Inter-Horizon Variability in Phosphorus-Sorption Capability of Sesquioxide-Rich Soils Southeastern Nigeria

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Abstract: This study estimated the variability of phosphorus sorption capacity among horizons of highly weathered soils of Otammiri River floodplain in southeastern Nigeria. Four profile pits representing 4 depositional stages of the river were studied. The soils were deep, sandy, acidic and of low cation exchange capacity. Total carbon (organic matter) decreased with depth. Soils were classified as Isohyperthemic Arenic Paleadults. The values of phosphorus-sorption maximum (Smax) ranged from 48.0-83.0 mg kg^{-1}. Total carbon had highest influence on the P-sorption characteristics of epipedal horizons (Ap) while Fe_{M3} and Al_{M3} controlled P-sorption capacity in the sub-surface horizons (AB – Bt). Variability among horizons were distributed as follows: Ap (CV = 35%), AB (CV = 25%), Bt_1 (CV = 10%) and Bt_2 (CV = 8%). [The Journal of American Science. 2007;3(1):43-48].

Keywords: Mehlich-3 extraction, phosphorus, P-saturation, sesquioxides, ultisols.

Introduction

Phosphorus plays an indispensable role as a universal fuel for all biochemical work of living cells, being the bearer of high energy adenosine triphosphate (ATP) bonds. Soil phosphorus influences crop productivity which affects animal and human health. Phosphorus saturation in soils estimates the degree to which P sorption sites, usually associated with reactive sites are filled, thus Beauchemin and Simard (1999) described the concept of P saturation as an indicator of potential desorbability of soil P.

Phosphorus sorption behaviour is influenced by some soil mineralogical and chemical properties. These parameters act singly or in combination to influence sorbability or desorbability of soil P. Mineralogical properties influencing soil P include clay type, clay content, $CaCO_3$, Al and Fe (Burt *et al.,* 2002; Giesle *et al.,* 2005). On the other hand, soil properties, such as soil pH (Dodor and Oya, 2000; Burt *et al.,* 2002), organic carbon and clay content (Dodor and Oya, 2000) were also found to influence soil P-sorption. As a result of autocorrelation, it becomes difficult to determine the principal components among these properties that contribute most to P sorption in soils.

Phosphorus sorption differs among soil horizons whether epipedons or sub-surface horizons (Schouman, 2000). Foth (1984) reported high P-sorption in anthropic epipedon due to heavy applications of P-fertilizers. He noted that P in soil solution is primarily a function of the solubility of the fixed forms of phosphorus, stating that there is a decreasing solubility in the order of calcium phosphates, clay-adsorbed phosphates, iron and aluminium phosphates. These determinants in interaction with organic matter increase the capacity of phosphate sorption (Gerke and Herman, 1992). It was earlier hypothesized that Fe in humic-substances is more finely distributed in organic surface and not present as Fe polymers, hence creating a larger number of surface sites for phosphate binding per Fe (Giesler *et al.,* 2005). Both ternary complexes involving metal-organic matter complexes and phosphate-Al-Fe precipitates with P may prevail at the epipedal layers of tropical soils. This study investigated variation in P-sorption capacity of common horizons found in tropical soils as this influences crop uptake of P.

Materials and methods

Study site: They study area, covering Otammiri floodplain in Imo State, lies between latitudes 4^o15^1 $49^{11}.670$ and $7^o181\ 42^{11}.055$ N and longitudes $5^o\ 30^1$ $15^{11}.365$ and $5^o5^152^{11}.610$ E (Global Positioning system–GPS Receiver-Garmin Ltd Kansas, USA). Soils are derived from Coastal Plain Sands known as "Acid Sands". It is a humid tropical environment with an average annual rainfall of about 2400 mm and 3 distinct months of dryness. Temperatures are high and change only slightly during the year and the mean daily temperature is about 27^oC. The watershed is of rainforest vegetation although its original nature has been altered by anthropogenic activities such as farming, sand mining, hunting and human constructions. The traditional slash and burn farming system is practiced and soil fertility regeneration is mainly dependent on natural fallows.

Field studies: Four profile pits were dug along depositional stages of the floodplain in such a way that the profiles were not less than 1 km from each other. The 4 profile pits represented depositional stages; thus, oldest (near upland), older (toeslope) middle (levee) and recent (backwamp) depositions and were presented as pedons 1, 2, 3, and 4

respectively. Soil samples were collected from the pedons based on horizon differentiation. These soil samples were air-dried, sieved using 2-m mesh sieve and bagged with black polythene bags in readiness for laboratory analysis.

Laboratory analyses: Particle size distribution was determined by hydrometer method according to the procedure of Gee and Or (2002). Bulk density (BD) was measured by core method (Grossman and Reinsch (2002). Total carbon was estimated using automated C and N analyzer (Carlo Erba, Milan Italy) (Nelson and Sommers, 1996). Soil pH was determined electrometrically using a pH meter in a soil solution ratio of 1:2.5 (Hendershot *et al.,* 1993). Cation exchange capacity (CEC) was obtained by a method described by Rhoades (1982).

Phosphorus adsorption isotherms were determined according to the procedure of Graetz and Nair (2000). One gram of soil sample was equilibrated with 25 ml of varying concentrations of P in 0.01 M $CaCl_2$ solution in 50 ml centrifuge tubes.

The concentrations of the solutions were 0.0, 0.5, 1.0, 5.0 10.0, 15.0 and 20.0 mg P l^{-1}. The tubes were shaken for 24 hours on an end-to-end shaker at 150 oscillations per minute. The samples were then centrifuged for 10 minutes at 5211 x g and the supernatant decanted. The P in solution was measured colourimetically using the ascorbic acid method (Juo, 1996). Amount of P adsorbed was determined as the difference between initial and final amounts of P in solution. Duplicate analyses were conducted on all the studied soil horizons. Linearized form of Langmuir equation was used in the determination of P adsorption isotherms.

Mehlich-3 (M3) extractable P, Al, and Fe were determined by shaking duplicate 2.0-g samples of soil and 20 ml M3 solution in 50-ml centrifuge tubes for 10 minutes on an end-to-end shaker at 150 oscillations per minute and centrifuged at 5211 x g for 10 minutes. The supernatants were analyzed by inductively coupled plasma-atomic emission spectroscopy (ICP-AES). Duplicate analyzes were conducted on all the studied horizons.

Calculations: P- saturation index (PSI) was calculated as follows:

$$PSI = \frac{P_{M3}}{Al_{M3} + Fe_{M3}} \quad \dots \; 1 \; (Kleinman \; and \; Sharpley$$

Where P_{M3} = Mehlich-3 extractable P
Al_{M3} and Fe_{M3} = Mehlich-3 extractable Al Fe respectively

Thereafter P saturation (Psat) was computed as follows:

$$Psat = \frac{P_{M3}}{Smax} \quad \dots. \; 2 \; (Mehlich, \; 1984)$$

Smax = P-sorption maximum / P-adsorption maximum

Data analyses: Means, minima, maxima, coefficient of variation (%) and correlation coefficients (r) were used to statistically analyze data. Variability of P-sorption capacity as represented by Smax was ranked according to the procedure of Aweto (1982).

Results and discussion

Soil properties: Results of soil properties are shown in Table 1. Soils were deep, sandy, acidic and of low cation exchange capacity. Total carbon was low in soils and decreased with depth in all pedons except in pedon 4. Bulk density generally increased with depth. Values of silt-clay ratio (SCR) were low, suggesting that soils are highly weathered. Sandiness of soils could be attributed to Coastal Plain Sands (Acid Sands) from which soils were derived as well as fluvial activities of the Otammiri River. Soils were classified as Isohyperthermic Arenic Paleudults (Soil Survey Staff, 2003). Again, parent material and translocatory processes of loss may have been responsible for the high acidity of soils as basic

cations were lost during leaching and eluviations. Irregular distribution of total soil carbon may be due to varying quanta of organic materials at different depositional periods of the river as well as the rate of organic material decompositions taking place in these horizons, as the site is subject to seasonal flooding and consequently seasonal anaerobiosis.

Phosphorus-sorption characteristics: The distribution of sorption attributes are presented in Table 2. Phosphorus saturation index (PSI) ranged from 23.2 to 47.2% while P-sorption capacity varied from 48 to 83 mg kg^{-1}. Ranges of PSI differed among horizons and as follows: Ap (23.2 – 44.7%), AB (27.8 – 46.4%), Bt_1 (27.4-44.0%) and Bt_2 (23.7-47.1%) while Smax values ranged from 67.0-73.0 mg kg (Ap), 43.0-83.0 mg kg^{-1} (AB), 59.0-74.0 mg kg^{-1} (Bt_1) and 49.0-81.0 mg kg^{-1} (Bt_2).

Results of correlations between P-sorption characteristics and some soil properties are indicated on Table 3. Total carbon (organic matter) had

significantly positive correlations with P-sorption characteristics in Ap horizons and this influence decreased with depth in response to reduced total carbon. The influence of clay on P-sorption parameters increased as depth of soils increased with highest impact shown in Bt_1 and Bt_2 horizons (r=0.7-0.8; p<0.01).

Phosphorus sorption related with total carbon, Al_{M3} and Fe_{M3} (Table 4). Mehlich-3 extractable aluminium had very poor relationship (r=0.4) with P-sorption at Ap horizon while total carbon had very significant high correlation with P-sorption (r = 0.8; p<0.01). Among the argillic horizons (Bt), P-sorption was controlled mainly by Al_{M3} (r = 0.7-0.8, p<0.05) and Fe_{M3} (r=0.8; p<0.01). These results show variation in the P-sorption-controlling factors among pedons in the study site as well as the relative influences of these components. Highest variability in P-sorption capacity was shown by Ap horizon (CV = 35%) (Table 5), possibly due to its exposure to climatic and anthropogenic activities.

Poor correlation between P-sorption and Al_{M3} could be due to competition for sorption sites among elemental components (Kaiser and Zech, 1997). It implies that organo-phosphorus compounds will predominate in Ap horizons (Shang *et al.,* 1990) while metal-organic matter complexes dominated the AB horizon (Giesler *et al.,* 2005) since it represented an interface between organic and mineral layers. Aluminium and Fe oxides exist in soils as discrete crystals, coatings on clay and humic substances and as mixed gel (Zhang *et al.,* 2005) and play an important role in adsorption in soils because of their high specific surface areas and reactivity (Sparks, 2003). These sorption parameters are therefore important in modelling P-availability to crops as well as ground water quality in tropical soils.

Conclusion

Phosphorus sorption capacity differed among horizons highly weathered soils due to influences of soil and mineralogical properties. The study showed that highest variation occurred in the Ap horizon. Soil organic matter (Total carbon) had very high impact on the sorption capacity of phosphorus in the Ap horizon while Fe and Al oxides dominated the sorption of P in deeper layers of soils. Knowledge of these relationships is therefore helpful in predicting P-availability for plants and/or for transfer from the terrestrial to aquatic environment where it causes eutrophication.

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Table 1. Pedon distribution of selected soil properties

Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	B.D (Mgm^{-3})	Total carbon (%)	pH (KCl)	CEC (cmolkg^{-1})	SCR
Pedon 1									
Ap	0-7	81	2	17	1.11	2.01	3.9	3.4	0.12
AB	7-40	75	3	22	1.32	0.82	3.6	3.0	0.13
Bt$_1$	40-110	74	4	24	1.34	0.32	3.7	3.8	0.08
Bt$_2$	110-130	78	1	21	1.45	0.19	3.8	4.2	0.04
Pedon 2									
Ap	0-11	81	1	18	1.22	1.86	4.0	3.5	0.05
AB	11-30	79	2	19	1.31	0.72	3.7	2.9	0.10
Bt$_1$	30-80	77	2	21	1.38	0.46	3.9	3.9	0.09
Bt$_2$	80-132	80	1	19	1.44	0.21	4.2	4.5	0.05
Pedon 3									
Ap	0-17	82	2	15	1.26	1.91	4.0	4.6	0.13
Bt$_1$	17-50	81	1	18	1.29	0.71	4.1	4.4	0.05
Bt$_2$	50-92	80	2	18	1.35	0.43	4.3	4.8	0.11
Bt$_3$	92-170	78	2	20	1.48	0.26	4.4	5.6	0.10
Pedon 4									
A	0-13	85	2	13	1.50	2.52	4.8	5.6	0.15
AB	13-56	82	2	16	1.56	0.48	4.3	5.1	0.13
Bt	56-90	81	2	17	1.71	0.94	4.4	6.8	0.12
BC	90-165	79	5	16	1.83	0.53	4.6	7.7	0.31

BD = Bulk density, CEC = cation exchange capacity; SCR = Silt – clay ratio

Table 2. Phosphorus sorption characteristics among horizon of floodplain soils

Horizon	Depth (cm)	Pedon	P$_{M3}$(mgkg^{-1})	Al$_{M3}$ (mgkg^{-1})	Fe$_{M3}$ (mg kg^{-1})	PSI$_{M3}$ (%)	Smax (mk kg^{-1})	Psat (%)
Ap	0-7	1	19.5	18.2	25.4	44.7	73	26.7
AB	7-40		26.8	26.4	32.3	46.4	81	33.1
Bt$_1$	40-110		22.2	21.6	29.0	44.0	72	30.8
Bt$_2$	110-130		19.6	17.6	24.0	47.1	77	25.5
Ap	0-11	2	17.0	35.1	38.1	23.2	68	25.0
AB	11-30		14.6	20.2	29.6	29.3	48	30.4
Bt$_1$	30-80		20.1	32.0	28.4	33.3	59	34.1
Bt$_2$	80-132		18.3	29.6	30.5	30.4	70	26.1
Ap	0-17	3	18.3	30.2	35.5	27.9	67	27.3
AB	17-50		19.9	33.5	38.2	27.8	69	28.8
Bt$_1$	50-92		15.6	27.5	29.5	27.4	61	25.6
Bt$_2$	92-170		12.4	25.6	26.8	23.7	49	25.3
Ap	0-13	4	20.6	28.6	30.6	34.8	71	29.0
AB	13-56		28.4	29.5	24.1	44.6	83	33.0
Bt$_1$	56-90		21.0	23.2	26.7	42.1	74	28.4
Bt$_2$	90-165		19.6	19.5	25.2	43.8	78	25.1

Mean	19.6	26.0	30.2	35.7	81	24.2
Minimum	12.4	17.6	24.0	23.2	48	24.2
Maximum	28.4	35.1	38.2	47.1	83	34.1

Table 3. Correlation coefficient (r) between soil properties and P-sorption parameters among horizons

Horizon	Factors	Correlated	Coefficient (r)	Level of significance
Ap	Clay	VS P_{M3}	0.6	*
	Total clay C	VS P_{M3}	0.8	*
	Clay	VS Al_{M3}	0.5	*
	Total C	VS Al_{M3}	0.9	*
	Clay C	VS Fe_{M3}	0.6	*
	Total C	VS Fe_{M3}	0.8	**
AB	Clay	VS P_{M3}	0.5	*
	Total C	VS P_{M3}	0.6	*
	Clay	VS Al_{M3}	0.5	*
	Total C	VS Fe_{M3}	0.5	*
Bt_1	Clay	VS P_{M3}	0.7	**
	Total C	VS P_{M3}	0.3	
	Clay	VS Al_{M3}	0.8	**
	Total C	VS Al_{M3}	0.2	NS
	Clay	VS Fe_{M3}	0.7	**
	Total C	VS Fe_{M3}	0.3	NS
Bt_2	Clay	VS P_{M3}	0.8	*
	Total C	VS P_{M3}	0.2	NS
	Clay	VS Al_{M3}	0.7	**
	Total OC	VS Al_{M3}	0.1	NS
	OC Clay	VS Fe_{M3}	0.8	**
	BD OC	VS Fe_{M3}	0.2	NS

** Significant at P <0.01, * significant at P <0.05, NS = Not significant

Table 4. Correlation coefficients (r) between P-saturation indices soil properties and P-sorption among soil horizon of the study site.

Horizon	Factors	Correlated	r	Level of significance
Ap	Smax	VS Al_{M3}	0.4	NS
	Smax	VS Fe_{M3}	0.5	^
	Smax	VS Total carbon	0.8	**
AB	Smax	VS Al_{M3}	0.8	*
	Smax	VS Fe_{M3}	0.7	*
	Smax	VS Total carbon	0.3	NS
Bt_1	Smax	VS Al_{M3}	0.7	*
	Smax	VS Fe_{M3}	0.8	**
	Smax	VS OC	0.2	NS
Bt_2	Smax	VS Al_{M3}	0.8	*
	Smax	VS Fe_{M3}	0.8	**
	Smax	VS Total carbon	0.1	NS

** = Significant at P <0.01, * = significant at p =<0.05 ns = Not significant.

Table 5. Variability in P-sorption capacity (Smax) among soil horizons

Horizon	CV (%)	Ranking
Ap	35	Moderate variation
AB	25	Moderate variation
Bt$_1$	10	Little variation
Bt$_2$	08	Little variation

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