FUTOJNLS 2016 VOLUME-2, ISSUE-1, PP- 48 - 56

Futo Journal Series (FUTOJNLS)
e-ISSN :2476-8456 p-ISSN : 2467-8325
Volume-2, Issue-1, pp- 48 - 56
www.futojnls.org

Research Paper July 2016

Properties of Soils of Contrasting Lithosequences in South-Eastern Nigeria

Ahukaemere, C.M., Onweremadu, E.U. Ndukwu, B.N and Nkwopara, U.N
Department of Soil Science and Technology, Federal University of Technology Owerri, P.M.B 1526 Owerri, Nigeria.

Corresponding email: mildredshine@yahoo.com, innocentck@yahoo.com

Abstract

This study was conducted in 2015 to investigate variability in horizon characteristics of soils underlain by different lithological materials. Three (3) parent materials (False bedded sandstone, Coastal plain sand and Shale) were investigated, and on each parent material, one (1) profile pit was dug. The profile pits were described; and identification and delineation of horizon boundaries were accomplished using FAO guidelines before actual sample collection for laboratory analyses. Soil data were subjected to coefficient of variation (CV) analysis. Results showed evidence of Ochric and Mollicepipedons, Argillic and Kandic diagnostic subsurface horizons. None of the horizons could be classified as Natric horizon hence their ESP values were < 15%. Particle size distribution results showed variations in particle size fractions of the soils across the different parent materials investigated. Soils developed on Coastal plain sand and false bedded sandstone were generally sandy while Shale-derived soils were least sandy and more clayey. Soils developed on the three dissimilar lithological materials were acidic, and low to high in organic matter content. Generally, parent material and other soil forming processes play important role in processes leading to the development of soil horizons and other inherent soil characteristics.

Keywords: *Epipedon, Horizon, Parent material, Soil group, Variation.*

1.0 Introduction

Most soil users in South-eastern Nigeria have regarded the soils to be the same in every respect simply because they are all in the same geographical location. Information on variations in soil properties enables potential users to appreciate the behaviour of the various soil types in the region, so that they can be utilized appropriately to derive optimum productivity. The productivity of a soil depends largely on its properties which are as a result of the interaction among the five soil forming factors (Esu, 1991) and pedogenetic processes occurring in the various horizons of the soil. Where the relative influence of these factors differs, this will give rise to different kinds of soils, with different qualities. Therefore, to ensure optimum soil productivity, it is imperative to understand its inherent characteristics in relation to lithology and horizon differentiation.

Different parent materials affect the morphology and chemistry of soils under the same agro-ecological conditions (Irmak *et al*., 2007). The changes in soil properties affect greatly the soil horizons and their development. It is in this regard that an index was developed to characterize and monitor changes in these horizons in soil survey and land evaluation studies (Grossman *et al*., 2001). Non-use of available information on field morphological evaluation of soil horizons could be responsible for the spate of land degradation in most South-eastern Nigerian soils. Soils of South-eastern Nigeria are formed from diverse lithological materials (parent materials) (Onweremadu *et al*., 2007a). Information on how these parent materials and their corresponding pedogenetic processes influence soil properties in South-eastern Nigeria is limited. Onweremadu *et al*., (2007b) reported on the variability of soil physical shrinkage relationship in some of these parent materials. However, it may be necessary to investigate other soil properties such as horizon characteristics. Based on the above, we investigated the variations in horizon characteristics of soils derived from three different parent materials.

2.0 Materials and Methods

2.1. Site Characteristics

South-eastern Nigeria lies between latitudes 4^o 40^1 N and 8^o 15^1 N, longitudes 6^o 40^1 and 8^o 30^1 E. Soils of the area are derived from vast parent materials including Bende-Ameki Shale, Coastal plain sand, false bedded sandstone, Alluvium, Lower coal measure and Upper coal measure. The study area has tropical climate with two seasons, the rainy season which lasts from April to October and dry season which is from mid-November to March. This area receive average rainfall of 2,134 mm and daily temperature ranges from 21 ^{o}C to 34 ^{o}C (NIMET, 2014). The relative humidity reaches a minimum of 60 % in January (at the peak of the dry season) and rises to 70 - 85 % in July (at the peak of the rains). The original vegetation of the region was the tropical rain forest (FDALR, 1985), which has however been destroyed largely through anthropogenic activities.

2.2. Field Studies

A reconnaissance study of the sites was conducted in the early 2015; and this was followed by field sampling. Three (3) parent materials (False bedded sandstone, Coastal plain sand and Shale) were randomly selected and on each soil group, one (1) profile pit was dug. The study sites and profile pits were geo-referenced with the aid of a hand held Global Positioning System (GPS) receiver. The profile pits were described using FAO, (2006) guidelines. Delineation of horizon boundaries was accomplished before actual sample collection for laboratory analyses and samples were collected according to horizons. A total of 42 soil samples were collected for the study. The soil samples were air dried, crushed and sieved through a 2 mm sieve mesh. Ten grams (10 g) of each sample was finely ground and preserved for determination of organic carbon and total nitrogen. Undisturbed soil samples for determination of bulk density were collected using core samplers.

2.3. Soil Analyses

Soil colour was determined using Munsell colour chart while other macro-morphological properties were determined by measurement (using tape and meter rule), visual observation and hand feel in the field. The physical and chemical properties of the soil samples were determined using routine analytical methods. The processed soil samples were analyzed for some physico-chemical properties following procedures outlined in Soil Survey Staff, (2010).

2.4. Data Analysis

The variability of soil properties within the horizons of the profiles was measured by estimating coefficient of variation (CV). The coefficient of variation was ranked according to the procedure of Wilding (1985) where cv $\leq$ 15 % = low variation, cv > z15 $\leq$ 35 % = moderate variation, cv > 35 % = high variation.

3.0 Results and Discussion

3.1 Morphological Properties of Soil

The details of the macro-morphological properties of soils are presented in Table 1. Soils were generally deep ensuring a good foothold for arable crops. Thin epipedon was observed (17 cm, 12 cm) in soils derived from Falsebedded sandstone while thick epipedons were observed in those derived from the Coastal plain sand (28 cm, 21 cm) and Bende-Ameki Shale (28 cm, 42 cm). The epipedal horizons across the parent materials showed evidence of cultivation practices as indicated by the presence of a plough layer (Ap horizon – Anthropic epipedon). An Ochricepipedon was observed in soils derived from the Falsebedded sandstone due to thin horizon ($\leq$ 17 cm), light coloured and low organic carbon content while mollicepipedon was observed in soils derived from Shale due to horizon thickness greater than 25 cm, high organic carbon content (32 - 63 g/kg) and base saturation > 50 %. Also, organic matter content of < 2.5 % (< 25 g/kg) recorded in soils of the Coastal plain sand is an indicative of a well-developed ochricepipedon.

In the three parent materials, there was presence of argillic and kandic diagnostic subsurface horizons (Bt) as a result of the development of clay-enriched horizons, horizon thickness and colour. In Coastal plain sand-derived soils, there was evidence of clay movement resulting to downward increase in clay content with well-developed argillic horizon. Argillic horizon is a diagnostic subsurface horizon that contains a significantly higher percentage of clay than the overlying soil material and shows evidence of clay illuviation (Wilson *et al*., 2010; Bockheirm & Hartemink, 2013). They further opined that these horizons and related horizons have been particularly important in soil stratigraphy, relative dating, pedo-diversity studies and climate change research. In addition, in soils derived from Bende-Ameki Shale , there was evidence of the development of the kandic horizon in the deepest horizon and its corresponding overlying horizons due to the presence of thick horizon (> 28 cm), irregular distribution of clay down the profile and low effective cation exchange capacity (ECEC) (< 12 $cmolkg^{-1}$).

Soils developed on the different parent materials had varying colours. The colour of soils derived from Falsebedded sandstones ranged from reddish brown (10 R 3/4) (moist) to reddish orange (10 R 6/8) (moist)**.** In soils derived from Bende-Ameki Shale, soil colour varied from grayish brown (10 R 4/8) (moist) to brownish red (7.5 R 5/3) (moist) while in Coastal plain sand , soil colour ranged from reddish brown (5 YR 5/3) (moist) to red (10 R 5/8) (moist). The variation in soil colour could be attributed to the iron content, organic carbon content, soil water content, texture and topography. The colour of iron containing soil minerals that undergo oxidation and reduction reactions can provide useful information on the hydrologic condition of soil and other related soil properties (Viscarra *et al*., 2006; Akbas, 2014).

Table 1: Macro-Morphological Properties of Soil

Depth (cm)	Hor.	Soil Colour (moist)	Horizon boundary	Soil structure	Consistency (moist)	Consistency (dry)	Texture
			Falsebedded sandstone				
0-17	Ap	10 YR ¾	Wavy& gradual	2, c sb.	Very Friable	Soft	LS
17-29	AB	10 YR 4/4	Wavy & gradual	2, c sb.	Friable	Slightly hard	LS
29-46	Bt1	10 YR 4/8	Smooth &diffuse	2, me. Sb.	Firm	Slightly hard	LS
46-98	Bt2	10 YR 5/8	Smooth & clear	3, c ab.	Very firm	Very hard	LS
98-178	Bt3	10 R 6/8		3, v c ab	Very firm	Very hard	LS
		Coastal plain sand					
0-28	Ap	5YR 5/3	Smooth & diffuse	1, f gr.	Very friable	Lose	LS
28-49	AB	5YR 5/6	Wavy & gradual	1,me gr.	Friable	Soft	LS
49-114	Bt1	7.5YR 4/4	Smooth & gradual	2, c sb.	Friable	Slightly hard	LS
114-150	Bt2	5YR 4/6	Wavy & gradual	2, me sb	Firm	Slightly hard	SL
150-200	Bt3	10R 5/8		2, me sb	Firm	Hard	SL
		Shale					
0-28	Ap	10 R 4/2	wavy gradual	2, me, sb.	Firm	Hard	C
28-70	AB	7.5 R 4/2	Wavy gradual	2, me, sb	Firm	Hard	C
70-89	Bt	5 Y6/2	Smooth &diffuse	2, c, sb.	Firm	Hard	C
89-117	Bss	7.5 R 5/3		2, v c sb.	Very firm	Very hard	C

Hor. = Horizon, **Texture**: LS = Loamy sand, SL = Sandy loam, S = Sand, C = Clay. **Structure:** 1 = weak, 2 = moderate, 3 = strong, me = medium, V = very , f = fine, c = coarse, gr. = granular, sb = sub-angular blocky, ab = angular blocky.

In soils formed from the Falsebedded sandstone, soil texture was mainly loamy sand. Sub-angular and angular blocky structures were common in the horizons of the profile. Structural grade was observed to be moderate at the epipedon and stronger with increasing depth of the profiles. In soils of the Coastal plain sands, soil texture ranged between sandy loam and loamy sand. Soil consistence (moist) ranged from very friable at the surface horizons to firm at the subsurface horizons. Weak granular structure was common in the surface horizon and changed to moderate sub-angular blocky down the profile. The change in structural grade from weak at the surface horizon to moderate down the profile in soils derived from the Coastal plain sand could be attributed to the increase in clay content down the profile (Yakubu & Ojanuga, 2013). Soils developed on Shale had clayey texture with sub-angular blocky structure across the horizons of the profile. Soil consistence (moist) varied from firm at the epipedon to very firm down the profile.

However**,** results showed variations in morphological properties of the soils across the different parent materials. These properties varied possibly due to differences in the composition of the parent rock, land use history and other soil forming factors (Akamigbo, 1999; Ahukaemere *et al*., 2012).

3.2 Physical Properties of Soil

The profile distributions of the physical properties of the soils are presented in Table 2. With exception of the pedon developed on the Coastal plain sand, the distribution of clay down the profile showed low variation (cv < 15 %) (Table2) revealing horizons homogeneity and precludes the existence of well-developed argillic horizons in these soil profiles. The mean bulk density values (1.24 -1.38 gcm^{-3}) recorded across the soils investigated were below the value quoted as the minimum bulk density at which rootrestricting conditions will occur (1.75 – 1.80 Mgm^{-3}) (Soil Survey Staff, 2003) indicating that the soils were not compacted (Ahukaemere *et al*., 2012). In individual profile, bulk density generally increased down the pit in all the soils. The results of coefficient of variation analysis showed low to moderate variation in the vertical distribution of the bulk density values (Table 2).

Table 2. Physical Properties of Soil

Depth (cm)	Horizon	Sand (gkg^{-1})	Silt (gkg^{-1})	Clay (gkg^{-1})	BD (gcm^{-3})	MC (%)
Falsebeddedsandstone						
0-17	Ap	824.00	108.00	68.00	1.12	8.2
17-29	AB	804.00	128.00	68.00	1.30	9.61
29-46	Bt1	844.00	68.00	88.00	1.15	9.07
46-98	Bt2	764.00	168.00	68.00	1.58	15.22
98-178	Bt3	744.00	168.00	68.00	1.58	14.82
Mean		796.00	128.00	72.00	1.35	11.38
CV (%)		5.21	33.15	12.42	16.66	29.52
Coastalplainsand						
0-28	Ap	818.00	94.00	88.00	0.96	7.69
28-49	AB	818.00	64.00	118.00	1.15	8.86
49-114	Bt1	838.00	34.00	128.00	1.21	13.11
114-150	Bt2	778.00	74.00	148.00	1.31	9.49
150-200	Bt3	738.00	94.00	168.00	1.54	11.19
Mean		798.00	72.00	130.00	1.24	10.07
CV (%)		5.01	34.58	23.33	17.29	21.05
Shale						
0-28	Ap	92.0	240.0	668.00	1.24	5.96
28-70	AB	232.0	200.0	568.00	1.24	8.20
70-89	Bt	142.0	190.0	668.00	1.41	12.07
89-117	Bss	152.6	180.0	668.00	1.62	16.30
Mean		154.65	202.5	643.00	1.38	10.63
CV (%)		37.5	13.0	7.8	13.1	42.7

BD = Bulk density, MC = Moisture content, Cv = Coefficient of variation, Cv $\leq$ 15% = low variation, Cv > 15 $\leq$ 35% = moderate variation, Cv > 35% = high variation.

Moisture contents of the soils showed moderate to high variations (cv > 15 %, $\leq$ 43 %) among the soil horizons. Generally, the epipedons contained lesser quantity of moisture compared to the sub-surface horizons and could be a reflection of the clay contents of these horizons. Clay has high rate of adsorption and can retain water easily. Moisture content increased with increasing clay content as clay would cause impaired drainage especially at the sub-surface horizons (Odunze, 2003).

3.3.Chemical Properties of Soils

The details of the chemical properties of soils are presented in Table 3. The pH values of the soils were strongly acidic with mean values ranging from 4.48 and 4.83. The acidic nature of the soils reveals the inherent characteristics of soils of the study area irrespective of their parent materials. Abua *et al*., (2010) and Iwara *et al*., (2011) reported similar findings in some soils of Southeastern Nigeria. Exchangeable sodium percent (ESP) which identifies the degree to which the exchange complex is saturated with Na was very low ranging from 0.43 – 4.35 % . Also in all the profiles, none of the horizons could be classified as natric horizons hence their ESP values were < 15 %. Natric horizon must have either a columnar or a prismatic structure in some part and ESP of 15 % or more (Bockheirm & Hartemink, 2013). The average organic matter contents of the soils ranged from 11.73 and 28.55 gkg^{-1} in soils of the three different parent materials. Organic matter decreased down the profile in all the pedons (Table 3). The higher proportion of organic matter at the epipedons could be due to the fact that most of the organic residues are incorporated or deposited on the soil surface. Top soil organic matter contents are directly related to organic carbon inputs and there have been a number of studies demonstrating improvements in soil quality and fertility after organic carbon additions (Dick & Greorich, 2004). The higher concentration of organic matter at epipedal horizons was further revealed by the high variation (cv > 35%) observed in the organic matter contents of the varying horizons in all the pedons.

Generally, the epipedal horizons of soils developed on Bende-Ameki Shale contained higher quantity of organic matter (63 gkg^{-1}) compared to similar horizons underlain by the Coastal plain sand and Falsebedded sandstone. High quantity of organic matter reported in soils formed from Bende-Ameki Shale could be explained by the protection of organic carbon by clay as earlier observed by (Chikezie *et al*., 2009; Ahukaemere *et al*., 2015). The mean total nitrogen contents of the soils varied from 0.34 – 1.5 gkg^{-1} . However, the nitrogen contents of the surface horizons were higher than the sub-surface horizons and may be attributed to the organic matter contents of these horizons. Low coefficient of variation (< 15%) was observed in soils of the Coastal plain sand while soils derived from Bende-Ameki Shale and Falsebedded Sandstone showed high variation (cv > 35%) among the horizons. The Effective Cation Exchange Capacity (ECEC) of soils was generally low ranging from 5.4 – 8.03 $cmol_+kg^{-1}$. Soils of South-eastern Nigeria had earlier been reported to be made of low ECEC and basic cations (Ogban & Ekerette, 2001).

Table 3: Chemical Properties of Soil

Horizon	pH (H_2O)	Om gkg^{-1}	TN gkg^{-1}	Av.P $mgkg^{-1}$	TEB	Al	EA cmol+kg^{-1}	ECEC	BS	ESP (%)	Al. sat
False bedded sandstone											
Ap	4.00	29.31	0.51	15.00	5.64	0.32	1.26	6.90	81.74	0.53	4.64
AB	4.50	18.79	0.43	15.70	3.63	0.40	1.52	5.15	70.49	0.55	7.77
Bt1	4.60	13.28	0.27	15.90	2.03	0.56	1.36	3.39	59.88	0.49	16.52
Bt2	4.60	13.96	0.41	13.10	2.85	0.64	1.92	4.77	59.75	0.35	13.42
Bt3	4.70	9.34	0.08	15.90	4.82	0.56	2.16	6.98	69.05	0.21	8.02
Mean	4.48	16.94	0.34	15.12	3.79	0.50	1.64	5.44	68.12	0.43	10.07
CV (%)	**6.19**	**45.40**	**49.74**	**7.86**	**38.40**	**26.5**	**23.28**	**27.95**	**13.32**	**33.76**	**48**
Coastal plain sand											
Ap	4.91	19.17	0.80	41.60	6.84	0.24	0.64	7.48	91.44	1.88	3.21
AB	4.64	11.72	0.70	20.00	4.63	1.12	1.84	6.47	71.56	1.94	17.31
Bt1	4.18	11.72	0.70	18.70	9.01	1.04	1.44	10.45	86.22	1.11	9.95
Bt2	4.90	8.81	0.70	19.30	6.62	0.80	1.20	7.82	84.66	1.96	10.26
Bt3	4.50	7.24	0.70	19.50	6.26	0.80	1.68	7.94	78.84	2.24	10.08
Mean	4.63	11.73	0.72	23.82	6.67	0.80	1.36	8.03	82.54	1.83	10.16
CV (%)	**6.58**	**39.08**	**6.20**	**41.77**	**23.50**	**43**	**34.55**	**18.30**	**9.20**	**23**	**49**
				Shale							
Ap	5.19	63.00	3.1	20.30	7.25	0.3	0.60	7.85	92.3	4.28	3.82
AB	5.19	32.00	1.6	23.00	3.65	1.1	1.40	5.03	73.1	4.38	21.86
Bt	4.5	11.00	0.9	26.30	2.96	1.2	2.10	4.25	69.6	4.39	28.23
Bss	4.46	8.20	0.4	28.20	5.01	1.3	2.30	5.26	50.4	4.35	24.71
Mean	4.83	28.55	1.5	24.45	4.72	0.98	1.60	6.00	71.35	4.35	19.66
CV (%)	**12.20**	**87.90**	**78.30**	**14.56**	**40.10**	**46.9**	**41.11**	**27.90**	**53.3**	**11.42**	**53.3**

ESP= Exchangeable Sodium Percentage, OM=Organic Matter AvP = Available P, TEB = Total Exchangeable bases, Al.Sat = Aluminum Saturation EA= Exchangeable Acidity BS= Base Saturation, ECEC= Effective Cation Exchange Capacity. Cv = Coefficient of variation, Cv $\leq$ 15% = low variation, Cv > 15 $\leq$ 35% = moderate variation, Cv >35% = high variation.

4.0 Conclusion

From the results, five diagnostic horizons in soil taxonomy were recognized and defined on the basis of clay movement and illuviation, horizon thickness, organic carbon content and presence of anthropogenic activities. The morphological features of soils exhibited contrasting developmental trends in terms of colour, structure, texture and horizon development. Also, soil physical and chemical properties varied in many respect. However, large scale studies may be necessary in future investigation for increased accuracy of predictions. In addition, more attributes of soil resources should be investigated to create greater confidence.

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