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Phosphorus sorption characteristics of amended LPA soils cultivated to oil palm seedlings

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Abstract

This study evaluated the effect of four amendments: raw, composted, and pyrolyzed oil palm empty fruit bunch in modified forms applied at the rate of 75 kg K ha^{-1} and NPKMg fertilizer; on their on phosphorus (P) sorption characteristics of three soil types (Lixisol, Plinthosol, and Acrisol). The research was carried out at the Ohosu experimental station of the Nigerian Institute for Oil Palm Research (NIFOR), Edo State, Nigeria (Latitude 6^0 39' 90.8" N - 6^0 39' 74.5" N and Longitude 5^0 7' 33.3" E – 5^0 9' 46.9"E) between November 2018 and December 2019. The soils used for the phosphorus study were arranged in a Completely Randomized Design with three replicates and incubated for two weeks. Soil samples were collected and analyzed for P sorption at 2 weeks after incorporation (WAI). The available P in the soil was extracted using the Olsen extract method, and the concentration of P in the clear extract was determined by the ascorbic acid method. Phosphorus that disappeared from the solution was considered as sorbed P which was plotted against P concentration in the solution to obtain a P sorption isotherm. Data collected were subjected to sorption isotherms (Langmuir, Freundlich, and Temkin), Analysis of Variance, and regression analysis. Treatment means were separated using the Least significant difference ($p \leq 0.05$). The results showed that there was a general increase in the amount of P-sorbed as the concentration of the phosphate solution increased. Lixisol amended with compost showed the highest P-sorbed at 55 mg/kg, a similar trend was observed in the Plinthosol amended with NPKMg showed the highest P-sorbed at 57 mg/kg. Furthermore, Acrisol amended with biochar gave the highest P-sorbed at 55 mg/kg. P - sorption results showed that Lixisol amended with raw empty fruit bunch had the highest sorption efficiency in the range of 71.12 to 99.96%, indicating high affinity and high adsorption capacity. The Freundlich isotherm gave the best fits with an R^2 value of 0.999 for Lixisol, and Plinthosol treated with biochar and compost, and Acrisol treated with biochar. The models were linearly correlated with the P sorbed. The Langmuir model was in the range for Lixisol 0.177 – 0.918, Plinthosol 0.665 – 0.952, and Acrisol 0.008 – 0.917, indicating that not all the amended soils fit the model. Data presented, fit the Freundlich model with Lixisol range between 0.987 and 0.999, Plinthosol 0.959 – 0.998, Acrisol 0.992 – 0.999. The study concluded that Lixisol and Acrisol with biochar or compost exhibited higher P- sorption.

Keywords: Phosphorus, Acrisol, Plinthosol, Lixosol, Sorption

Introduction

Phosphorus is commonly a limiting nutrient for plant growth in many soils around the world (Akemo *et al.,* 2000). Generally, soils have hundred-time more reserves of total P than the plant-available P (Akemo *et al.*, 2000). In the semi-arid and arid regions of the world, about 80 to 90% of soils are deficient in available phosphorus (Glaser *et* *al.,* 2002, Bolland, *et al.,* 2001 and NFDC, 2001). Soil fertility survey indicated that phosphorus after nitrogen is the most deficient nutrient in soils (Yanni, 2011). Phosphorus is often applied more than plant demand, this results in the accumulation of residual P in soil which is either slowly available to plants or even turns into unavailable P compounds. The type of soil, properties of soil, and amount of P fertilizer applied among other factors determine the density of surplus fertilizer added and the sorption/desorption of P in soils (Keeney and Larson, 2000). The amount of available soil P has been more frequently evaluated than the factors affecting its release and the rate of its release when studying the P sorption/desorption of plants. The availability of nutrients to plants depends on the pH of the soil, moisture content, organic matter, concentration of N and P, soil type, and the rate at which it is released to replenish the soil solution (Minkova *et al.,* 2001). There can be a significant residual effect due to desorption of phosphate from the soil of long-term fertilization history and this can lead to an underestimation of the benefit of phosphate fertilizer if not taken into consideration (Miller *et al.,* 2002). Natural equilibrium among solid, solution phases, and soil constituents controls P availability in soil.

Lixosol, Plinthosol, and Acrisol (LPA) soils have been found to exhibit deficiency in Phosphorus and Nitrogen which requires urgent attention toward enhanced oil palm growth performance and productivity (Oko-Oboh *et al.,* 2016). LPA soils cultivated to oil palm, research on phosphorus (P) has given great emphasis to agronomic experiments measuring the response of crops to P. The past research has been directed mainly towards evaluating the effect of concentration on the sorption of P without due consideration of the factors affecting P sorption and desorption in the soils as well as the rate at which P is being released and adsorbed by the oil palm. Also, the assessment of the possible residual effect that may arise due to the desorption of phosphate from the soil on long-term fertilizer application was not considered (Abera, *et al.*, 2012, Adeniyan, *et al.,* 2011). This forms the basis for this study, which entails the study of the effect of composted, pyrolyzed, and raw application of the oil palm empty fruit bunch on the phosphorus sorption characteristics in LPA soils of the Nigerian Institute for Oil Palm Research (NIFOR) Ohosu Experimental Station.

Methodology

The study was conducted at the Nigerian Institute for Oil Palm Research (NIFOR) Ohosu Experimental Station in Ovia Southwest Local Government Area of Edo State, Nigeria. The site is 2,100 hectares, it lies within (Latitudes 6^0 39' 90.8" N and 6^0 39' 74.5" N; and Longitudes 5^0 07' 33.3" E 5^0 09' 46.9" E). Five soil types were identified in the study area according to Oko-oboh (2016) as Rhodic Kanhanpludalf (Lixisol), Plinthic Kandiudalf (Plinthosol), Aquic Kandiudalf (Acrisol), Aquic Kandiudalf (Luvisol), and Aquic Kanhapludalf (Acrisol). The oil palm empty fruit bunch was collected from the main station of the Nigerian Institute for Oil Palm Research. The bunches were modified into biochar by pyrolysis, composted using cow dung, and applied as soil nutrient amendments.

Preparation of Amendments

The raw oil palm empty fruit bunches were pruned, dried at a temperature of 105^0C, ground into a fine powder, and stored in an air-tight container. In addition, compost was prepared from the empty fruit bunch using cow dung manure. Also, some of the empty fruit bunches were charred (pyrolyzed), ground into a fine powder, and stored in airtight bags for physical and chemical analyses (Burke, *et al.,* 2014). All chemicals used were products of Sigma-Aldrich Chemicals, Germany. The oil palm empty fruit bunch was separated from the palm stalk and reduced to small sizes using a shredder (Model 5146P, CC-D Nut crusher). These shredded bunches were loaded into a biochar kiln pyrolyzer and ignited. The temperature of the pyrolyzer was monitored using an infrared thermometer at 350^{o}C and left for one hour, thirty minutes to char. The charred empty fruit bunch was then milled to a fine powder using a mechanical grinder (Rajkot Model SG225). The biochar particles were sieved and characterized (Burke, *et al.,* 2014).

Characterization of the Samples and the Soils

Physical and chemical properties of the raw oil palm empty fruit bunch (raw, composted, and pyrolyzed) samples were determined using standard procedures. Particle size analysis of the soil was determined by the hydrometer method (IITA, 2012). The proportion of sand, clay, and silt was used to determine the textural class of the soil using USDA textural triangle. Soil pH was measured in a 1:2 soil-water ratio. Soil organic carbon was estimated using the Walkley and Black, 1934 procedure. Total nitrogen was determined by the regular macro-Kjedahl digestion method (AOAC, 2003). Available phosphorus (P) was extracted using the Bray-1 method (Ubi *et al.,* 2012) and determined colorimetrically (Ubi *et al.,* 2012) Exchangeable bases (K, Na, Ca, and Mg) were extracted with 1 N ammonium acetate buffered to pH 7.0. K and Na in the extract were determined by flame photometer while Ca and Mg were determined by Atomic Absorption Spectrophotometer (AAS). The experiment was laid out in a Completely Randomized Design (CRD) replicated three (3) times using the three soil types (Lixisol, Plinthosol, and Acrisol) obtained from NIFOR Ohosu experimental station in Edo state with four amendments and controls included.

Soil sample preparation and Phosphorus sorption

The Phosphorus sorption characteristics were determined by batch equilibrium methods in which soil samples were agitated with the solution of known concentrations (0, 10, 20, 30, 40, and 50 mg/l) P. Samples of soils collected previously from the three soil types at a depth of (0-20 cm) was used for the P-sorption study. All samples were air dried at ambient temperature (between 20-25^{0}C) crushed and sieved through a 2mm sieve. The soil samples were weighed (200 g each) inside the incubation plastics and the four treatments were added and mixed with the soil. 60ml of water was added and the samples were kept in the field for two weeks. Sub –Samples of the soils were dispensed into the extracting bottles and the corresponding p equilibrating solutions of 0-50 ppm, respectively were added (Bolland, 2006, and Walworth, 2013)

Phosphorus as (KH_2PO_4) was dissolved in a 0.01M solution of calcium chloride in distilled water. 5 g of air-dried samples of each soil was placed in a 100 ml plastic bottle to leave free space for 25 ml of 0.01M $CaCl_2$ in which the final volume was adjusted to 30 ml. The following concentration of P stock solution was prepared as 0, 10, 20, 30, 40, and 50 mg/l P. Each sorption set for P was replicated thrice. The mixture was shaken for 30 minutes with a maximum speed of 380 rpm and equilibrated for 24 hr. After equilibrium time, the suspension was filtered through Whatman No. 42 filter paper and the concentration of P in the clear extract was determined by ascorbic acid method. Phosphorus that disappeared from the solution was considered as sorbed P which was plotted against P concentration in the solution to obtain a P sorption isotherm. The sample (without P) was added and subjected to the same procedure above. The entire test including blank was performed in triplicate. The P sorption data for the soils were fitted into Langmuir, Freundlich, and the Temkin equations (Hussain, *et al.* 2003).

Langmuir equation: $C/X=1/K.\ Xm+C/Xm$

where C(mgl^{-1}) is the equilibrium concentration, X (mg kg^{-1}) is the amount of P adsorbed per unit mass of adsorbent, K (Lmg^{-1}) is a constant related to the energy of sorption, and Xm (mg kg^{-1}) is P sorption

maximum. X is calculated as [Co-Ce]/mass of soil (kg) x V
where Co is the initial concentration, C_e is the equilibrium concentration, and V is the volume of the solution.

Freundlich equation: $X=K_fC^b$ $\log X=\log K_f + b\log C$ where K and b (b<1) are constant, X ($mgkg^{-1}$) is the amount of P adsorbed per unit mass of adsorbent, and C (mgl^{-1}) is the equilibrium concentration. Phosphorus sorption curves were drawn by plotting the quantity of sorbed P against the P concentration in the equilibrated soil solution (Moody et al., 1994; Moody, 2013, Hue, et., al. 1994).

The Temkin Isotherm This isotherm contains a factor that explicitly takes into the account adsorbent–adsorbate interactions.

As implied in the equation, its derivation is characterized by a uniform distribution of binding energies (up to some maximum binding energy) was carried out by plotting the quantity sorbed q_e against *ln* C_e and the constants were determined from the slope and intercept.

$$q_e=\frac{RT}{b}\ln\left(A_TC_e\right)$$

$$q_e=\frac{RT}{b_T}\ln A_T+\left(\frac{RT}{b}\right)\ln C_e$$

$$B=\frac{RT}{b_T}$$

$$q_e=B\ln A_T+B\ln C_e$$

A_T =Temkin isotherm equilibrium binding constant (L/g)
b_T = Temkin isotherm constant
R= universal gas constant (8.314J/mol/K)
T= Temperature at 298K.
B = Constant related to the heat of sorption (J/mol)

The external P-requirement of each soil or the amount of P required for each soil at 0.2 mg/L equilibrium solution of P also known as the standard P requirement (SPR) was calculated based on Langmuir and Freundlich models/ Equations developed for each soil. The soil solution P of 0.2 mg/L is the amount of P that should be available in the soil for optimum plant growth.

Statistical Analysis
Data collected were subjected to analysis of variance (ANOVA) using Genstat-12 software. The significant treatment means were separated using the Least Significant Difference (LSD) test at a 5% level of probability. Data collected were also subjected to correlation and regression analysis to determine the relationship between the nutrient release, and sorption characteristics.

Results and discussion
Results
3.1.1 Results of the physical and chemical properties of the soil and amendments
The physical and chemical properties of the three soil types (Lixisol, Plinthosol, and Acrisol) are presented in Table 1 below. The soil used for the experiment was sandy clay loam in texture, the pH of the soil was slightly acidic and ranged between (6.6 - 6.8).

Nitrogen content ranged from 0.010 to 0.017 g/kg, 0.015 to 0.019 g/kg, and 0.014 to 0.018 g/kg for Lixisol, Plinthosol, and Acrisol at 0- 15 and 15-30 cm depths, respectively.

Organic carbon ranged between 4.88 to 5.21 g/kg, 4.52 to 5.81 g/kg, and 4.26 to 5.46 g/kg for Lixisol, Plinthosol, and Acrisol at 0- 15 and 15-30 cm depths, respectively.

The chemical composition of the amendments is presented in Table 2 . The results indicated that pH was slightly acidic (6.59), to alkaline (9.45) and (11.03) for compost, raw empty fruit bunch, (REFB) and biochar, respectively.

The electrical conductivity of compost and REFB was 0.01ds/m and 0.02 ds/m for biochar.

The ash content of compost 64.00 g/kg was considered low compared with 91.56 and 93.73 g/kg for REFB and biochar. The nitrogen content of the amendment was high in compost followed by REFB and biochar.

Results of Phosphorus Sorption

The amount of P- sorbed for the three soil types and amendments are presented in Figures 1-3. There was a general increase in the amount of P-sorbed as the concentration of the phosphate solution increased. Lixisol amended with compost shows the highest P-sorbed at 55 mg/kg (Fig. 1), followed by Lixisol amended with biochar, REFB, and NPKMg relative to the control.

A similar trend was observed in Fig. 2 where Plinthosol amended with NPKMg showed the highest P-sorbed at 57 mg/kg followed by Plinthosol amended with REFB, compost, and biochar as the concentration of the phosphate solution increases.

Furthermore, Acrisol amended with biochar gave the highest P-sorbed at 55 mg/kg (Fig. 3), followed by Acrisol amended with REFB, NPKMg, and B. compost with an increase in the concentration of the phosphate solution compared with the control. The amount sorbed for the concentration of P was subjected to isotherm models; Langmuir, Freundlich, and the Temkin isotherms. The models were linearly correlated with the P sorbed.

The Langmuir model was in the range for Lixisol 0.177 – 0.918, Plinthosol 0.665 – 0.952, and Acrisol 0.008 – 0.917, indicating that not all the amended soils fit the model. Data presented in Table 3, fitted the Freundlich model with Lixisol range between 0.987 and 0.999, Plinthosol 0.959 – 0.998, Acrisol 0.992 – 0.999. Acrisol amended soils best fit the model with an R^2 value of 0.999.

The data were also subjected to the Temkin model with Lixisol range from 0.924 to 0.981, Plinthosol 0.925 – 0.967, and Acrisol 0.916 – 0.969, showing that all the data fit the model.

The sorption efficiency of P from the results shows that Lixisol was in the range of 71.12 – 99.96, Plinthosol 72.76 – 96.04, and Acrisol 72.03 – 97.98.

The unamended soils had lower sorption efficiency compared with amended soils. The highest sorption efficiency was observed in the Lixisol amended with REF

Table 1: Physical and chemical properties of the soils used for the study

S/N.	Sample Depth (cm)	pH Water	N	O.C	Av. P (mgkg^{-1})	Ex. A $H^+ + Al^{3+}$	Na	K	Ca	Mg	Sand	Silt	Clay
			gkg^{-1}			cmolkg^{-1}						gkg^{-1}	
1	Lixisol 0-15	6.8	0.017	5.21	23.78	0.4	0.471	0.602	0.210	0.301	702	29	269
2	Lixisol 15-30	6.6	0.010	4.88	23.01	0.4	0.464	0.589	0.241	0.352	652	98	250
3	Plinthosol 0-15	6.8	0.019	5.81	26.12	0.2	0.456	0.586	0.216	0.304	745	31	293
4	Plinthosol 15-30	6.6	0.015	4.52	24.56	0.4	0.442	0.571	0.245	0.321	681	26	224
5	Acrisol 0-15	6.8	0.018	5.46	24.38	0.2	0.468	0.592	0.221	0.334	689	97	286
6	Acrisol 15-30	6.8	0.014	4.26	21.22	0.2	0.450	0.581	0.238	0.341	673	41	214

Abbreviation: Av.P Available phosphorus, Ex.A: Exchangeable acidity, Org. C: Organic Carbon, N: Nitrogen, Na: Sodium, K: Potassium, Ca: Calcium, Mg: Magnesium

Table 2: Chemical properties of the amendments

Parameters	Compost	REFB	Biochar
pH	6.59	9.45	11.03
Electrical Conductivity (ds/m)	0.01	0.01	0.02
Ash Content (gkg^{-1})	64.00	91.56	93.73
Nitrogen (gkg^{-1})	0.73	0.57	0.42
Organic Carbon (gkg^{-1})	5.04	3.89	8.26
Phosphorus (gkg^{-1})	0.723	2.77	2.64
Potassium (cmolkg^{-1})	2.84	5.76	0.74
Sodium (cmolkg^{-1})	0.31	0.58	0.34
Calcium (cmolkg^{-1})	0.50	0.72	0.69
Magnesium (cmolkg^{-1})	0.34	0.48	0.61
Iron (gkg^{-1})	1.36	0.26	0.90
Copper (mgkg^{-1})	38.23	34.47	69.12
Zinc (gkg^{-1})	0.24	0.22	0.21
Manganese (gkg^{-1})	0.40	0.16	0.33

REFB; Raw oil palm empty fruit bunch

Table 3: Estimated equilibrium isotherm models for P- sorption of amended and unamended soils

Soil + Amendment	Langmuir Model			Freundlich Model			Temkin Model				Sorption
(kg/ha)	q_{max}	K_L	R^2	K_F	n	R^2	B_I	b_T	K_T	R^2	Efficiency (%)
Lixisol (control)	86.96	0.013	0.177	1.809	1.13	0.689	15.57	159.12	0.187	0.781	71.12
Lixisol + REFB	277.8	0.003	0.451	1.025	1.00	0.999	24.07	102.93	0.126	0.962	99.96
Lixisol + Compost	177.8	0.003	0.638	1.354	0.91	0.999	26.70	92.79	0.124	0.954	96.62
Lixisol + Biochar	140.9	0.010	0.677	1.537	1.14	0.993	22.11	112.06	0.150	0.948	95.72
Lixisol + NPKMg	454.6	0.002	0.918	1.101	0.97	0.987	25.19	98.36	0.128	0.924	98.32
Plinthosol (control)	243.90	0.003	0.575	1.828	0.94	0.798	17.87	138.64	0.126	0.847	72.76
Plinthosol + REFB	277.8	0.004	0.952	1.391	1.10	0.999	22.41	110.56	0.148	0.967	96.04
Plinthosol + Compost	196.1	0.006	0.712	1.067	0.99	0.999	23.87	103.79	0.127	0.943	96.24
Plinthosol + Biochar	163.9	0.005	0.665	9.680	0.61	0.959	26.39	93.88	0.119	0.925	97.60
Plinthosol + NPKMg	212.8	0.007	0.749	1.883	1.17	0.997	24.33	101.62	0.153	0.934	88.98
Acrisol (control)	192.3	0.005	0.358	1.036	1.07	0.892	14.12	175.47	0.175	0.773	72.03
Acrisol + REFB	232.6	0.004	0.678	1.083	0.97	0.994	27.54	89.96	0.125	0.969	86.84
Acrisol + Compost	122.0	0.006	0.757	1.976	0.85	0.997	27.04	91.63	0.112	0.955	97.98
Acrisol + Biochar	263.2	0.003	0.898	1.338	0.92	0.999	26.42	93.78	0.122	0.936	84.96
Acrisol + NPKMg	400	0.003	0.271	1.127	0.97	0.995	24.55	100.92	0.140	0.916	88.92

q_{max}:maximum amount of adsorbate adsorbed per gram of adsorbent(mg/g), K_L:Langmuir isotherm constant(L/mg), K_F: Freundlich isotherm constant(mg/kg), R^2: coefficient of determination n: adsorption intensity, b: constant

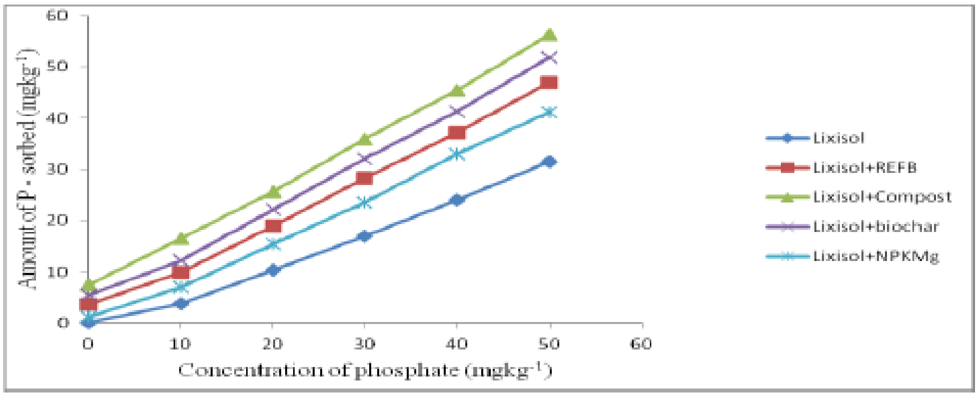

Figure 1: Amount of P-sorbed for Lixisol amended and unamended soils.

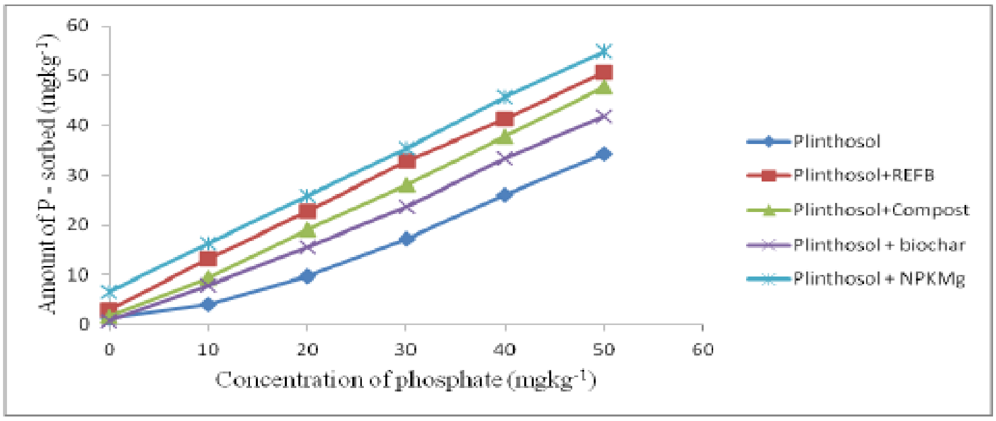

Figure 2: Amount of P-sorbed for Plinthosol amended and unamended soils.

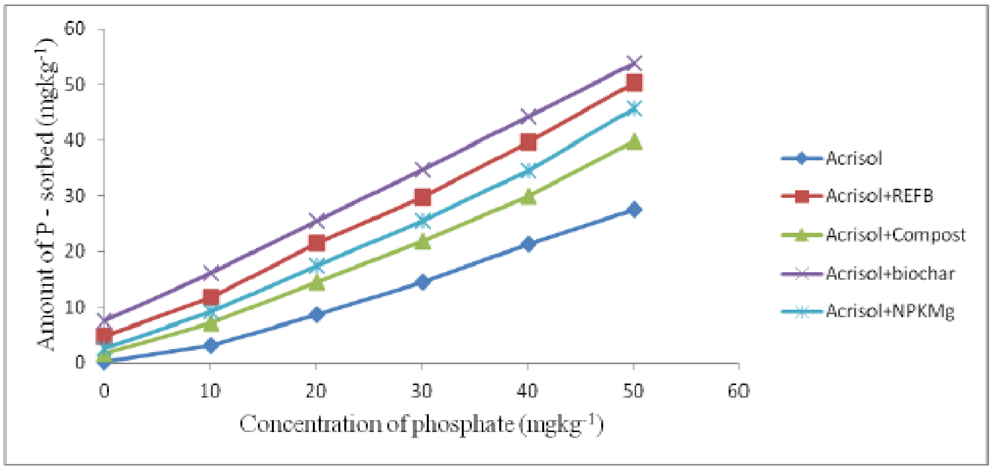

Figure 3: Amount of P-sorbed for Acrisol amended and unamended soils.

Discussion

The textural classes of the soils used for the experiment were identified as Sandy Clay Loam in texture with a relatively high proportion of sand content over the mineral particles which decreased with increasing soil depths. This observation corroborates the findings of Osayande *et al.*(2013) who reported that the parent material originating from coastal plain soils may influence the texture of the native soil. Clay was next to sand in dominance and increased with increasing soil depths, while the silt content decreased with depths.

This observation corroborates earlier findings by Raji *et al.* (2001) in Northern Nigeria; who reported that clay content increased with increasing soil depths. The low fertility status may be attributed to the high temperature prevailing in the area, which was probably responsible for the low organic matter content (Edmeades, 2003). The soil reaction in the study area was slightly acidic with pH values 6.6 - 6.8. The pH observed in this study was, however, confirmed with the pH of most agricultural soils in the tropics as reported by Rosenani and Mohd Zikri (2006).

The nitrogen content of the soils ranged between 0.014 to 0.019 g/kg and was found to be below the critical level of 1.50 g/kg for optimum crop production in Nigeria (Amlinger *et al.,* 2007). The organic carbon content of the soils ranged between 4.26 to 5.81 g/kg, and was below the critical level of 30 g/kg as reported by Amlinger *et al.* (2007). However, this observation is in line with the findings of Rosenani and Mohd Zikri (2006) who reported that low to medium organic carbon rate for tropical soil may be attributed to rapid mineralization of organic matter, inadequate return of crop residue, and bush burning. Available P was moderate thus indicating the good phosphorus fertility of the soils being above critical P level in Nigerian soils of 15 mg/kg (Antelo *et al.,* 2007). The moderate phosphorus content of the soils as observed may be due to the soil forming minerals of some tropical soils occasioned by high apatite content (Atiyeh *et al.,* 2000).

The soils were generally low in exchangeable K, Na, Ca, and Mg indicating the high permeability, hence leachability of nutrients in the soil which might be amendable by the use of amendments (Ehsan *et al.*, 2006; Atafar *et al.,* 2010).

Phosphorus sorption characteristics show that Plinthosol amended with NPKMg had the highest amount of P- sorbed than the other amendments. The highest sorption efficiency was recorded in the amended soils than unamended and the experimental P- sorption data were fitted to Langmuir, Freundlich, and Temkin models to determine the importance of the soil parameters in P retention and availability to plant roots. The observation agrees with the earlier findings of Azeez and Adetunji (2004) who stated that sorption is faster in the amended soils than unamended soils.
Figures 1-3 showed the P sorption by the soils. The amount of P concentration increased from 2-50mg/l. This is because in batch sorption the initial concentration of sorbate is attributed as a driving force to overcome the mass transfer resistance bewteen the aqueous and solid phases. The increase in uptake of P as the initial concentration increrase up to 50 mg/L also enhanced the interaction bewteen the sorbate and the soils (Ehsan et al., 2006; Atafar et al., 2010)..

It is clear from Table 3, that the values of the Freundlich exponent, 1/n, were approximately equal to (n<1), which represents a normal favorable sorption condition. Examination of the linear isotherm plots suggested that the Freundlich model yielded a much better fitting than the other models.
The analysis of the isotherm data is important to develop an equation which represents the results and which could be used for design purposes. To investigate the sorption isotherm three equilibrium

models were analyzed. These include the Langmuir, the Freundlich, and the Temkin isotherm models.

Initial ions concentration plays an important role in determining the amount of micronutrient sorption by a sorbent. In this study, the sorption amounts of P ions on the soils were measured at different ion concentrations (1.0-50mg/l). The result shows that the maximum sorption amount (qmax) increased almost linearly with the initial ion concentration from 0-50mg/l. For lixosol, when the C_o was 1.0mg/l for P, the q_m reached 454.6 mg/g (lixosol + NKPMg)), 277.8mg/g (lixosol + REFB), 140.9 mg/g (lixosol + biochar) and 177.8 mg/g for (lixosol + compost). For plinthosol, when the C_o was 1.0 mg/L for P the q_m reached 277.9 mg/g (plinthosol + REFB)), 212.8mg/g (plinthosol + NPKMg), 196.1 mg/g (plinthosol + compost) and 163.9 nmg/g(plinthosol + biochar). For acrisol, when the C_o was 1.0mg/l for P the q_m reached 232.6 mg/g (acrisol + REFB)), 400 mg/g (acrisol + NPKMg), 122.0 mg/g(acrisol + compost) and 263.2 mg/g(acrisol + biochar) respectively, which corresponds with some literature –reported qm of P ions on other similar soil characteristics (Table 3). This demostrates that the soil types have an excellent capacity for P availability.

Based on the results, the high coefficient of correlation (R^2) of Freundlich (0.9999) for Lixosols and (0.9999) for Plinthosol of P sorption, (0.9999) for acrisol confirmed the applicability of the model, which assumes strong interaction for the sorption of P in the soils. Freundlich model was able to give a good fit to the equilibrium data as the calculated q_{max} agrees with the experimental q_e values by a batch factor, with the R^2 values were (between 0.959-0.999 for Freundlich. This means that the sorption process of the soils encompassed the heterogeneity of the sorption sites in the soils. The fittings of the isotherm also suggested that the P sorption in the soils was more than a physical process. The heterogeneous sorption process is indicated by the heterogeneity factor value ($n \leq 1$). Thus, the isotherm that best describes the sorption behavior of soils is the Freundlich isotherm.

Conclusion

It has been shown that raw oil palm empty fruit bunch, compost, and biochar were successfully prepared with significant NPK nutrient levels which improve the nutrients of the soils. The use of the amendments for enhanced P- sorption was technically feasible, eco-friendly, and with high efficiency. The results from the studies have provided baseline information on the use of the amendments to enhance the sorption efficiency of phosphorus.

Conflict of interest

The authors confirm that there is no conflict of interest in the publication.

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