile pit of the study soil

Horizon	Depth	pH (H_2O)	pH (KCl)	SOC	OM	TN	Av. P	Ca^{2+}	Mg^{2+}	Na^+	K^+	H^+	CEC	BS
	--cm--			--------g kg^{-1}-------			mg kg^{-1}	--------------------------cmol$_c$kg^{-1}--------------------						%
Ap	0-14	5.9	5.1	0.68	1.16	0.06	21.98	1.40	0.20	0.04	0.09	1.40	5.60	30.89
AB	14-52	6.0	4.8	0.53	0.92	0.06	3.38	1.00	0.20	0.03	0.07	2.20	6.00	27.08
B	52-101	5.4	4.0	0.39	0.67	0.04	4.23	0.80	0.20	0.02	0.06	1.80	5.60	19.29
Bt1	101-152	5.1	3.9	0.36	0.61	0.07	3.38	0.60	0.40	0.02	0.05	2.40	5.20	20.58
Bt2	152-200	5.1	3.8	0.14	0.24	0.06	3.38	0.40	0.40	0.01	0.03	1.60	4.40	19.09
Mean		5.5	4.32	0.42	0.72	0.06	7.27	0.84	0.28	0.024	0.06	1.88	5.36	23.39
CV		6.99	12.20	42.69	42.72	15.81	101.26	40.96	34.99	42.49	33.33	19.73	10.12	20.33

SOC = soil organic carbon, OM = organic matter, TN = total nitrogen, Av. P = available phosphorus, Ca^{2+}, Mg^{2+}, Na^{2+}, K^+, and H^+ = exchangeable magnesium, calcium, sodium, potassium and hydrogen, respectively, CEC = cation exchange capacity, BS = base saturation.

Table 7: **Mean values of the chemical properties of the study soil**

Soil Depth	pH (H_2O)	pH (KCl)	SOC	OM	TN	Av. P	Ca^{2+}	Mg^{2+}	Na^+	K^+	CEC	H^+	BS
----cm-----			--------g kg^{-1}--------			mg kg^{-1}	-----------------------------cmol$_c$kg^{-1}--------------------------						%
0-30	5.7	5.0	0.36	0.61	0.10	24.67	1.00	0.20	0.02	0.06	4.80	1.40	26.60
0-30	5.6	4.7	0.32	0.55	0.06	15.22	0.80	0.20	0.02	0.06	3.20	1.60	33.75
0-30	5.8	4.7	0.36	0.61	0.08	28.75	0.80	0.20	0.02	0.06	4.40	1.60	24.55
0-30	5.9	5.2	0.71	1.22	0.08	10.15	1.80	0.40	0.05	0.11	6.00	2.20	39.33
30-60	5.3	4.1	0.39	0.67	0.04	5.07	0.80	0.20	0.02	0.06	6.00	1.40	18.00
30-60	5.6	3.8	0.53	0.92	0.04	6.76	0.80	0.20	0.04	0.09	6.00	2.00	18.83
30-60	5.8	4.5	0.46	0.80	0.06	10.15	1.00	0.80	0.03	0.07	4.40	1.60	43.18
30-60	5.9	4.8	0.68	1.16	0.07	6.76	1.20	0.20	0.04	0.09	5.60	1.40	27.32
Mean (Top)	5.8	4.9	0.43	0.75	0.08	19.70	1.10	0.25	0.03	0.07	4.60	1.70	31.06
Mean (Sub)	5.7	4.3	0.52	0.89	0.05	7.19	0.95	0.35	0.03	0.08	5.50	1.60	26.83

SOC = soil organic carbon, OM = organic matter, TN = total nitrogen, Av. P = available phosphorus, Ca^{2+}, Mg^{2+}, Na^{2+}, K^+, and H^+ = exchangeable magnesium, calcium, sodium, potassium and hydrogen, respectively, CEC = cation exchange capacity, BS = base saturation.

Mean Values of the Chemical Properties of the Random Soil Samples

The mean values of the chemical properties of the study area (Table 7) showed that the pH of the top and subsoils was moderately acid (5.7 to 5.8). The values of pH, TN, Av. P, Ca^{2+}, H^+, and BS were higher at the surface (0-30 cm) than in the subsurface (30-60 cm) soil. Furthermore, the subsurface soil exhibits higher values of SOC, Mg^{2+}, K^+, and CEC in comparison to the surface soil. The Na^+ values were found to be similar (0.03 cmol$_c$ kg^{-1}) at the surface and the subsurface soils, respectively. The fertility status of the study area was low to moderate based on the ratings of Chude *et al*. (2011), and could be related to the leaching and erosion potential of the soil due to its inherent texture. The underlying factors contributing to this status, as identified by Mtali-Chafadza *et al*. (2020) and Umeugokwe *et al*. (2023), include excessive cropping without adequate fertilization, soil erosion, poor drainage, and a deficiency in OM.

Land Suitability Evaluation of the Study Area for Cocoyam and Bitter Yam Production

The land qualities/characteristics of the study area were matched with the land use requirements of the various crops (Tables 8 and 9) using non-parametric methods. The soils of the study area are not suitable (NS) for the growing of cocoyam but are marginally suitable (S3) for bitter yam production. The predominant constraint on the cultivation of both crops in the study area pertains to soil fertility, as demonstrated by the low levels of total nitrogen and soil organic matter. This investigation has enabled the establishment of a profound comprehension of the impact of the soil variations on the suitability and production potential for these crops on soils overlain by FBS. The potentials for continuous and sustainable cocoyam and bitter yam cultivation on the study soil lie in the judicious utilization of soil fertilization and conservation practices for the purpose of enhancing soil fertility.

Table 8: **Land suitability evaluation of Cocoyam**

Land Characteristics	Unit	Value	Rating
Climate (C)			
Temperature	°C	24	S1
Total rainfall	mm	1517	S2
Fertility (f): Nutrient Availability			
Total N	g kg^{-1}	0.09	NS
Available P	mg kg^{-1}	24.67	S2
Exchangeable K	$cmol_c$ kg^{-1}	0.06	S1
Organic matter	g kg^{-1}	0.612	NS
pH		5.7	S1
Fertility (f): Nutrient Retention			
Base saturation	%	26.6	S3
Soil Physical Characteristics (S)			
Top soil texture		SL	S3
Topography (t)			
Slope	%	2-4	S2
Overall Suitability			NS (f)

N = nitrogen, P = phosphorus, K = potassium, NS = Not suitable

Table 9: Land suitability evaluation of bitter yam

Land characteristics	Unit	Value	Rating
Climate (C)			
Temperature	°C	24	S1
Rainfall	mm	1517	S1
Relative Humidity	%	70	S1
Fertility (f)			
CEC	$cmol_c$ kg^{-1}	5.6	S1
SOC	g kg^{-1}	6.8	S3
Topography (t)			
Slope	%	3	S1
Overall Suitability			S3 (f)

CEC = cation exchange capacity, SOC = soil organic carbon

CONCLUSION AND RECOMMENDATIONS

The study examined the physical and chemical properties of soils in Nkpamute-Ulo, Enugu Ezike. In terms of physical properties, the study area displayed different textural and morphological characteristics. The chemical properties of the study area showed that the pH was strongly to moderately acidic in reaction. The organic carbon, total nitrogen and available phosphorus levels of the FBS soils decreased with depth, whilst exchangeable Ca^{2+} was dominant, followed by Mg^{2+}, Na^{+} and K^{+} bases. The exchangeable bases and the CEC were generally low, indicating limited nutrient retention capacity and the potential necessity for soil fertility improvement.

The suitability evaluation of the study area indicates that the area exhibits marginal suitability for bitter yam cultivation, but is not suitable for cocoyam production owing to constraints such as the low K^{+}, Av. P and CEC concentrations. The study results suggest that, while the area is currently not suitable for these crops, it possesses the potential to become suitable through the implementation of appropriate soil amendments and fertilization practices, aimed at enhancing nutrient availability and CEC in the soil.

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Authors' Contributions

CBO: study conception and design. CFG: data collection. CFG & CPU: analysis and interpretation of results. CBO & CPU: draft manuscript preparation. All authors reviewed the results and approved the final version of the manuscript.

Ethical Statement

Not applicable

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