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Characterization, Classification and Suitability Evaluation of Soils on Three Geological Formations in Nsukka Area of Enugu State for Pepper Production

Umeugokwe, C.P.[1], *Ajoagu, G.M.[1], and Asadu, C.L.A.[1]

[1]Department of Soil Science, Faculty of Agriculture, University of Nigeria, Nsukka

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Corresponding Author's E-mail Address:

ginika.ajoagu@unn.edu.ng

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ABSTRACT

This study aimed to characterize, classify, and evaluate the soils on three geological formations in Nsukka, Eastern Nigeria for pepper production. The geological formations included Upper Coal Measure (UCM), False Bedded Sandstone (FBS), and Nkporo Shale (NS). Three pedons were excavated to represent each of these geological formations. Soil properties were determined using appropriate methods. The pedons were very deep (> 150 cm). Bulk density, porosity, and soil texture varied among the geological formations. The pH values ranged from 5.0 to 7.3, indicating moderately acidic to neutral conditions. The SOM content varied from 0.14-1.24 g/kg, indicating low levels. Similarly, sodium, potassium, acidity, and available phosphorus levels were also low, with values ranging from 0.01-0.05 cmol/kg, 0.03-0.07 cmol/kg, 0.60-2.20 cmol/kg, and 0.93-4.66 mg/kg, respectively. Exchangeable calcium and magnesium were moderate, ranging from 2.40-5.00 cmol/kg and 0.40-1.60 cmol/kg, respectively. Total nitrogen content was relatively high, ranging from 0.30 to 1.50 g/kg. Base saturation values varied, with high values of 61% for UCM, moderate values of 53% for NS, and low values of 33% for FBS. Based on the USDA classification system, the soils in the UCM, NS, and FBS were classified as Typic Hapludalfs, Typic Eutrustox, and Arenic Kanhapludults respectively. In terms of suitability for pepper production, UCM soils were determined to be moderately suitable, NS soils were marginally suitable, and FBS soils were deemed not suitable. Based on our findings, we recommend implementing appropriate soil management practices to enhance soil fertility and optimize pepper crop production in the study area.

1.0 Introduction

Soil is a natural resource that serves as a physical support for crops and buildings and as a source of water and nutrients for crops as well as a medium in which organic materials are recycled for future generations (Kefas *et al*., 2020). Its properties are known to exhibit high heterogeneity (Young *et al*., 2009) at different spatial scales, and can also vary substantially under different land uses (Nadrowski *et al*., 2010). Differences in soil morphological, physical, and chemical properties are related primarily to parent materials (Alem *et al*., 2015). Knowledge of the kinds of soils in an area is critical for decision making on crop production and other land use types (Yitbarek *et al*., 2016).

Soil information enables accurate, and useful data prediction for specific soil functions. To achieve this, there is a need to characterize the soil in a way that is useful to predict land use potential (Aruleba and Ajayi, 2013). Characterization and classification of soils are fundamental to all soil studies and help to document soil properties which are essential for the successful transfer of research results to other locations (Dinssa and Elias, 2021). Also, soil resources must be studied in detail through the rating of land qualities for the land evaluation under consideration (Osujieke *et al*., 2022a); such information highlights soil characteristics, and conditions that are suitable for growing specific crops (Ogunkunle, 2005).

Nigeria is one of the major pepper producing countries in the world (FAOSTAT, 2019). Nsukka aromatic yellow pepper (*C. annum*) is a popular crop in the eastern part of Nigeria for its fruits which are characterized by unique aroma and adaptability to the existing cropping systems (Abu and Uguru, 2006). Typically, they are grown as a crop that relies on rainfall and are green when fully mature, however, there is also a deep yellow or orange variety that has developed over time (Uguru, 2005). It is a rich source of Vitamins A and C (Wahyuni *et al*., 2011). It has both nutritional and medicinal properties, making it a popular choice for food manufacturers to use as a seasoning in processed foods (Onwubuya *et al*., 2009).

Nsukka agricultural zone in the northern part of Enugu State is generally considered to be the home of Nsukka Yellow Pepper hence the name was so derived (Maga *et al*., 2012). Despite the agricultural potential of the area, there is a scarcity of soil information regarding geological formations, soil characteristics and classification, which could be valuable for pepper farmers. Previous research (Asadu *et al*., 2017; Ugadu and Asadu, 2019) in the region has not adequately explored the suitability of soils for pepper cultivation, despite it being a popular crop in the area. Such land suitability assessments can help prevent inappropriate land use and mitigate land degradation (Osujieke *et al*., 2022b; Magaji *et al*., 2022). The need to generate soil information on geological formation, soil potentials and constraints for pepper production necessitated this study. Therefore, the objective of this study was to characterize, classify and evaluate qualitatively some geological formations identified in Nsukka Area of Enugu State for the production of Nsukka Yellow Pepper.

2.0 Materials and Methods

2.1 Description of the Study Area

The study was conducted at Agu-Ibagwa (latitude 6° 56'53.556"N and longitude 7°19'11.41"E), Nkpologwu (latitude 6°44'36.91"N and longitude 7°17'9.344"E), and Opi-Agu (latitude 6°41'47.728"N and longitude 7° 33'10.883"E), all in Nsukka area of Enugu State. Agu-Ibagwa, Nkpologwu and Opi-Agu soils are derived from upper coal measure, false bedded sandstones and Nkporo shale, respectively (Fig. 1). The vegetation type is of derived savannah. The land use types predominant in the area are arable crop production, grassland, grazing and oil palm plantation. The region has a humid tropical climate with two main seasons: the wet season, lasting from March to October, and the dry season, lasting from November to February. There is also a brief dry period in August known as the "August break." The average annual rainfall and humidity are 1550 mm and 60%, respectively. The average annual temperature does not exceed 35 °C (Akamigbo and Asadu, 1983).

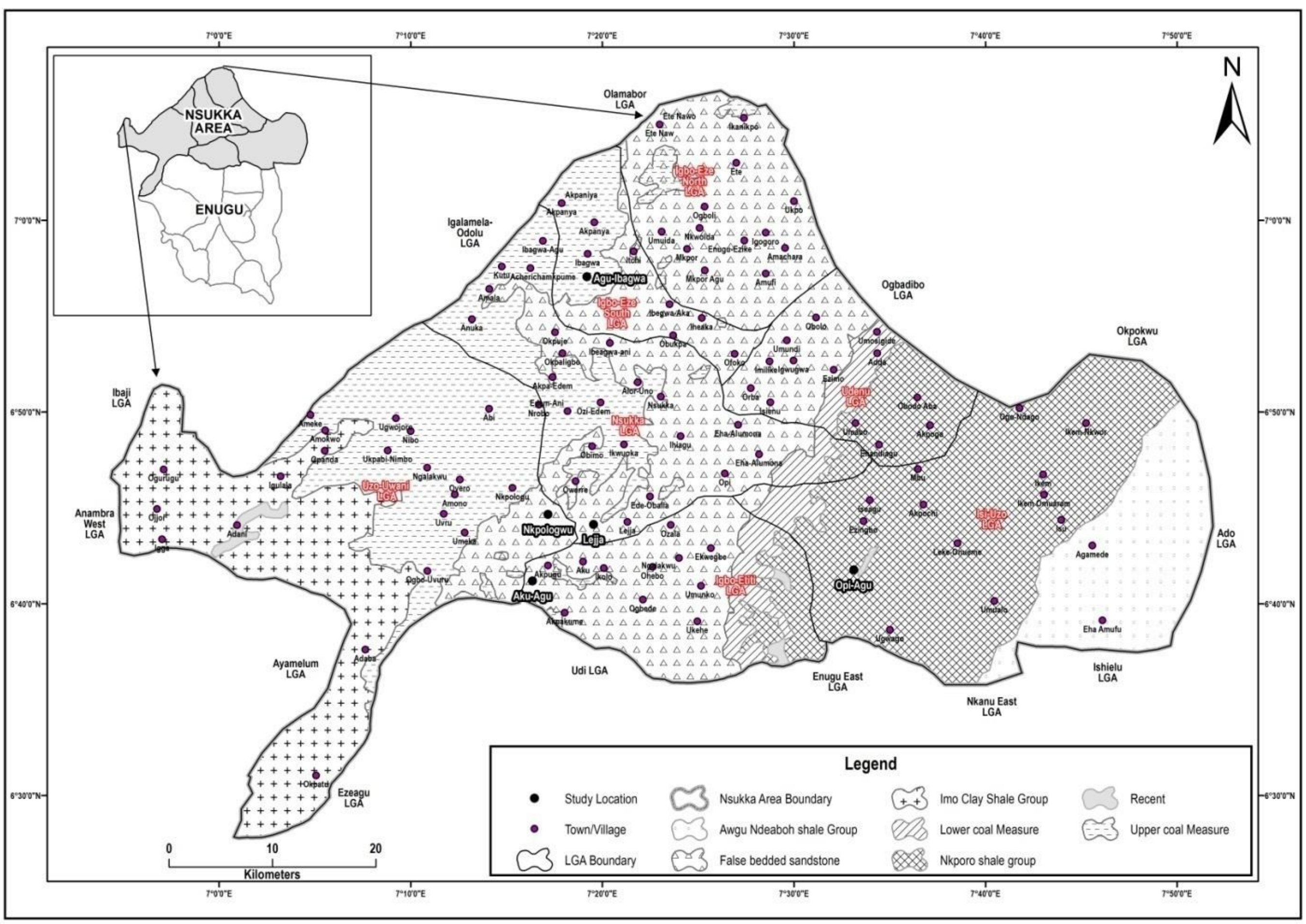

Figure 1: Map of Nsukka Area showing the Geology of the study area

2.2 Field studies

Soil profile pits were dug following a free survey technique, guided by a geological map of Enugu State developed by Nigeria Geological Survey Agency (2006). Three representative pedons were selected to represent the Upper Coal Measure (UCM), False Bedded Sandstone (FBS), and Nkporo Shale (NS) geological formations. The description of soil horizons followed the guidelines provided by the USDA Soil Survey Staff (2014). Samples were collected from distinct horizons within each pit and appropriately labeled for subsequent laboratory analysis.

2.3 Laboratory analysis

The soil samples collected, were air-dried, gently crushed and later sieved with a 2 mm sieve. Analysis of the physicochemical properties was carried out following standard laboratory procedures. Particle size distribution of the soils was determined on the < 2 mm soil fraction using the Bouyoucous hydrometer method (Gee and Or, 2002), with 0.1N NaOH as dispersant. Total porosity was calculated from the relationship between bulk density and particle density using equation (1):

$$TP = \left(1 - \frac{\ell b}{\ell s}\right) \times 100; \quad (1)$$

Where, ℓb = bulk density (g cm^{-3}) and ℓs = particle density (2.65g cm^{-3}). Bulk density was determined using core method (Grossman and Reinch, 2002). Saturated hydraulic conductivity (Ksat) was determined using a set of undisturbed core samples collected with metallic core cylinders (Reynolds, 1993) and computed from the equation (2) below:

$$K_{sat} = ; \frac{QL}{At.\Delta H} \quad (2)$$

Where, Ksat = Saturated hydraulic conductivity (cm h^{-1}), Q = volume of water (cm^3), L = height of water above soil column, A = cross sectional area of sample (cm^2), ΔH = hydraulic head difference (1 + h), cm and t = time (min). The soil pH was determined in distilled water and in 0.1NKCl solution using soil to liquid ratio of 1:2.5. The solutions were stirred for about 30 minutes and corresponding pH values read using a glass electrode pH meter (McLean, 1982). Organic carbon was determined using the method described by Nelson and Summers (1996), while organic matter was calculated by multiplying the value of organic carbon by 1.724 (Van Bermelen factor) which is based on the assumption that soil organic matter contains 58% carbon (Allison, 1982). The CEC were determined titrimetrically using ammonium acetate (NH_4OAc) displacement method (Rhoades, 1982). The following exchangeable basic cations: calcium (Ca^{2+}), sodium (Na^+), potassium (K^+), and magnesium (Mg^{2+}) were determined by complexometric titration method, described by Chapman (1982). K^+ and Na^+ were extracted using 1N ammonium acetate (NH_4OAc) solution and will be determined by flame photometry, and the exchangeable acidity by titration method after extraction with 1NKCl (McLean, 1982). The total nitrogen was determined by the Kjeldahl digestion and distillation method (Bremmer and Mulvaaney, 1982). The available phosphorus of the soil samples was determined using Bray-2 method as described by Olson and Sommers (1982). The percentage (%) base saturation was calculated thus (equation 3):

$$\% \text{ Base Saturation} = \frac{\text{Total Exchangeable Base}}{\text{Effective Cation Exchange Capacity}} \times \frac{100}{1} \quad (3)$$

2.4 Soil Classification

The soils were classified using USDA Soil Taxonomy (Soil Survey Staff, 2014) and World Reference Base (WRB) (FAO, 2014) classification systems, with classification based on field and laboratory data, including morphological, physical, chemical properties, and general site information.

2.5 Land Suitability Evaluation

A non-parametric method was utilized to assess the land suitability evaluation for pepper cultivation. This evaluation was conducted using guidelines from Naidu *et al*. (2006) for determining land suitability. The characteristics of each pedon were compared to the land requirements for pepper production to assign a suitability class. The performance of a soil type was determined by applying Liebig's Law of minimum to the most restrictive characteristic within a group. Detailed land and soil requirements for pepper according to Naidu *et al*. (2006) are presented in Table 1.

Table 1: Land requirement for suitability classes for pepper (Capsicum annuum L.)

Land Qualities characteristics	Suitability class			
	Highly suitable S_1	Moderately suitable S_2	Marginally suitable S_3	Not suitable N
	100-75	74-50	49-25	25-0
Climatic Regime				
Mean temperature in growing season (^{0}C)	28-35	20-27 36-38	18-19 39-40	<18 >40
Total Rainfall (mm)	2000-3000	1200-1500	800-1200	<800
Elevation (m)	200-1200	1200-1500	1500-1800	>1800
Nutrient Availability				
Texture (class)	SCL, L, CL, SC	CL, SL, C	C (55%)	S, LS, C (>60%)
Organic Carbon (%)	>2	1-2	0.5-1	<0.5
Rooting conditions				
Effective soil depth (cm)	>100	100-50	50-25	<25

Source: Naidu *et al*. (2006)

2.6 Statistical Analysis

The coefficient of variation (%CV) was calculated using Microsoft Excel (2016) software to assess the variability of soil properties. The obtained %CV values were then compared to the classification proposed by Tabi and Ogunkunle (2007). In this classification, %CV values ranging from 0 to 15% were categorized as low variability, values from 16 to 35% were considered moderate variability, and values exceeding 35% were classified as high variability.

3.0 Results and Discussion

3.1 Morphological Characteristics of the Soils

The morphological characteristics of the soils are presented in Table 2. The pedons at UCM and FBS were characterized by dark reddish-brown (2.5YR 4/3 and 2/3 respectively) color at the surface and varying color was obtained at the subsurface horizons. The NS pedon had a brown (7.5 YR 4/4) color on the surface to red (10 R 4/6) in the subsurface. The reddish colour denotes iron oxidation and aerated soil. The variations in color are due to differences in organic matter content, parent material, and drainage conditions (Alem *et al*., 2015). The brownish color observed on the surface horizons of the studied soil aligns with the findings reported by Oti and Mbe (2020) in Southeastern Nigeria.

In UCM, the soil structure exhibited fine, medium, and subangular characteristics in the surface horizon, while the subsurface horizon showed a moderate, medium, and subangular structure. NS displayed a moderate, coarse, and subangular structure in the Ap and A_1 horizons, transitioning to a strong, coarse granular to moderate, coarse granular structure in the Bt and C horizons. FBS demonstrated a very fine weak and crumb structure in the Ap and AB horizons, while the B_1, B_2, and BC horizons displayed fine, medium, and subangular structures. This soil structure indicates that the soil has a good water holding capacity, and appropriate nutrient content (Osujieke *et al*., 2022a) and better aggregation and arrangement of soil particles.

The consistence was mostly friable except for the C horizon of NS, which was very firm (dry); non plastic top soils over slightly plastic for UCM, moderately plastic in AP and A_1 transitioning to slightly plastic for NS and non-plastic in all the horizons for FBS (wet). In terms of drainage, the soils were generally well-drained, except for the Bt_3 and C horizons, which were poorly drained primarily due to their high clay content. In the UCM, roots were present in the Ap and Bt_1 horizons but absent in the Bt_2, Bt_3, and C horizons. Similarly, in the FBS, roots were observed in the Ap and AB horizons, while they were absent in the B1, B2, and BC horizons. In contrast, NS showed root distribution in all horizons. The presence of the roots is an indication of biological activities in the soils.

All of the pedons were very deep (>150 cm) according to soil depth class classification by Ditzler *et al*. (2017). The amount of plant nutrients and water available to the plant roots is determined by the soil's rooting depth. The UCM and NS horizons exhibited clear distinctness and smooth topography at the surface, while the subsurface soils showed gradual distinctness and smooth topography in UCM and abrupt distinctness and smooth topography in NS. In FBS, there was a transition from gradual distinctness and smooth topography at the surface to clear distinctness and smooth topography in the subsurface. The observed variations in horizon boundaries, both on the surface and in the subsurface, indicate distinct morphological features at different depths within the studied soil. These findings align with previous research conducted by Nwaoba *et al*. (2021) and suggest that the study site is in the early stages of soil development.

3.2 Physical Characteristics of the Soils

The physical characteristics of the soils are presented in Table 3. Sand dominates the particle sizes and decreased with increase in soil depth. The soils derived from UCM had loamy sand and sandy clay loam (SCL) texture in both the surface and subsurface horizons. The transition to SCL in the subsurface horizon was due to the downward migration of clay particles, contradicting the findings by Ndukwu *et al*. (2012) who reported sand texture in both surface and subfurface horizons of UCM. The surface horizon at NS Pedon had sandy texture, while the A1 and C horizons had sandy loam (SL) texture and the Bt horizon had SCL texture. The texture of the False Bedded Sandstone (FBS) in both the surface and subsurface horizons was determined to be sand. This finding contradicts the previous research conducted by Onweremadu et al. (2021), which reported FBS in the humid tropical zone as having a texture of SL in all horizons. Furthermore, the consistent distribution of silt fractions (50 g kg^{-1}) within the profile in FBS Pedon could be attributed to the geological formation's homogeneous nature. The variations of textural classes in relation to geological formations could be attributed to the nature of their parent materials, similar to the findings of Ihem *et al*. (2017).

The surface bulk density (BD) values of UCM, NS, and FBS were 1.71, 1.41, and 1.50 g cm^{-3} respectively while the subsurface BD ranged from 1.67 to 1.83 g cm^{-3} for UCM, 1.58 to 1.75 g cm^{-3} for NS, and 1.42 to 1.81 g cm^{-3} and the values varied irregularly with soil depth. UCM soils showed higher bulk density values than NS and FBS soils which might be attributed to the geological formation which consist of coal, sandstone, shale and siltstone (Nigeria Geological Survey Agency, 2006). The coal itself would not permit root penetration and would have a highly solid structure. The FBS values is similar to the findings of Aririguzo *et al*. (2019) who researched on the FBS soils of Abia State, Southeastern Nigeria. The BD values were generally lower than the threshold limit (1.85 g cm^{-3}) that would impede root proliferation, air and water transport.

The total porosity (TP) for all the geological formations was very high according to Jahn *et al*. (2006). This is similar with the findings of Ihem *et al*. (2017) of the soils of Southeastern Nigeria. Soils with a total porosity of greater than 40%, may offer significant high moisture retention for plants and no risk of compaction (Nwaoba *et al*., 2021). However, when TP is less than 40%, it exhibits extra strength indicative of likely risk of compaction and inadequate aeration. The Ksat values decreased with increase in soil depth across all the geological formations and this variation might be attributed to differences in the particle size distribution.

3.3 Chemical Characteristics of the Soils

Table 4 shows the chemical characteristics of the soils of the study area. The surface soil reactions of UCM, NS, and FBS were 5.0, 7.3 and 6.0, respectively while the subsurface soil reactions ranged from 5-6.8, 5.5-6.9, and 5.8-6.3

respectively and changed erratically with depth. According to Chude *et al*. (2011), these values were strongly acidic to neutral. The acidic nature of the soils in general may be attributed to high rainfall intensity in the area which may have resulted in leaching out of soil basic cations, resulting in dominance of acidic cations (Okoli *et al*., 2019).

The soil organic matter (SOM) content generally declined with depth and is evidence of organic material assimilation into the soils, with epipedons values of 1.20 g kg^{-1} for UCM, 2.12 g kg^{-1} for NS, and 1.10 g kg^{-1} for FBS. UCM, NS, and FBS subsoil values ranged from 0.62 to 1.24 g kg^{-1}, 0.83 to 1.45 g kg^{-1}, and 0.62 to 1.10 g kg^{-1} respectively. According to Esu (1991), the SOM contents were moderate to low which may be linked to the low organic matter decomposition rate by agricultural operations (Obi *et al*., 2012). This supports the findings of Ndukwu *et al*. (2012) and Aririguzo *et al*. (2019) on the decrease in SOM with depth.

The total N had an irregular trend with depth in NS geological formation except for UCM and FBS geological formations that decreased down the depth. The TN values were lower than 2-10 g kg^{-1} recommended by Enwezor *et al*. (1990) and Federal Fertilizer Department (2012) for productive soils in the tropics. The low content could be ascribed to rapid microbial activities and crop removal, leading to nitrate loss in the soil environment (Aiboni *et al*., 2007). This result contradicts the findings of Onweremadu *et al*. (2021) of humid tropical soils.

Exchangeable Ca^{2+} was dominant in all the geological formations and the values decreased consistently with depth in UCM and NS while that of FBS increased consistently with depth. The values for exchangeable Ca^{2+} (2.40-5.00 cmol kg^{-1}) were generally moderate based on the rating of Sheru *et al*. (2015). The preponderance of calcium shows the affinity of calcium over other cations at exchange sites. Exchangeable Mg^{2+} ranked next to Ca^{2+} on the exchangeable site. The surface values of Mg were 0.80 cmol kg^{-1} for UCM and NS and 0.40 cmol kg^{-1} for FBS while the subsurface values ranged from 0.4 to 1.20, 0.40 to 0.60 and 0.20 to 1.20 for UCM, NS, and FBS respectively. Mg^{2+} values were generally in the medium range which might be due to inherent magnesium parent material as Abate *et al*. (2014) suggested. Reports have shown that pH H_2O values of 5 to 9 are optimum for calcium and magnesium availability (Hazelton and Murphy, 2016). This is similar to the findings of Nsor *et al*. (2016) of soils of Southeastern Nigeria. Although Ca and Mg were dominant exchangeable bases in all the geological formations, NS recorded the highest Ca^{2+} mean value of 4 cmol kg^{-1} while the UCM recorded the highest Mg^{2+} mean value (0.92 cmol kg^{-1}). In all the geological formations surface and subsurface horizons, the exchangeable K^+ and Na^+ content was low and decreased with depth. However, exchangeable K^+ and Na^+ were higher in NS, followed by UCM and FBS similar to the findings of Ndukwu *et al*. (2012) in their studies of soils underlain by three lithologies in Southeastern Nigeria. This further confers higher fertility status on soils of NS than those of the rest two geological formations.

According to the rating of Esu (1991), exchangeable acidity was low in the study area's surface soils, while for the subsurface soils EA is low for NS and FBS and low to moderate for UCM. The low EA could reflect the low amount of exchangeable Al^{3+} and H^+ in the soils. Nsor *et al*. (2016) and Nwaoba *et al*. (2021) found similar results and concluded that the contribution of exchange acidity to potential acidity in soils of Southeastern Nigeria is relatively low.

The cation exchange capacity (CEC) of the surface soils of UCM was 6.00 cmol kg^{-1} and 10.00 cmol kg^{-1} for NS and FBS. CEC values show a variation (decrease) with depth in NS and irregularly with depth in UCM and FBS. In the subsoil horizons, CEC varies between 5.20 and 12.40, 7.20 and 9.60, and 9.00 and 12.40 cmol kg^{-1} for UCM, NS, and FBS respectively. The subsurface horizons CEC value was higher when compared with surface values in some pedons and could be indicative of mineralogical nature and composition rather than the presence of organic carbon (Obalum *et al*., 2012; Osujieke *et al*., 2022a). The overall CEC of the study area was low according to the ratings of Esu (1991) in all the geological formations. This conformed with the findings of Ihem *et al*. (2017) that the soils of derived savannah have low CEC values.

The available phosphorus levels showed a consistent pattern across NS and FBS, with higher concentrations in the surface horizons compared to the deeper layers. In contrast, UCM exhibited minimal or negligible values of available phosphorus within the studied pedons. According to Esu (1991), soils with available phosphorus values below 5 mg kg^{-1} are considered low. This low availability could be attributed to the characteristics of the parent material as well as the fixation of phosphorus by iron and aluminum oxides, particularly under well-drained acidic conditions (Orimoloye *et al*., 2018).

The percent base saturation (PBS) varied over the soil depth for all pedons studied. UCM, NS, and FBS had surface horizons values of 71.83, 59.30 and 31.10% respectively. In the subsurface soil, PBS for UCM, NS, and FBS varied from 29.68 to 83.39%, 44.90 to 59.44%, and 26.13 to 38.85%, respectively. The presence of the basic cations in the exchange site was shown by UCM's greater PBS compared to NS and FBS. The higher values (>40%) highlight the significance of good soil management by indicating that the soils have the capacity to provide plant nutrients (Talha *et al*., 2022). The soil's PBS value agreed with research by Ndukwu *et al*. (2012) and Osinuga *et al*. (2020) that found UCM and shale geological formations to have high PBS values.

3.4 Variability of Soils of the Geological Formations

Among the physical properties, the clay (15.80-41.44%), silt (18.07-46.35%), and sand (>35%) exhibited moderate to high variability, while bulk density (BD) and total porosity (TP) showed low variability (<10% and <15%, respectively). In contrast, hydraulic conductivity (Ksat) displayed high variability (>35%) (Table 3). Similar findings have been reported by other researchers (Tabi et al., 2012; Osinuga et al., 2020) in different regions of the West-African Savanna. Soil pH (H_2O and KCl) demonstrated low variability (<15%), while soil organic matter, exchangeable bases, and total exchangeable acidity exhibited moderate to high variability (>15%). Additionally, cation exchange capacity and total nitrogen displayed low to moderate variability (>10%), while available phosphorus showed high variability (>35%) (Table 4). Variations in base saturation are likely attributed to pH variations, as observed in the study by Asongwe et al. (2016).

3.5 Classification of Soils of the Geological Formations

The soils derived from UCM have an argillic horizon and base saturation of > 35% in all the horizon within 150 cm hence classified as order Alfisols. An ustic moisture regime was established because the soils are dry in some or all the parts for 90 or more consecutive days in normal years, and this qualified them as Ustalfs in the suborder category. They are also characterized by a textural class of loamy sand, extending from a mineral soil surface to the top of an argillic horizon, placing them in the great group of Haplustalfs (Soil Survey Staff, 2014).

The NS soils fit the characteristics of oxisols as they have an oxic horizon within 150 cm of the mineral soil. However, they are moist in some areas for more than 180 cumulative days per year or for 90 or more consecutive days, which places them in the Ustox sub-order. They are also classified as the great group Eutrustox, due to the presence of base saturation (by NH_4OAc) of more than 35% throughout all horizons within 125 cm of the mineral surface (Soil Survey Staff, 2014).

False bedded sandstone soils were classified as order Ultisols owing to the presence of Kandic horizon and base saturation of < 35 % in all the horizon within 150 cm of the mineral soil surface. They were further classified as sub-order Ustults, great group Kanhaplustults and subgroup Arenic Kanhaplustults. They were classified as Arenic Kanhaplustults as they possessed sandy textural class throughout the layer extending from the mineral soil surface to the top of the kandic horizon.

According to World Reference Base (WRB), the soils derived from UCM and NS were classified into the Reference group Lixisols due to presence of an argillic horizon, CEC of < 24 cmol kg^{-1} and base saturation of > 50%. Owing to the loamic textural class at the depth of ≥ 30 % from the mineral surface, the soils was further classified as Loamic Lixisols (FAO, 2014). The soils derived from FBS were classified as Acrisols due to its presence of agric horizon; < 24 cmol kg^{-1} and base saturation of > 50%. At the lower level, they are classified as Arenic Acrisols owing to the presence of sandy textural class at depth of ≥ 30 cm within the 100 cm of the mineral surface.

Table 1: Land requirement for suitability classes for pepper (*Capsicum annuum* L.)

Depth (cm)	HD	Colour (moist)	TC	Structure	Consistency Moist	wet	Drainage	Roots	Hb	others
Upper Coal Measure										
0-26	Ap	2.5YR 4/3	LS	f m sab	fr	np	wd	present	cs	-
26-61	Bt_1	2.5YR 6/6	SCL	mod m sab	fr	sp	wd	present	gs	-
61-127	Bt_2	2.5YR 5/8	SCL	mod m sab	fr	sp	wd	absent	gs	-
127-176	Bt_3	2.5YR 5/8	SCL	mod m sab	fr	sp	pd	absent	gw	-
176-200	C	2.5YR 6/8	SCL	mod m sab	fr	sp	pd	absent	-	Many Stones
Nkporo Shale										
0-29	Ap	7.5 YR 4/4	S	mod co sab	fr	msp	wd	present	cs	-
29-55	A_1	2.5YR 5/4	SL	mod co sab	fr	msp	wd	present	as	-
55-121	Bt	5 YR 5/8	SCL	s co g	fr	sp	wd	present	gd	-
121-200	C	10 R 4/8	SL	mod co g	vf	sp	wd	present	-	-
False Bedded Sandstone										
0-20	Ap	2.5YR 4/3	S	vf w cr	fr	np	wd	present	gs	-
20-62	AB	2.5YR 3/6	S	vf w cr	fr	np	wd	present	cs	-
62-98	B_1	10R 4/6	S	f m mag	fr	np	wd	absent	cs	-
98-161	B_2	2.5YR 4/8	S	f m mag	fr	np	wd	absent	cs	-
161-200	BC	10YR 4/6	S	f m mag	fr	np	wd	absent	-	-

HD = Horizon Designation, TC = Textural Class, LS = Loamy Sand, SCL = Sandy Clay Loam, S = Sand, SL = Sandy Loam. Structure: w - weak, mod - moderate, s - strong, f - fine, m - medium, co - coarse, cr - crumb, gr - granular, sab - sub-angular blocky, b - blocky. Consistency: ns - non-sticky, ss - slightly sticky, s - sticky, vs - very sticky, lo - loose, fm - firm, fr - friable, vf - very firm. Boundary: a - abrupt, c - clear, g - gradual, d - diffuse, s - smooth, w - wavy, i - irregular. Drainage: wd - well drained, pd - poorly drained

Table 3: Physical characteristics of the soils of the study area.

Horizon	Depth (cm)	Clay	Silt (g kg^{-1})	Sand	Textural Class	BD (g cm^{-3})	MAP	MIP (%)	TP	Ksat ($cmhr^{-1}$)
Upper Coal Measure										
Ap	0 – 26	110	70	820	LS	1.71	11.28	34.43	45.71	87.68
Bt1	26 – 61	270	90	640	SCL	1.67	13.99	29.54	43.33	77.78
Bt2	61 – 127	250	50	700	SCL	1.76	14.61	32.08	46.69	66.67
Bt3	127 – 156	250	70	680	SCL	1.83	11.63	31.4	43.03	33.94
C	176 – 200	250	70	680	SCL	1.8	13.93	28.98	42.91	38.89
CV (%)		25.89	18.07	65.49		3.32	10.38	6.21	3.52	34.75
Nkporo Shale										
Ap	0 – 21	50	30	920	S	1.41	18.01	33.90	51.91	16.81
A_1	21 – 55	190	170	640	SL	1.75	20.07	28.19	48.26	11.62
Bt	55 – 121	230	130	640	SCL	1.58	15.40	25.35	40.75	12.61
C	121 – 200	190	110	700	SL	1.70	16.13	24.22	40.35	12.61
CV (%)		41.44	46.35	41.44		8.13	10.40	13.42	10.90	14.93
False Bedded Sandstone										
Ap	0 – 20	50	30	920	S	1.50	12.08	39.27	51.35	13.89
AB	20 – 62	50	30	920	S	1.42	11.15	41.09	52.24	3.27
Bt	62 – 98	70	30	900	S	1.51	12.35	44.71	57.06	1.73
BC	98 – 161	70	30	900	S	1.81	14.58	35.75	50.33	4.36
2BC	161 – 200	70	30	900	S	1.76	13.12	37.39	50.51	8.89
CV (%)		15.80	0	6.06		9.69	9.09	7.83	4.73	68.90

LS = Loamy Sand, SCL = Sandy Clay Loam, S = Sand, BD = Bulk Density, MAP = Macroporosity, MIP = Microporosity, TP = Total Porosity, Ksat = Hydraulic Conductivity

Table 4: Chemical characteristics of the soils of the study area

Horizon	Depth (cm)	pH H_2O	pH KCl	SOM (g kg^{-1})	TN (g kg^{-1})	Exchangeable Cations Na^+	K^+	Ca^{2+}	Mg^{2+}	TEB	Exch. Acidity Al^{3+}	H^+	TEA	CEC	BS (%)	Av.P mg kg^{-1}
						cmol kg^{-1}										
Upper Coal Measure																
Ap	0 – 26	5.0	4.8	1.20	1.50	0.04	0.07	3.40	0.80	4.31	0.40	0.20	0.60	6.00	71.83	0.93
Bt1	26 – 61	5.0	4.8	1.24	0.30	0.03	0.05	3.20	0.40	3.68	0.80	0.60	1.40	12.40	29.68	0.93
Bt2	61 – 127	6.3	4.8	0.96	0.30	0.03	0.05	3.20	0.60	3.88	2.00	0.20	2.20	9.60	40.42	0.93
Bt3	127 – 156	6.8	4.9	0.69	0.60	0.02	0.05	3.00	1.60	4.67	0.60	0.20	0.80	5.60	83.39	0.93
C	176 – 200	6.6	5.0	0.62	0.40	0.02	0.05	3.00	1.20	4.27	0.60	0.20	0.80	5.20	82.12	0.93
	CV (%)	13.20	1.64	26.98	73.13	26.72	14.81	4.74	46.83	8.35	65.24	57.14	50.44	36.10	36.13	0
Nkporo Shale																
Ap	0 – 21	7.3	6.5	2.12	0.60	0.05	0.08	5.00	0.80	5.93	0.40	0.60	1.00	10.00	59.30	4.66
A_1	21 – 55	6.0	4.8	1.45	1.40	0.04	0.07	3.60	0.60	4.31	0.40	0.60	1.00	9.60	44.90	0.93
Bt	55 – 121	5.5	4.8	1.10	0.30	0.03	0.05	3.60	0.40	4.08	1.20	0.20	1.40	8.80	46.36	0.93
C	121 – 200	6.9	4.9	0.83	0.70	0.03	0.05	3.80	0.40	4.28	0.80	0.40	1.20	7.20	59.44	0.93
	CV (%)	11.08	13.77	35.13	53.75	22.11	20.78	14.58	30.15	16.01	40.82	36.85	28.17	12.05	13.12	66.73
False Bedded Sandstone																
Ap	0 – 20	6.0	5.1	1.10	0.70	0.04	0.07	2.60	0.40	3.11	0.60	0.80	1.40	10.00	31.10	3.73
AB	20 – 62	6.1	5.1	1.10	0.30	0.03	0.05	2.60	0.40	3.08	0.60	0.20	0.80	10.00	30.80	2.80
Bt	62 – 98	6.3	5.0	1.10	0.40	0.03	0.05	2.40	1.00	3.48	0.60	0.60	1.20	9.00	37.83	0.93
BC	98 – 161	5.8	5.0	0.14	0.30	0.01	0.03	2.80	0.40	3.24	0.60	0.20	0.80	12.40	26.13	0.93
2BC	161 – 200	6.3	5.1	0.62	0.40	0.01	0.03	3.80	0.20	4.04	0.60	0.60	1.20	10.40	38.85	2.80
	CV (%)	3.11	0.97	47.29	35.00	50.00	32.54	17.48	56.52	4.89	0.00	50.00	13.61	10.81	14.44	50.07

Table 4: Classification of soils of the study area

Geological Formation	Order	Suborder	Great group	Sub group	FAO/UNESCO WRB
UCM	Alfisols	Ustalfs	Haplustalfs	Typic Haplustalfs	Loamic Lixisols
NS	Oxisol	Ustox	Eutrustox	Typic Eutrustox	Loamic Lixisols
FBS	Ultisols	Ustults	Kanhaplustults	ArenicKanhaplustults	Arenic Acrisols

UCM = Upper Coal Measure, NS = Nkporo Shale, FBS = False Bedded Sandstone

3.6 Land Evaluation

Table 5 shows the suitability ratings for the production of pepper in the Nsukka area. The results indicate that UCM soils are moderately suitable (S_2), while NS and FBS soils are marginally (S_3) and not suitable (N) respectively for pepper production. In UCM, inadequate annual rainfall poses a significant limitation for pepper cultivation, as it falls below the recommended 2000 mm. Implementing water conservation strategies like mulching and efficient irrigation management can improve suitability from morderately (S_2) to highly (S_1) suitable. Another constraint in UCM and NS formations is low organic carbon content, which is below the critical level of 2 g kg^{-1} (Esu, 1991), rendering the areas moderately (S_2) and marginally (S_3) suitable respectively. Adding organic matter is advised to increase organic carbon content and maintain soil health. FBS, with its sandy texture, presents a major limitation for pepper cultivation, making the entire area not suitable (N). According to Naidu *et al*. (2006), sandy clay loam, loam, clay loam, and sandy clay soils are highly recommended for optimal pepper production. Incorporating organic matter, like compost, can enhance soil structure, nutrient content, and water-holding capacity in sandy soils.

Table 5: Suitability evaluation of the soils for pepper production

Land qualities	Unit	UCM	FBS	NS
Climatic regime				
Mean temperature in growing season	°C	S_1	S_1	S_1
Total Rainfall	mm	S_2	S_2	S_2
Topography				
Elevation	m	S_1	S_1	S_1
Wetness				
Soil drainage	class	S_1	S_1	S_1
Soil physical properties				
Texture	class	S_1	N	S_2
Effective soil depth	cm	S_1	S_1	S_1
Soil chemical properties				
OC	%	S_2	S_3	S_3

UCM= Upper Coal Measure, FBS = False Bedded Sandstone and NS = Nkporo Shale

4.0 Conclusion

The soil analysis revealed slightly acidic pH for NS and FBS, and moderately acidic pH for UCM. Nutrient levels, including nitrogen, phosphorus, exchangeable bases, and acidity, were generally low. Base saturation varied, with UCM showing a range from low to high, NS being moderate, and FBS being low. Organic carbon content was low to moderate. According to soil classification systems, UCM, NS, and FBS were categorized as specific soil types. UCM soils were moderately suitable for pepper production, while sandy texture in FBS and low organic carbon in NS made them unsuitable or marginally suitable for pepper cultivation.

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