Nigerian Journal of Soil Science 25 (2015) 108 – 115

Nigerian Journal of Soil Science

Journal homepage:www.soilsjournalnigeria.com

PHOSPHORUS SORPTION BY SOME HYDROMORPHIC SOILS OF SOUTHERN NIGERIA

Aghimien A.E.[1], Ilori E.G.[1] and Ehigiator J.O.[2]

[1]Chemistry Division, NIFOR, P.M.B. 1030 Benin City, Edo State, Nigeria

[2]Department of Soil Science, University of Benin, Benin City, Edo State, Nigeria

e-mail: aiyowie_aghimien@yahoo.com

ABSTRACT

A laboratory experiment was conducted on fifty eight (58) surface soils from five different soil parent materials in Southern Nigeria. Samples were equilibrated with different P concentration ranging from 0 - 150 mg/L prior to evaluation sorption potentials. The Phosphorus Sorption Index (PSI) of the soils ranged from 4.80 to 64.90. The PSI values correlated significantly with some of the soil parameters analyzed at $P \leq 0.05$ and $P \leq 0.01$ level of significance in the soil samples on crystalline metamorphic and igneous rock, shale mixed with sandstone and clay and coastal plain sands but not in the fresh water swamp and coastal alluvium soils. Also the results indicated that at any specific P concentration, the coastal alluvium soils had the highest amount of P sorbed than the other soils.

Keywords: Phosphorus sorption; hydromorphic soils; Sorption isotherm; Sesquioxides.

INTRODUCTION

Phosphorus (P) is an essential macronutrient for both plant and animal growth (Fox. 1993). However, excessive application of P can play a major role in the eutrophication of freshwater systems (Sharply, 2000). A number of studies have been conducted on the sorption reactions of phosphorus in soil both for agronomic (Uwumarongie-Ilori et al., 2012) and environmental purposes (Zhang et al., 2005).

In Nigeria, numerous studies have been carried out on the phosphorus status of Nigerian upland soils (Udo and and Ogunwale, 1977) but very little has been reported on the lowland soils that are permanently under water with different chemistry and transformation of phosphorus from well drained soils. Aghimien et al., (1985) reported that the lowland soils of Nigeria have a wide range of capacities to retain P.

P sorption takes place when P is added to soils or sediments and it refers to the fast surface reaction and slow reaction of P on solid phase. Sorption of P proceeds initially by a rapid exothermic ligand exchange reaction with the reactive surface groups resulting in the released of a hydroxyl or water molecule from the surface and formation of a phosphate surface complex (Frossard et al., 1995). This fast reaction is followed by a slow reaction which occurs by ion exchange with exchangeable cations or cations in crystal lattices. Phosphorus sorption involves adsorption and retention and it's controlled by the concentration of P in solution and the ability of the solid phase to replenish Pinto solution (Zhou and Li, 2001).

Hydromorphic soils may act as sinks or as sources of P, hence this study is aimed at assessing P sorption-desorption characteristics of hydromorphic soils from fifty nine representative samples formed on Basement Complex and Sedimentary parent materials. The equilibrium P concentration obtained shall be correlated with the physicochemical properties of the soils to better understand the P dynamics.

MATERIALS AND METHODS

Soil collection: The study was conducted in the laboratory on fifty eight surface soil samples collected from hydromorphic soils formed from different parent materials; Table 1. Sixteen soils on crystalline metamorphic and igneous rock (A); twelve soils on shale mixed with sandstone and clay (B); thirteen soils on coastal plain sands (C); nine soils on coastal alluvium (D) and eight soils on fresh water swamps (E).

The area covered in this study was the flat lowland part of southern Nigeria south of 8°N, stretching across the country from east to west. The region is in the humid tropics with a mean annual rainfall ranging from 2000 to 4000mm. The vegetation is derived Savannah in the Northern fringe, through thick tropical rain forest to fresh water swamp consisting of mainly fresh water raffia palm species.

Physico-chemical analysis

Selected soil physicochemical properties such as pH, total organic carbon, total nitrogen, available phosphorus, effective cation exchange

Table 1: Soil Parent Materials, Classification and Sample Locations

Parent Materials (USDA Taxonomy)	Sample Location (Town and Cities)
Chrystalline metamorphic igneous basement complex rocks (typictropaqualfs)	Iseyin, Fidity, Ondo, Ibadan, Asejire, Ilesha, Ado-Ekiti, Aramoko, Ikare, Owo, Akure, Akamkpa, Obubra, Ogbomosho
Shale mixed with sandstone and clay (typictropaquults)	Ijebu-Ode, Igbogila, Agwu, Okigwe, Owode, Itori, Shagamu, Ubiaja, Umuahia, Awka, Mbaise, Afikpo
Coastal plain sands (typictropaquults/Typictropaquepts)	Gbara, Ito-Eki, Ilaro, Ikorodu, Epe, Okitipupa, Evboneka, NIFOR, Abudu, Agbor, Aba, Ikot-Ekpene, Etinan
Costal Alluvium (Typictropaquents)	Egbunke, Abak, Badagry, Odo-Olowu, Ikot-Abasi, Calabar, bori, Porth-Harcourt, Abedo
Freshwater swamp (typictropaquents)	Ozubulu, Ologbo, Mosogar, Otegbo, Kwale, Degema, Ekpan-Ovu, Ahoada

capacity (CEC) and particle size distribution were determined using standard methods (IITA, 1982).

Phosphorus sorption

The sorption study was carried out on the fifty nine (59) surface soils according to standard procedure recommended by Nair et al. (1984). One gram air dried soil was weighed into series of 50 ml plastic bottles. Twenty five millilitres of 0,0 I M CaCb solution containing 0, 20, 40, 60, 80, 100 and 150 mg/l P were added to these bottles. Three drops of chloroform was added to inhibit microbial activity. The soil suspension was shaken at 2YC for 24 hours on a reciprocating shaker. After equilibration, the soil suspension was centrifuged at 1200 x g for 5 min, and the clear supernatant was filtered through a 0.45μm membrane filter. Phosphorus concentration in the filtrate was determined by the colorimetric method of Murphy and Riley (1962) at 882nm. The concentration of P in the initial solution was also measured. The difference between the quantity of P in solution after shaking with soil and the quantity initially present was calculated as the quantity of P sorbed by the soil in mg kg-I. The data obtained from the phosphate adsorption experiment were fitted to the Freundlich equation (1);

$$X = a\,C^{n} \qquad (1)$$

Where X is the amount of P sorbed per unit weight of soil (mg P kg-I soil), C the concentration of P in equilibrium solution (mg L-l), a is a constant related to sorption capacity, n is phosphate sorption energy.

The amount of P sorbed, x (mg/l00g), from addition of 1.50g P/kg of soil was also determined after shaking for 24 hours at a water to soil ratio of 10: 1. The P sorption index (PSI) was then calculated using the quotient;

$$x/\log c \qquad (2)$$

where c is the solution P concentration (Bache and Williams, 1971). This quotient correlate closely with P sorption maximum obtained from a Langmuir sorption isotherm for a wide range of soils.

Phosphorus remaining in solution (mg L-l, x-axis) was plotted against P sorbed (mg kg-1, y-axis), and a line was fitted using simple linear regression equation (3).

$$S = KC = S_0 \qquad (3)$$

Where S is P sorbed on solid phase (mg kg-I), C is P remaining in solution after 24 h equilibration (mg L-1), S0 is y-axis intercept representing the initial quantity (mg kg-I) of sorbed soil P and K is slope.

RESULTS AND DISCUSSION

The physico-chemical properties of the fifty eight (58) surface soil samples from five different locations formed from different parent materials (A - E) are given in Table 2. The soils were acidic with the highest acidity in the fresh water swamps and the lowest acidity in the crystalline metamorphic and igneous rock soils. The organic carbon content of the soils had a wide range from 0.60 to 12.70% with the coastal alluvium soils having the highest average amount of 3.38% and the coastal plain sands the lowest amount of carbon (1.59%). The soils were found to be generally coarse with high sand content and low silt and clay contents. Nitrogen contents of the soils were low, the coastal alluvium soils having the highest amount than the other soils. The cation exchange capacity (CEC) and effective cation exchange capacity (ECEC) of the soils were low; CEC values ranged from 0.84 to 4.89 while the ECEC values ranged from 2.44 to 6.54cmol/kg with the highest amounts in crystalline metamorphic and igneous soils. The base saturation of the crystalline metamorphic and igneous rock soils was the highest, averaging about 91 %. This was followed by base saturation values of about 71 % in shale mixed with sandstone and clay soils. The least base saturation value was obtained in the fresh water swamp soils.

The mean values of available P estimated by Bray P-l method varied largely amongst soils and ranged from 1.00 to 145.00 mg/kg. The result revealed that there was no correlation with the estimated available P, indicating that the P sorption capacities are not associated with the estimated available P. The highest PSI (25.17) was obtained in the coastal alluvium soils while the least (15.41) was obtained in the fresh water swamp soils. The PSI varied among the different parent soil materials. The PSI of the crystalline metamorphic and igneous rock soils ranged from 6.10 to 48.90, the PSI of the Shale mixed with sandstone and clay soils ranged from 4.80 to 64.90, the PSI of coastal plain sand soils ranged from 6.60 to 36.20, the coastal alluvium PSI soils ranged from 11.00 to 61.00 while the PSI of fresh water swamp soils ranged from 10.50 to 23.50. On the average the PSI of all soils ranged from 4.80 to 64.90.

The correlation analysis conducted on the data showed that PSI was significantly correlated positively and negatively with some of the soil parameters in the crystalline metamorphic and igneous rock, shale mixed with sandstone and clay, coastal plain sands and freshwater swamp soils at $P \leq 0.05$ and $P \leq 0.01$ level of significance. In the crystalline metamorphic and igneous rock soils, the P sorption index (PSI) was significantly and negatively correlated with only pH and sand while PSI was significantly and positively correlated with nitrogen and clay content of the soils. Sand and clay content in crystalline metamorphic and igneous rock ($r = -0.777$ and $r = 0.903$ respectively) and shale mixed with sandstone and clay ($r = -0.828$ and $r = 0.827$ respectively) soils were strongly correlated with PSI. Effective cation exchange capacity (ECEC) was only strongly correlated with PSI in Coastal plain sands. It was observed in the fresh water swamp soils that PSI was significantly correlated with only A13+.

The correlation analysis also revealed that there was strong positive correlation between the sesquioxides of shale mixed with sandstone and clay and coastal plain sands soil samples with PSI at 0.01 level of significance. The other location samples sesquioxides did not correlation with PSI of the samples.

Table 3: Relationship between phosphorus sorption index (PSI) and soil chemical properties

Parameters	A	B	C	D	E
pH	- 0.501*	- 0.606*	- 0.363	- 0.208	- 0.343
Organic C (%)	0.376	0.730**	0.774**	0.660	- 0.274
N (%)	0.716*	0.582*	0.410	0.499	- 0.238
P (mg/kg)	- 0.615	- 0.367	- 0.195	- 0.340	- 0.012
K (cmol/kg)	0.239	0.704*	-0.041	0.410	-0.073
Na (cmol/kg)	-0.052	-0.231	0.207	-0.016	0.142
Mg (cmol/kg)	-0.049	-0.284	-0.182	-0.087	0.584
Ca (cmol/kg)	-0.274	-0.357	-0.520	0.003	0.317
CEC (cmol/kg)	-0.172	-0.360	-0.374	-0.004	0.477
Al^{3+} (cmol/kg)	0.535*	0.783**	0.734**	0.648	0.773*
H^{+} (cmol/kg)	0.521*	0.514	0.668*	0.631	0.442
ECEC (cmol/kg)	- 0.067	0.119	0.711**	0.333	0.630
BS (%)	- 0.409	- 0.601*	- 0.615*	- 0.165	- 0.327
Sand (%)	- 0.777**	- 0.828**	- 0.639*	0.010	- 0.515
Silt (%)	0.400	0.777**	0.375	0.588	0.581
Clay (%)	0.903**	0.827**	0.489	- 0.257	0.615
Free oxides	0.363	0.734**	0.734**	-0.358	0.450
Amorphous oxide	0.299	0.827**	0.827**	0.178	0.049
Total oxide	0.392	0.773**	0.773**	-0.288	0.419

and ** indicate significance at 0.05 and 0.01 level respectively

Phosphorus Sorption

The relationships between the amounts of phosphorus sorbed and phosphorus concentrations of the hydromorphic soil samples are shown in Figure 1. It was observed that the amount of P sorbed increased with an increase in the concentration of phosphorus added to the soil. The result showed that at any specific P-concentration, the amount of P sorbed by the coastal alluvium soils was higher than that of other hydromorphic soils.

The isotherm results showed that each soil exhibited different adsorption characteristics. The Crystalline metamorphic and igneous rock soils had the lowest amount of P sorbed amongst the different soil types. A close linear relationship between equilibrium P concentration and added P was obtained and the correlation coefficients were 0.995 for crystalline metamorphic and igneous rock soils, 0.994 for shale mixed with sandstone and clay soils, 0.991 for coastal plain sand soils, 0.988 for coastal alluvium soils and 0.990 for fresh water swamp soils.

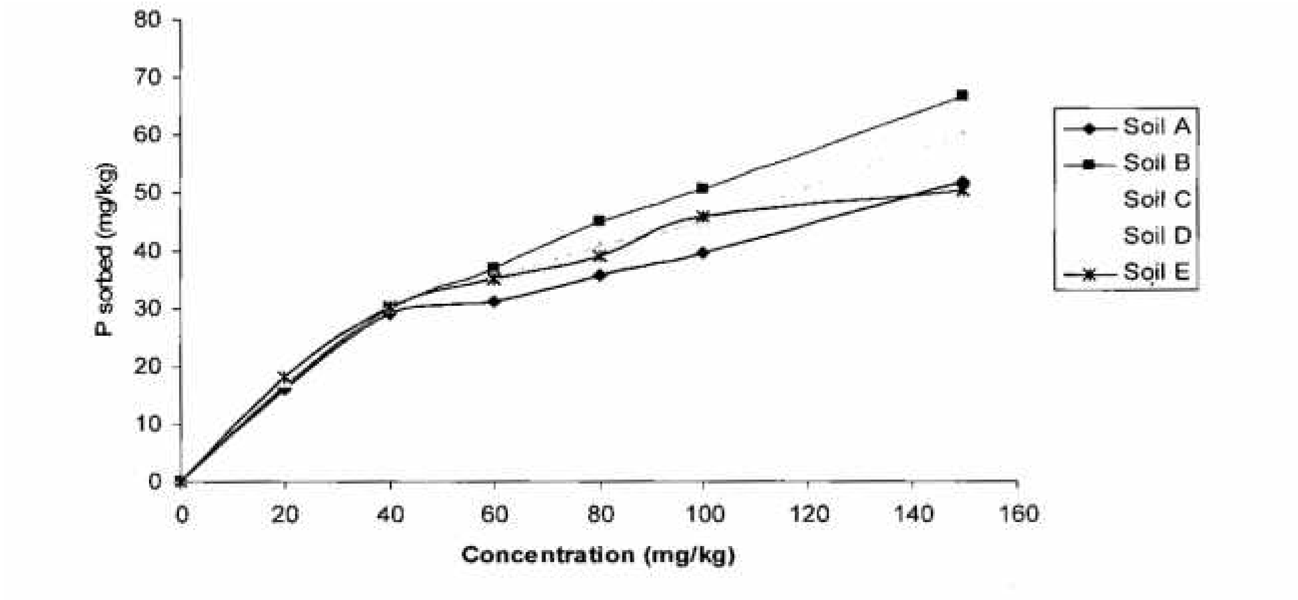

Fig 1: Phosphorus sorption isotherm of the different hydromorphic soils

The Freundlich parameters, sorption capacity (a), P sorption energy (n) and correlation coefficient (r) obtained from the data plotted according to P sorbed vs P in equilibrium solution are given in Table 4. The correlation coefficients obtained for the various plots showed the goodness of fit of the model as all plots were highly correlated with r2 values > 0.95 indicating very high conformity of the adsorption data to the Freundlich model. The values of sorption capacity (a) for the five different hydromorphic soils ranged from 2375 to 2626 mg kg-l while the P sorption energy (n) ranged from 0.258 to 0.434 L kg-1.

In classifying the hydromorphic soils using capacity factor (a) as proposed by Shayan and

Davey, (1978) were soils having larger (a) values have larger adsorbing capacity than soils having smaller (a) value, it was observed in this study that coastal alluvium soils has the highest (a) value, followed hy the fresh water swamp soils, the coastal plains sand soils, the crystalline metamorphic and igneous rock soils and the shale mixed with sandstone and clay soils.

The usefulness of Freundlich parameter (a) in summarizing the adsorption properties of soil over wide range of equilibrium concentration was found in this study. The order of soils according to their adsorption capacities was:

Coastal alluvium soils > Fresh water swamp soils > Coastal plains sand soils > Crystalline metamorphic and igneous rock soils> Shale mixed with sandstone and clay soils.

Regression analysis conducted on the various concentration of P added to the different hydromorphic soils showed regression equation b = 6.42 and a = 359.64 for crystalline metamorphic and igneous rock soils, b = 9.36 and a = 313.00 for shale mixed with sandstone and clay soils, b = 7.11 and a = 402.78 for coastal plain sand soils, b = 10.41 and a = 370.95 for coastal alluvium soils and b = 6.00 and a = 455.25 for fresh water swamp soils. Also, regression equation was statistically found to be significant at $P < 0.01$ levels.

CONCLUSION

Phosphorus (P) sorption-desorption characteristics of hydromorphic soils are important in designing best management practices to reduce risk of P losses to surface water. The results obtained in this study revealed that a good estimation can be done on PSI based on some soil physical and chemical properties. PSI was influenced by soil physical and chemical characteristics as differences in the magnitude of change in PSI between the soils indicates that soil type in addition to the amount of P added to the soils will determine a soil potential to release P in the soil. The wide range in the differences in PSI of the soils from the different parent materials showed that a comprehensive phosphate recommendation may not be a good strategy for the soils in this hydromorphic region as it may lead to under or over application of P. The study revealed that the coastal alluvium soils sorbed more phosphorus than the other soils indicating that this soil needs more phosphorus fertilization to attain optimum phosphorus concentration in soil solution. Also correlation analysis conducted on PSI and sesquioxides forms of the hydromorphic soils revealed that fertilizer application in hydromorphic soils are site specific.

REFERENCES

Aghimien, E. A., E. J. Udo and D. O. Ataga, 1985. Phosphorus status of hydromorphic soils from Southern Nigeria. Niger. J. Sci. 79:62-67.

Bache, B.W., and Williams, E.G. 1971. A phosphate sorption index for soils. Journal of Soil Science 22:289-301.

Jox, L.E. 1993. The chemistry of aquatic phosphate: inorganic processes in rivers. Hydrobiologia.253:1-16.

Frossard, F, M. Brossard, M.J. Hedley, and A. Metherell. 1995. Reactions controlling the cycling of P in soils. p. 107-137. In H. Tiessen (ed.) Phosphorus in the global environment: Transfers, cycles and management. John Wiley & Sons, NY.

IITA, (1982) Automated and semi-automated methods for soil and plant analysis

Murphy, J., and J.R. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta. 27:31-36.

Nair, P. S., Logan, T. J., Sharpley, A. N., Sommers, L. E., Tabatabai, M. A. and Yuan, T. L. 1984. Interlaboratory comparison of a standardized phosphorus adsorption procedure. Journal of Environmental Quality. 13:591-595.

Sharpley, A.N. 2000. Agriculture and phosphorus management: The Chesapeake Bay.

CRC Press, Boca Raton, FL.

Udo, E.J. and J. A. Ogunwale, 1977. Phosphorus fractions in selected Nigerian soils. Soil Sci. Soc. Am. J. 41:1141-1146

Udo, E. J. and V. I. Dambo, 1979. Phosphorus status of the Nigerian coastal plain sands. J. Agric Sci. 93 :281-289

Uwumarongie-Ilori, E. G., P. O. Oviasogie and A. E. Aghimien (2012). Evaluation of Rock Phosphate-Phosphorus Sorption and Release in Basement Complex Soil Cultivated to the Oil Palm. E3 Journal of Agricultural Research and Development Vol. 2(3). pp. 070-076.

Uzu, F. O., A. S. R. Juo and A. A. Fayemi, 1975. Forms of phosphorus in some important agricultural soils in Nigeria. Soil Sci. 212 – 218

Zhang, H., J.L. Schroder, J.K. Furman, N.T. Basta, and M.E. Payton. 2005. Path and multiple regression analyses of phosphorus sorption capacity. Soil Sci. Soc. Am. J.

Zhou, M., and Li, Y. 2001. Phosphorus-sorption characteristics of calcareous soils and limestone from the southern Everglades and adjacent farmlands. Soil Science Society of America Journal. 65: 1404-1412.