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FORMS OF PRIMARY NUTRIENT ELEMENTS IN SOILS OVERLYING CONTRASTING PARENT MATERIALS IN SOUTH-EASTERN NIGERIA

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ABSTRACT
Appropriate management of soil fertility should rely upon sound knowledge of the nutrients reserve and their availability. This is only possible if there is adequate information on the influence of parent material on the dynamics and availability of these nutrient elements. Research was carried out in 2014 at three locations underlain by three different parent materials namely Basalt (Ikom in Cross River State, Sandstone (Nto-Ndang in Akwa-Ibom State) and Alluvium (Ohaji-Egbema in Imo state) to provide information on the status and dynamics of the major primary nutrient elements (N, P, K) in the soils of these areas. Results showed that Basalt-derived soils were more clayey, contained higher quantities of organic matter and exchangeable bases (TEB) than soils of other parent materials. Significantly ($P<0.05$) higher proportions of total P (1383 $mgkg^{-1}$), organic P (974 $mgkg^{-1}$) and active inorganic P (275.4 $mgkg^{-1}$) were recorded in soils derived from Basalt than other parent materials. Significantly ($P<0.05$) higher total nitrogen (2.90 $mgkg^{-1}$) was recorded in Basaltic soils than soils developed on Sandstone (1.8 $mgkg^{-1}$) and Alluvium (1.3 $mgkg^{-1}$). Available nitrogen and potassium contents of the soils of the varying parent materials did not differ significantly ($P<0.05$). The highest quantity of total K (198 $mgkg^{-1}$) was recorded in soils derived from Sandstone compared to those of Basalt (119 $mgkg^{-1}$) and Alluvium (106 $mgkg^{-1}$). Soil primary nutrient elements (potassium and phosphorus) varied due to parent materials while no variation was obtained in the nitrogen contents of the soils of the different parent materials investigated. It is therefore, recommended that in soil fertility studies, the primary nutrient element contents of soil lithological materials should be considered.
Key words: Parent material, Nitrogen, Phosphorus, Potassium, Alluvium, Sandstone, Basalt.

INTRODUCTION

Soil properties are determined by its parent material and by the interactions between the parent material and the hydrosphere, atmosphere, and biosphere. Nutrient elements in soils are generally dependent on the lithology of soil parent material, geochemical and pedological processes responsible for the formation of soils (Hardy and Cornu, 2006). Variations in soils could be attributed to the nature of parent material as it influences soil characteristics (Ibanga, 2006). Parent material also constitutes and influences the primary source of plant nutrients (Giesleret *et al.,* 2005).

Primary nutrient elements (N:P:K) are those yield limiting nutrient elements required by crops in large amounts (Alfaro *et al.*, 2003; Zhang *et al.*, 2011). Nitrogen is considered the most important growth-limiting factor in non-legumes (Zebarth *et al.*, 2009). The relative importance of phosphorus (P) and nitrogen (N) in limiting plant productivity can vary across ecosystems due to differences in a range of factors such as, N deposition, parent material, the nutrient element forms, soil age, pH, and concentrations of soluble aluminum (Al), iron (Fe) and calcium (Ca) (Weintraub, 2011). Potassium (K) plays a very significant role in crop growth due to its functions as an activator of numerous enzymatic reactions and in electrochemical process (Krauss and Johnson, 2002). The ability of a soil to supply potassium to a crop depends on its forms and distribution as influenced by soil physico-chemical properties. Potassium occurs in different forms in the soils such as water soluble, exchangeable, non-exchangeable and in mineral form (Idigbor *et al.*, 2009). However, the concentration of these varying forms of potassium and other macro nutrient elements depends relatively on parent material and other related soil factors. Therefore, the major objective of the present study is to evaluate the effects of lithological materials on the availability and dynamics of primary nutrient elements (N.P.K) in soils of Southeastern Nigeria.

MATERIALS AND METHODS

Study Area

The research was carried out in three different locations in South-eastern Nigeria. Geology maps were used to guide the location of the sampling areas based on their lithologies. These areas include; Ikom in Cross River State (Latitude 6^0 081 N and Longitude 8^0 621 E), Nto- Ndang in Akwa-Ibom State (Latitude 4^0 981 N and Longitude 7^0 621 E) and Ohaji-Egbema in Imo state (Latitude 5^0 771 and Longitude 6^0 541). They have humid tropical climates with average annual rainfall ranging from 1750 to 3000 mm, a mean annual temperature range of 26 ^{0}C to 31^0C and high relative humidity (above 80 %) during the rainy season.

Soil Sampling

Three sites underlain by three different parent materials (Basalt, Sandstone and Alluvium) in South-eastern Nigeria were randomly selected for the study. In each site, a 100 × 100 m land area was delineated for soil examination and sampling. Eight (8) composite soil samples were aided using soil auger. Undisturbed core samples were collected for bulk density determination. The samples were air-dried, passed through 2-mm sieve and stored in polythene bags for laboratory analysis. A small portion of each soil sample was further ground with mortar and pestle and sieved through a 0.05 mm sieve for organic P, organic carbon and total P determination while Wet samples were used for the determination of various forms of nitrogen.

Laboratory Analysis

The processed soil samples were analyzed for some physico-chemical properties following standard procedures. Briefly, particle size analysis was determined by hydrometer method (Gee and Or, 2002), soil pH in 1:2.5 water suspension was measured with pH meter (Thomas, 1996) and organic carbon by the method of Nelson and Sommers, (1996). Exchangeable base cations were extracted with 1N ammonium acetate, potassium (K) and sodium (Na) were determined by flame photometry and calcium (Ca) and magnesium (Mg) by EDTA titration (Thomas, 1996). Total exchangeable bases (TEB) = summation of the base ctions.

Available P in the soil was extracted by Bray P2 method of Olsen and Sommers, (1982). Total, Organic and Inorganic P were extracted by the modified method of (Tchienkoua *et al.*, 2010).

Phosphorus in the extract was determined colorimetrically and the phosphorus in the solution was determined using spectrophotometer at 880 nm wavelength.

Available N was extracted using 2 M KCl in a 1: 5 (soil: water) ratio. NH_4^+ in the supernatant solution was determined by steam distillation of ammonia, using heavy MgO while nitrate nitrogen was determined by Phenol-disulphonic acid colorimeteric method (Keeney and Nelson, (1982).

Total K and water soluble K were determined by the method of Timtong *et al.* (2010). Non-exchangeable K was calculated as the difference between total and available K (exchangeable K plus water soluble K).

Data Analysis

Soil data were statistically analyzed using GenStat statistical software (Payne *et al.,* 2007). Analysis was made according to Randomized Complete Block Design having parent materials as treatments and a number of soil samples collected per parent material as replicates. Least significant difference was computed at $p < 0.01$ and $P \leq 0.05$ to estimate degree of variability of soil properties among parent materials.

RESULTS AND DISCUSSION

Physical and Chemical properties of the Soils

The results of the physical and chemical properties of the soils are presented in Table 1. The particle size analysis showed that sand and clay contents of the soils varied from 631 to 851gkg^{-1} and 55 to133 gkg^{-1}. Soils derived from Sandstone contained significantly ($p<0.05$) higher proportion of sand compared to those of Alluvium and Basalt. High sand content of soils derived from Sandstone could be attributed to sandy nature of their parent rocks and is a reflection of the characteristics of acid sands of South-eastern Nigeria (Enwezor *et al.*, 1989). However, soils formed from basaltic parent material had significantly ($p<0.05$) higher clay content compared to other soils. High clay content recorded in soils derived from Basalts confirms the reports of Eshett (1987) in some Basaltic soils of Southeastern Nigeria.

Higher (1.33 g/cm^3) mean bulk density was recorded in Basaltic soils when compared with soils derived from Alluvium (1.28 g/cm^3) and Sandstone (1.04 g/cm^3). As expected, total porosity followed inverse direction with bulk density with the highest mean value (60.7 %) recorded in Sandstone-derived soils. Pores are of different sizes, shapes and continuity which influence the infiltration, storage and drainage of water, the movement and distribution of gases and the ease of penetration of soil by growing roots (Kay and Vandebygaart, 2002). Moisture contents of the soils ranged from 21 to 6.8% in soils derived from the three different parent materials with Alluvium soils containing significantly highest quantity (Table 1). Soil water content is closely related to the topography, precipitation, evaporation, soil type and composition of vegetation; and always remains fluctuating (Zhao *et al.,* 2006). Soil physical and chemical properties show variability as a result of dynamic interactions among environmental factors such as climate, parent material, topography and land use (Dengiz *et al.*, 2006).

The soils are acidic with pH ranging from 4.23 to 4.76. The acidic nature of the soils could be due to the nature of the lithological material, pedogenic processes, excessive rainfall and leaching. High acid content of soil could encourage P fixation and inhibit P availability in soils. In addition, nitrification bacterial are sensitive

TABLE 1. Physico-chemical Properties of Soils of Dissimilar Parent Material.

Parent material	Sand	Silt	Clay	BD	TP	MC	pH	OM	Ca	Na	K	Mg	TEB
	→	(gkg^{-1})	←	(gcm^{-3})	(%)	(%)		gkg^{-1}	→		$cmol_+kg^{-1}$	←	
Basalt	631	235	133	1.33	50.1	7.6	4.77	36.5	1.79	0.31	0.09	1.20	3.40
Sandstone	851	88	61	1.04	60.7	6.8	4.23	35.5	0.41	0.20	0.04	0.15	0.80
Alluvium	774	171	55	1.28	51.9	21	4.23	26.5	0.06	0.39	0.04	0.09	0.59
LSD(0.05)	15.3	14.1	39.4	NS	NS	5.6	NS	5.78	1.25	NS	NS	NS	0.65

MC = Moisture content, Ca = Calcium, Mg = Magnesium, K = Potassium, Na = Sodium, TEB = Total exchangeable bases, OM. = Organic Matter, Al = Aluminum.

to the effect of environmental factors where soil pH represents one of the limiting factors. Significantly ($p<0.05$) higher organic matter contents were recorded in soils developed on Basalt (36.5 gkg^{-1}) and Sandstone (35.5 gkg^{-1}). The proportions of total exchangeable bases of the soils were low (3.40 - 59 $cmol+kg^{-1}$) across the parent materials. Low values of these base cations have however been reported in most of Nigerian soils (Uzoho *et al.,* 2007) and could be attributed to leaching losses due to high rainfall as well as low content in parent rocks.

Forms of Phosphorus in the Soils

The results of the various forms of phosphorus are presented in Table 2. Significantly ($p<0.05$) higher proportions of total (1383 $mgkg^{-1}$) and organic phosphorus (974.0 $mgkg^{-1}$) were recorded in Basalt-derived soils compared to soils derived from Sandstone (948 and 651 $mgkg^{-1}$) and Alluvium (587 and 516 $mgkg^{-1}$). However, the values of total and organic P recorded in soils derived from Basalts and Sandstones were higher than those of Osodeke and Uba, (2005) (150 – 750 $mgkg^{-1}$, 40 – 65 $mgkg^{-1}$, 125 -275 $mgkg^{-1}$ and 20 – 120 $mgkg^{-1}$) in soils derived from similar parent materials in Southeastern Nigeria. The distribution of soil phosphorus among the various forms depends on natural lithological background, agronomic practices and soil properties (Malorie *et al.,* 2010). Organic P reserves are sensitive to the quantity of phosphorus added to the soil (Idigbor *et al.,* 2008). Significantly ($p<0.05$) higher available P (12.8 $mgkg^{-1}$) was recorded in Sandstone-derived soils than those of Alluvium (0.4 $mgkg^{-1}$) and Basalts (0.3 $mgkg^{-1}$). Phosphorus availability can be attributed to some combinations of soil parent material, soil age, topography, climate and biological activity (Amundson and Jenny, 1997). According to the ratings of Esu, (1991), available P content of Sandstone-derived soils was moderate while those of Alluvium and Basalt were rated very low. Low concentration of available phosphorus in these soils could be attributed to high P fixation capacity of soils of Southeastern Nigeria. Significantly ($p<0.05$) higher quantities of Fe-P (68.5 $mgkg^{-1}$) and Ca-P (103.6 $mgkg^{-1}$) were recorded in soils derived from Basalt than in those derived from Sandstone (27.1 and 48.3 $mgkg^{-1}$) and Alluvium (8.5 and 15.5 $mgkg^{-1}$) (Table 2). According to Cooper and Gillian (1987), mineral P-bound to iron often increases with clay content. This may explain the reason why Basaltic soil with highest clay content (Table 1) also had the highest Fe-P content. Generally, soils developed on Basalts contained significantly ($p<0.05$) higher active inorganic P (275.4 $mgkg^{-1}$) compared to soils derived from Alluvium (137 $mgkg^{-1}$) and Sandstone (192 $mgkg^{-1}$) (Table 2). The results of correlation analysis showed that Soil pH had significant ($p < 0.05$) positive relationship with Al-P (r = 0.49), Fe-P (r = 0.81), Ca-P (r = 0.75) and total- P (r = 0.53) (Table 4). Idigbor *et al.* (2008) noted that the distribution of the active fractions of inorganic phosphorus and their abundance in soil are dependent on soil reaction. Also, Organic carbon had significantly ($p<0.05$) positive correlation with organic-P (r = 0.781), Al-P (r = 0.53), Ca-P (r = 0.464) and total P (r = 0.60) indicating that increased organic carbon contents of the soils resulted to increased organic, calcium and aluminum phosphorus.

Forms of nitrogen and potassium

Nitrogen contents of the soils are presented in Figure 1. Total nitrogen contents of the soils ranged from 6.49 -7.56 $mgkg^{-1}$. No significant variation was recorded in the total nitrogen contents of the soils investigated. Total nitrogen

Table 2. Phosphorus Forms in Soils of Dissimilar Parent Materials ($mgkg^{-1}$)

Parent material	Total P	Org. P	Av.P (Bray-2P)	Al- P	Fe-P	Ca-P	Act. Inorg.P	Inact. P	Inorg. P
Basalt	1383.0	974.0	0.30	103.3	68.5	103.6	275.4	133.6	409.0
Sandstone	948.0	651.0	12.8	116.6	27.1	48.3	192.0	105.0	297.0
Alluvium	587.0	516.0	0.40	113.2	8.5	15.5	137.2	247.0	384.3
LSD(0.05)	261.7	171.4	7.50	11.21	44.5	47.95	71.28	100.1	303.0

Org P = organic P, Al- P = Aluminum P, Fe- P = iron P, Ca- P = calcium P, Av.P = available P, LSD = least significant difference (0.05)

Table 3. Potassium Forms in Soils of Dissimilar Parent Materials ($mgkg^{-1}$)

Parent material	Non Exch. K	Exch. K	H_2O Soluble K	Total K
Basalt	97.00	0.04	4.00	119.0
Sandstone	160.0	0.09	3.00	198.0
Alluvium	82.00	0.04	6.20	106.0
LSD(0.05)	5.60	NS	NS	6.21

K = Potassium, Exch .K = Exchangeable potassium

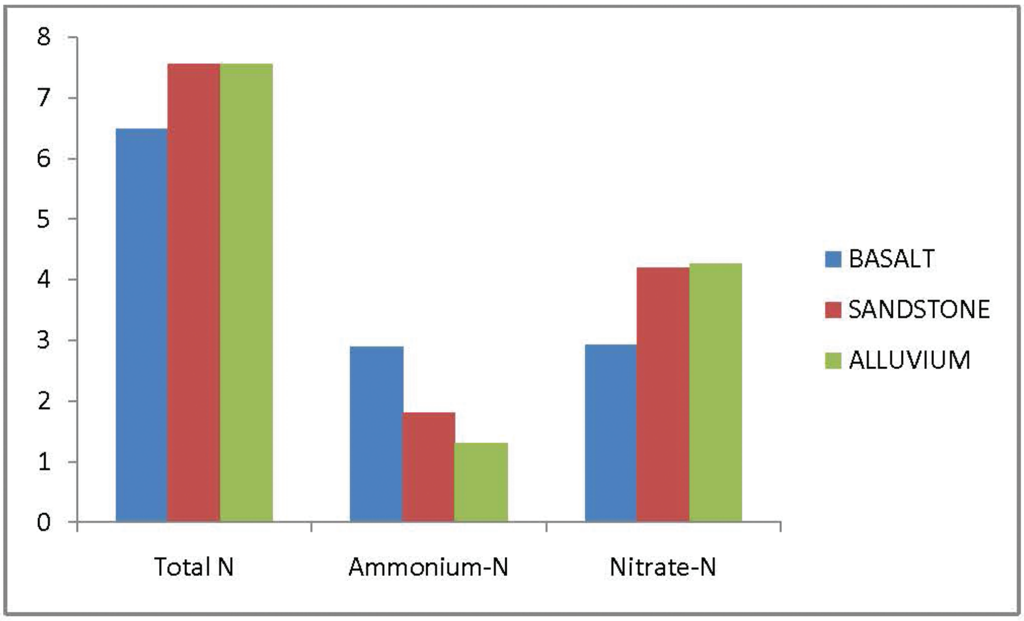

Fig. 1: Forms of nitrogen ($mgkg^{-1}$) in soils derived from three different parent materials

across the studied soils were rated low when compared with the critical values of 0.1 – 0.2 % (10 - 20 mg kg^{-1}) reported by Landon (1991) in soils of the tropics. The low nitrogen concentration is a common phenomenon in the soils of South-eastern Nigeria and is as a result of the high nitrogen losses sustained in these soils through the leaching of nitrates, as well as the rapid mineralization of organic matter under the isohyperthermic soil temperature regime (Eshett *et al.*, 1990). Significantly ($p<0.05$) higher ammonium nitrogen was recorded in soils developed on Basalt (2.9 $mgkg^{-1}$) than those of Sandstone (1.8 $mgkg^{-1}$) and Alluvium (1.3 $mgkg^{-1}$). Nitrate-nitrogen contents of the soils did not vary statistically. Generally, no significant variation observed in most nitrogen forms indicated that the parent materials from which the soils are developed on had little or no influence on the nitrogen contents of the soils. Parent material is a major source of most soil nutrients with notable exception of hydrogen (H^+), nitrogen and carbon, which are primarily derived from the atmosphere and organic material (Gray and Murphy, 2002).

The results of the various forms of potassium showed significantly ($p<0.05$) higher proportion of total K in soils formed from Sandstones (198.0 $mgkg^{-1}$) than those of Basalts (119 $cmolkg^{-1}$) and Alluvium (106.0 $cmolkg^{-1}$) parent materials (Table 3). The variations in the total amount of potassium released from different parent materials could be attributed to the soil environment and nature of K-bearing minerals such as crystal structure, chemical composition, degree of depletion and layer charge alteration (Hosseinpour and Kalbasi, 2002). Similarly, significantly ($p<0.05$) higher non exchangeable. K was also recorded in soils formed from Sandstone (160.0 $mgkg^{-1}$) compared to Basalt (97.0 $mgkg^{-1}$) and Alluvium soils (82 $mgkg^{-1}$) (Table 3). However, no significant variations were recorded in soil water soluble and exchangeable potassium contents of the soils. Generally, exchangeable and water soluble-K constituted 0.03 – 6 % of total K while the non exchangeable.- K constituted

Table 4. Correlation between Macro Nutrient Forms and Soil Properties

	Sand	Clay	M.C	pH	OC	Av. P	T N	TEB
Org. P	0.3NS	0.76**	0.3 NS	0.424*	0.781**	0.1 NS	0.78**	0.75**
Al- P	0.2 NS	0.537*	0.06NS	0.49*	0.63**	0.3NS	0.636**	0.75**
Fe – P	0.3NS	0.72**	0.265	0.81**	0.3 NS	0.398	0.35 NS	0.74**
Ca – P	0.289	0.715**	0.388	0.75**	0.464*	0.3NS	0.99**	0.78**
T P	0.4NS	0.81**	0.38 NS	0.532*	0.601*	0.048	0.601**	0.68**
NO_3^-	0.02NS	0.448*	-0.695*	-0.21NS	0.517*	0.0NS	0.631**	0.04NS
Ex. K	0.215NS	0.56**	-0.612*	0.419*	0.716**	0.03NS	0.421*	0.521*
Total K	-0.315NS	0.421*	0.542*	0.716*	0.452*	0.112NS	0.21NS	0.11NS

Ns = not significant, ** = significant at $p < 0.01$, * = significant at $p < 0.05$, Org P = Organic phosphorus, Al- P = Aluminum phosphorus, Fe- P = Iron phosphorus, Ca- P = Calcium phosphorus, Av.P = Available phosphorus, TP = Total phosphorus, Ex. K = Exchangeable potassium.

77 - 82 % of total K in soils formed from Alluvium, Sandstone and Basalt.

Exchangeable K showed significant correlation with clay (r = 0.56**), pH (r = 0.419*) and organic carbon (r = 0.716**). However, exchangeable K showed negative significant ($p<0.05$) relationship with moisture content (r = -0.612*). Also, soil moisture had significant negative relationship (r = -0.695*) with soil moisture (Table 4).

CONCLUSIONS

From the results, soils derived from sandstone, basalt and alluvium differed significantly in their phosphorus forms and total potassium contents. However, no significant variation was recorded in Total nitrogen contents of the soils. From this study, it can be deduced that, although parent material is a major source of most soil nutrients, nitrogen is primarily derived from the atmosphere and organic material.

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