PEDOLOGY OF SOILS ON THE FOOT OF THE MAMBILA PLATEAU WINDWARD IN THE GUINEA SAVANNA, NORTH-EAST NIGERIA

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Abstract:

A pedological investigation was carried out on the soils on the foot of the Mambila plateau windward in the guinea savanna, north-east Nigeria. The soils of Ussa in Ussa local government area of Taraba was used for the study. Ussa was selected for the study based on the high amount of precipitation and its toposequence. Based on the criteria of USDA soil taxonomy, the soils were classified as Typic isohyperthermic kandihaplustults and this corresponds to Arenic Acrisol (WRB). Three land use pattern was used in the identification and delineation. The profile pits were sunk and samples were collected based on horizon differentiation. Most horizons had greater than 76% sand, 4.28% silt and 8.07% clay with a distinct clay bulge at the B horizons. The preponderance of sand is attributed to translocation of finer soil particles and the major textural class was sandy loam. The soils have reddish brown as the dominant hue (5YR5/3, 5YR7/6, 10YR6/8, 10R7/4). The bulk density was low with a corresponding high porosity. The soils had strong pH mean value 5.09, 5.06 and 5.18% for the oil palm, arable land and floodplain pedons respectively. Low OC mean values in all the profiles (6.4 g/kg, 4.0 g/kg and 2.8 g/kg for the oil palm, arable land and floodplain pedons respectively). The ECEC has the highest mean value (6.71 cmol/kg) at the oil palm landuse. The available phosphorus ranges from very low to low in all the profiles (3.55 mg/kg, 3.75 mg/kg and 2.61 mg/kg), the base saturation (%) very low (25.10%, 23.01% and 23.38%) with preponderance of Ca and Mg of the basic cation in the exchange site. The mineralogy of the soils was dominated by quartz and kaolinite. Single use of urea fertilizer will increase the chances of acid forming agents (H^+). The use of N:P:K (20:10:10) fertilizer and use of integrated soil fertility/nutrient management is recommended.

Key words: pedological properties, topography, precipitation, landuse

Introduction

Soil's inherent characteristics on the foot of the plateau are generally governed by topography (valley bottom) and climate (rainfall/ precipitation) and to some extent landuse practices. However, it is the topography and climate itself that informs landuse pattern. Soil pedology focuses on understanding and characterizing soil formation, evolution, and the theoretical frameworks through which we understand a soil body(s), often in the context of the natural environment. Among the key components of pedological properties of the soil are the morphological, physical and chemical characteristics of the soil (Obasi *et al.,* 2021). Topography and landuse on the other hand influences use- dependent properties of the soil and this according to Ibia et al (2010) are soil organic carbon, bulk density, pH, salinity, aggregate stability. The use- dependent properties were termed/ referred to as dynamic soil properties (Tugel *et al* 2005). These dynamic properties are characterized as those changes possible within human life frame (Grossman *et al* 2001). The activities of climate are mainly via precipitation (intensity and duration) and temperature and its ability to speed up the rate of soil reaction and degradation. Topography is both internal and external factor in pedogenesis as it affects soil formation or a consequence of same (Ibia *et al* 2010, Temgoua *et al* 2005). The differences between soils of a toposequence are generally related to physiogragrphic positions as different geochemical condition and drainages are experience depending on hydrology (Lucas and Chanvel, 1992). According to Ayoade (1993), who stated climate near the ground, is influenced by landscape features, vegetation and man through his various activities, he further stated that geomorphological, pedological and ecological processes and the forms they give rise to can only be properly understood with reference to the climate prevailing. The hydrology of an area is primarily related to amount precipitation and nearness to water bodies. Agroclimatic condition of any area is influenced by the direction of moisture laden wind, pressure and temperature of wind and the obstacles it encounters, this influences the rate of precipitation and hydrology of the area. The soils on the foot of the Mambila plateau on the windward direction has not been given much scholarly attention, hence this work is to assess the influence of the interplay of topography and climate on the properties of soil in the study area in Ussa, Ussa local government area of Taraba state Northeast Nigeria. The objectives of this work were therefore to understudy the properties of the soil with a view to improve the agricultural productivity of the land and to characterise and classify the soil according to the criteria of the USDA soil taxonomy system and correlate with those of world reference base for soil resources classification system (FAO, 2006).

Materials and Methods

Study Area

The study area is Ussa, southern Taraba state. It lies on latitude 7° 10’ - 8°40’ N and longitude 9°30’- 10° 10’ E with an elevation of about 262 meters above sea level (figure 1). Ussa local government area occupies an area of about 4126km^2 and located at the foot of highest point in Nigeria (Gembu-Mambila plateau of about 2419 masl) where the Mandara hills begins from (Esu and Akpan-Idiok, 2010). The geology of the area is the cretaceous sediment over igneous and metamorphic undifferentiated basement complex rock resulting in sandstone as the chief parent material. Other soil forming processes apart from topography and climate are argillipedoturbation and fauna activities. The landscape is characterized by undulating landform. Rock outcrop is common and abundance termitaria and anthills. The climate of the area is typic tropical, characterized by marked distinctive wet and dry seasons the mean annual precipitation ranges between 1500-2200mm. The rainy months are April-October and dry months are November-March. The rainy months are characterized by heavy rainfall, high relative humidity and heavy cloud cover akin to what is obtained in south eastern Nigeria (Senior Secondary Atlas, 2005). The hydrology of the study area is governed by river Kashimbila. The vegetation ranges from forest-grassland-savanna characterized by indigenous trees such as *Daniella olivera, Pyteracarpus erinaceous (Rose wood).*The major socioeconomic activities in the area is farming (arables and tree cropping) and fishing. The major produce is maize, cassava, soybean, groundnut, rice, palm oil, cocoa, oranges, mangoes, plantain.

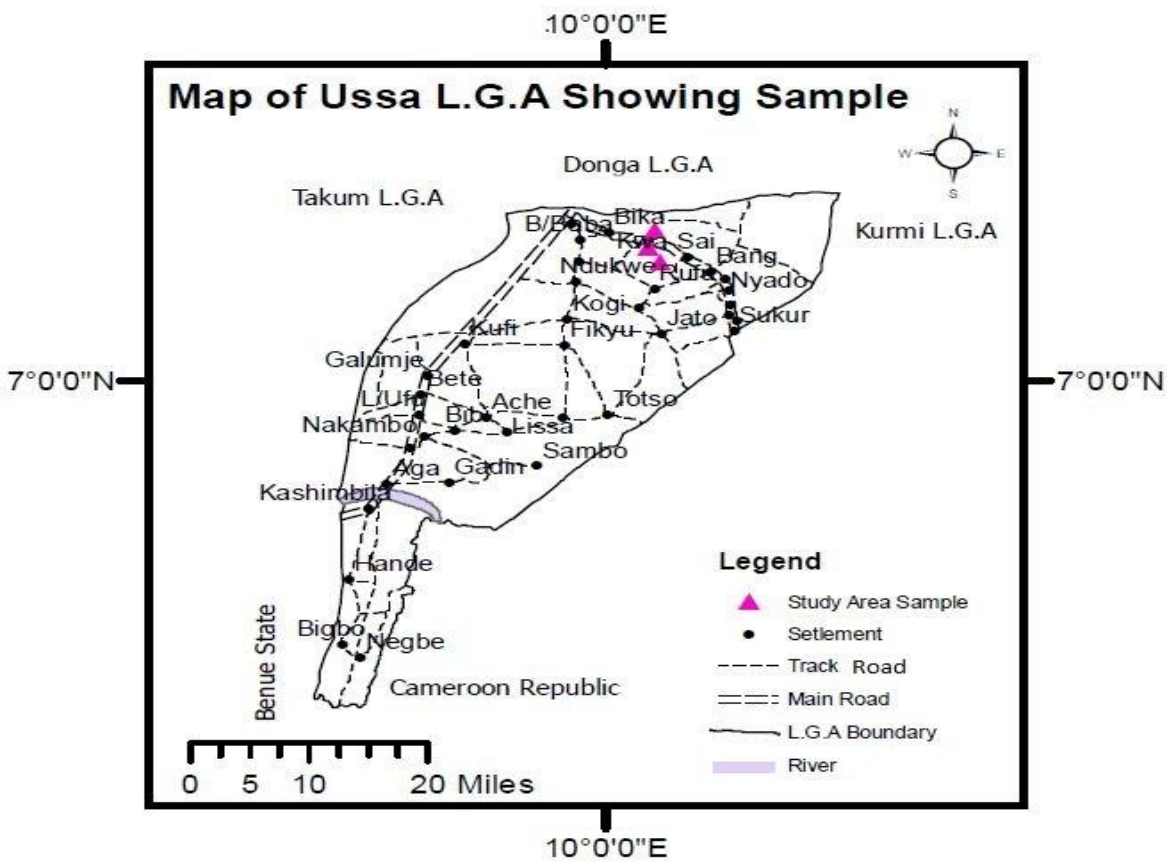

Figure 1: Map of the study Areas Showing Pedon Sampling Points

Field Work

The field study was free survey conducted based different land uses namely; oil palm plantation, fadama land and fallowed arable land. At each site, a profile pit was sunk to reveal the intrinsic properties of the soil. Samples were collected based on horizon differentiations and profile description was as described by Nwaka (2000). The soil samples collected were analyzed for morphological, physical and chemical properties.

Laboratory Analysis

The pH was determined by glass electrode ph meter, particle size analysis was by hydrometer method. Organic carbon was determined by wet dichromate method. Total nitrogen was determined by micro-Kjeldal method. Extraction of available phosphorus was done using Bray 1 method. Exchangeable cation (K, Ca, Mg, and N) were extracted by neutral normal ammonium acetate, K and Na in the extraction were determined by flame photometer while Ca and Mg were by atomic absorption spectrophotometer. Cation exchange capacity was by summation method. The exchangeable acidic cations: hydrogen and aluminium were estimated titrimetrically. Bulk density was measured by core method (Grossman and Reinsch, 2002). Total porosity (P_o) was obtained from bulk density (ℓp) values with assumed particle density (ℓs) 2.65 g cm^{-3} as follows,

$$\text{Porosity (F)} = 100 - (\frac{e_b}{e_s}) \times \frac{100}{1}$$

Where e_b = bulk density (g/cm^3)

e_s = particle density (2.65g/cm^3

Statistical Analysis

Statistical analysis was performed using Genstat statistical package for mean, ANOVA and simple correlation at 1% and 5% levels of probability.

Results and Discussion

Soil Morphology

The morphological properties of the soils are presented in table 1. The soil formed under the influence of topography and climate is somewhat well drained and fewer to no mottles an indication of aerobic conditions characteristics of Ultisols. The oil palm plantation soil possess reddish brown (5YR5/3) loamy surface soil over a not too contrasting sub soil (reddish yellow 5Y5/3) and pink (5YR7/4) and yellow (5YR7/6). The reddish and yellowish coloured subsurface soils may be due to excessive (relative) rainfall, well drained nature of the soil with oxidized iron and laterization process (Ofem and Esu, 2015). The structure ranges from granular to sub angular blocky with clear horizon boundaries and the consistence is friable. The arable soil pedon showed brownish yellow (10YR6/8) in the Ap horizon followed by sub soil B to Bt horizon showing a more intense contracting colour. The peds are arranged in sub angular blocky with few mottles in the B-horizons. The floodplain soils in the study area has colours ranging from black (7.5YR 2.5/1) in the Ap horizon to pale red (10R7/4) and pink (5YR7/6) and 2.5YR8/2. The dark colour in this pedon are indicative of depositional activities of erosion and condition characteristics of hydric soil common to floodplains with reduced aeration leading to pale or pinkish colouration down the profile. The textural classes are loam in the Ap horizon and sandy clayey loam/ sandy loam in the B and Bt horizons for the oil palm plantation while the arable land has sandy loam in the Ap and Bt2 horizons, loamy sand in the B-horizon with sand in the Bt1

Table1: Soil Morphological Properties of soils in Ussa

Landuse	Horizon Design.	Depth	Colour (moist)	Structure	Mottles	Horizon Boundary	Texture	Const.	Vegetation	Root Presence
Palm Plantation (Pedon 1 7^{0}10’48.5’’N and 10^{0}03’51.5”E) 262masl										
	AP	0-30	Reddish Brown 5YR 5/3	Granular/ Crumby	Fewer mottles	SC	LS	Friable	Secondary Regrowth	Common (vf-c)
	AB	30-60	Reddish Yellow 5Y 5/3	Sub-angular blocky	Fewer mottles	SC	SCL	Friable	Secondary Regrowth	Many (vf-c)
	Bt1	60-80	Pink 5YR7/4	Sub-angular blocky	Fewer mottles	SC	SL	Friable	Secondary Regrowth	Many (m-c)
	Bt2	80-100	Yellow 5YR 7/6	Sub-angular blocky	Fewer mottles	SC	SL	Friable	Secondary Regrowth	Few (m-c)
Arable Land (Pedon 7^{0}12’02.5’’N and 010^{0}03’01.1”E) 258masl										
	AP	0-25	Brownish yellow 10YR6/8	Granular/ Crumby	None	SC	SL	Friable	Secondary Regrowth	Common (vf-c)
	B	25-55	Reddish Brown2.5YR7/4	Sub-angular blocky	Fewer mottles	SC	LS	Friable	Secondary Regrowth	Many (vf-m)
	Bt1	55-75	Dark yellowish brown 10YR4/6	Sub-angular blocky	Fewer mottles	SC	S	Friable	Secondary Regrowth	Many (vf-m)
	Bt2	75-100	Brownish yellow 10R 6/6	Sub-angular blocky	Fewer mottles	SC	SL	Friable	Secondary Regrowth	Few (m-c)
Swampy Area (Pedon 7^{0}13’30.8’’N and 10^{0}03’28.9’’E) 260masl										
	AP	0-37	Black 7.5 2.5/1	Granular/ Crumby	Fewer mottles	SC	S	Friable	Secondary Regrowth	Common (vf-m)
	B	37-75	Pale red 10R7/4	Sub-angular blocky	Fewer mottles	SC	LS	Friable	Secondary Regrowth	Many (vf-m)
	Bt1	75-100	Pink 5YR 7/6	Sub-angular blocky	Fewer mottles	SC	LS	Friable	Secondary Regrowth	Many (f-m)
	Bt2	100-150	Pink 2.5YR 8/2	Sub-angular blocky	Fewer mottles	SC	S	Friable	Secondary Regrowth	Few (vf-f)

The flood plain land use has sand and loamy sand as its textural classes. The structure of the soil is predominantly sub angular blocky moderate to medium weak grade and the higher clay content at the sub surface horizons accounts for greater aggregation hence firmer consistency and this agrees with the finds of Obalum et al (2012).

Physical Characteristics of the Soil

The soil physical properties are presented in table 2.the particle size distribution data indicates the preponderance of sand in all the pedons in the study area, this suggests the impact of parent material and climate (precipitation) as translocation of finer soil particles in to the sub soil horizon. This agrees with the findings of Esu and Akpan-Idiok (2010) where they studied the morphological, physico-chemical properties of soil in Adamawa state. The irregular profile depth distribution of clay in the argillic (Bt) horizon attests to the stratified nature of the parent materials. The average silt/clay ratios (SCR) were 1.75, 0.28 and 0.82 and SCR of < 1 is an index for the extent of weathering (Imadojemu, et al 2017; Oleghe and Chokor, 2015). In their reports SCR (< 1) also indicates reserved weatherable mineral in the substratum. The silt may have undergone transformation in to clay or has been eroded into lower landscape. The total porosity mean values of 52.93, 46.23 and 47.27 % for the oil palm, arable land and floodplain pedons respectively and the low total porosity observed in the arable landuse agrees with the work of Omenihu and Opara-Nadi (2015) where they find out that conventional tillage (CT) induced the lowest total porosity as a result of high bulk density. The bulk density values were generally lower than 1.60 g/cm3 an indication that air and water movement in the soils are at optimum for plant development (Esu, 2010).

Table 2: Physical Properties of the Soils in Ussa

Horizon	Depth (cm)	Sand	Silt %	Clay	SCR	TC	BD g/cm^3	Po %
PEDON 1 7^{0}10'48.5''N and 10^{0}03'51.5"E								
A	0-30	85.92	4.28	9.80	0.4	LS	1.34	49.44
Bt1	30-60	74.42	3.50	22.08	0.2	SCL	1.20	54.72
Bt2	60-80	78.92	6.28	14.80	0.4	SL	1.14	56.99
Bt3	80-100	67	14.2	18.80	0.7	SL	1.31	50.56
Mean		76.56	7.07	16.37	1.75		1.25	52.93
PEDON 2(7^{0}12'02.5''N and 010^{0}03'01.1"E)								
Ap	0-25	67.92	9.28	22.80	0.4	SL	1.51	43.02
AB	25-55	85.92	1.28	12.80	0.1	LS	1.31	50.57
BA	55-75	88.92	2.28	8.80	0.3	S	1.47	44.53
Bt1	75-100	78.92	4.28	16.80	0.3	SL	1.41	46.79
Mean		80.42	4.28	15.3	0.28		1.43	46.23
PEDON 3 (7^{0}13'30.8''N and 10^{0}03'28.9''E)								
A	0-37	89.28	2.12	8.60	0.2	S	1.38	47.93
Bt1	37-75	85.28	1.12	13.60	0.1	Ls	1.29	51.32
Bt2	75-100	86.28	0.12	13.60	0.009	Ls	1.53	42.27
Bt3	100-150	93.28	0.12	6.60	0.02	S	1.39	47.55
Mean		88.55	0.87	10.6	0.82		1.40	47.27
$LSD_{(0.05)}$		11.79	5.66	8.07	0.2375		0.149	5.64

Chemical Characteristics of the Soil

The chemical properties of the studied soils are presented in table 3. The pH of the soils with a mean value of 5.09, 5.06 and 5.18 for the oil palm, arable land and floodplain pedons respectively. These indicated that the soils were strongly acidic and shows that there are significant exchangeable AL^{3+} and H^+ hence the entire soil will have net negative charges on soil colloids and this will engender cation adsorption on the soil exchange complex site (Kolay, 2002). The organic carbon was generally low with the highest value of 11.7 g/kg recorded in the top soil of the oil palm land use with a sharp decrease in the subsoil (FMANR, 1990). Asadu et al (2012) stated that coarse textured soils were usually low in soil organic compound. The nitrogen content of the soil were rated low and this agreed with those reported by Wapa and Olowookere (2013). The CN ratio were less than 25 an indication for low nitrogen forms in the soil which has impact on the rate of soil organic matter (SOM) transformation while mean values for available phosphorus 3.55 mg/kg, 3.75 mg/kg and 2.61 mg/kg for the oil palm, arable land and floodplain pedons respectively. The low values of P may due to phosphorous fixation which is a common problem in tropical soils (Osodeke, 2017). The lowest mean value was obtained in the floodplain pedon, though these values are generally low for the requirement of most crops. The exchangeable cations: Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} had mean values of 0.61cmol/kg. 0.32 cmol/kg, 2.91 cmol/kg and 0.58 cmol/kg respectively in the oil palm pedon and it tend to increase down the profile while for the arable pedon a decreasing trend was observed whereas for the floodplain pedon an irregular pattern was observed.the total exchangeable acidity: Al^{3+} and H^{+} had mean values of 5.03 cmol/kg, 5.13 cmol/kg and 4.98 cmol/kg for the oil palm, arable land and floodplain pedons respectively. These mean values suggest strong acidity and could lead to management problem requiring liming. This acidity problem is due to leaching of basic cation occasioned to high amount of precipitation which create semblance to soils of south eastern Nigeria (Onweremadu, 2007a&b). The base saturation was low with mean values of 25.10 %, 23.01 % and 23.38 % for the oil palm, arable land and floodplain pedons respectively. However, the low %BS recorded agrees the findings of Onweremadu (2008) on soil quality morphological index in assessing soil health of a floodplain in southeastern Nigeria. The low values of percentage base saturation are characteristic of highly weathered soil and falls in the soil order of ultisols (USDA, 2015 and Soil Survey Staff, 2006) while a very high %BS was recorded in not too far away Manya soils (Imadojemu et al 2022). The ECEC of the studied pedons rated low to medium with the mean values as 6.71 cmol/kg, 6.65 cmol/kg and 6.49 cmol/kg for the oil palm, arable land and floodplain pedons respectively. This is in agreement with the works Osujieke et al (2017), Oti (2007) and Ojanuga and Awojuola (1981). They both suggested that dominance of kaolinitic clay minerals, high rainfall, leaching of basic cations, low organic matter content and parent materials as the leading cause of low values of ECEC in tropical soils. The correlation matrix (table 4) indicated highly significant correlation between soil properties. SCR had negative but significant correlation with sand and clay, while TEB had negative but significant relationship with sand, it however, had positive correlation with clay. % BS had a positive highly significant correlation with TEA while it had negative highly significant relationship with soil pH, the relation with the pH is not unconnected with the acid soil which has now left the cation exchange site to be dominated by Al^{3+} and H^{+}

Table 4: Correlation matrix of selected physical and chemical Properties of the soils in Ussa

SAND	1												
SILT	-0.87**	1											
Clay	-0.92**	0.61*	1										
SCR	-0.71**	0.93**	0.41	1									
BD	0.16	-0.15	-0.15	-0.19	1								
pH	-0.23	-0.20	0.12	O.15	0.01	1							
OC	-0.40	0.20	0.96	0.42	-0.22	-0.37	1						
TN	0.26	-0.13	0.64	-0.33	-0.98	0.42	-0.27	1					
Av,P	0.21	0.10	0.25	0.12	-0.32	-0.64	0.15	0.13	1				
TEB	-0.83**	0.64*	0.86**	0.47	-0.19	-0.93	-0.55	-0.97	0.05	1			
TEA	0.08	-0.17	0.01	-0.13	0.15	0.03	-0.41	-0.43	-0.19	-0.83	1		
ECEC	-0.35	0.16	0.44	0.13	0.04	-0.21	-0.40	-0.44	-0.15	-0.44	0.86**	1	
BS	-0.73**	0.59*	0.71**	0.45	-0.22	-0.11	0.02	0.11	0.15	0.88**	-0.54	0.14	1

Soil Classification

Based on the criteria of USDA soil taxonomy (2015), the soils meet the requirement (based on diagnostic horizons) for placement in the order; Ultisols (where leaching,eluviation and illuviation and subsequent accumulation of clay at subsurface horizon in an acidic environment as well as presence of/or occurrence of coarse-textured overlying a horizon with clay augmentation) since the percentage base saturation by NH_4OAC at pH 7.0 is less than 50% in the Bt horizon with an argillic/ kandic diagnostic subsurface horizons in the sub order as ustult and aquult for floodplain soils. The rainfall amount and soil characteristics were similar to those recorded for southeastern Nigeria (Onweremadu, 2008). The preponderance of sand in all the horizons, the moisture regime and the decrease of clay by > 20% indicated psammentic haplustults (great group). The temperature is isohyperthermic and moisture regime is ustic, the reddish brown colour is an indication of good aeration and oxidation of Fe^{2+} to Fe^{3+}. The soils are therefore Typic isohyperthermic kandihaplustults (sub group) and this corresponds to Arenic Acrisol (WRB, 2006).

Conclusion

The pedology of the soils on the foot of the Mambila plateau windward in the guinea savanna, north-east Nigeria are strongly affected by topography and climate (precipitation). The rainfall amount and soil characteristics were similar to those recorded for Southeastern Nigeria. Other soil forming process in the study are includes eluviation- illuviation of clay (translocation process), kaolinization, argillipedoturbation and faunal activities. They occur on an undulating landform and its morphology showed attribute of soils that is highly leached though with good bulk density as well as total porosity. The dominance sand over silt and clay in all the pedogenic horizons shows the sandiness of the textural class. The soils are inherently low in fertility status. It is characterized by low percentage base saturation and strongly acidic in reaction but low/deficient in basic cations. The low C/N ratios and organic carbon in the profiles studied were low for most tropical crops. Based on the criteria of USDA soil taxonomy the soil were classified as Typic isohyperthermic kanhaplustults and this corresponds to Arenic Acrisol (WRB), hence is placed in S2 suitability class. The use of N:P:K (20:10:10) fertilizer and use of integrated soil fertility/nutrient management is recommended

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