Relationships Between Phosphorus Forms and Parent Materials in Soils of Southeastern Nigeria

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Abstract

A study was conducted to investigate the relationships between phosphorus forms and soils formed on seven parent materials in Southeastern Nigeria. Forms of P studied included total, organic, aluminium bound P (Al-P), iron bound P(Fe-P), calcium bound P(Ca-P) and available P (Bray 1 and 2). Total active P, total inorganic P and reverted P were obtained by calculation. The parent materials type included coastal plain sands (CPS), Beach ridge sands (BS), Alluvial deposits (AD), Basement complex (BC), Basaltic rocks (BR), Sandstones (SS) and Shale (SH). Results showed that total P levels varied widely among the parent materials, ranging from 119 mgkg^{-1} *in BS to 1892 mgkg*$^{-1}$ *in BR with the order of relationship being BR>SH>AD>CPS>SS>BC>BS. The relative abundance of the various forms of inorganic P indicated high variability among the soils, showing trace amounts in some parent materials and high amounts in others. The same pattern of distribution was observed for total active and total inorganic P forms being in the order BS<BC<SS<CPS<AD<BR<SH and BS<BC<SS<CPS<AD<SH<BR, respectively, indicating lower values of total active and total inorganic P fractions in the sandy textured soils of BS, BC, SS and CPS which are considered more strongly weathered compared to those of AD, SH and BR parent materials. Generally, P forms strongly and significantly correlated with some soil properties. Available P indices (Bray 1 and 2) showed that soils formed from CPS, BR, and SH are relatively more endowed with plant available P than others.*

Keywords: *Phosphorus forms, parent materials, reverted P, total P, organic P, and active P.*

Introduction

The inorganic phosphorus fractions dominate total P-pool in most soils on a global scale (Cross and Schlesinger, 2001). Quantifying the distribution of soil P among inorganic and organic fractions is however needed across different agro-ecological zones worldwide (Barret, *et al.*, 2002; Blecker *et al.*, 2006; Oluleye *et al.*, 2008; Wang *et al.*, 2008). The inorganic phosphates in soils have been classified into calcium phosphates (Ca-P), iron phosphates (Fe-P), aluminum phosphates (Al-P), and reductant-soluble or occluded phosphates (RS-P), (Chang and Jackson, 1957). These phosphate fractions occur in all soils, but differ in proportion according to soil characteristics and parent materials. Strongly acid soils, usually highly weathered are dominant in Al-P, Fe-P and RS-P. Neutral soils and slightly acid soils usually contain all the fractions in comparable amounts.

Routine characterization of phosphorus is required in soil testing programmes especially in the humid tropical regions where the dominant acidic soils are known to pose problems for P management. Equally, characterization of the various forms of P is useful in estimating P availability to crops as well as the degree of soil development (Chang and Jackson, 1957; Udo and Dambo, 1979; Wang *et al.*, 2008). In both soil and hydrologic systems, the sources of phosphates in the ecosystem have been attributed to weathering of soil and rocks (Green et al., 2008).

Loganathan and Sutton (1987) and Ibia and Udo (1993) reported the influence of parent material on the forms and distribution of P in southern Nigeria and concluded that soils formed on coastal plain sands and sandstones parent materials were more weathered than those on alluvium, beach sands and shale parent materials. Udo (1985) observed a wide variation in the abundance of total P ranging from 68 $mgkg^{-1}$ in some acid coastal plain sands to over 2000mgkg-1 in soils derived from basaltic rocks and deltaic deposits. Also, Uzu *et al.* (1975), Udo and Dambo (1979), Loganathan and Sutton (1987) and Ibia and Udo (1993) found that the relative abundance of the active inorganic P fractions decreased in the order Fe-P > Al-P > Ca - P in most Nigerian soils. Generally, agricultural production has declined owing to demographic pressure and farming systems that do not have adequate programme for soil fertility management. Increases in soil productive capacity and crop yields require complete characterization of the soil resources and assessment of P status in particular.

The objectives of this study were to assess the relationships between P forms and parent materials and between P fractions and some soil properties in southeastern Nigeria in order to guide proper soil management with respect to phosphorus.

Materials and Methods

Description of study area

The study was conducted in soils representative of seven parent materials namely, coastal plain sands (CPS), beach ridge sands (BS), alluvial deposits (AD), basement complex (BC), basaltic rocks (BR), sandstones (SS) and shale (SH) in the two contiguous states of Akwa Ibom and Cross River in southeastern Nigeria. The area lies between latitudes 40 30' and 70 00' N and longitudes 70 30' and 90 30' E and has a land mass of 29,412 km^2.

The climate of the area is hot humid tropical and characterized by two seasons, the wet or rainy season which lasts for about 9 to 10 months (April to October) and a short dry period which lasts from November to March. The total annual rainfall ranges from about 4000 mm in the coastal areas to about 1750mm in the hinterland, providing an ustic soil water regime. Temperatures are uniformly high throughout the year with slight variations between 27^0C and 35^0C producing a hyperthermic soil temperature regime such as would encourage cropping throughout the year provided there is adequate water supply. The months with the highest temperature (December to March) and the lowest temperature (July to August) coincides with the dry and rainy seasons, respectively.

Although the study area is contiguous, with plains dissected by steep-sided hills, the dominant feature, distinct physiographic formations exist. These are the mangrove swamps and floodplains with recent alluvial accumulations, beach ridges, level to gently undulating sandy plains, sandstone/shale hilly ridges, undulating sandstone plains and steep-sided hills of undifferentiated igneous and metamorphic rocks and dissected basement complex plains and pediments.

Beach ridge sands constitute river-deposited sands and clays and cover over 80 per cent of the southwestern part of the study area. The central and northeastern areas are underlain by the cretaceous sandstones and shale and the basement complex, the latter comprising predominantly granites, gneisses and basalts (acid and basic crystalline rocks), and covers over 75 per cent of these latter areas and is a continuation of the (African Basement) Cameroon crystalline complex. Tertiary fluvial deposits of the upper river valley occur along the Cross river and Qua Iboe river and their tributaries in the study area.

Land use for agricultural production in the area is extensive and is the traditional low external input production systems.

Field and Laboratory methods

Three replicate soil samples were collected from the top 30cm soil depth of each parent material group and bulked for laboratory analyses. The soil samples were air-dried, sieved through a 2mm mesh and preserved for selected physical and chemical analyses using standard methods. Particle size distribution was done by the Bouyoucos hydrometer method (Bouyoucos, 1951). Soil pH was determined on a soil: water suspension in a ratio of 1:2 using the pH meter.

Organic carbon was determined by the wet oxidation method of Walkley and Black (1934). Exchangeable bases were extracted with 1M NH_4OAc solution. The exchangeable bases, K and Na in the extract were determined using flame photometer, while Ca and Mg were obtained by atomic absorption spectrophotometry. Exchangeable Al^{3+} and H+ were measured after extracting the soil with 1M KCl as described by McLean (1965). The summation method (IITA, 1979) was used to obtain effective cation exchange capacity. Total P was extracted by the perchloric acid digestion method (Jackson, 1964) and organic P was obtained by ignition method of Legg and Black (1955). Phosphorus fractionation was done according to the method of Chang and Jackson (1957) as modified by Peterson and Corey (1966), using 0.5M NH_4F for Al-P, 0.1M NaOH for Fe-P and 0.25M H_2SO_4 for Ca-P. Available P was extracted using Bray and Kurtz (1945) extractants (Bray P-1 and P-2), and P in the extracts was determined using the molybdenum blue colour method of Murphy and Riley (1962). From these, the active P form was obtained by summation of Al-P, Fe-P and Ca-P and reverted P form corresponding to inactive form was calculated as the difference between total P and the sum of organic P and active P forms (IMPHOS, 1989). Also, total inorganic P was obtained as the difference between total P and organic P forms.

Correlation analysis was performed on the data to examine relationships between the forms of P and parent materials and forms of P and some soil properties.

Results and Discussion

Particle size distribution

Values of particle size distribution as they relate to the various parent materials are presented in Table 1. Sand separate was highest in the coastal plain sands (CPS) soil and least in basalt (BS), and generally in the order of CPS> BS> BC> SS> RA> SH> BA. The trend in clay content was however the reverse, with the highest value obtained for BA and least for CPS parent materials. The distribution pattern for silt fraction differed from the trends observed for sand and clay. Soil texture therefore varied among the parent materials, being generally sandy in CPS, BS, BC and SS; the soils decreasing from parent materials that are similar in nature, and clayey in soils derived from BA, SH and RA. That is, the texture of the soils varies from coarse to fine, with implications for nutrients retention and leaching.

Soil chemical properties

The soils on all parent materials were acidic, with pH values ranging from 5.0 to 5.6. The content of organic carbon ranged from 22 gkg^{-1} in BC to 48 gkg^{-1} in BR (Table 1), indicating that the soils were generally medium to high in soil organic C storage. The content of the exchangeable bases was low with levels of Ca and Mg being higher than those of K and Na in the soils/ parent materials. With a critical value of 4.0 $cmolkg^{-1}$, only SH and BR soils could meet Ca requirement for crop production in these soils. The concentration of Mg was high and with a critical value of 0.5$cmolkg^{-1}$, only CPS soil will need Mg supplementation for increases in crop yields. Exchangeable acidity was moderate with H+ contributing more while exchangeable Al value was low in the soils/ parent materials. Although ECEC values of the soils were low, percent base saturation ranged from 59 % in CPS to 87 % in SH.

Table 1. Physical and chemical properties of the top 30 cm of soils from different parent materials.

	Soils of different parent materials						
Soil Properties	CPS*	BS	BR	BC	SS	SH	AD
Sand (gkg^{-1})	845	831	158	769	689	290	443
Silt (gkg^{-1})	29	61	141	70	119	280	334
Clay (gkg^{-1})	126	107	699	161	192	430	222
pH (H_2O)	5.1	5.0	5.2	5.0	5.6	5.0	5.0
Organic C (gkg^{-1})	21.9	25.7	45.8	25.1	22.5	35.1	20.9
Exch Ca (cmol/kg)	1.40	1.95	5.92	2.11	3.80	8.27	2.09
Exch Mg (cmol/kg)	0.45	1.25	1.86	1.78	1.10	2.19	1.27
Exch K (cmol/kg)	0.09	0.07	0.18	0.08	0.18	0.19	0.36
Exch Na (cmol/kg)	0.12	0.10	0.15	0.06	0.13	0.04	0.33
Exch Ac (cmol/kg)	1.48	1.58	1.92	1.31	0.78	1.79	2.70
Exch Al (cmol/kg)	0.92	0.48	1.55	0.93	1.03	1.04	1.40
ECEC (cmol/kg)	3.54	5.21	10.30	6.00	7.48	16.89	7.98
Base Sat. (%)	59	69	76	78	74	87	66

*CPS: coastal plain sand; BS: beach sand; BR: basaltic rock; BC: basement complex; SS: sand stone; SH: shale; RA: river alluvium.

Relationship between P forms and soil parent materials

The data for forms of P in relation to the parent materials are shown in Table 2. The results showed that total P levels varied widely among the parent materials, ranging from 119 $mgkg^{-1}$ in BS to 1892 $mgkg^{-1}$ in BA. The order of relationship is BR> SH>AD> CPS> SS> BC> BS. The results obtained are comparable to those reported in other studies (Uzu *et al.,* 1975; Udo and Ogunwale, 1977; Enwezor, 1977; Ibia and Udo, 1993).

The accumulation of organic P also varied widely among the soils/parent materials with values ranging from 56gkg^{-1} in BS to 477gkg^{-1} in SH, and in the order BS< SS< BC<AD< CPS< BR< SH. These results are also comparable to those reported by Uzu *et al.*, (1975), Udo (1977), Udo and Ogunwale (1977), Udo and Dambo (1979) and Loganathan and Sutton (1987)

Results of the relative abundance of the various forms of inorganic P as shown in Table 2 (active P, reverted P or inactive P, and total extractable inorganic P), indicated very high variability among the soils/ parent materials, being trace to high. While total active ranged from 12 $mgkg^{-1}$ in BS to 1013 $mgkg^{-1}$ in SH, and in the BS< BC< SS< CPS<AD< BR< SH, total inorganic P ranged from 64 $mgkg^{-1}$ in soils of BS to 1612 $mgkg^{-1}$ in BA, and followed the order BS< BC< SS< CPS< AD< SH< BR. In other words, both active and total inorganic P had similar pattern of distribution among the soils/ parent materials. This trend indicated lower values of total active and total inorganic P in the sandy textured soils/ parent materials (BS, BC, SS, CPS) than in the clayey textured soils/ parent materials (AD, SH, BR). This would indicate that soils on the latter parent materials may have higher sorption capacity for these forms of P than those formed on the former group of parent materials. This pattern was similar to that of total P and organic P.

TABLE 2: Forms of P in the top 30 cm of soil depth from different parent materials.

Forms of Phosphorus	Soil of different parent materials						
	CPS*	BS	BR	BC	SS	SH	AD
	(mgkg^{-1})						
Total P	367	119	1892	209	288	1759	568
Organic P	136	56	280	71	69	477	97
Al-P	16	trace	106	2	35	trace	19
Fe-P	75	9	548	16	14	519	229
Ca-P	16	1	64	2	2	508	57
Total active P	109	12	708	20	51	1013	305
Total inorganic P	230	64	1612	139	219	1282	471
Reverted P	122	52.	905	146	169	250	167
Bray P-1	36	6	26	2	7	52	15
Bray P-2	47	10	48	6	8	64	42

*CPS: coastal plain sand; BS: beach sand; BR: basaltic rock; BC: basement complex; SS: sand stone; SH: shale; AD: river alluvium

Chang and Jackson (1957) used the relative abundance of inorganic P fractions to indicate the degree of chemical weathering of soils. They reported that soils which are strongly weathered tend to have high proportions of inactive and Fe-P forms than the other forms. For this reason, soils on CPS, BS, BC, and BR are more strongly weathered than soils formed on SH and SS. Thus, except for soils formed on SH, the relative abundance of the total active fraction was generally low, constituting less than 50% of total inorganic fraction, compared to the reverted P. This may account for the relative limited capacity of some of these soils to supply available P when the inorganic P pool is considered (Juo and Ellis, 1968; Uzu *et al,* 1975).

The data on available P extracted with Bray (1 and 2) methods showed that Bray P-2 extracted the more available P in CPS, BR, AD and SH, compared to Bray P-1 (Table 2). However, the available index has been used to determine P fertility status of soils. Thomas and Peaslee (1973) reported that soils having available P lower than 15 mgkg^{-1} (Bray P-1) were deficient in phosphorus. The results of this study thus showed that soils formed on CPS, BR and SH have relatively high P availability compared to soils on SS, BC, BS and AD.

Forms of P in relation to soil properties

The relationships between forms of P and soil properties are presented in Table 3. The total sand fraction was negatively highly significantly correlated with clay (r= -0.910***), exchangeable Al (r= -0.913***) and inorganic P (r= -0.892***), as well as with Al-P (r= -0.774*),

Table 3: Pearson correlation coefficients of forms of P with soil properties

	S	Si	Clay	pH	Org. C	Ca	Ex. Al	ECEC	Total P	Org. P	Al. P	Fe. P	Ca. P	Active P	Inorg. P	Rev. P	Bray-1	Bray-2
S	1.000																	
Si	-0.584	1.000																
Clay	-.0.910**	0.343	1.000															
pH	0.001	-0.195	0.016	1.000														
Org C	-0.669	0.274	0.767*	-0.306	1.000													
Ca	-0.636	0.530	0.777	0.070	0.568	1.000												
Ex Al	-0.913**	0.488	0.782*	0.100	0.451	0.428	1.000											
ECEC	-0.585	0.686	0.663	-0.083	0.495	0.965**	0.370	1.000										
Total P	-0.821	0.472	0.940**	-0.104	0.810*	0.893**	0.665	0.825*	1.000									
Org..P	-0.523	0.469	0.707	-0.192	0.679	0.915**	0.351	0.901**	0.900**	1.000								
Al..P	-0.774*	-0.004	0.784*	0.366	0.524	0.312	0.792*	0.120	0.562	0.178	1.000							
Fe..P	-0.851*	0.576	0.915*	-0.197	0.834*	0.856*	0.692	0.821*	0.987***	0.881**	0.525	1.000						
Ca.. P	-0.268	0.584	0.397	-0.246	0.422	0.832*	0.075	0.907**	0.669	0.906**	-0.210	0.672	1.000					
Act. P	-0.706	0.617	0.895*	-0.199	0.744	0.929**	0.522	0.926**	0.955**	0.967***	0.308	0.961**	0.850*	1.000				
Inorg. P	-0.892**	0.436	0.982***	-0.064	0.821*	0.828*	0.754*	0.741	0.984***	0.809*	0.689	0.973***	0.531	0.894*	1.000			
Rev. P	-0.867*	0.114	0.941**	0.095	0.691	0.534	0.809*	0.374	0.784*	0.454	0.926**	0.749	0.071	0.567	0.875*	1.000		
Bray-1	-0.290	0.334	0.460	-0.181	0.621	0.647	0.240	0.632	0.705	0.872*	0.061	0.702	0.784*	0.792*	0.605	0.252	1.000	
Bray-2	-0.533	0.543	0.571	-0.292	0.735	0.601	0.494	0.614	0.765*	0.811*	0.219	0.811*	0.825	0.825*	0.709	0.394	0.999***	1.000

*= 0.05; **= 0.01; ***= 0.001; S=sand; Si=silt; Rev. P= reverted P

Fe-P (r= -0.851*) and Re-P (r= -0.867*). This may be due to the fact that sand is a less reactive soil separate with a low sorption capacity. Therefore, increasing content of the sand separate indicates decreasing clay content, negating the accumulation of these P fractions. The silt separate was positively significantly correlated with K (r= 0.896***), indicating that the silt fraction may be the main sources of K in the soils. The clay separate correlated positively significantly with organic C (r=0.767*), total N (r=0.761*), Ca (r=0.777*), exchangeable Al (r=0.782*), indicating that clay is not only a source but that there is a synergy between the clay separate and organic C in relation to the fertility status of the soils. The clay separate also correlated positively significantly with total P (r=0.940**), Al-P (r=0.784*), Fe-P (r=o.915**), active P (r=0.805*), inorganic P (r=0.982***), and Rev-P (r=0.941**), indicating that much of these P fractions in the soils occur in the clay fraction.

Soil organic C was positively significantly related with total N (r=0.999***), indicating that the bulk of N in the soil is in the organic form and increasing the organic matter content of the soils will elevate the level of N in the soils. The relationship with P forms is positively significant with total P (r=0.810*), Fe-P (r=0.834*), and inorganic P (r=0.821*). Total N was also positively significantly related to total P (r=0.810*), Fe-P (r=0.834*), and inorganic P (r=0.818*).

Being a major cation in the sorption complex, exchangeable Ca was positively significantly related to ECEC (r=0.965***), Mg (r=0.754*), Base saturation percentage (r=0.796*), total P (r=0.893**), organic P (r=o.915**), Fe-P (r=0.856*), Ca-P (r=0.832*), active P (r=0.929**) and inorganic P (=0.828*), thus indicating that the status of these parameters is associated with the status of Ca in the soils. Effective CEC was also positively significantly related with Base saturation percentage (r=0.806*), total P (r=0.825*), organic P (r=0.901*), Fe-P (r=0.821*), Ca-P (r=0.907**), and active P (r=0.926**), indicating that the relative availability of these parameters will have high positive influence on the availability of the basic cations.

Generally, P forms were strongly correlated in these soils (Table 3): total P is positively significantly correlated with organic P (r=0.900**), Fe-P (r=0.987***), Active P (r=0.955**), inorganic P (r=0.984***), Rev-P (r=0.784*) and Bray P-2 available P (r=0.765*). Equally, organic P was positively significantly correlated with Fe-P (r=0.881**), Ca-P (r=0.906**), active P (r=0.967***), inorganic P (r=0.809), and the available forms (Bray P-1: r=0.892*; Bray P-2: r=0.811*). Al-P was significantly related with Rev-P (r=0.926**), indicating that much of the inactive P was held in the sorption complex as Al-P.

Phosphorus is an essential nutrient for crop growth and fertilization sometimes is necessary to achieve optimal levels for crop production and yields. However, P fertilization seldom is needed for crop production in soils testing high in available P (Jokela, 1992; Webb et al., 1992) and excessive P application can cause eutrophication of surface water sources (Cornell, 1998; Sharpley and Rekolainen, 1997) with adverse implication for aquatic life and portable water supply.

Conclusion

The soils in Southeastern Nigeria differ in their P status in relation to the parent materials. Soil formed on shale and basalt parent materials had higher values of total P compared to those formed on coastal Plain sands, beach ridge sands, basement complex rocks, sandstones and alluvial materials. Various P forms correlated with available P indices. Very high levels of available P were obtained for soils formed from CPS, BR, SH, and AD whereas the levels for BS, BC, and SS were relatively low. Soils in this zone with levels of available P greater than 15mgkg-1 may not require P fertilization for some period of cropping, thus justifying the need for routine soil test for P in order to achieve fertilizer best practice for crop production.

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