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Phosphorus sorption in selected soil orders in southwestern Nigeria

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ABSTRACT

Phosphate fertilizer application to correct soil P efficiency is important in agricultural production because only a small portion of the fertilizer applied is available for plant uptake as a result of P fixation. Phosphorus sorption capacities and properties are tools that can be employed to predict the response of different soil types to applied P fertilizers. Therefore, this study was carried out to investigate the phosphorus sorption capacities of three soil orders (Alfisol, Inceptisol, and Entisol) in Lagos and Oyo States, Southwestern Nigeria. Soil samples were collected from three different locations in triplicate at 0–15 and 15–30 cm of known pedological classification from previous studies. Soils were subjected to routine analysis to determine their chemical and textural properties. In the sorption study, soil sample was equilibrated with 0.01 M $CaCl_2$ containing different concentrations of phosphorus (0, 2, 4, 8, 16, and 20 ppm) prepared from potassium di-hydrogen phosphate (KH_2PO_4). Data from the sorption study were fitted into Langmuir and Freundlich equations. The soil pH ranged from slightly acidic to neutral, and the soils were rich in exchangeable bases. The organic carbon and available content of the soil were low and decreased as the depth increased. Mn, Cu, Zn, and Fe were adequate in the soils. The soils ranged from sandy to sandy-loamy in texture. The P sorption data in all soils fitted well with the Freundlich equation but did not to fit with the Langmuir equation except for inceptisol at 0–15 cm depth. This implies that phosphorus was sorbed more on multiple sites of the soils except for inceptisol at 0–15 cm depth, on which adsorption took place on a single site. The result further indicates that Entisols had the least P-fixing ability, followed by Inceptisols, with Alfisol having the highest ability to fix P. Organic matter, Zn and sand showed a significant positive correlation with the P value at $p < 0.05$.

Keywords: Phosphorus, sorption, Entisol, Alfisol, and Inceptisols

INTRODUCTION

Phosphorous is one of the essential macronutrients needed for plant growth. It is generally added to soil as a fertilizer to increases the physiological efficiency of crops. Tropical soils are deficient in phosphorus and its availability when applied in forms of fertilizers, tend to decrease as a result of retention and fixation. Some chemical reactions responsible for the fixation of phosphorus in soils include: Adsorption and precipitation reactions with sesquoxides, clay minerals and calcium carbonate in alkaline soils (Johan *et al*., 2021). The decline in soil Phosphorus could be attributed to continuous cropping, indiscriminate application of organic and inorganic fertilizers, and soil erosion (Wakene and Heluf, 2003). In African soils, which are often acidic in nature, P sorption varies among soils in different location as a result of differences in their physical and chemical properties (Brady and Weil, 2002) and management (Moazed *et al*., 2010). Thus, understanding the P-sorption characteristics of soil is important for designing appropriate management strategies and predicting fertilizer requirements (Zhang *et al*., 2005).

Data obtained from P sorption studies are veritable tools to determined its requirement and proper management for sustainable crop production. The highest P requirements are found in volcanic ash soils, rich in disordered minerals such as allophane, as found in some parts of the world (Jensen *et al*., 2019). Volcanic ash soils are important locally but large areas, especially in West Africa, are dominated by soils with low phosphate sorption (Gonzalez-Rodriguez, and Fernandez-Marcos, 2018 Entisols are soils that show little or no horizon development in the profile. They are mostly derived from colluvial and alluvial materials. Inceptisols are young soils with limited soil profile development and are weakly developed soils. Alfisols are described as soils with relative high native fertility, and are moderately leached. Their subsurface horizons are rich in clay (Soil Survey Staff, 2014; UIdaho, 2022). Crop responses to phosphorus and phosphate sorption are related to soil type and orders. Therefore, this study was conducted to determine the phosphorus sorption characteristics of selected soils orders, most especially Alfisol, Inceptisol and Entisol in the southwestern area of Nigeria.

MATERIALS AND METHODS

Description of the study sites

Soils were collected from three different locations which were previously classified in Ibadan and Lagos based on soil orders (Figure 1). Alfisol was obtained from a pasture field on University of Ibadan dairy farm. Inceptisol was taken from the valley bottom in the University of Ibadan dairy farm. Entisol was collected from Eleko beach in Lagos (Table 1).

Routine Soil Analysis

The samples were air-dried, crushed and sieved to pass through 2mm and 0.5mm sieve respectively, depending on the analysis to be carried out on the soils. All Soil chemical analysis was carried out using the methods in the Udo and Ogunwale manual (1986). Soil pH was determine in 1:1 soil water ratio with a glass electrode pH meter in distilled water. Hydrometer method. (Bouyoucos, 1934) was used for determination of particle size distribution.

Table 1: Location, Order, Identifier, Coordinate and Depth of Selected soils

Location	Order	Identifier	Depth(cm)	Coordinate
Lagos	Entisol	EN1	0-15	6º 43` 86``N, 3 º84` 96`` E, 200m
Lagos	Entisol	EN2	15-30	6º 43` 86``N, 3º 84` 96`` E, 200m
Ibadan	Inceptisol	IC1	0-15	7º45` 86``N, 3º 90` 16``E, 192m
Ibadan	Inceptisol	IC2	15-30	7º45` 86``N, 3º 90` 16``E, 192m
Ibadan	Alfisol	AL1	0-15	7º 46`N, 3º 90’E, 207m
Ibadan	Alfisol	AL2	15-30	7º 46’N, 3º 90’E, 207m

Lagos (Eleko Beach), Ibadan (UI Dairy Farm), Alfisol- Pasture field, Inceptisol – valley bottom

The textural class of the soils was determined by using the USDA textural triangle (NSSC, 1995). Exchangeable cations were extracted with neutral ammonium acetate and Na and K were read with the flame photometer while Mg and Ca were read with the atomic absorption spectrophotometer. Total exchangeable bases (TEB) were calculated by the addition up the concentrations of the basic cations that have been analysed. Exchangeable acidity was determined with KCl extraction method (Mclean, 1965). Effective Cation Exchange Capacity (ECEC) was computed as the summation of exchangeable bases and exchangeable acidity and expressed in cmol/kg. The Walkey and Black procedure of 1934 was used to analyse the soil organic matter. Organic Carbon (OC) was calculated by multiplying organic matter by a factor (1.724).

The Bray P-1 method (Bray and Kurtz, 1945) was employed to determine soil Available Phosphorus while the micronutrients (Mn, Fe, Cu & Zn) were extracted with 0.1N HCl and read off on an the Atomic Absorption spectrophotometer (AAS). The Kjedahl method as modified by Jackson, 1970 was used for Total Nitrogen.

Phosphate Sorption Experiment

The P sorption experiment was conducted by adding 3g of air-dried soil samples to 50 ml centrifuge tubes containing 30 ml of 0.01M $CaCl_2$ at equilibrating P concentrations (0, 2, 4, 8, 16, and 20 ppm) using potassium di-hydrogen phosphate (KH_2PO_4) as carrier (Adejumo and Omueti, 2016). Two drops of toluene were added to minimize the potential bacterial uptake of P during the equilibration period. The tubes were sealed, placed in a reciprocal platform shaker, and shaken for 30 minutes twice daily for six days at room temperature. At the end of the equilibration period, the samples were centrifuged for a period of 20 minutes at 2,000 rpm (Fox and Kamprath, 1970). The P in the supernatant was determined using the Murphy and Riley (1962) method. The amount of P added less the amount of P in solution was taken to be that sorbed by the soil. It was then plotted against the concentration in solution to give the P sorption isotherm curve.

RESULTS

Soil Characteristics

Table 4.1 shows some chemical properties of the soils. The pH of the Entisol ranged from 6.6 to 6.8. The pH values of the inceptisol ranged from 5.2 to 6.3. The pH values of the Alfisols ranged from 4.3 to 5.2. The organic carbon content of the Entisols ranged from 2.52g/kg to 6.39g/kg, with Entisol from 0 to 15cm depth and Entisol from 15 to 30cm depth. Those of Inceptisols ranged from 4.4g/kg to 15.69g/kg, with inceptisol from 0–15 cm depth and inceptisol from 15–30 cm depth. Those of Alfisols ranged from 1.35g/kg to 7.21g/kg, with Alfisol from cm 0–15 cm and Alfisol from 15–30 cm depth. The total N of Entisols ranged from 0.27 g/kg to 0.70 g/kg; those of Inceptisols ranged from 1.03 g/kg to 1.45 g/kg; and those of Alfisols ranged from 0.15 g/kg to 0.79 g/kg. The exchangeable bases in the order of abundance are Ca, Na, Mg, and K. The exchangeable Ca of Entisol from 0 to 15cm depth ranged from 4.64 to 6.19 cmol/kg, with a mean value of 5.42 cmol/kg. The exchangeable Ca of Entisol from 15–30 cm depth ranged from 5.49–8.86 cmol/kg, with a mean value of 7.18 cmol/kg. The exchangeable Ca of Inceptisol from 0 to 15cm depth ranged from 0.21 to 0.30 cmol/kg, with a mean value of 0.26 cmol/kg. The exchangeable Ca of Inceptisol from 15 to 30cm depth ranged from 0.27 to 0.29 cmol/kg, with a mean value of 0.28 cmol/kg. The exchangeable Ca of Alfisol from 0 to 15cm depth ranged from 0.02 to 0.03 cmol/kg, with a mean value of 0.25

cmol/kg. The exchangeable Ca of Alfisol from 15 to 30cm depth ranged from 0.01 to 0.03 cmol/kg, with a mean value of 0.02 cmol/kg. The exchangeable Na of Entisol from 0 to 15cm depth ranged from 2.74 to 2.96 cmol/kg, with a mean value of 2.85 cmol/kg.

The exchangeable Na of Entisol from 15–30 cm depth ranged from 1.69–2.65 cmol/kg, with a mean value of 2.17 cmol/kg. The exchangeable Na of Inceptisol from 0 to 15cm depth ranged from 0.21 to 0.31 cmol/kg, with a mean value of 0.26 cmol/kg. The exchangeable Na of Inceptisol from 15 to 30cm depth ranged from 0.16 to 0.19 cmol/kg, with a mean value of 0.18 cmol/kg. The exchangeable Na of Alfisol from 0 to 15cm depth ranged from 0.13 to 0.17 cmol/kg, with a mean value of 0.15 cmol/kg. The exchangeable Na of Entisol from 0 to 15cm depth ranged from 0.14 to 0.17 cmol/kg, with a mean value of 0.16 cmol/kg. The exchangeable Mg of Entisol from 0 to 15cm depth ranged from 2.29 to 2.42 cmol/kg, with a mean value of 2.36 cmol/kg. The exchangeable Mg of entisol from 15–30 cm depth ranged from 1.99–2.54 cmol/kg, with a mean value of 2.27 cmol/kg. The exchangeable Mg of inceptisol from 0 to 15cm depth ranged from 0.12 to 0.20 cmol/kg, with a mean value of 0.16 cmol/kg. The exchangeable Mg of Inceptisol from 15 to 30cm depth ranged from 0.13 to 0.14 cmol/kg, with a mean value of 0.135 cmol/kg. The exchangeable Mg of Alfisol from 0 to 15cm depth ranged from 0.06 to 0.13 cmol/kg, with a mean value of 0.095 cmol/kg. The exchangeable Mg of Alfisol from 15 to 30cm depth ranged from 0.09 to 0.11 cmol/kg, with a mean value of 0.10 cmol/kg.

The exchangeable K of Entisol from 0 to 15cm depth ranged from 0.14 to 0.15 cmol/kg, with a mean value of 0.145 cmol/kg. The exchangeable K of Entisol from 15 to 30cm depth ranged from 0.13 to 0.16 cmol/kg, with a mean value of 0.145 cmol/kg. The exchangeable K of Inceptisol from 0 to 15cm depth ranged from 0.16 to 0.20 cmol/kg, with a mean value of 0.18 cmol/kg. The exchangeable K of Inceptisol from 15 to 30cm depth ranged from 0.13 to 0.13 cmol/kg, with a mean value of 0.13 cmol/kg. The exchangeable K of Alfisol from 0 to 15cm depth ranged from 0.14 to 0.16 cmol/kg, with a mean value of 0.15 cmol/kg. The exchangeable K of Alfisol from 15 to 30cm depth ranged from 0.12 to 0.13 cmol/kg, with a mean value of 0.125 cmol/kg. The exchangeable acidity of Entisol from 0 to 15cm depth is 0.30 cmol/kg. The exchangeable acidity of Entisol from 15 to 30cm depth ranged from 0.30 to 0.50 cmol/kg. The exchangeable acidity of Inceptisol from 0 to 15cm depth ranged from 0.30 to 0.40 cmol/kg. The exchangeable acidity of Inceptisol from 15 to 30cm depth ranged from 0.40 to 0.50 cmol/kg. The exchangeable acidity of Alfisol from 0 to 15cm depth ranged from 0.30 to 0.40 cmol/kg. The exchangeable acidity of Alfisol from 15 to 30cm depth ranged from 0.30 to 0.40 cmol/kg. The available P of Entisols from 0–15 cm depth ranged from 4.9–6.2 mg/kg. The available P of Entisol from 15–30 cm depth is 4.8 mg/kg. The available P of Inceptisol from 0–15 cm depth ranged from 12.8–20 mg/kg. The available P of Inceptisol from 15–30 cm depth ranged from 12.5–18.6 mg/kg. The available P of Alfisol from 0–15 cm depth ranged from 5.1–5.5 mg/kg. The available P of Alfisol from 15–30 cm depth ranged from 4.4–6.0 mg/kg. The ECEC of Entisol from 0–15 cm depth was 11.07 cmol/kg, and entisol from 15–30 cm depth was 12.16 cmol/kg. The ECEC of inceptisol from 0–15 cm depth was 1.21 cmol/kg, and Inceptisol from 15–30 cm depth was 1.17 cmol/kg. The ECEC of Alfisol from 0–15 cm depth was 0.77 cmol/kg, and Alfisol from 15–30 cm depth was 0.75 cmol/kg.

Particle Size Distribution

Table 4.2 shows the particle size distribution of the soils. Entisols from 0–15 and 15–30 cm depth had a sand content of 978 g/kg, a silt content of 14 g/kg, and a clay content of 8 g/kg. The textural class is sand. Inceptisols from 0–15 and 15–30 cm depth had a sand content of 758 g/kg, a silt content of 154 g/kg, and a clay content of 88 g/kg. The textural class is sandy loam. Alfisols from 0–15 cm depth have a sand content of 858 g/kg, a silt content of 74 g/kg, and a clay content of 68 g/kg. The textural class is loamy sand. Alfisols from 15–30 cm depth had a sand content of 798 g/kg, a silt content of 94 g/kg, and a clay content of 108 g/kg. The textural class is sandy loam.

Soil Micronutrients (Cu, Mn, Fe and Zn)

Soil micronutrients were in the order of abundance Mn > Fe > Zn > Cu as shown in table 4.3. Extractable Mn of Entisol from 0 – 15cm depth ranged from 9.2 – 11.3 mg/kg with a mean value of 10.25 mg/kg. Extractable Mn of Entisol from 15 - 30cm depth ranged from 11.5 – 11.7 mg/kg with a mean value of 11.6 mg/kg. Extractable Mn of Inceptisol from 0 – 15cm depth ranged from 50.0 – 74.4 mg/kg with a mean value of 62.2 mg/kg. Extractable Mn of Inceptisol from 15 – 30 cm depth ranged from 55.5 – 11.3 mg/kg with a mean value of 91.4 mg/kg. Extractable Mn of Alfisol from 0 – 15cm depth ranged from 144 – 194 mg/kg with a mean value of 169 mg/kg. . Extractable Mn of Alfisol from 15 - 30cm depth ranged from 194 – 204 mg/kg with a mean value of 199 mg/kg. Extractable Fe of Entisol from 0 – 15cm depth ranged from 65.1 – 76.4 with a mean value of 70.75 mg /kg. Extractable Fe of Entisol from 15 - 30cm depth ranged from 50.6 – 74.1 with a mean value of 62.35 mg /kg. Extractable Fe of Inceptisol from 0 – 15cm depth ranged from 920 – 1605 with a mean value of 1262.5 mg /kg. Extractable Fe of Inceptisol from 15 - 30cm depth ranged from 490 – 890 with a mean value of 690 mg /kg. Extractable Fe of Alfisol from 0 – 15cm depth ranged from 121 – 156 with a mean value of 138.5 mg /kg. Extractable Fe of Alfisol from 15 - 30cm depth ranged from 140 – 152 with a mean value of 70.75 mg /kg.

In Entisol from 0 – 15cm depth, extractable Zn ranged from 1.60 – 1.84 mg /kg with mean value of 1.72 mg/kg While in Entisol from 15 - 30cm depth Zn ranged from 1.87 – 2.00 mg /kg with mean value of 1.94 mg/kg. For extractable Zn, inceptisol from 0 - 15cm depth ranged from 11.8 – 16.92 mg /kg with mean value of 14.36 mg/kg. In Inceptisol, at 15 - 30cm dept, Zn ranged from 11.9 – 13.3 mg /kg with mean value of 12.6 mg/kg . While in Alfisol, Zn from 0 - 15cm depth ranged from 3.73 – 4.33 mg /kg with mean value of 4.03 mg/kg. Also in Alfisol from the depth of 15 - 30cm, Zn ranged from 2.71 – 3.04 mg /kg with mean value of 2.88 mg/kg.

Phosphate Sorption Isotherms

Two-dimensional plots of the amount of P adsorbed as a function of the P concentration of the equilibrium solution for the soils orders are shown in figures 4.1, 4.2, 4.3, and 4.4 (for Entisols); figures 4.5, 4.6, , and 4.7 (for Inceptisols), and figures 44.8, 4.9, and 4.11 (for alfisols). The linear forms of Freundlich and Langmuir isotherms were adopted, and so they are all straight-line graphs. Inceptisol at 0–15 cm and 15–30 cm depth on the Freundlich isotherm graph, Alfisol at 0–15 cm and 15–30 cm depth on the Freundlich isotherm graph, and Alfisol at 15–30 cm on the Langmuir isotherm graph fell on the negative intercept, suggesting the release of weakly held phosphate ions into solution, otherwise known as desorption.

Table 4: Chemical Properties and textural classes of the Soils Selected in Ibadan and Lagos

Soil order	Depth	pH	OC	TN	Av. P	Ca	Mg	K	Na	Ex.A	ECEC	Mn	Cu	Zn	Fe	Sand	Silt	Clay	Tex. Class
		(H_2O)	g/kg		mg/kg				Cmol/kg					mg/kg			g/kg		
EN1	0-15	6.7	3.1	0.34	6	5.415	2.36	0.15	2.85	0.3	11.07	10.25	1.11	1.72	70.75	978	14	8	Sand
EN2	15-30	6.8	4.55	1.55	5	7.18	2.27	0.15	2.17	0.4	12.16	11.6	1.12	2.34	62.35	978	14	8	Sand
IC1	0-15	6.4	8.79	7.77	16	0.26	0.16	0.18	0.26	0.4	1.21	62.2	3.01	14.36	1262.5	758	154	88	Sandy Loam
IC2	15-30	5.7	11.05	4.37	16	0.28	0.14	0.13	0.18	0.5	1.17	73.45	3.18	12.6	690	758	154	88	Sandy Loam
AL1	0-15	4.8	3.34	0.37	5	0.03	0.1	0.15	0.15	0.4	0.77	169	3.88	4.03	138.5	858	74	68	Loamy Sand
AL2	15-30	5.2	4.28	0.47	5	0.02	0.1	0.13	0.16	0.4	0.75	199	4.58	2.88	746	798	94	108	Sandy Loam

EN1- Entisol Lagos 1, EN2- Entisol Lagos 2, IC1 –Inceptisol Ibadan 1, IC2 –Inceptisol Ibadan 2 , AL1- Alfisol Ibadan 1, AL2- Alfisol Ibadan 2. OC – Organic Carbon, TN – total nitrogen, Av. P- available phosphorus, Ex. A- Exchangeable acidity, ECEC – Effective cation exchange capacity

Inceptisol at 15–30 cm depth on the Langmuir isotherm graph, Alfisol at 0–15 cm depth on the Langmuir isotherm graph, inceptisol at 0–15 cm depth on the Langmuir isotherm graph, and entisol at 0–15 cm depth and 15–30 cm depth on both Langmuir and Freundlich isotherm graphs had positive intercepts.

In all the soil orders, the Freundlich equation conformed mostly to the experimental results better than the Langmuir equation. Only the adsorption data for inceptisol at 0–15 cm depth conform to the Langmuir adsorption isotherm. The adsorption data of the soils were better described by the Freundlich isotherm. Although both equations are used to interpret the shape of graphs of P adsorbed and in equilibrium solution in mathematical terms, Langmuir's adsorption isotherm works on the assumption that we have only one surface carrying out the adsorption process, while Freundlich's adsorption isotherm works on the assumption that we have more than one surface that is doing the adsorption.

Relationship between P adsorbed and some soil properties

The P adsorbed was related to some soil properties in a correlation matrix. Table 4 shows these relationships. For all six soils studied, only sand content (r2 = 0.8714*) showed a significant positive correlation with the P sorbed at p< 0.05. The organic matter (r^2 = 0.9414**) had a high positive and significant correlation with the available P at $p < 0.01$. Manganese (r^2 = -0.9335**) had a high negative and significant correlation with pH at $p < 0.01$. Copper (r^2 = 0.9398**) had a high positive significance with manganese at $p < 0.01$. Zinc (r^2 = 0.9251**) had a high positive significance with organic matter at $p < 0.01$. Zinc (r^2 = 0.9882**) had a high positive significance with available phosphorus at $p < 0.01$. Sand (r^2 = 0.8601*) had a high positive significance with iron at $p < 0.01$.

Relationship between P. Sorbed, Langmuir, and Freundlich Models of Soils

From Table 4.5, the P sorption data were fitted into Langmuir and Freundlich adsorption equations for all the soils. The P sorbed in Entisol at 0–15 cm and 15–30 cm depth were 68.72 mg/kg and 34.06 mg/kg, respectively, and this is higher than the P sorbed in Alfisol at 0–15 cm and 15–30 cm depth, which were 19.97 mg/kg and 10.87 mg/kg, respectively, which is also higher than the P sorbed in Inceptisol at 0–15 cm and 15–30 cm depth, which were -1.5 mg/kg and 4.42 mg/kg, respectively. The sorption data fitted generally for both adsorption models but more to Freundlich adsorption isotherms for all the soils except for Inceptisol at 0–15 cm depth. Langmuir and Freundlich adsorption data collected on

Entisol at 0–15 cm depth had a mean coefficient of correlation (R^2 = 18.7 and R^2 = 99.9, respectively). Langmuir and Freundlich adsorption data collected on Entisol at 15–30 cm depth had a mean coefficient of correlation (R^2 = 6.7 and R^2 = 99.1, respectively). Langmuir and Freundlich adsorption data collected on Inceptisol at 0–15 cm depth had a mean coefficient of correlation (R^2 = 95 and R^2 = 5.0, respectively). Langmuir and Freundlich adsorption data collected on Inceptisol at 15–30 cm depth had a mean coefficient of correlation (R^2 = 20.3 and R^2 = 90.0, respectively). Langmuir and Freundlich adsorption data collected on Alfisol at 0–15 cm.

depth had a mean coefficient of correlation (R^2 = 2.2 and R^2 = 99.7, respectively). Langmuir and Freundlich adsorption data collected on Alfisol at 15–30 cm depth had a mean coefficient of correlation (R^2 = 18.3 and R^2 = 97.9, respectively).

The bonding energies (K_L and K_f) of entisol at 0–15 cm depth were -18.5 L/mg and 0.69 L/mg, respectively. The bonding energies (K_L and K_f) of entisol at 15–30 cm depth were -50.08 L/mg and 0.66 L/mg, respectively. The bonding energies (K_L and K_f) of Inceptisol at 0–15 cm depth were 9.17 L/mg and -1.27 L/mg, respectively. The bonding energies (K_L and K_f) of inceptisol at 15–30 cm depth were 12.82 L/mg and 3.69 L/mg, respectively. The bonding energies (K_L and K_f) of Alfisol at 0–15 cm depth were 314 L/mg and 1.59 L/mg, respectively. The bonding energies (K_L and K_f) of Alfisol at 15–30 cm depth were 19.17 L/mg and 0.76 L/mg, respectively. Sorption maxima (b) was significantly high in Alfisol at 0–15 cm depth, having a sorption maxima of 250 mg/kg, and significantly low in entisol at 15–30 cm depth, with a sorption maxima of -42.74 mg/kg.

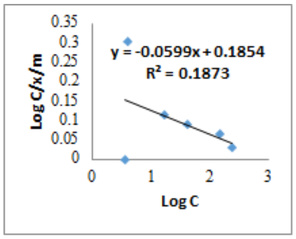

Figure 4.1 : P sorption in EN1 by Langmuir plot

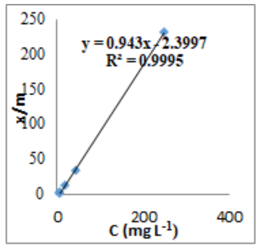

Figure 4.2: P sorption in EN1 by Freundlich plot

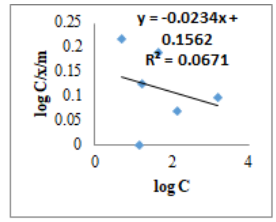

Figure 4.3 : P sorption in EN2 by Langmuir plot

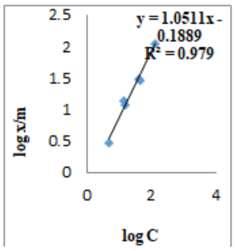

Figure 4.4: P sorption in EN2 by Freundlich plot

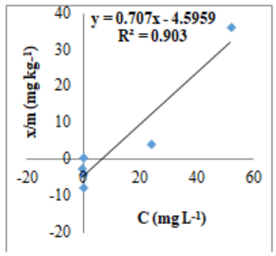

Figure 4.5: P sorption in IC2 by Freundlich plot

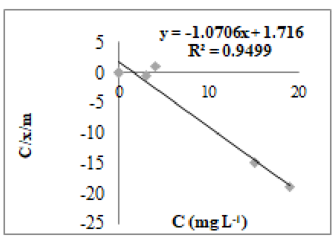

Figure 4.6: P sorption in IC1 by Langmuir plot

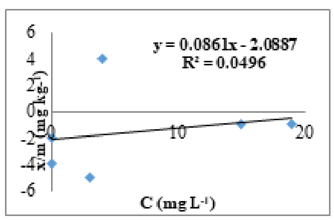

Figure 4.7: P sorption in IC1 by Freundlich plot

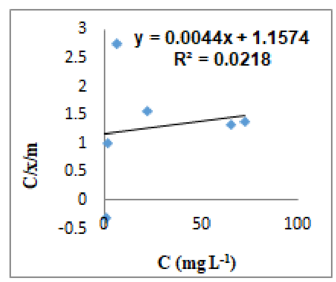

Figure 4.8: P sorption in AL1 by Langmuir plot

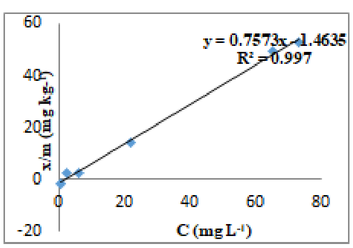

Figure 4. 9: P sorption in AL1 by Freundlich plot

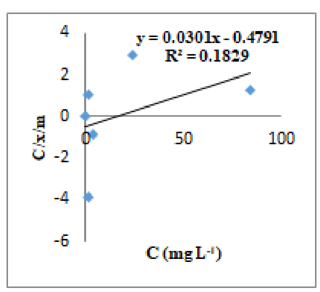

Figure 4.10: P sorption in AL2 by Langmuir plot

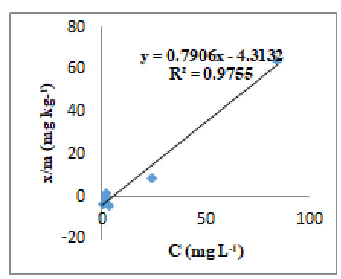

Figure 4.11: P sorption in AL2 by Freundlich plot

Table 4.4: Linear Correlation Coefficient between P Sorbed and Chemical and Physical Properties of the soil

	P Sorbed	pH	OM	Av.P	Ex.A	Mn	Cu	Zn	Fe	Sand	Silt
pH	0.4671										
OM	-0.5884	0.0675									
Av_P	-0.571	0.1142	**0.9414****								
Ex_A	-0.7146	-0.3816	0.7674	0.5656							
Mn	-0.5287	-0.9335**	-0.1656	-0.1893	0.2512						
Cu	-0.7342	**-0.8908***	0.1675	0.1554	0.4583	**0.9398****					
Zn	-0.6705	0.0184	**0.9251****	**0.9882****	0.6117	-0.0914	0.2474				
Fe	-0.779	-0.0831	0.6894	0.7833	0.4024	0.219	0.5009	0.8053			
Sand	**0.8714***	0.5111	-0.7192	-0.7331	-0.68	-0.5193	-0.78	-0.7839	**-0.8601***		
Silt	**-0.8339***	-0.3605	0.8365	0.8621*	0.7035	0.3302	0.6324	0.8993	**0.8713***	**-0.9755****	
Clay	-0.8488*	-0.6853	0.4845	0.4803	0.5855	0.7487	0.926	0.5462	0.7676	**-0.9472****	**0.8533***

* Significance (P< 0.05); ** Significance (P< 0.01), , Av. P- available phosphorus, Ex.A Exchangeable acidity, OM-Organic matter

Table 4.5: Relationship between P_Sorbed, Langmuir and Freundlich Models

Soils Sampled	P Sorbed	Langmuir			Freundlich	
		R^2	B	K_L	R^2	K_f
EN1	68.72	0.187	-16.69	-18.5	0.999	0.69
EN2	34.06	0.067	-42.74	-50.08	0.991	0.663
IC1	-1.5	90.5	-0.934	9.17	0.05	-1.27
IC2	4.42	0.203	21.1	12.82	0.9	3.69
AL1	19.97	0.022	250	314	0.997	1.59
AL2	10.87	0.183	33.22	19.17	0.979	0.76

EN- Entisol (Eleko beach), IC- Inceptisol (valley bottom dairy farm, UI), AL- Alfisol (Pasture field dairy farm, UI)

DISCUSSION

Physical and Chemical Properties of the Soils Selected

Entisols from 0.15cm depth were slightly acidic, and Entisols from 15–30 cm depth were neutral. Inceptisols from 0–15 cm depth were slightly acidic, and Inceptisols from 15–30 cm depth were moderately acidic. On the other hand, Alfisols were strongly acidic at the two depths. The results showed that pH increases with depth, most especially in Entisol and Inceptisol. This may be due to the fact that less H+ is available as a result of decreased organic matter decomposition, which in turn is due to low organic matter content in the experimental soils (Buol *et al*., 2003; FFD, 2012).

The organic carbon content of the Entisols was very low at 0–15 cm and low at 15–30 cm. While in Inceptisols, organic carbon at 0–15 cm was low but moderate at 15–30 cm. And in Alfisol, organic carbon followed the same trend as in Entisol. The classes were according to the findings of FFD, 2012. Low organic carbon content in soils could be attributed to low soil organic carbon generally in tropical soils, which could be a result of continuous cultivation of land and high temperatures (Abdulkadir *et al*., 2021).

The total N of Entisols ranged from low to medium, with high levels of inceptisol and low levels of alfisol. Nitrogen content in Southwestern soils has been reported to be below medium (Ande *et al*., 2017). The soils were rich in exchangeable bases (Shehu *et al.*, 2015). According to Sobulo and Adepetu (1987), the critical level for K is 0.15–0.30 cmol/kg, and as such, none of the soils had values higher than the critical values. This means the soils would need fertilizer K applications. The soils were not deficient in exchangeable Mg, as they had values above the 0.4 cmol/kg soil given as the critical value for south-western Nigerian soils (FMANR, 1990). The exchangeable acidity in all the soils is high when compared to the 0.1 cmol/kg reported by Raji and Mohammed (2000). This suggests that the soils had problems with acidity, which could be a result of the leaching of basic cations. Available P is low in entisol and Alfisols but adequate in inceptisol, according to the rating of Akinrinde and Obigbesan, 2000. That means that any value > 10mg/kg is adequate. The low availability of P could be attributed to the low organic carbon in these soils.

The Effective Cation Exchange Capacity (ECEC) in Entisol is higher than that of Alfisol and inceptisol at both depths. The low values of the ECEC of the Alfisol and Inceptisol reflect the higher degree of weathering and leaching associated with soil-forming processes (Kang *et al.*, 1990; Shehu *et al*., 2015). This also confirms the age-old concept of low ECEC in tropical soils resulting from the predominance of kaolinite clay, a low-activity clay. This low ECEC of these soils is believed to essentially responsible for the high dependence of tropical soils on their organic matter content as the main nutrient storage depot (Agboola and Omueti, 1982). All three soil orders are within the critical value of 5 mg/kg for Mn in the soils of South West Nigeria. These indicate that the soils have an adequate amount of Fe, using 5.0 mg/kg as the critical level for the availability of Fe in the soils (Lander, 1984). In Entisol, extractable Zn is in the medium class of soil fertility, while it is high in Inceptisol and Medium in alfisol, according to FFD (2012

All the soils were adequate in Cu, using 0.2 mg/kg as the critical level for Cu in Nigerian soils (Esu, 1991; Olowolafe et al., 2012). The sandy to sandy-loamy texture of the soil orders in this study was in conformity with the findings of Adegbite *et al.,* 2020. Which is a peculiarity of soils from Southwestern Nigeria.

Relationship between P. Sorbed, Langmuir, and Freundlich Models of Soils

The sorption data fitted generally for both adsorption models but more to Freundlich adsorption isotherms for all the soils except for inceptisol at 0–15 cm depth. It is natural that the P sorption data of different soils fit with different equations to different degrees, and there are occasions where the P sorption data of particular soils may not obey with one, two, or none of such sorption equations (Chaudhary *et al.,* 2003; Hussain *et al*., 2003).

The P sorbed in Entisol at both depths was higher than the P sorbed in Alfisol. However, the P sorbed by Alfisol was also higher than those from Inceptisol. Based on the indices of sorption capacities, the experimental soils were in decreasing order: entisol, Alfisol, and inceptisol.

The coefficient of Correlation ($R^{2)}$ from the Langmuir and Freundlich adsorption data for Entisol was higher than those of Inceptisol and Alfisol at both depths. Due to the high rate of correlation in P sorption using the Freundlich isotherm model, phosphorus was sorbed more on multiple sites of the soil order. This implies that adsorption took place on multiple sites in all the soils except for inceptisol at 0–15 cm depth, on which adsorption took place on a single site. Langmuir's adsorption isotherm works on the assumption that we have only one surface carrying out the adsorption process (Udo and Uzu, 1972; Osodeke and Omueti, 1995), while Freundlich's adsorption equation works on the assumption that are more than one surface that are effecting the adsorption (Kinniburgh and Jackson, 1982). The boding energies (K_L and K_f) values showed the tenacity with which P is adsorbed by soils, with the highest being Alfisol at 0–15 cm depth and the lowest being Entisol at 15–30 cm depth for the Langmuir isotherm. And inceptisol at 15–30 cm depth is the highest, and inceptisol at 0–15 cm depth is the lowest for the Freundlich isotherm.

Sorption maxima (b) was significantly high in Alfisol at 0–15 cm depth with sorption maxima and significantly low in Entisol at 15–30 cm depth with sorption maxima of -42.74 mg/kg, very much lower than that reported for tropical soils (Hartono et al., 2005). This means that Entisols have the least P-fixing ability, followed by Inceptisols, with Alfisol having the highest ability to fix P. This can be due to variations in their stages of weathering. Birru *et al*. (2003)

Correlations between Soil Properties Influencing the P Sorption

For all six soils studied, Organic matter, Zn and sand content showed a significant positive correlation with the P value at $p < 0.05$. This indicates that as these parameters in the soil increased, the P absorbed also increased. Also, as the amount of silt and clay content increased, the P sorbed decreased, as shown by the negative correlation. The other soil properties didn’t show any significant correlation with P sorbed.

CONCLUSION

The soil is a complex system, and the chemistry of phosphorus sorption in different soil orders is important for a proper understanding of the mechanism of P retention in Nigerian soils in order to establish good management practices for P fertilizer. Langmuir and Freundlich fitted well for the sorption data, but Freundlich fitted better in all the soils except for Inceptisol at 0–15 cm depth. Phosphorus was sorbed more on multiple sites of the soil orders except for Inceptisol at 0–15 cm depth, on which adsorption took place on a single site. The boding energies (K_L and K_f) were highest in the Alfisol at 0–15 cm depth and lowest in the Entisol at 15–30 cm depth for the Langmuir isotherm; for the Freundlich isotherm, the Inceptisol at 15–30 cm depth was the highest and the Inceptisol at 0–15 cm depth was the lowest. Entisols had the least P-fixing ability, followed by Inceptisols, with Alfisol having the highest ability to fix P. As the sand content in the soil increased, the P sorbed also increased, and as the amount of silt and clay content in the soil increased, the P sorbed decreased.

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