Available online at www.worldnewsnaturalsciences.com

World News of Natural Sciences

An International Scientific Journal

WNOFNS 22 (2019) 84-92 EISSN 2543-5426

Morphological and Physicochemical Properties of Basaltic Soils on a Toposequence in Ikom, South Eastern Nigeria

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ABSTRACT

Three profile pits were sunk along a toposequence of basaltic soils in Ikom, Cross River State, to determine their morphological and physico-chemical properties. The profile pits were morphologically described and thirteen (13) soil samples were collected from different horizons of the profiles for physico-chemical analysis. Morphologically, the soils were deep and well drained with no concretions. The colour of the surface soils varied between dark reddish gray (5YR4/2) and dark brown (7.5YR 3/2), to dark reddish brown (5YR 3/4), while that of the subsurface varied between red (2.5YR 4/6) to reddish brown (2.5YR 4/4). The soils had sub-angular blocky structure of different grades and classes with predominantly clayey texture in the Ap horizons and very gravelly clayey texture in the Crtg horizons. The chemical analysis revealed that exchangeable Ca^{2+} was the most dominant cation amongst the exchangeable bases. The soils were low in total nitrogen, organic carbon, available phosphorus, and very high in base saturation. The study showed that the soils are moderately fertile and as such, a lot has to be done to improve their fertility status through the application of organic and inorganic fertilizers with good management practices, such as mulching with crop residue after harvest, sowing of crops at low density per hectare, conservative tillage, strip cropping, crop rotation and shifting cultivation to ensure sustainable productivity.

***Keywords*:** Physico-chemical properties, morphological properties, basaltic soils, fertility status, management practices

(Received 28 November 2018; Accepted 14 December 2018; Date of Publication 15 December 2018)

1. INTRODUCTION

Variation in soil characteristics and potential is usually a reflection of the differences in parent materials from which soils are formed. Soils derived from basaltic rocks under tropical and subtropical environments are reported to contain kaolinite and sesquioxides as the major clay constituents, and are variously classified as Oxisols, Alfisols, and Ultisols, Markus *et al*. [7]. The soils have been described as lateritic, deep with clay in the subsoil and little horizon differentiation [3]. During early pedogenesis, the chemical composition of soil is controlled by the composition of geological parent material, whereas the chemical composition of mature soils strongly reflects the effects of weathering environment. With time, soil composition, diverges progressively from that of parent material under the influence of pedogenic processes determined by vegetation, topography and in particular climate. The divergence may be manifested initially by redistribution of elements within the soil fabric, then between profile horizons, and finally between soils within the landscape. Adequate knowledge of soil characteristics, therefore, is necessary before proper management practices can be applied to ensure sustainable productivity.

Soil morphology refers to the physical constitution of a soil profile, as exhibited by kinds, thickness, and arrangement of the horizons in the profile by the texture, structure, consistence, and porosity of each horizon. Soil colour as a morphological property is an important indicator of several characteristics, such as geological origin, degree of weathering, oxidation and reduction reaction, content of organic matter, leaching and accumulation of chemical compounds, horizon differentiation, and drainage status of the soil. Basaltic rock impacts it coloration on the soil after weathering as the underlying geology of a place determined to a greater extend it's the soil type, Kparmwang *et al.* [6]. The morphology of basaltic soils is characterized by sandy loam to clay texture with a strong medium to moderate mediums sub-angular blocky structure. The soils have effective depth, dark reddish-brown colour, and a dry consistence which is usually hard to very hard [10]. Basaltic soils generally occur on low rises and hilly regions, highly weathered, and are generally acidic dystrophic red ferrasols with kaolinite as a dominant clay mineral along variable amounts of hematite, goethite and gibbsite. The soils are derived from edaphic igneous rock (basalt), with less than 20% quartz and less than 10% felspathoids by volume, and where at least 65% of the feldspatr is in the form of plagioclase.

Adequate knowledge of soils of a particular area is necessary for sustainable agriculture and food security. Therefore, the provision of information on the properties of soils of agrarian societies, such as ours, has become the best option.

2. MATERIALS AND METHODS

2. 1. The study area

The study was carried out at the China Civil Engineering Construction Company (CCECC) basaltic quarry site at Ikom Cross River State. The area lies between latitude 06º13' 290" N and 08º42' 770" E of the equator with an elevation of 19.73 m above sea level. The area has typical humic climatic condition with an annual rainfall range of 1,600-3,520 mm/Annum, relative humidity of 83%, and average temperature of 27.1-28.6 ºC [13]. It is gently sloping and only slightly affected by erosion because of the tropical rainforest vegetation, Akpan-Idiok *et* *al.* [1]. The underlying geological materials within the area consist of basalt (basaltic larva), an igneous rock characterized by large and medium grain size and weathered debris (Saprolite) lying on top of basaltic larva. Serious human activities, such as quarrying, deforestation, and subsequent cultivation have somewhat degraded the vegetation; hence, the secondary growths were dominant within the study area. The land use of the area at present is quarry for excavation of basalt bed rock.

2. 2. Field work

Thirteen (13) soil samples were collected from different horizons from the (3) deep basaltic soil profiles sunk at the study area, following a toposequence. The samples were then processed and transported to the laboratory for analysis.

2. 3. Laboratory analysis

Soil samples were air-dried, crushed and sieved with 2 mm sieve, and analyzed in the laboratory using standard routine methods. Particle size distribution was determined using Bouyoucous hydrometer method. Soil pH was determined using the procedure reported by Bamgbose *et al.* [2]. Organic carbon was determined by Walkley-Black wet oxidation method described by Srinkanth *et al*. [12]. Total nitrogen was determined using modified micro-Kjeldhal method while available phosphorus was determined using Bray P-1, described by Srinkanth *et al.* [12]. Exchangeable bases were determined by leaching the soil samples with 1 ml neutral NH_4OAc as the extractant solution. Ca and Mg were determined by the EDTA complexometric titration method, while K and Na were determined by flame photometry. Exchangeable acidity was determined by titration method, described by Srinkanth *et al.* [12]. ECEC was obtained by the summation method, and base saturation obtained by expressing the exchangeable bases as a percentage of the ECEC.

3. RESULTS AND DISCUSSION

3. 1. Morphological properties

The morphological properties of the profile pits studied are presented in **Table 1**. The profiles had distinct A, B, and C horizons with the occurrence of transitional horizons in the entire profiles. The depths to weathered parent rock of the profiles were variable. The weathered parent rocks (parent material) were encountered at 315 cm, 158 cm, and 52 cm for the three profiles (crest, back slope, and lower slope) respectively indicating that the soils are deep, as reported by Mamzing *et al*. [8].The colour of the surface soils in all the profiles varied between dark reddish grey (5YR 4/2) and dark brown (7.5YR 3/2), to dark reddish- brown (5YR 3/4), while the sub-surface soils colour varied between red (2.5YR 4/6) to reddish brown (2.5YR 4/4). The red to reddish brown colour of the soils may be due to dehydrated and oxidized iron oxide in the soils. Hence, basalts have high amount of ferromagnesian minerals.

The texture of the soils in the three profiles was clayey, except for the soils in the Crtg horizons that were gravely clayey probably because of the influence of the weathered parent rock. The soils had sub-angular blocky structure of different grades and classes. The structure of the surface soils varied from moderate medium sub-angular blocky to fine medium sub-angular blocky while the sub-surface soils of the profile at the crest, the BA and Crtg horizons had moderate sub-angular blocky structure (Table 1).

Similarly, Bt_1 and Bt_2 horizons had moderate medium crumb to sub-angular blocky structure. The sub-surface soils of the profile at the back slope had moderate medium sub-angular blocky structure at the BA and Bt horizons, while the Crtg horizon had a strong medium sub-angular structure (Table 1). The BA and Bt horizons of the sub-surface soils of the back slope had moderate medium crumb to sub-angular blocky structure, while the Crtg horizon had moderate medium sub-angular blocky structure. The consistence of the soils of all the profiles was sticky and slightly plastic under wet condition and varied between friable and firm to very friable and firm for the surface soils, between firm and friable to firm for the sub-surface soils under moist condition, respectively (Table 1).

The soil horizon boundary was mainly clear smooth at the surface soils of all the profiles, while that of the sub-surface soils varied between gradual wavy, gradual irregular and gradual smooth to clear smooth, respectively. The morphological properties agreed with those reported by Nsor and Ibanga, [10] for similar soils in the area.

Table 1. Morphological properties of the soils studied.

Profile	Horizon	Depth (cm)	Colour	Mottles	Texture	Structure	Consistence	Boundary	Other features
	Ap	0-11	5YR 4/2	-	C	2fmsbk	W s slp Mvfri	cs	Ant and worm cast
IC	BA	11-90	2.5YR4/4	-	C	2msbk	W s slp Mfri	gw	
(CREST)	Bt_1	90-210	2.5YR4/6	-	C	2mcsbk	W s slp Mfrif	gi	Powdery feldspars
	Bt_2	210-315	2.5YR4/6	-	C	2mcsbk	W s slp Mfrif	cs	Ant holes
	Crtg	315-390	2.5YR4/6	2.5YR4/1	Vgrc	2msbk	Mfri	cs	Rotten basalt
2B	Ap	0.20	7.5YR3/2	-	C	2msbk	W s slp Mfri	cs	Ant holes
(BACKSLOPE)	BA	20-82	2.5YR4/4	-	C	2mcsbk	W s slp Mfrif	gs	Many charcoal
	Bt	82-158	2.5YR4/4	-	C	2mcsbk	W s slp Mfrif	cw	Ant holes
	Crtg	158-243	2.5YR4/6	5YR4/6	Vgrc	3msbk	W s slp Mfrif	cs	Yellowish iron oxide
3 L (LOWER SLOPE)	Ap	0-7	5YR ¾	-	C	2fmsbk	W s slp Mfri	cs	-
	BA	7-23	2.5YR4/4	-	C	2mcsbk	W s slp Mfri	Cs	-
	Bt	23-52	2.5YR4/6	-	C	2mcsbk	W s slp Mfrif	Cs	Ant and worms cast
	Crtg	52-190	2.5YR4/6	7.5YR6/6	Vgrc	2msbk	Mf	Cs	-

Texture: C = clay, Vgrc = very gravelly clay
Structure: 2 = moderate, 3 = strong, f = fine, m = medium, c = crumb, sbk = subangular blocky
Consistence: M = moist, W = wet, s = stricky, slp = slightly plastic, f = firm, fri = friable, v = very
Boundary: c = clear, s = smooth, g = gradual, i = irregular, w = wavy

3. 2. Particle size distribution

The results of the particle size distribution are presented in **Table 2**. The results show that the soils were mainly clayey in texture in the entire profiles studied. The clay content ranged from 41 to 47%, and 45 to 67%, with means of 43.7 and 59.2%, and had CV of 6.8% and 10.8% and SD of 3.0 and 6.5 for surface and sub-surface soils, respectively. The clay fraction was higher than other fractions, in line with [11] who reported that basalt derived soils have higher content of clay, but in contrast to Manzing *et al.* [8] and Akpan-Idiok *et al.* [1] who reported higher values for sand than clay in similar soils, in Jos Plateau and Ikom, respectively. The low content of clay in the surface soils probably suggests the eluviation of clay from the surface soils.

The silt content ranged between 12 to 16%, and 4 to 24%, with means of 14 and 9.6 and CV of 14.2% and 60.4%, and SD of 2.0 and 5.8 for both, surface and sub-surface soils, respectively (Table 2). These values were low compared to those reported by [4] for basaltic soils in the same area but similar to those obtained for basaltic soils in the Northern Ireland by [9]. The percentage of sand ranged from 37 to 45% and 23 to 41, with means of 42.3 and 30.2, and had CV of 10.8% and 17.5%, and SD of 4.6 and 5.3 for surface and sub-surface soils, respectively (Table 2). The values of percentage sand agreed with 36.23%, 33.05%, and 39.9% reported by Mamzing *et al.* [8] for similar soils in Jos but low compared to those reported by Akpan-Idiok *et al.* [1].

Table 2. Particle size distribution of the soils studied

Horizon	**Depth (cm)**	**Particle Size Distribution (%)**			**Texture**
IC (CREST)		Sand	Silt	Clay	
Ap	0-11	37	16	47	Clay
BA	11-90	29	8	63	Clay
Bt_1	90-210	27	6	67	Clay
Bt_2	210-315	23	4	63	Clay
Crtg	315-390	31	10	59	Clay
2B (Backslope)					
Ap	0-20	45	12	43	Clay
BA	20-82	41	14	45	Clay
Bt	82-158	29	8	63	Clay
Crtg	158-243	37	4	59	Clay
3L (Lower Slope)					
Ap	0-7	45	14	41	Clay
BA	7-23	25	24	51	Clay
Bt	23-52	29	10	61	Clay
Crtg	52-90	31	8	61	Clay
Mean	Surface	42.3	14	43.7	
	Subsurface	30.2	9.6	59.2	
SD	Surface	4.6	2.0	3.0	
	Subsurface	5.3	5.8	6.5	
CV (%)	Surface	10.8	14.2	6.8	
	Subsurface	17.5	60.4	10.9	
Range	Surface	37-45	12-16	41-47	
	Subsurface	23-41	4-24	45-67	

4. CHEMICAL PROPERTIES

The chemical properties of the soils studied are presented in **Table 3**.The pH value of the surface soils of the three profiles ranged from 5.6 to 5.7, with mean of 5.6 and had CV and SD of 0.89% and 0.5, respectively, while the sub-surface soils had a range of 5.4 to 6.2, with mean of 5.8 and had CV and SD of 4.2% and 0.24. The results obtained are quite similar to values (4.6 to 5.2) obtained for soils of the same area by [4]. The results of surface and sub-surface soils showed that the soils are moderately acid in reaction. Low pH may be due to a high rainfall in the area that caused the leaching of basic cations couple with the use of acid forming fertilizers in intensive cultivation. Organic carbon content of the soils ranged from 1 to 1.4% and 0.1 to 1.0% and had means of 1.2% and 0.43%, with CV and SD of 13.3% and 67.4% and 0.16 and 0.29 for both, the surface and sub-surface soils, respectively. Organic carbon was higher in the surface soils than subsurface, as observed by Mamzing *et al*. [8] and Hassan *et al.* [5]. Organic carbon content was very low in contrast to Akpan-Idiok *et al.* [1], who reported moderate values of organic carbon for similar soils of the area. Low value of organic carbon may be as a result of frequent clearing of the vegetation that leads to low litter fall and poor accumulation of organic matter. The result, however, showed that the organic carbon level was higher in the surface soils due to a greater organic matter accumulation than in the sub-surface soils.

Total nitrogen content of the soils ranged from 0.08 to 0.12% and 0.01 to 0.09%, with means of 0.1% and 0.03%, and had CV and SD of 20% and 66%, and 0.02 and 0.02 for surface and sub-surface soils, respectively (Table 3), and was highly variable in the surface soils than in sub-surface soils. These values conformed to those reported by Mamzing *et al.* [8] for similar soils. Total nitrogen content of the soils was very low, to low, confirming the report of [10] for the same soils in Ikom. Higher level of total N in surface soils than sub-surface may be due to a higher content of organic carbon in surface than sub-surface soils. These values showed that the soils will require the addition of nitrogen fertilizer and organic matter incorporation into the soil. Available phosphorus content of the soils ranged from 2.63 mg/kg to 4.38 mg/kg, and 2.45 mg/kg to 5.08 mg/kg, having means of 3.73 mg/kg and 3.71 mg/kg, with CV and SD of 20.9% and 24%, and 0.78 and 0.79 for both, surface and sub-surface soils, respectively (Table 3).The soils were low in available P, with findings almost the same with those of [10].

The exchangeable bases, Ca^{2+} , Mg^{2+} , K^{+}, and Na^{+} ranged from 5.6 to 6.2 cmol/kg and 3.2 to 4.8 cmol/kg, 1.8 to 3.4 cmol/kg, and 0.6 to 2.6 cmol/kg, 0.08 to 0.12 cmol/kg and 1.8 to 3.4 cmol/kg, 0.06 to 0.08 cmol/kg, and 0.05 to 0.08 cmol/kg, with means of 5.8 and 4.06 cmol/kg, 2.3 and 1.8 cmol/kg, 0.1 and 0.09 cmol/kg, and 0.07 and 0.07 cmol/kg, and had CV of 5.86% and 14%, 40%, and 37.7%, 10% and 11.1%, and 14.2% and 14.2%, and SD of 0.34 and 0.57, 0.92, and 0.63, 0.10, and 0.01, 0.01, and 0.01, for both, the surface and sub-surface soils, respectively (Table 3). The result is in line with that of Hassan *et al*. [5], and Akpan-Idiok *et al*., [14], who reported higher values for calcium than other bases for similar soils in Plateau State. Exchangeable Ca^{2+} was the most predominant amongst the bases. Akpan-Idiok *et al.* [1, 14] also observed higher content of Ca^{2+} than other exchangeable bases for similar soils.

These soils are generally low to moderate in exchangeable bases. Low to moderate values of the exchangeable bases may be as a result of leaching, caused by a high rainfall in the area. Exchangeable acidity of the area is due to Al^{3+} and H^{+}. Al^{3+} had a range of 0.1 to 0.2 cmol/kg and 0.2 to 0.8 coml/kg, with means of 0.16 and 0.38 cmol/kg, with CV and SD of 31.2% and 50%, and 0.05 and 0.19 for both, the surface and sub-surface soils (Table 3). Al^{3+} was highly variable in the sub-surface than surface soils, while the reverse was the case for H^{+}.

The H^{+} content of the soils ranged from 0.2 to 0.5 cmol/kg and 0.2 to 0.8 cmol/kg, with means of 0.33 and 0.35 cmol/kg, and had CV and SD of 45.5% and 31.4%, and 0.15 and 0.11 for surface and sub-surface soils, respectively (Table 3). ECEC of the soils was low and had ranges of 8.14 to 9.59 cmol/kg, and 4.23 to 8.06 cmol/kg, with means of 8.81 cmol/kg and 6.73 cmol/kg, and had CV and SD of 8.2% and 18.2%, and 0.73 and 1.23 for both, the surface and sub-surface soils, respectively (Table 3). This is in line with findings of Akpan-Idiok *et al.* [1, 14], but differs from the findings of [15], which observed that basaltic soils have very high CEC. Low ECEC of the soils may be due to a very low organic matter content of the soils which did not create greater surface area for adsorption of cations. The soil had very high base saturation (80-100%), contrary to the report of Hassan *et al.* [5]. For similar soils with ranges of 92 to 95%, and 83 to 93%, and having means of 94% and 89%, with CV and SD of 1.61 and3.4 %, and 1.52 and 3.11, respectively, in both surface and sub-surface soils (Table 3).

Table 3. Chemical properties of the soils studied

Profile	Horizon	Depth (Cm)	pH	Org.C (%)	Total N (%)	Avail. P (mg/kg)	Exch.Bases (cmol/kg) Ca^{2+} →	Mg^{2+}	K^+	Na^+ Cmol/kg	Exch.Acidity (Cmol/kg) ← Al^{3+}	H^+	ECEC	BS (%)
	Ap	0-11	5.7	1.0	0.08	2.63	6.2	1.8	0.12	0.08	0.2	0.3	8.70	94
IC (CREST)	BA	11-90	5.8	0.4	0.03	2.45	4.8	2.0	0.08	0.06	0.3	0.4	7.64	91
	Bt_1	90-210	5.9	0.3	0.02	2.63	4.2	0.8	0.06	0.05	0.4	0.4	5.91	86
	B_{t2}	210-315	6.0	0.1	0.01	2.45	3.6	2.4	0.10	0.08	0.4	0.5	7.08	87
	Crtg	315-390	6.2	0.2	0.01	4.03	3.2	0.6	0.09	0.06	0.2	0.2	4.23	93
	Ap	0-20	5.7	1.4	0.12	4.20	5.6	1.8	0.08	0.06	0.1	0.5	8.14	92
2B (BACKSLOPE)	BA	20-82	5.4	0.9	0.07	4.03	4.6	2.0	0.10	0.06	0.8	0.5	8.06	83
	Bt	82-158	5.5	0.3	0.01	4.38	4.8	2.2	0.09	0.06	0.6	0.3	8.05	88
	Crtg	158-243	5.7	0.3	0.01	3.85	3.6	2.4	0.10	0.06	0.2	0.4	6.76	91
	Ap	0-7	5.6	1.2	0.10	4.38	5.6	3.4	0.11	0.08	0.2	0.2	9.59	95
	BA	7-23	5.6	1.0	0.09	5.08	4.4	2.6	0.10	0.08	0.4	0.2	7.78	92
3L (LOWERSLOPE)	Bt	23-52	5.6	0.6	0.04	4.03	3.8	1.4	0.09	0.07	0.3	0.2	5.86	91
	Crtg	52-190	5.5	0.2	0.01	4.20	3.6	1.6	0.09	0.07	0.2	0.4	5.96	90
MEAN	Surface		5.6	1.2	0.10	3.73	5.8	2.3	0.10	0.07	0.16	0.33	8.81	94
	Subsurface		5.7	0.43	0.03	3.71	4.06	1.8	0.09	0.07	0.38	0.35	6.73	89
SD	Surface		0.05	0.16	0.02	0.78	0.34	0.92	0.10	0.01	0.05	0.15	0.73	1.52
	Subsurface		0.24	0.29	0.02	0.89	0.57	0.68	0.01	0.01	0.19	0.11	1.23	3.11
CV(%)	Surface		0.89	13.3	20.0	20.9	5.86	40.0	100	14.2	31.2	45.5	8.20	1.61
	Subsurface		4.2	67.4	66.6	24.0	14.0	37.7	11.1	14.2	50	31.4	18.2	3.40
Range of Value	Surface		56-5.7	1.0.1.4	0.08-0.12	2.63-4.38	5.6-6.2	1.8-3.4	0.08-0.12	0.06-0.08	0.1-0.2	0.2-0.5	8.14-9.59	92-95
	Subsurface		5.4-62	0.1-1.0	0.01-0.09	2.45-5.08	3.2-4.8	0.6-2.6	0.06-0.11	0.05-0.08	0.2-0.8	0.2-0.5	4.23-8.06	83-93

5. CONCLUSION AND RECOMMENDATION

The results obtained revealed that the soils are mostly clayey in texture. The soil colour varied from dark reddish grey (5YR 4/2) to reddish brown (2.5YR 4/4) and red (2.5YR 4/6). The soils are moderately acid in reaction. They are characterized by low content of organic carbon and total nitrogen, low available P and ECEC, and very high base saturation. From the results, it is believed that the morphological and physico-chemical properties of basaltic soils in the area are good enough for cultivation of crops but a lot has to be done to improve the organic matter content of these soils.

The soils will require the addition of doses of NPK fertilizer for sustainable soil fertility because the soils are poorly buffered, as indicted by the CEC but high percentage base saturation.

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