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Fertility status of selected soils developed on shale and sandstone parent materials in Odukpani Local Government Area, Cross River State, Nigeria

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Abstract

The study evaluated the fertility status of soils developed on shale and sandstone parent materials in Odukpani LGA of Cross River State as a critical determinant of their proper management and utilization. Four pedons were sunk- two on each parent material and a total of sixteen soil samples were collected from different horizons of the profiles, processed and taken to the laboratory for analysis. Particle size analysis revealed that the texture of the soils of the two-parent materials varied from sandy clay, silty clay,sandy loam to sandy clay. The pH showed that soil of shale parent material was very strongly acidic with surface and subsurface means of 4.25 and 4.36 while that of sandstone was strongly acidic with mean values of 5.0in both top and subsoils. Except for pH, all other chemical properties were higher in shale parent material than in sandstone parent material. Organic carbon had surface and subsurface means of 2.82 g/kg and 0.91 g/kg, 1.71 g/kg and 0.37 g/kg, while total N had surface and subsurface, means 0.13 % and 0.08 %, 0.13 % and 0.03 % in soils of shale and sandstone parent materials respectively. Available P had surface and subsurface means of 19.7 mg/kg and 8.04mg/kg in shale parent material, 11.4 mg/kg and 7.44mg/kg in sandstone parent materials. Exchangeable Al^{3+} was higher than H^+ in both soils meaning that Al^{3+} was the primary cause of acidity. ECEC was low in both soils with surface and subsurface means of 10.72cmol/kg and 5.94cmol/kg in shale, 7.23 cmol/kg and 4.56 cmol/kg in sandstone while BS was high with mean values 84.04 % and 76.9 % in shale, 77.02 % and 72.07 % in sandstone representing surface and subsurface soils accordingly. The study revealed that soil developed on shale stone is more fertile than that of sandstone and as such more agronomic inputs and management practices will be required to enhance sustainable production in soils developed on sandstone than their shale stone counterpart.

Keywords: Fertility status; shale stone; sandstone; Acidity; parent materials

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1.0. Introduction

The primary parent materials from which soils are formed in Cross River State include coastal plain sands, beach ridge sand, basalt, basement complex (granite, gneiss, quartzite and schist), sandstone-shale intercalation and alluvium (Ekwueme, 2003). The characteristics of these soils, including their fertility status, are primarily determined by the parent materials and also by climate, topography and the general agricultural land use and management (Esu, 1991). Blatt and Robert(1996) reported that shale is a composition of clay minerals and quartz and is characterized by breaks along thin laminae or parallel layering or bedding less than one centimetre in thickness called fissility.

Soil fertility determines the productive capacity of the soil. Soil pH, cation exchange capacity, effective cation exchange capacity, exchangeable cations, K, Mg, Ca, total nitrogen, available phosphorus and base saturation are chemical components of soil fertility index. Gregorich*et al*. (1994) stated, "soil quality is a composite measure of both a soil's ability to function and how well it functions, relative to a specific use.

The ability of any soil to supply the required quantity of plant nutrients is mostly affected by the soil genetic composition. Therefore, the soil productive potential and its resilience to amendment and management for sustainable agricultural production depend mainly on the soil parent material (Ajiboye and Ogunwale, 2010). Data derived from the fertility of a given soil enables the users to manage the soil resources in such a way to derive maximum yield and performance from the land. Planting a particular kind of crop in a soil that does not possess the requirements for that crop will result in low yield. Many commercial and resource-poor farmers in Southeastern Nigeria including Cross River State have incurred huge losses of their investment due to poor crop yield resulting from low fertility status of the soil (Law-Ogbomo and Nwachokor, 2010). Several studies have been carried out on some aspects of the soils of different parts of Southeastern Nigeria regarding their fertility status (Uzoho and Ekeh, 2014).

Most farmers in Southeastern Nigeria, including Cross River State, have regarded the soils in which they base their production on to have the same fertility status simply because they are in the same geographical location. This study, therefore, tries to provide information on soils developed on shale and sandstones parent materials in Odukpani LGA of Cross River State.

2.0. Materials and methods

2.1 The study area

The study was carried out in Mbaraka Community in Odukpani LGA of Cross River State. The area lies within latitude 5°7'0" N and longitude 8°20' 0" E. The area has a humid tropical climatic condition with a mean annual rainfall of 2650mm, mean annual temperature of 26.3 ^{0}C, mean relative humidity of 80 to 90% at the peak of the rainy season with an elevation of 45m above sea level (Esu, 1991). The underlying geological parent materials of the area are shales and sandstones.

2.2 Fieldwork

Four soil samples were collected from each of the four profiles sunk in the study area, making a total of sixteen (16) soil samples.

2.2 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 as outlined by Juo (1979). Soil pH was determined using the procedure reported by Bamgbose *et al.* (2000). Organic carbon was determined by Walkley-Black wet oxidation method described by Srinkanth *et al.,*(2013). Total nitrogen was determined using a modified micro-Kjeldahl method while available phosphorus was extracted and determined using the method outlined by Udoh *et al*., (2009). Exchangeable bases were determined by leaching the soil samples with 1ml neutral NH_4OAc as the extractant solution. Calcium and Mg were determined by the EDTA complexometric titration method, while K and Na were determined by flame photometry (IITA, 1979). Exchangeable acidity was determined by the titration method described by Srinkanth *et al.* (2013).ECEC was obtained by the summation method and base saturation obtained by expressing the exchangeable bases as a percentage of the ECEC.

2.3 Data Analysis

The data obtained were statistically analyzed using descriptive statistical tools for mean, range and coefficient of variability.

3.0. Results and Discussion

3.1 Particle size distribution

The particle size distribution of shale and sandstone parent materials is presented in Table 1, and 2 shows that and content decreased with depth while clay increased with depth in all the profiles in sandstone soils. Contrarily, the irregular trend was observed in shale stone soils. Chikezie *et al.*,(2009) and Esu *et al*.,(2008) reviewed that increased in clay content of the soil with depth may be the consequence of eluviation-illuviation processes as well as contributions of the underlying geology through weathering. The results show that soil developed from shale stone is finer in texture than that developed on sandstone as evident in the relatively lower percentage of sand in the shale stone soil. This means that sandstone soil may be more porous and allowing for leaching of basic nutrients than shale stone soil. The texture of the soils varied from sandy clay to sandy clay loam in shale parent material while the texture of the sandstone soil ranged from sandy loam, sandy clay, sandy clay loam. Sand ranged from 54 to62% and 57 to 69% with means of 58 % and 60.3% and had a CV of 2.66% and 7.39% in the surface and subsurface soils of shale stone parent materials accordingly while in sandstone parent material sand varied from 74 to 75% and 48 to 75% with means of 74.5% and 59.33%, CV of 0.94% and 18.42% in surface and subsurface soils. Silt varied from 9to 17% and 7 to 11% with means of 13 % and 8.5%, CV of 17.5% and 39.6%in surface and subsurface soils developed on shale, 12 to 17%, 5 to 16%and had means of 14% and 9.5%, CV of 24.41% and 42% in surface and subsurface of sandstone soils respectively. Clay ranged from 29 to 29% and 24 to 36% with means of 29% and 31.2%, CV of 0.2% and 36.9% in surface and subsurface soils of shale, 8 to 14% and18 to 44% with average values of 11% and 31.2% and had a CV of 38.5% % and 40% in surface and subsurface soils of sandstone soils accordingly. Similar results were obtained by Osujieke *et al.,(*2017) in soils of developed from false bedded sandstone and clay shale parent materials in Imo state.

3.2 Chemical properties

The results of chemical properties presented in Tables 1 and 2 show that pH was higher in sandstone soil than shale stone soil. In shale, pH with means of 4.25 and 4.38 and had a CV of 1.68% and 5.02in surface and subsurface accordingly while in sandstone soils it has mean of 5.0 for both surfaces, had CV 11.4% and 14.8% in surface and subsurface soils accordingly. The pH was homogenous in soils of the two-parent materials (CV<15%) (Essington, 2005). The pH of both soils was low (<5.5) following Landon (1991) rating. Low pH in this soils means that macronutrient availability will be hindered (Brady and Weil, 2002). Organic carbon decreased with depth in all the profiles and was high in the surface (>2.0 g/kg), low in the subsurface of soils of shale (<1.5g/kg). It was moderate in the surface and low in the subsurface of sandstone (Landon, 1991) and ranged from 2.25 to 3.39 g/kg, and 0.19 to 1.86g/kg with mean values of 2.83g/kg and 0.91 g/kg, and had a CV of 28.74% and 59.34%, in surface and subsurface of shale developed soil. In sandstone soil, it varied from 1.12 to 2.3g/kg, 0.12 to 0.68 g/kg and had mean values of 1.71g/kg and 0.37g/kg, CV of 48.53% and

54.59% in surface and subsurface soils respectively. Organic carbon was heterogeneous in both soils (CV >36%) (Esssington, 2005). In a similar study, Osujieke (2017) reported higher organic carbon values in soils of false bedded sandstone parent material than in clay shale parent material which disagrees with the result of this study. The high content of organic in the surface horizons is due mainly to the accumulation of litter falls (Tisdale *et al.,*1995). Low values of organic carbon may be due to bush burning, leaching probably due to the high rainfall in the area, rapid mineralization of organic matter couple the cultivation of non-nitrogen replenishing crops in the area. Total N was heterogeneous (CV >36%) in both soils except the surface soil of shale that was homogeneous (CV <15%) (Essington,2005). Like organic carbon, total N decreased with depth in all the profiles and was low (0.1 to 0.2%) in soils of both parent materials following Landon (1991) rating. Rapid mineralization of organic matter with other factors that lead to a low level of organic carbon is the major cause of the low level of nitrogen in soils (Mulugeta, 2004). Total N varied from 0.12 to 0.13%, 0.04 to 0.11% with average values of 0.13% and 0.08%, CV of 5.6% and 37.5% in surface and subsurface soils of shale stone accordingly, 0.01 to 0.16 mg/kg , 0.01 to 0.05% with average values of 0.13% and 0.03%, CV of 30.8% and 66.7% respectively in surface and subsurface soils of sandstone. Total N was low in all the soils which may be due to continuous cultivation of and frequent bush burning in the area. Total N content is lower in continuously and intensively cultivated and highly weathered soils of the humid and sub-humid tropics due to leaching (Tisdale *et al*., 1995). Available P varied from 17.1 to 22.2 mg/kg and 6.1 to 10.04mg/kg with means of 19.7 mg/kg and 8.04 mg/kg, CV of 18.1 % and 17.9 %respectively in surface and subsurface soils of shale while in sandstone soil it ranged from 6.88 to 16mg/kg, 6.5 to 7.75mg/kg,and had average values of 11.4 mg/kg and 7.44mg/kg, CV of 58.2% and 6.75%.Available P was higher in shale stone soils than in sandstone soils which may be probably due to the presence of phosphorus bearing minerals in the shale parent material. Higher available P in shale soil than sandstone disagrees with the findings of Osujieke (2017) who obtained higher P values in sandstone soil than in shale stone soil. But the disparity in available P content amongst the soils is in line with the report of Foth and Ellis, (1997) who stated that phosphorus content is influenced by organic matter content, rock types and level of weathering and fixation processes. Both soils had a moderate level of available P (8 to 20mk/kg) (Landon, 1991).

Exchangeable bases were higher in shale stone soils than in sandstone soils. In all the soils, Ca^{2+} was the highest, Na^{+} was the least and Mg^{2+} the most heterogeneous in the soil layers. Calcium, Mg^{2+}, K^{+} and Na^{+} had mean values of 6.4 and 4.03 cmol/kg, 2.7 and 0.45 cmol/kg , 0.16 and 0.08 0.09cmol/kg, 0.075 and 0.06 cmol/kg with CV of 0.0% and 21.1%, 26.3% and 107%, 21.21 % and 37.5%, 9.33 % and 33 % in surface and subsurface soils of shale stone respectively while in sandstone parent material Ca^{2+},Mg^{2+}, K^{+} and Na^{+}had average values of 3.2 and2.6cmol/kg, 2.2 and0.62 0.105 and 0.07 cmol/kg, 0.075 and 0.65cmol/kg with CV of 8.75% and 15.76 %, 38.63 % and 58.06 %, 9.52 % and 28.57 %, 13.33 % and 20 % representing the surface and subsurface soils respectively. The values of exchangeable bases are higher relative to those obtained by Osujieke (2017), Nuga and Akinbola (2011) in a similar study. Calcium and Mg^{2+} were moderate and low in surface and subsurface soils of shale accordingly, while K^{+} and Na^{+} were low. In sandstone parent materials, all the bases were low(Landon 1991).

Aluminium is said to be the major contributor acidity in both soils as shown by a higher level of aluminium ion than hydrogen ion in both soils. Aluminium and H^{+} ranged from 0.98 to1.5cmol/kg and 0.86 to 1.34 cmol/kg and had mean values of 1.27cmol/kg and 1.08cmol/kg with a CV of 32.28 % and 18.51% respectively in surface and subsurface soils of shale parent materials. In sandstone soil, Al^{3+} varied from 1.3 to 1.6 cmol/kg and 1.0 to 1.26 cmol/kg with means of 1.45 cmol/kg and 1.15 cmol/kg and had a CV of 14.48% and 7.82 % in surface and subsurface soils respectively. Aluminium was low (<4cmol/kg) in soils of both parent materials Landon (1991). Hydrogen varied from 0.42 to 0.6 cmol/kg with mean and CV of 0.51cmol/kg and 24.9% and from 0.04 to 0.38 cmol/kg with mean and CV of 0.2cmol/kg and 60% in the surface and subsurface soils of soil developed on shale. In sandstone parent materials it varied from 0.17 to 0.24cmol/kg and 0.04 to 0.16 cmol/kg with means of 0.205cmol/kg and 0.11cmol/kg and had CV of 24.39 % and 36.36 % in surface and subsurface soils respectively. ECEC was generally low (<10cmol/kg) except in the surface soil of shale (Landon,1991) but relatively higher in shale stone soil compared to sandstone soil and varied from 10.39 to 11.05 cmol/kg and 4.49 to 8.4 cmol/kg with means of 10.72 cmol/kg and 5.94 cmol/kg, CV of 0.43% and 24.4 % in surface and subsurface soils respectively in shale soil while in sandstone soil it ranged from 6,96 to 7.51 cmol/kg and 3.54 to 5.76 cmol/kg and had average values of 7.23cmol/kg and 4.56 cmol/kg with a CV of 5.39 % and 18.85 %in the surface and subsurface soils respectively. Base saturation was generally high (>60%) (Landon, 1991) and had similar trend like ECEC and had ranges of 83.29 to 84.79 %, 72.74 to 80.71 % with mean values of 84.04 % and 76.9 % and had a CV of 1.26 % and 3.45 % in surface and subsurface soils of shale parent material respectively. In sandstone, it had ranges of 74.56 to79.49 %, 65.53 to 75.34 % with means of 77.02 % and 72.07 % and had a CV of 4.53 % and 4.87 % for surface and subsurface soils respectively. BS was homogeneous (CV< 15 %), according to Essington (2005) rating in both soils of the two-parent materials. Contrary ECEC of 4.65cmol/kg and BS of 42.1% were obtained in soils developed in sandstone parent material by Eyong and Akpa (2019)

4.0 Summary and recommendations

Results obtained indicated that the soils have predominantly sandy clay and sandy clay loam texture in shale and sandy loam, sandy clay and sandy clay loam in the sandstone parent material and are acid in reaction with most chemical properties higher in shale soil stone than in sandstone soil. All the chemical properties are rated low except for base saturation that was high in both shale and sandstone soils, calcium that was moderate in surface soil of shale and available P that was moderate in both soils. Base on the low level all the fertility indices, it is recommended that organic matter and organo-mineral fertilizer should be used to improve the fertility of the soils with the cultivation of acid-tolerant crops,practising crop rotation, cultivation of nitrogen furnishing crops and intercropping to increase fertility and crop yield. Liming is also recommended to raise pH to between 5.5 and 7.0 enhance nutrient solubility.

Table 1: Physico-chemical properties of soils obtained from shale stone parent material

Profile & Horizon	Profile depth	PSD			TC	pH	Org. C.	Total N	Avail. P	Exch. Bases				Exch Acid.		ECEC	BS
	(cm)	Sand	Silt	Clay			(g/kg)	(%)	(mg/kg)	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H^+		
													(cmol/kg)				(%)
Prof.1 Ap	0-12	62	9	29	CL	4.3	3.39	0.13	22.2	6.4	3.2	0.19	0.08	1.56	0.42	11.05	83.29
Bt_1	12-39	69	7	24	SCL	4.4	1.86	0.11	10.4	5.2	1.4	0.11	0.07	1.34	0.28	8.4	80.71
Bt_2	39-79	58	7	35	SC	4.6	0.98	0.1	8.51	4.6	0.4	0.08	0.06	1.28	0.18	6.4	77.18
Crt	79-145	57	7	36	SC	4.7	0.88	0.05	7.21	3	0.2	0.06	0.05	1.14	0.1	4.55	72.74
Prof.2 Ap	0-10	54	17	29	SCL	4.2	2.25	0.12	17.1	6.4	2.2	0.14	0.07	0.98	0.6	10.39	84.79
Bt_1	Oct-50	59	10	31	SCL	4.2	0.79	0.08	8.02	4.2	0.4	0.1	0.07	0.96	0.04	6.13	77.81
Bt_2	50-95	58	11	31	SCL	4.2	0.76	0.08	8	4.1	0.2	0.07	0.06	0.91	0.38	5.71	77.58
Crt	95-138	61	9	30	SCL	4.2	0.19	0.04	6.1	3.1	0.1	0.04	0.03	0.86	0.24	4.47	75.39
Surface soil																	
Mean		58	13	29		4.25	2.82	0.13	19.7	6.4	2.7	0.165	0.075	1.27	0.51	10.72	84.04
Min		54	9	29		4.2	2.25	0.12	17.1	6.4	2.2	0.14	0.07	0.98	0.42	10.39	83.29
Max		62	17	29		4.3	3.39	0.13	22.2	6.4	3.2	0.19	0.08	1.56	0.6	11.05	84.79
CV(%)		2.66	17.5	0.2		1.64	28.74	5.6	18.1	0.0	26.3	21.21	9.33	32.28	24.9	0.43	1.26
Subsurface soil																	
Mean		60.3	8.5	31.2		4.38	0.91	0.08	8.04	4.03	0.45	0.08	0.06	1.08	0.2	5.94	76.9
Min		57	7	24		4.2	0.19	0.04	6.1	3	0.1	0.04	0.03	0.86	0.04	4.47	72.74
Max		69	11	36		4.7	1.86	0.11	10.4	5.2	1.4	0.11	0.07	1.34	0.38	8.4	80.71
CV(%)		7.39	39.6	36.9		5.02	59.34	37.5	17.9	21.1	107	37.5	33.33	18.51	60	24.4	3.45

SiL=Silty loam,SC=sandy clay,SiC=Silty clay,SL=sandy loam, SC=sandy clay, PSD= particle size distribution, TC= textural class.

Table 2: Physico-chemical properties of soils obtained from sand sandstone parent material.

Profile & Horizon	Profile depth	PSD			TC	pH	Org.C.	Total N	Avail. P	Exch. Bases				Exch Acid.		ECEC	BS
	(cm)	Sand	Silt	Clay			(g/kg)	(%)	(mg/kg)	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}	H^{+}		
			(%)										(cmol/kg)				(%)
Prof.3 Ap	0-20	75	17	8	SL	5.4	2.3	0.16	16	3	2.8	0.1	0.07	1.3	0.24	7.51	79.49
Bt_1	20-60	75	7	18	SL	5.6	0.42	0.03	7.75	3	1.2	0.08	0.06	1.26	0.16	5.76	75.34
Bt_2	60-90	66	16	18	SL	3.7	0.22	0.02	7.5	2.8	0.4	0.08	0.06	1.12	0.14	4.6	72.6
Crt	90-139	65	11	24	SCL	5.8	0.12	0.01	7.5	2	0.2	0.07	0.05	1.1	0.12	3.54	65.53
Prof.4 Ap	0-16	74	12	14	SL	4.6	1.12	0.1	6.88	3.4	1.6	0.11	0.08	1.6	0.17	6.96	74.56
Bt_1	16-50	53	5	42	SCL	4.8	0.68	0.05	7.75	2.8	0.8	0.08	0.06	1.2	0.09	5.03	74.35
Bt_2	50-81	49	7	44	SC	4.9	0.48	0.03	7.63	2.7	0.7	0.07	0.06	1.2	0.08	4.81	73.38
Crt	81-134	48	11	41	SC	5.0	0.28	0.01	6.5	2.1	0.4	0.04	0.03	1.0	0.04	3.61	71.19
Surface soil																	
Mean		74.5	14.5	11		5	1.71	0.13	11.4	3.2	2.2	0.105	0.075	1.45	0.205	7.235	77.02
Min		74	12	8		4.6	1.12	0.1	6.88	3	1.6	0.1	0.07	1.3	0.17	6.96	74.56
Max		75	17	14		5.4	2.3	0.16	16	3.4	2.8	0.11	0.08	1.6	0.24	7.51	79.49
CV(%)		0.94	24.41	38.5		11.4	48.53	30.8	58.2	8.75	38.63	9.52	13.33	14.48	24.39	5.39	4.53
Subsurface soil																	
Mean		59.33	9.5	31.2		5.0	0.37	0.03	7.44	2.6	0.62	0.07	0.05	1.15	0.11	4.56	72.07
Min		48	5	18		3.7	0.12	0.01	6.5	2	0.2	0.04	0.03	1.0	0.04	3.54	65.53
Max		75	16	44		5.8	0.68	0.05	7.75	3	1.2	0.08	0.06	1.26	0.16	5.76	75.34
CV(%)		18.42	42	40		14.8	54.59	66.7	6.75	15.76	58.06	28.57	20	7.82	36.36	18.85	4.87

SC=sandy clay,SiC=silty clay,SL=sand loam, SC=sandy clay,TC =textural class,PSD=particle size distribution, Max=maximum, Min=minimum

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