

Modeling the movement of phosphorus in some selected agricultural soils in Nigeria

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Received: 2 December 2015; Received in revised form: 21 November 2016; Accepted: 25 January 2017

Abstract

This research investigate clayey, lateritic and sandy soils have been selected from agricultural lands in the South-Eastern Nigeria, for their phosphate sorption characteristics using column experiments, in order ascertain the movement of phosphate in the soils. The soil samples were equilibrated in 25ml of 0.01M CaCl₂ containing different concentrations of P as KH₂PO₄ to produce initial concentrations of 250, 375, 500, 625 and 750µg/L of P for 14 days at room temperature. Six samples and a backup treatment were prepared for each concentration for each soil sample giving a total of 25 samples of each soil. Fitting the adsorption results from all the soil tested into Freundlich, Langmuir and Van Huay linear isotherms revealed that the adsorption of phosphate increased with the concentration of P and contact time. Values of P sorption maximum (S_{max}) for all the soils were obtained in day 10 and were 12, 15 and 12 mg/kg soil for clayey, lateritic and sandy soil respectively. The higher sorption of lateritic over clayey soil was due to its high content of clay and clay minerals. The Freundlich isotherm perfectly fitted the clayey soil with the highest accuracy than the Langmuir and Van Huay isotherms, and also gave better description of the lateritic soil but did not adequately describe the sandy soil like the other isotherms. Comparison of the three isotherms showed that the Freundlich isotherm was the best for predicting the phosphorus adsorption behaviour in soils. The leaching of P in the soil column experiment was time-depth dependent and therefore, the use of slow phosphate fertilizer and lime could improve p-adsorption on the soil.

Keywords: Phosphate movement; Soil; Sorption experiment; Column experiment; Isotherm

1. Introduction

The soil may be regarded as a complex matrix consisting of various kinds of mineral and non-mineral elements, ions, water, organic matter, and diverse colonies of living organisms. Phosphate which is often found in fertilizers is one of the essential macro elements found in soils and should be present in sufficient concentration because its availability in the soil increases the physiological efficiency of crops (Idris and Ahmed, 2012). Phosphate sorption in the soil is the major contributing factor that reduces the effectiveness of added phosphate fertilizers leading to the need to add of larger quantities of phosphate fertilizers in order to

achieve good crop yield (Gichangi *et al.*, 2008; Siradz, 2010). This is because plants need phosphorus for the formation of their roots, reproductive systems, energy, proteins and attainment of maturity. In order to increase the phosphate content of a soil, P-fertilizer is often applied and this always sparks up various reactions between the added phosphate and the soil constituents resulting in the removal of most of the P in the solution phase in a process known as sorption or P-fixation (Idris and Ahmed, 2012).

The primary forms of phosphorus taken up by plants is the orthophosphate, H₂PO₄ and HPO₄. However, when pH of the soil is less than 7, H₂PO₄ becomes the most common form in the soil (Silva *et al.*, 2000). When sorption takes place, the orthophosphate binds tightly to soil particles, resulting in decrease in the amount of P available to plants. The fraction of

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P that is soluble in water represents the most leachable, the weakly sorbed P, and the most available P to plants (Manning *et al.*, 2006). Previous studies showed that phosphate sorption experiments are important techniques for measuring the intensity and capacity of soils to absorb P, and that a concentration of 0.2 mg/kg of phosphorus in solution in soil is adequate for most crop species (Beckwith, 1965; Idris and Ahmed, 2012).

Other research works have also shown that P-sorption is time dependent (Munhoz *et al.*, 2011), and that sandy soils rank the highest in losing their phosphate content to soil runoff (Ho and Notodarmojo, 1995). The lost phosphate is often contained in the run-off from agricultural lands and wastewater treatment facilities and have been identified as important source of pollution of groundwater, rivers, estuaries, and wetland and near shore.

Some studies have shown that the concentration of phosphate in the soil and aquatic environment is determined by the oxides of iron (Fe) especially goethite which is the most abundant form of iron because Fe oxides sorb phosphate by ligand exchange with the hydroxyl (OH) groups and the Fe atoms (Torrent *et al.*, 1992). Previous research have shown that the sorption of phosphate in the soil by Fe oxides could be classified as specific sorption or chemisorption process which depends on the intrinsic properties of the Fe oxides, P-concentration in solution, time of contact, temperature and the cation content (Barrow, 1983; Ruan and Gilkes, 1996; Tsado *et al.*, 2012; Hoseini and Taleshmikael, 2013). Alkaline calcareous soils are most susceptible to P-deficiency because the available P in such soils because the available P in the soil reacts with calcium to form insoluble calcium phosphate compounds (Siradz, 2010; Idris and Ahmed, 2012). P-sorption in soil has been extensively studied in terms of equilibrium reaction or isotherm in which the amount of P sorbed is a function of the concentration of the P-solution as described by the Langmuir and Freundlich equations (Väänänen *et al.*, 2008; Siradz, 2010; Hoseini and Taleshmikael, 2013).

Farming is the major occupation of Nigerian people and majority of the populace depend on subsistence farming for survival. However, regular reduction in crop yields over the years, even with increasing population is an issue of concern. Thus, it is necessary to investigate the cause of this alarming reduction in produce. It is likely that loss of essential plant nutrients such as nitrogen, potassium and phosphorus could be the major reason for poor harvest. However, at the moment, only few studies related to loss of plant nutrients in Nigerian soils exist. Thus, the main objective of this study was focused on one of the essential plant nutrients in Nigerian soils –Phosphorus(P), and to determine P-sorption capacity of three main agricultural soils in order to establish the behaviour of these soils in terms of nutrients adsorption, so as to be able to regulate the rate of application fertilizers increase optimum crop yield.

2. Materials and Methods

2.1. Site description and sample collection

The three soil types namely: clayey, laterite and sandy soils were selected for this study were collected from farm lands within Federal University of Technology (FUTO) Owerri in Imo State Nigeria located on 5°23'20.5"N 6°59'30.1"E (Fig 1). The laterite and clay soils were collected at a depth of 1.5 m from a foundation of an on-going building project within the study area. The sandy soil soil was collected at the bank of Otamiri River at a depth of 1.5 m below the sea level. Each soil sample was collected in a hard water-proof bag to reduce oxidation and dehydrate and then transported to the laboratory for analysis.

2.2. Soil characterization

Their physiochemical properties such as pH, moisture content, atterberg limits, compaction test were determined according to B.S standards. Sorption experiment was then conducted on all the soils and column experiment on the sandy soil.

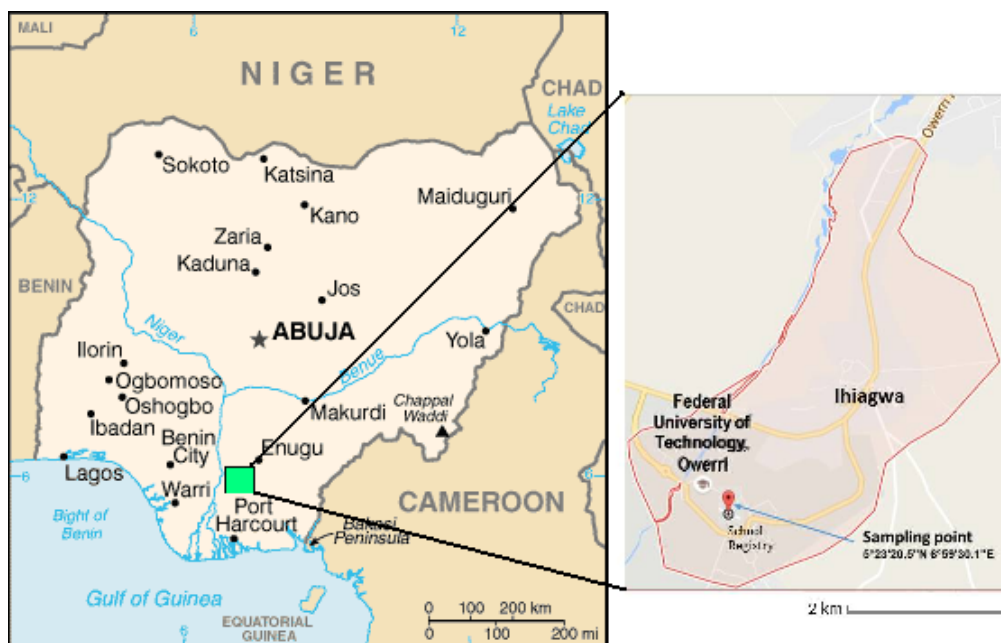


Fig. 1. Location of the study site

2.3. Sorption experiment

The P sorption isotherm study was conducted by equilibrating 10g of the three selected soil samples with different concentrations, $C = 10, 15, 20, 25$ and $30 \mu\text{g/L}$ of phosphate in solution as Monopotassium phosphate (KH_2PO_4) dissolved in 25 ml of Calcium chloride (CaCl_2) solution water. Six samples and a blank were prepared for each concentration for each soil sample giving a total of 25 samples of each soil. These sets of heterogeneous mixtures were capped tightly and equilibrated by shaking for 1 minute and allowed to stand undisturbed for two days to allow time for sorption to take place. On the third day, five samples with concentrations ranging from 10, 15, 20, 25 and $30 \mu\text{g/L}$ were picked from each soil type, and then centrifuged and filtered using Whatman No.2 filter paper. The concentration of the orthophosphate, P in the clear filtrate was determined using the method detailed in (Murphy and Riley, 1962) using a Spectrophotometer set at wavelength of 882nm. Samples were also collected from the groups and analyzed on day 5, day 7, day 10 and day 14 respectively. The difference between the P-added and the P found in the filtrate gave the P sorbed by the soil in $\mu\text{g/kg}$ of soil. The data obtained from the sorption experiment were fitted into the Freundlich, the Langmuir and the Van Huay Isotherm equations. The Freundlich equation is given by:

$$X = aC^n \quad (1)$$

The above equation can also be expressed in logarithm form as:

$$\text{Log}X = \text{Log}a + n\text{Log}C \quad (2)$$

where X is the amount of P adsorbed per unit weight of the soil (mgP/kg soil), C is the concentration of P in equilibrium solution (mg/l), a is a constant related to sorption capacity while n is phosphate sorption energy. This equation shows that adsorption energy decreases exponentially with decreasing adsorption surface in soil due saturation of the soil surface.

The Langmuir equation is given by:

$$\frac{C}{X} = \frac{1}{aS_{\max}} + \frac{C}{S_{\max}} \quad (3)$$

where C = concentration of P in equilibrium solution ($\mu\text{g P/mL}$), S = amount of P sorbed ($\mu\text{g P/g}$ soil), x_m = sorption maximum ($\mu\text{g P/g}$ soil), a = coefficient related to bonding energy. A graph of c/x against c usually gives a straight line with slope $1/S_{\max}$ and intercepts $1/aS_{\max}$. The importance of this equation is that it could easily be used to determine the adsorption maximum (S_{\max}) (Siradz, 2010; Hoseini and Taleshmikael, 2013).

The Freundlich Isotherm is accurate in the determination of variation of adsorption with

pressure at lower values but fails in the prediction of adsorption at higher pressure, hence the Van Huay equation was defined to handle the prediction (Hoseini and Taleshmikael, 2013). The Van Huay equation is given by:

$$X / m = m + n\sqrt{c} \quad (4)$$

where c is the concentration of fluid phase, n = Van Huay constant.

In the simplest form of chromatographic theory, it is assumed that the adsorption isotherm for the solute is linear, i.e. $C_s = K \times C_m$, where C_s – the concentration of the solute on the surface, C_m – the concentration of the solute in the mobile phase, K – adsorption constant of the solute to the stationary phase surface. The amount of phosphorus adsorbed onto the soil was calculated using the formula:

$$(Amount\ Sorbed)\ q = \frac{(C_f - C_i)V_{Solution}}{m_{Sorbed}} \quad (5)$$

Where $C_f - C_i$ represent the final equilibrium concentration adjusted for the solution volume, m = mass of the soil (sorbent) used for the

adsorption test, and V = volume of the p in solution. The unit of q is either mg/kg , (ppm) , $mmol/kg$, depending on the unit of concentration. The distribution coefficient (K_d), was calculated as follows:

$$\text{Distribution Coefficient} = \frac{\text{Concentration in the solid phase}}{\text{Concentration in the solution phase}} \quad (6)$$

2.4. Statistical Analysis

The data obtained in this work was analyzed using correlation and regression analysis in Microsoft excel and SPSS.

2.5. Column Experiment

Soil column study was carried out on the sandy soil using a 1.2m high metallic drum which was painted black at the outside to prevent algae growth. Discharge collection points were installed by the side of the drum by perforating notches of diameter 2cm and welding a 10 cm long stainless steel pipe of same diameter on the notch (Fig 2).

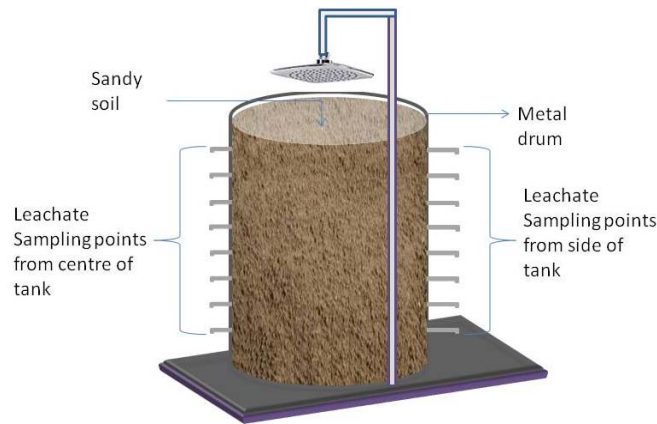


Fig. 2. Setup for the sand column experiment showing the installation of the sampling points (Naseri *et al.*, 2011)

This was done on a straight line and spaced at about 20 cm intervals from the top to the bottom of the tank. Similar sampling pipes were also installed on the other side of the tank but originating from the centre of the tank. The drum was filled up with sandy soil. Rainfall was simulated on the upper part of the column (open surface of the sand) using a bathroom shower positioned 0.5m centrally above the column. The shower was connected to an electric pump which drew rain water from a water storage tank. When the soil was saturated, pumping was stopped and the soil left to drain for 24hrs

before 50 ml of 50 ml P/I in the form of orthophosphate was dosed uniformly onto the centre of the surface of the column which is ideally the rate of application of phosphate fertilizer to most soils in Nigeria. Rainfall was once again simulated for 5 minutes. Leachates were then collected from the different depths on the column at 15, 30, 45 and 60 minutes intervals from the centre of the tank and the sides of the tank. This process was repeated for 3 days. A portion of each of the samples was analyzed for P concentration and the left over discarded.

3. Results and Discussion

3.1. Effect of Soil Characteristics on Nutrient Adsorption

The variation in the physical characteristics of the soils such as the moisture content, bulk density and dry bulk density and pH, is presented in Table 1. These properties were determined on the air-dried soil samples using compaction test and Atterberg limit tests (B.S. 1377:1975). The clay soil was reddish in colour and fine textured with particle sizes less than 0.002mm diameter. The reddish colouration of the soil could possibly be due to its high content

of trace iron oxide. This assumption strongly agrees with previous study which revealed that clay soil is very rich in clay minerals - majorly aluminosilicates [$Al_4Si_4O_{16}(OH)_8$], trace metal oxides and organic matter (Foley, 2009). Research has also shown that clayey soil has large negatively charged adsorption surface area which is estimated to be about 1000 times that of sand (Tucker, 1999), and which according to (Foley, 2009), enables the soil to easily attract and store positively charged ions in solution and release them when condition changes. This is probably why clayey soils are able to reduce nutrient loss from the soil by holding them onto their charged surfaces.

Table 1. Physical and chemical characteristics of the studied soil

Soil type	pH	Particle size distribution%			Moisture content (%)	Bulk density (g/cm ³)	Dry bulk density (g/cm ³)	Atterberg Limits test		
		Clay	Silt	Sand				Plasticity limit (PL)	Liquid limit (LL)	Plasticity index (P.I)
Clayey	6.8	47	22	31	23.4	1.85	1.50	29	44.6	15.6
Lateritic	5.6	11	34	55	8.33	2.21	2.03	9.5	26.2	16.7
Sandy	7.1	2	5	93	20.5	1.6	1.4	---	---	---

Natural lateritic soil as found in tropical climates is typically porous and clay-like with high content of iron oxide minerals, titanium oxides and the hydrated oxides of aluminium (Lotha and Sinha, 2014). Previous work by Wood and McAtamney (1996) also showed that lateritic soil is the source of aluminium ore which exists largely in clay minerals and hydroxides, and that it has higher clay content, cation exchange and water-retaining capacity than the sandy soil. Due to its rich mineral contents, laterite has been used to remove phosphorus from wastewater treatment plants in Northern Ireland where it was reported to remove phosphorus and heavy metals below detectable concentrations (Wood and MacAtamney, 1996). Lateritic is low cost adsorbent for the removal of phosphorus in water because it has the ability to selectively adsorb phosphate ions in mixed solution in the midst of other competing ions, including carbonate and sulphate (Nga, 2013). Therefore, it is likely that good adsorption capability for nutrients in solution is an intrinsic property of lateritic soil.

Sandy soil is characterised by large and coarse texture, neutral particles of silicon dioxide (SiO₂) ranging from 0.05 to 2.0mm diameter, which have poor ability to adsorb and retain nutrients, water or positively charged ions in solution (Tucker, 1999). According to Nga (2013), the adsorption of nutrients by anions present in soil may be influenced by iron (Fe) and Manganese (Mn) oxides, pH, and the redox

potential in the soil. This means that adsorption in sandy soil would be low unless if the soil contains organic materials and other charged ions which can influence the adsorption of phosphorus.

3.2. Adsorption Characteristic of the Soils

In all soil types, adsorption of the added phosphate was rapid between 3- 7 days (Table 2). Immediately after the 7th day, adsorption rate decreased. The sorption data shows that the soils attained saturation points after the 7th day. This was evident from the constant maximum adsorption recorded from day 10 to day 14 for all the soil samples. The clayey and the lateritic soils showed comparatively similar maximum adsorption rates (S_{max}) of 1.85 ± 1 and 1.20 ± 0.03 mg/kg soil respectively with standard deviation of 0.49. This similarity may be due to high clay and mineral contents in the lateritic soil which may have possibly increased its adsorption ability over the clay. The results also suggests that the high moisture content in the clayey (Table 1) may have prevented it from adsorbing much of the phosphate as supposed because the clay pore spaces were almost saturated with 90.2% of moisture. The sandy soil showed rather smaller maximum adsorption maximum, S_{max} of 1.78 mg/kg soil, recorded after day 7, with a standard deviation of 0.21. The summary of the results obtained by fitting the results into the isotherms are presented in Table 3. It is likely that when the soils became

saturated with the added phosphate ions in solution, absorption and desorption of excess or free phosphorus from the soils followed which was evident from reduction in the p-adsorbed onto the soil surface. This is possible because

the adsorb of phosphorous or phosphate in the soil is affected by the presence of the hydroxyl of aluminum polymers in clay and carbonate minerals which may be present in the soil (Gustafsson *et al.*, 2012).

Table 2. Maximum adsorption related to deferrent initial concentrations and contact times

Texture	Initial P-conc. (mg/L)	Adsorption values, S(mg/kg soil)			
		Day 3	Day 7	Day 10	Day 14
Clayey	0.250	0.591	0.604	0.607	0.614
	0.375	0.905	0.909	0.918	0.924
	0.500	1.223	1.224	1.215	1.211
	0.625	1.494	1.519	1.526	1.530
	0.750	1.831	1.841	1.850	1.850
Lateritic	0.250	0.592	0.614	0.608	0.622
	0.375	0.923	0.912	0.926	0.929
	0.500	1.223	1.237	1.239	1.225
	0.625	1.546	1.527	1.543	1.549
	0.750	1.855	1.858	1.862	1.864
Sandy	0.250	0.561	0.573	0.580	0.581
	0.375	0.846	0.847	0.864	0.890
	0.500	1.156	1.144	1.152	1.177
	0.625	1.395	1.430	1.458	1.460
	0.750	1.694	1.702	1.729	1.779

According to (Boland *et al.*, 2006), phosphate sorption is pH dependent. This implies that at lower pH, more ions in the soil become soluble in the soil water making it possible for the P in aqueous solution to easily react with iron, calcium, and many other cations at the surface of the soil in the presence of oxygen. Research has shown that the optimum pH for the solubility of many important soil nutrients is between pH = 6.0 - 7.8 and that this range of pH influences both the microbial and plant growth in the soil (Brady, 1990). The risk of soil having a pH <6 lies on the fact that most heavy metals, such as aluminum which is toxic to plants and microbial community, are soluble at low pH (Brady, 1990). Thus, pH adjustment in soils, does not only affect the adsorption ability of the soil, but also would influence the amount of pollutants (heavy metals) which may be released by the soil into the water cycle, subsequently leading to groundwater contamination.

3.3. Extraction Adsorption isotherms from laboratory experiments

The fitting of the adsorption experimental data into Linear, Freundlich, Langmuir and Van Huay isotherm equations produced linear graphs (Figs 3, 4, 5) and phosphorus adsorption characteristics are shown on Tables 3. Results

indicated that the accuracy of soil phosphorous adsorption isotherms decreased slightly from the Linear to the Van Huay, Freundlich, and Langmuir adsorption isotherms, respectively. The Linear, Van Huay and Freundlich equations gave good fits for the data which were consistent at all concentrations in sandy soil. Previous work by Hoseini (2015) has agreement with this results. This was followed by the Freundlich isotherm. The adsorption maximum (S_{max}) was high for lateritic soil followed by the clayey soil. This result suggests that both soils contain high amount of adsorbate, and that lateritic soil fixes higher amount of phosphate which is evident from the higher adsorption values. This result disagrees with the findings of (Kulkani, 1994) that reported maximum adsorption for red sandy soil loam soil followed by forest lateritic soil possibly because his red sandy soil may have higher concentration of metallic ions and organic compounds that increased its energy of adsorption over the lateritic soil. Conversely, for the sandy soil, Increase in its adsorption maximum led to decrease in binding energy. That means that the adsorbed phosphate could be desorbed easily in sandy soil compared to lateritic and clayey soils. Thus, it is possible that increase in p-adsorption in any soil is likely due to its high energy of adsorption possessed by ions present in the soil. Therefore, loss of P

in lateritic and clayey soils will be difficult compared to sandy soil because they have greater binding energy on the nutrients.

Table 3. Adsorption Isotherm values for Phosphate by Langmuir, Freundlich and Van Huay Isotherms

Soil Type	Langmuir Isotherm			Freundlich Isotherm			Van Huay Isotherm		Linear isotherm	
	S _{max}	a	r ²	a	n	r ²	n	r ²	K	r ²
Clayey										
Day 3	3.65	26.3	0.089*	12.6	0.58	0.22 ^{ns}	10.16	0.25 ^{ns}	36.5	0.25 ^{ns}
Day 7	-4.5	-16.4	0.079*	364	1.3	0.67 ^{ns}	24.5	0.58 ^{ns}	106	0.55 ^{ns}
Day 10	12	9.8	0.011 ^{ns}	82	0.93	0.46 ^{ns}	17.4	0.34 ^{ns}	80	0.31 ^{ns}
Day 14	3.7	26	0.58 ^{ns}	19	0.6	0.61 ^{ns}	12.5	0.44 ^{ns}	60	0.37 ^{ns}
Lateritic										
Day 3	4.2	22.5	0.07 ^{ns}	0.06	-0.61	0.22 ^{ns}	-13.8	0.20 ^{ns}	-79	0.25 ^{ns}
Day 7	-4.8	-15.6	0.07 ^{ns}	7.6	0.38	0.19 ^{ns}	7.6	0.12 ^{ns}	38.7	0.1 ^{ns}
Day 10	15	7.7	0.007 ^{ns}	0.9	-0.04	0.007 ^{ns}	2.4	0.003 ^{ns}	17.8	0.003 ^{ns}
Day 14	2.1	142	0.58 ^{ns}	10.9	0.4	0.51 ^{ns}	10.4	0.25 ^{ns}	57	0.15 ^{ns}
Sandy										
Day 3	3.3	28.2	0.100 ^{ns}	18.9	0.92	0.88*	8.9	0.89*	20	0.88*
Day 7	-4.4	-15.8	0.077 ^{ns}	21.5	0.94	0.97**	9.9	0.97**	24.3	0.97**
Day 10	12	9.3	0.011 ^{ns}	28.2	0.97	0.97**	11.2	0.95**	29.7	0.95**
Day 14	2.1	134	0.58 ^{ns}	47.5	1.04	0.88*	13.5	0.86*	40.3	0.85*

Langmuir: S_{max} = sorption maxima (mgP/kg), a = sorption affinity constant (L/mg), r² = coefficient of determination, * = Correlation is significant at the 0.05 level, ** = Correlation is significant at the 0.01 level, ns = Correlation is not significant at the 0.01 & 0.05 levels, Freundlich: a = sorption affinity, n = a measure of sorption surface; Van Huay: n = Van Huay constant, m = Van Huay constant parameter

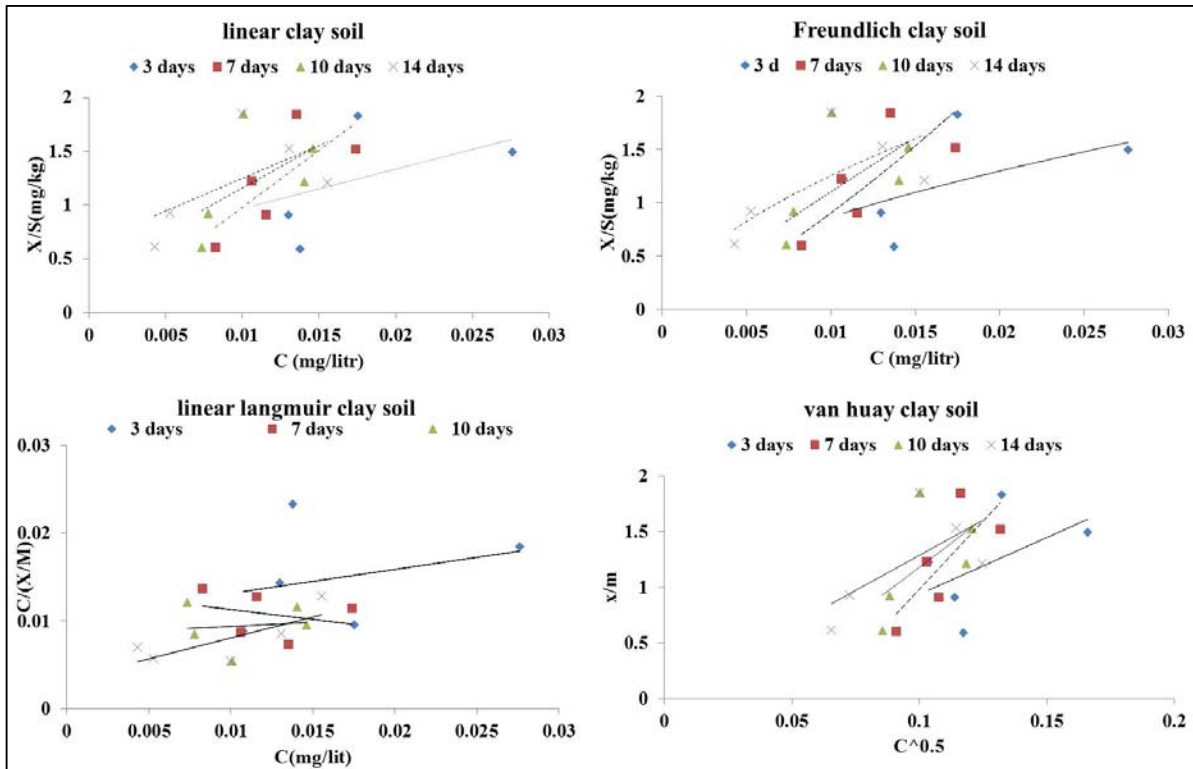


Fig. 3. Fitting the adsorption data from clayey soil into linear, Freundlich, Langmuir and Van Huay Isotherms to determine adsorption isotherms constants

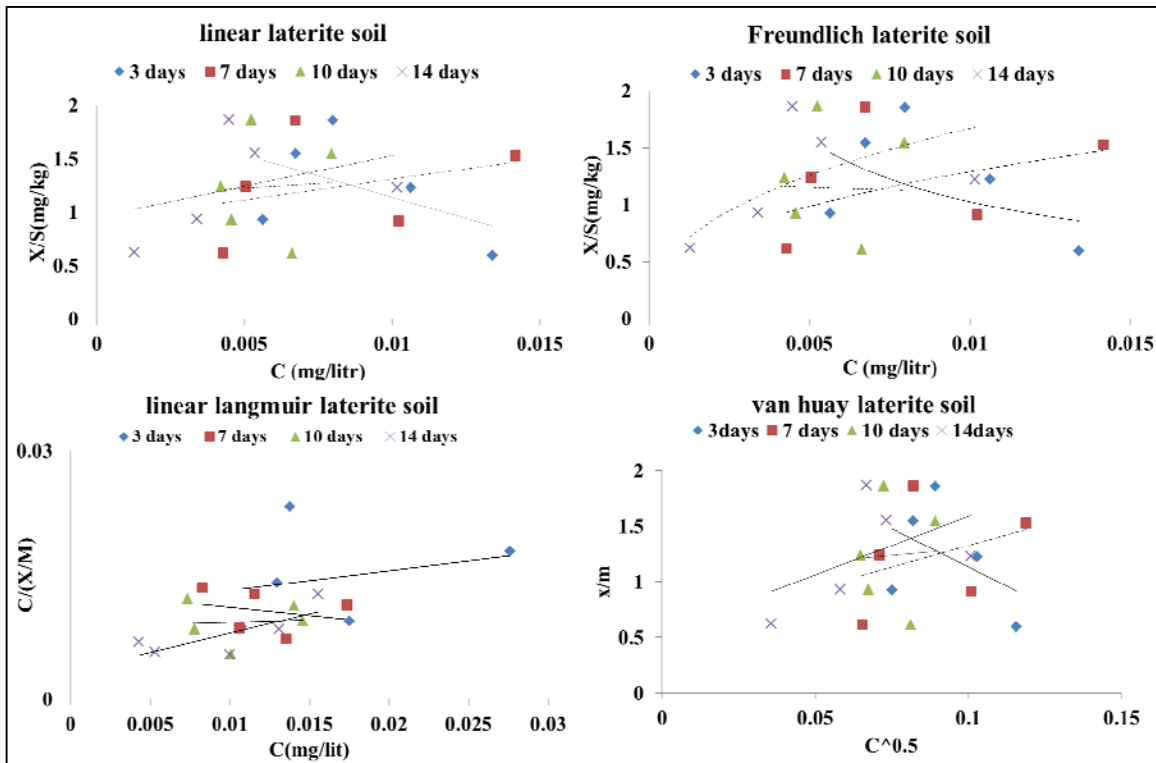


Fig. 4. Fitting the adsorption data from lateritic soil into linear, Freundlich, Langmuir and Van Huay Isotherms to determine adsorption isotherms constants

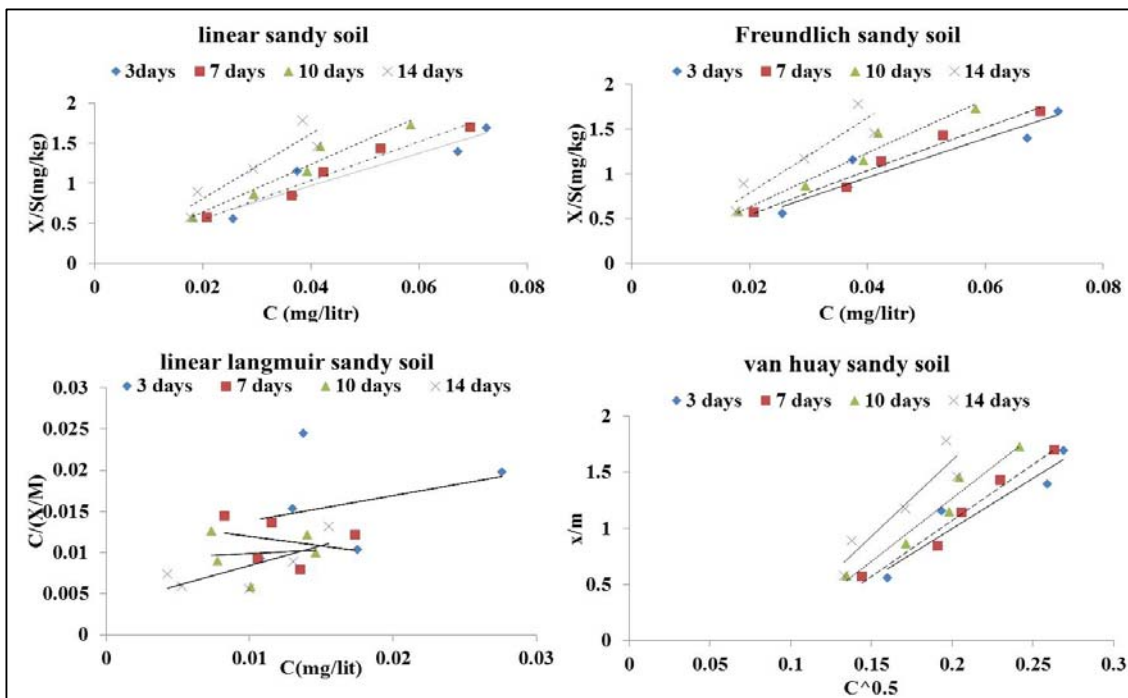


Fig. 5. Fitting the adsorption data from sandy soil into linear, Freundlich, Langmuir and Van Huay Isotherms to determine adsorption isotherms constants

However, the Freundlich isotherm perfectly described the clayey soil with higher accuracy than the Langmuir and Van Huay isotherms, and also gave better description of the lateritic soil but did not adequately describe the sandy soil like the other isotherms. Comparison of the three isotherms showed that the Freundlich isotherm was the best for predicting the phosphorus adsorption behaviour in soils. The coefficient of determination of some of the adsorption isotherms, R^2 for day 14 in the Langmuir isotherm gave the best description for the soils. The sandy soil was correctly described by all the isotherms. These results agree with Nga (2013) whose experimental data revealed that the adsorption of anions in the soil in the order of selectivity or preference is phosphate > sulphate > carbonate. Thus, it is obvious that soils with low phosphorus sorption ability would require higher concentration of phosphate in solution to supplement any loss in the total available phosphorus in the system. This is because, low p-sorption capacity of soil increases phosphorus loss which can increase environmental pollution. Soils textures were clay to sandy with clay content ranging from 2 to 47%. Soils were acidic with pH ranging from 5.6 to 7.1. For a number of plant species growing in solution 0.2 mg P kg^{-1} in equilibrium solution has been suggested by Beckwith (1965) as a standard for comparative purpose. For 0.2 mg kg^{-1} equilibrium soil solution concentration of predicted P according to the regression equation calculated for logarithmic form of Freundlich isotherm. for individual soil solid phase P was 18.3 mg kg^{-1} for clayey soil and 5.7 mg kg^{-1} for lateritic soil and 8.9 mg kg^{-1} for sandy soil in 0.2 mg kg^{-1} equilibrium soil solution concentration. Soil clay influenced adsorption maxima of P in soils. Similar findings were made by Zhang *et al.* (2005) and soil pH had significant

relationship with P-adsorption. this the same with results of other researchers (Sims *et al.*, 2002; Dodor and Oya, 2000). Result shown that clay soil had the highest Buffering Index(BI) value ranging from 7.3 to 76 while lateritic soil had the lowest ranging from 2.8 to 4.38 and sandy soil values changing from 17.3 to 49.4. The BI data followed a similar pattern to the generated isotherm curves of the different soil types. Most interest was in identifying soils with low BIs as they have greater potential for P leaching through runoff into waterways in this research Clay content don't showed positive correlation with BI, These results disagree with Goundar *et al.* (2014) whose experimental data revealed that Clay content has a strong positive correlation with BI.

3.4. Soil phosphorus loss as a function of depth of soil and contact time of Phosphorus solution with soil

The relationship between concentration, contact time and depth of soil profile in terms of P movement in the soil in the column experiment showed that at low initial P-concentration, all the applied P was adsorbed onto the sand surface. However, as the P-concentration added to the soil increased, the P-concentration in the effluent also increased (Fig. 6). At any given depth on the soil column, the P-concentration in the leachate decreased progressively with increase in contact time. Similarly, at constant time, the p-concentration in the leachate was also found to decrease with depth. These results show that adsorption of phosphate onto the soil is directly proportional to the concentration of the added phosphate in the soil solution and inversely proportional to the depth of the soil column and the contact time between the soil and the added phosphate.

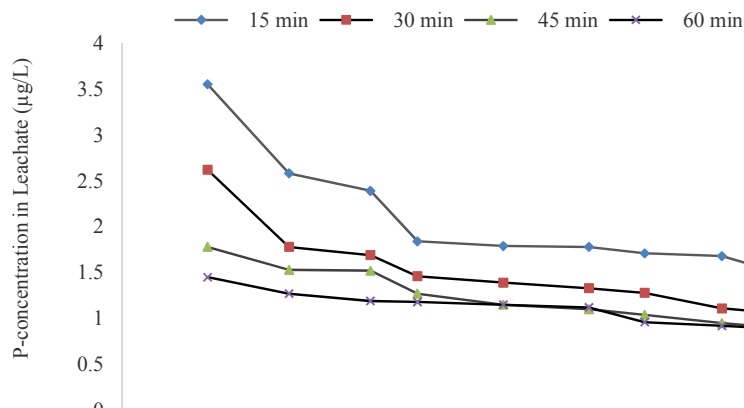


Fig. 6. Variation of P-concentration in leachate from center of soil column with time and depth of soil column

Similarly, the concentration of phosphate decreased from the centre of the column to the side of the column (Fig.7). These findings agree with the work of Boland *et al.* (2006) that explained the concentration of P in soil solution varies spatially, vertically and horizontally in the soil depending on the spatial distribution of the surface properties of the various soil constituents, other ions in the soil, moisture content and soil pH. Thus, in agricultural lands, where crops absorb phosphorus either the applied phosphorus from fertilizer or natural phosphorus in the soil with their root hairs, there is likelihood of progressive decrease in the soils

p-concentration. It was also observed that increase in the frequency of the simulated rainfall led to an increase in the rate of desorption and leaching of some portions of the adsorbed phosphate from the soil and which might end up in the water cycle, leading to high risk of water contamination according to (Heredia and Fernández, 2007). Therefore, soil amendment with lime targeted at adjusting soil to pH=6, and then moderating the quantity of slow dissolving fertilizer applied to soil could enhance p-adsorption by both plants and microbial biomass which would subsequently release the nutrient to the plant for its growth.

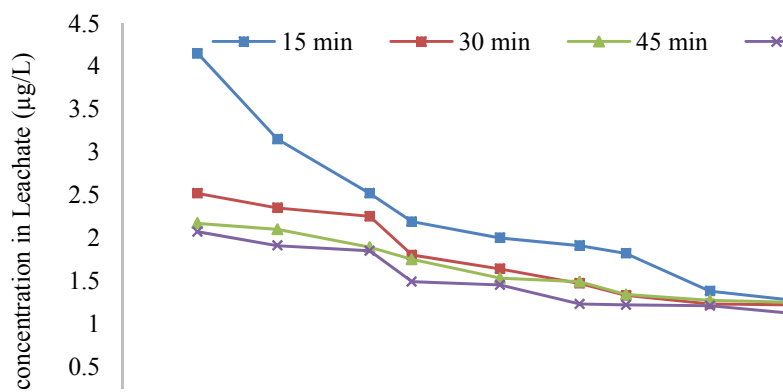


Fig. 7. Variation of P-concentration in leachate from side of soil column with time and depth

It was also observed that increase in the P-concentration applied on the soil surface lead to increase in the leachable P. This was possible because sandy soils have low adsorption capacity hence more leachable P. Similarly Pizzeghello *et al.* (2016) summarized that In the light-textured soils, the low P sorption capacity and absence of change points evidenced high P leaching and potential contamination of surface and ground waters. This demonstrates the possible movement of applied fertilizers or animal manure on the soil profile. According to (Heredia and Fernández, 2007), these phosphate may likely end up in water table, posing high risk of water contamination due to the release of their phosphorus. Therefore, application of highly soluble P fertilizers on farm lands could enhance desorption of phosphorus from the soil into the water cycle, and that could lead to serious environmental pollution. Soil amendment using lime to a pH of 6 and then, avoidance of the use excessive fertilizers on soils would likely enhance P-adsorption by both plants and microbial biomass that would subsequently released the nutrient for plant growth.

4. Conclusion

This study revealed that out of the three isotherms used to describe sorption behaviours of the soils, the Freundlich Isotherm showed a higher correlation in terms of the adsorption rate of the soils over time. The results also suggests that P-adsorption in the soil depended greatly on the type of ions present in the soils, their adsorption energy of the ions and the nature of the soil particles. The high clay content, water retaining capacity and cation exchange capacity in the lateritic soil may be responsible for its higher adsorption ability over the finer clayey soil despite the larger surface areas of clayey soil which should have possibly provided more adsorption sites for the phosphate than laterite and sandy soil with smaller surface area. The Freundlich and Van Huay isotherms adequately described the adsorption behaviour of the sandy soil with high accuracy than the Langmuir isotherm. However, for the lateritic soil, the accuracy of the isotherms were not good enough with an exception of the Freundlich isotherm which gave a better description of the adsorption pattern. The Freundlich isotherm perfectly fitted the clayey soil with the highest

accuracy than the Langmuir and Van Huay isotherms. Comparing all the three isotherms employed in this research, the Freundlich isotherm is the best for predicting the phosphorus adsorption in soils. Thus, the p-adsorption strength of the soils is lateritic > clayey > sandy soil. Based on this study, in order to retain phosphate in these soils especially in the sandy soil, farmer would achieve greater result by using phosphate fertilizers that have low dissolution rates in soil water as this will increase the contact time and adsorption of the phosphate by plant roots thereby reducing the amount of leachable phosphate and the attendant environmental pollution. The soil amendment with lime targeted at reducing the pH to 6 would possible enhances adsorption of phosphorus in the soil.

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