

INFLUENCE OF SOIL PHYSICAL AND CHEMICAL PROPERTIES ON PHOSPHORUS FIXING CAPACITY OF SELECTED SOIL SERIES IN SOUTHWESTERN NIGERIA

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ABSTRACT

Selected soil series (Jago, Mamu, Apomu, Itagunmodi, Egbeda, Ondo, Iwaji, Iwo and Gambari Series) from Southwestern Nigeria were evaluated for their Phosphorus (P) sorption characteristics as influenced by soil physical and chemical properties. The samples were equilibrated in 50 ml of 0.01M CaCl₂ containing various amounts of P as KH₂PO₄ to give 0, 1, 2, 3, 5, 8, 10, 15, 20 and 25 ppm for seven days at room temperature. The physical and chemical properties as well as P sorption characteristics of the soil series were determined. The adsorption isotherm of the samples showed different curves for samples of each soil series. The rates of P adsorption increased with increased concentrations of P, but at a certain level of higher concentration, the level of P became almost constant and had no more capacity to adsorb P. Phosphorus adsorption capacity decreased in the following order Itagunmodi > Gambari > Ondo > Egbeda > Iwaji > Mamu > Jago > Iwo > Apomu. Percent clay, Ca, Effective Cation Exchange Capacity (ECEC) and total exchangeable bases (TEB) were significantly positive correlated with P fixation while silt, soil pH, soil organic matters were positively insignificant correlated with P fixation. Percent sand, available P, extractable Fe, total exchangeable acidity (TEA) were negatively correlated with P fixation. The binding energy have negative relationship with percent sand, available P, extractable Fe and TEA while positive relationship was observed with % clay, pH, organic matter, TEB and ECEC. The result showed that Itagunmodi soil series required large amount of P fertilization for productive cultivation activities. The reduction of P sorption will require management practices like regular application of P fertilizers to improve the P solution concentrations and improvement of soil structure through the application of organic manure.

Keywords: Soil Series, Phosphorus, Langmuir Adsorption Isotherm, Southwestern.

INTRODUCTION

The low Phosphorus in tropical soils has been attributed to the nature of the chemical forms of soil P and the high contents of Fe and Al oxides which are associated with high P fixation (Udo, 1981). Phosphorus sorption in soil poses a severe constraint on the ability of many soils to supply adequate amounts of phosphorus to plants (Bainbridge *et al.*, 1995). Shen *et al.* (2001) reported that fertilizer P can largely be fixed by oxides, hydroxides and oxyhydroxides of Fe and Al and clay minerals in acidic soil, which makes it less available or effectively unavailable to plants. This is because the availability of both applied and native phosphorus is largely controlled by sorption and desorption characteristics of the soil. Phosphorus adsorption and desorption reactions in the soil depend on factors such as soil type, soil pH, organic matter content, type of clay and sesquioxides, amount of phosphorus applied, contact time, prevailing mechanisms of the phosphorus reactions and microbiological activities and so on. It has also been established that

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phosphorus fixing capacity of soils increased with increasing rates of phosphorus addition over time of equilibration (Ibia, Udo and Omueti, 2009).

Adsorption equations such as those of Langmuir and Freundlich have been used to evaluate phosphate adsorption. Langmuir equation is often used to estimate the maximum phosphorus sorption potential of soils (Harter and Smith, 1981). Phosphorus adsorption isotherm technique that uses the relationship between adsorbed P (capacity factor) and solution P (intensity factor) has been successfully used in predicting P requirement of crops in different soil (Agbede 1988). It is based on the principle that crop P requirement is directly related to the amount of P sorbed at a critical supernatant solution P known to be non – limiting to plants. The phosphorus fractional recovery approach and the single point adsorption methods have also been used (Ibia, Udo and Omueti, 2009). Fractional Recovery which involves the measurement of applied phosphorus in the soil by means of soil test method; generally used in estimating phosphorus form, an approach in establishing a basis for phosphorus recommendation. The fraction of added P not recovered is taken as the P fixed or retained by the soil when known rates of P are applied to the soil and allowed to equilibrate after which Bray P-1 extracted values are determined at different time intervals. There is a general observation that a considerable portion of the phosphate fertilizer applied to soil is not recovered in the crop that is immediately planted. Soil chemists have developed concepts to rationalize these observations. The explanations assume that the unrecoverable phosphate is either consumed by soil microbes or precipitated by soluble ions in soil solution or adsorbed by the colloidal complex of the soil. Most investigators seem to agree that only those of soluble ions and colloidal complexes are important nutrition (Sauchelli, 1965).

There had been various research works on the impact of soil P fixing capacity on P uptake but more information is needed on the impact of physical and chemical properties of Nigerian soils on their P fixing abilities. The objective of this study was to evaluate the phosphorus fixing potential of different soil series and its relationship on the physical and chemical properties of some soils of southwestern Nigeria.

MATERIALS AND METHODS

Soil Sampling and Characterization

Soil samples (0-15cm) were collected from nine soil series in Southwestern Nigeria (Iwo (Ultisol), Ondo (Ultisol), Egbeda (Ultisol), Apomu (Inceptisol), Gambari (Alfisol), Itaganmodi (Ultisol), Iwaji (Ultisol), Jago (Inceptisol) and Mamu (Ultisol). The air dried soil samples were used for laboratory analysis. The particle size analysis was carried out using the hydrometer method by Bouyoucous (1951). Soil pH in 0.01M CaCl₂ was determined using the soil – solution ratio 1:2. The soil organic matter content of each soil series was determined using the Chromic Acid Digestion Method by Walkley-Black (1934). Exchangeable basic cations were extracted with 1N NH₄OAc at pH 7 with potassium (K), sodium (Na) and calcium (Ca) determined by flame photometry. Exchange acidity was determined by shaking the samples with 1.0 M KCl and titrating with 0.1 M NaOH. Available P was determined by Bray 1 method (Bray and Kurtz, 1945). The effective cation exchange capacities of the soils were then calculated using the summation method. Extractable iron was determined

by extracting with 0.1N HCl and read off using an Atomic Adsorption Spectrophotometer (AAS).

Determination of Phosphorus Adsorption

Five grams of soil was weighed into each 250ml conical flask and 50ml of equilibrating solution added. Soil samples were equilibrated in 50 ml of 0.01M CaCl₂ containing various amounts of P as KH₂PO₄ to give 0, 1, 2, 3, 5, 8, 10, 15, 20 and 25µg L⁻¹ P for seven days at room temperature. Two drops of toluene were added to each conical flask to prevent microbial growth. The suspensions were covered and mechanically shaken for 30 minutes each day longitudinally and at the end of the seventh day, they were centrifuged at 10,000rpm and filtered through Whatman No. 42 Filter paper. Phosphorus content in the supernatant solution was determined colorimetrically according to the procedure described by Murphy and Riley (1962). The change in solution P between what was added initially and what remained at equilibrium stage was regarded as having been adsorbed by soil particles. The P sorption data for the soil samples used in this study were fitted into the following form of Langmuir equation: $C/X = 1/kb + c/b$. where C = P concentration in equilibrium solution, X = P adsorbed by the soil (µg P g⁻¹), b = adsorption maximum (µg P g⁻¹) k = a constant related to the binding energy of the soil for P or affinity constant.

The Adsorption Isotherms

The adsorption isotherm is a curve obtained by plotting the concentration of phosphorus adsorbed per gramme of soil (Q) against P concentration of the equilibrium solution (C) at equilibration.

$$Q = (C_i - C_f)V/x$$

Where,

Q	=	Amount of P adsorbed per unit weight of soil
C _f	=	Final concentration of P in solution
C _i	=	Initial P concentration in solution
V	=	Volume of solution added
X	=	Weight of soil used

Langmuir Adsorption Isotherms

The Langmuir adsorption equation is given as

$$Q = kcb/1 + kC$$

$$b = 1/slope$$

$$k = slope/intercept$$

Where,

Q	=	Amount of P adsorbed per unit weight of soil
K	=	A constant related to the binding energy between the soil and the adsorbed P
B	=	The maximum amount of solute that can be adsorbed (Adsorption maxima)
C	=	Equilibrium solution concentration of P

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The statistical tools used in the course of this study were arithmetic mean, correlation analysis and graphs to show the relationships between the adsorption maxima and the physical and chemical properties of the soil series.

RESULTS AND DISCUSSION

The Physical and Chemical Properties of the Soil Series

The physical and chemical properties of the soil series used were shown in the Tables 1 and 2. The particle size distribution showed that the texture of the soil varied from sandy loam (Egbeda and Jago Series) to sandy clay loam (Iwo, Ondo, Apomu, Gambari, Iwaji and Mamu Series) to clay (Itaganmodi Series). The samples were slightly acidic with pH in 0.01M CaCl_2 values ranging from 4.1 to 6.37. The least pH value was recorded for soil sample from Mamu (4.10) while highest value was recorded for Ondo (6.37). The Soil organic matter content of the soil samples was highest in Jago (5.94%) while the least value was recorded in Apomu (2.57%). The highest available P content of the soils was recorded for Apomu (50.5ppm) while the least value was from Itaganmodi (21.25ppm). The total exchange acidity also ranged from 0.8 to 1.9 while the extractable iron ranged from 22.84ppm (Ondo) to 231.42ppm (Jago). Exchangeable bases were in the order of $\text{Ca} > \text{K} > \text{Na}$ for all the soil series. The highest value for effective cation exchange capacities of the soil series was recorded for Ondo (5.38cmol/kg^{-1}) while Apomu (2.40cmol/kg^{-1}) has the least value.

There was a decline in fractions of added P adsorbed with increasing solution concentrations of P for most of the soil series (Ondo, Jago and Mamu) which shows that the soils have maximum adsorption capacity and the maximum could be reached with high phosphorus saturation. The adsorption isotherms of the soil series used are shown in Figures 1, 2, and 3.

The following graphs (Fig. 4 to 7) are the Langmuir adsorption plots. At high equilibrium solute concentration, deviation from the linear Langmuir adsorption equation was observed and this has been attributed to the presence of more than one adsorption sites which have distinct b and k values; hence the reason for the more than one values of b for most of the soils (Table 3).

The Adsorption Maxima of the Soil Series

The adsorption maxima of the soil series used in the course of the study was shown in Table 3. In respect to the adsorption maxima, Apomu series had the least value ($92.7\ \mu\text{g/g}$) while Itaganmodi had the highest value ($1,286.64\ \mu\text{g/g}$). This may be due to the fact that Itaganmodi has the highest clay content of all the soil series used. Also, P adsorption is caused more by the linkage of phosphate through replacement or displacement of structural OH groups which is more predominant in 1:1 type of clays than in the 2:1 type of minerals, due to the higher content of exposed Al-OH groups in the 1:1 type of clays. The Organic matter(OM) content is higher in Itaganmodi because of high clay content which provide the basis for chelating actions of OM with P thereby increasing the P fixing capacity of the series.

The Binding Energies of the Soil Series

The binding energies, that is, the energy with which the phosphorus is bounded to the adsorption sites of each soil series were shown in Table 4. Itagunmodi series had the highest value (24.82 ml/ μ g) which may be due to its high clay content while Jago series had the lowest value (0.99 ml/ μ g) due to its low clay content.

Phosphorus Fixation and Soil Physical and Chemical Properties

Positive insignificant ($p > 0.05$) relationship was observed between soil pH and the adsorption maxima (Table 5). The same relationship was observed with adsorption energy. This is contrary to the work of Naidu *et al.* (1990) who reported that as soil pH increases, P fixation decreases which they attributed to interactions between added P, negative charge and the electrostatic potential in the plain of sorption. The reason for this deviation may be due to the fact that most of the soils used in this research are tending towards neutrality, thus resulting in low amount of elements such as aluminum which has the ability to fix phosphorus in the soil. Negative significant ($p < 0.05$) relationship was observed between adsorption maxima and % sand while the highly significant ($p < 0.01$) negative was observed with adsorption energy (Table 5). This is due to the inert or unreactive nature of the sand particles. This was in conformity with result of the research by Woodruff and Kamprath (1965) who found that sandy soils retain less phosphorus than clayey soils of similar mineralogy. Percent clay was positively significant correlated with adsorption maxima ($p < 0.05$) and adsorption energy ($p < 0.01$) (Table 5). This is due to the fact that our soils are mostly oxisols and ultisols which are rich in amorphous clay minerals which have the ability to fix P in the soil. The percent silt was insignificant positive correlated with adsorption maxima and binding energy. This is because silt which is similar to clay has mini adsorption sites where phosphorus can be fixed in the soil. Negative insignificant ($p < 0.05$) relationship existed between adsorption maxima and exchange acidity and also with binding energy. That is, as exchange acidity increases, P fixation decreases. Highly Positive significant ($p < 0.01$) relationship was observed between P adsorption maxima and exchangeable bases (Table 5). That is, the concentration of basic cations in the soil increased the P fixation of such soil. This may be due to ability of calcium to fix P when the pH increases. P adsorption maxima and binding energy were positively correlated with soil organic matter content (Table 5). This suggested possible active participation of organic matter in governing P sorption in the soils, possibly through Al-organo complexes as suggested by Haynes and Swift (1989). However, other researchers (Awad and Al-Obaidy, 1989) have found that the addition of organic matter to soils increase the availability of the element. Available P was negatively correlated with P adsorption maxima and binding energy (Figure 10), though the relationship was only significant ($p < 0.01$) with adsorption energy. That is, increased in available phosphorus content of the soil reduced P fixation of the soil. Extractable Fe was insignificant ($p > 0.05$) negative correlated with P adsorption maxima and binding energy plant extractable iron in the soil (Table 5). This result is contrary to the findings of Samson (1978) who reported a direct and positive relationship between phosphorus fixation and plant extractable iron. Effective Cation Exchange Capacity (ECEC) and Total Exchangeable Bases (TEB) were significantly ($p < 0.01$) positive correlated with adsorption maxima (Table 5). That is, as ECEC and TEB increased P fixation of the soil. Positive insignificant correlation was observed between exchangeable H and adsorption maxima but no correlation was recorded with binding energy. Positive significant

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($p < 0.01$) relationship existed between adsorption maxima and exchangeable calcium. Calcium is a dominant element that fixes P at high pH.

CONCLUSION

Generally, most of the soil series used has more than one adsorption sites; hence the soils have multiple adsorption maxima and binding energies. The implication of this is that more of P fertilizer will be needed to satisfy plant requirement. The adsorption isotherm of the samples showed different curves for samples of each soil series. Out of the nine soil series used in the course of this study, Apomu series was found to have the lowest adsorption maximum, therefore has very low phosphorus fixing capacity. Hence, little amount of P fertilizer is required for cultivation on such soil. Itagunmodi series was found to have the highest adsorption maximum which may be as a result of its high clay content. Hence such soil needed large amount of P fertilizer for productive cultivation activities. P adsorption capacity decreased in the following order Itagunmodi > Gambari > Ondo > Egbeda > Iwaji > Mamu > Jago > Iwo > Apomu. Percent clay, Ca, effective Cation Exchange Capacity and total exchangeable bases (TEB) were significantly positive correlated with P fixation while silt, soil pH, soil organic matter was positively insignificant correlated with P fixation. Percent sand, available P, extractable Fe, total exchangeable acidity (TEA) were negatively correlated with P fixation. The binding energy have negative relationship with percent sand, available P, extractable Fe and TEA while positive relationship was observed with % clay, pH, organic matter, TEB and ECEC. It can therefore be concluded that the physical and chemical properties of the soil are good indicators for P fixing capacities of the soils. Farmers and researchers can make use of these soil properties to predict the P fixing capacities of the soils and P fertilizer requirement of the plants.

Table 1: The Physical Properties of the Soil Series

Soil Series	USDA Equivalent	Particle Size Distribution (%)			
		Sand	Silt	Clay	Textural Class
Iwo	Ultisol	70.4	8	21.6	Sandy clay loam
Ondo	Ultisol	73.1	6.6	20.3	Sandy clay loam
Egbeda	Ultisol	72.4	10	17.6	Sandy loam
Apomu	Inceptisol	76.4	9	14.6	Sandy clay loam
Itagunmodi	Ultisol	37.1	19.3	43.6	Clay
Gambari	Alfisol	58.4	14.7	26.9	Sandy clay loam
Iwaji	Ultisol	63.1	12	24.9	Sandy clay loam
Jago	Inceptisol	67.1	18	14.9	Sandy loam
Mamu	Ultisol	65.1	8	26.9	Sandy clay loam

Table 2: Chemical Properties of the Soil Series

	Iwo	Ondo	Egbeda	Apomu	Itagunmodi	Gambari	Iwaji	Jago	Mamu
pH(CaCl ₂)	5.33	6.37	5.60	5.27	5.83	5.37	4.70	4.60	4.10
OM (%)	3.44	4.88	3.71	2.57	5.65	5.34	5.54	5.94	3.29
Avail. P (mgkg ⁻¹)	35.00	24.10	34.65	50.50	21.25	28.60	40.40	36.10	36.10
Extr. Fe (mg/kg)	31.40	22.84	22.96	42.66	27.71	53.49	153.58	231.42	153.93
Exch. Al (cmol/kg)	0.60	0.40	0.50	0.30	0.30	0.40	0.90	0.80	1.20
Exch. H (cmol/kg)	0.20	0.40	0.40	0.50	0.60	0.50	0.90	0.60	0.70
TEA (cmol/kg)	0.80	0.80	0.90	0.80	0.90	0.90	1.80	1.40	1.90
Exch. Ca (cmol/kg)	1.90	3.95	2.90	1.30	3.65	3.50	1.90	0.60	1.10
Exch. K (cmol/kg)	0.28	0.32	0.28	0.19	0.47	0.45	0.33	0.56	0.31
Exch. Na (cmol/kg)	0.13	0.31	0.12	0.11	0.27	0.13	0.72	0.18	0.11
TEB (cmol/kg)	2.31	4.58	3.30	1.60	4.39	4.08	2.95	1.34	1.52
ECEC	3.11	5.38	4.20	2.40	5.59	4.98	4.75	2.74	3.42

SOM = Soil Organic Matter
 TEA = Total Exchangeable Acidity
 TEB = Total Exchangeable Bases
 ECEC = Effective Cation Exchange Capacity

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The following graphs illustrate the adsorption isotherms of the soil series.

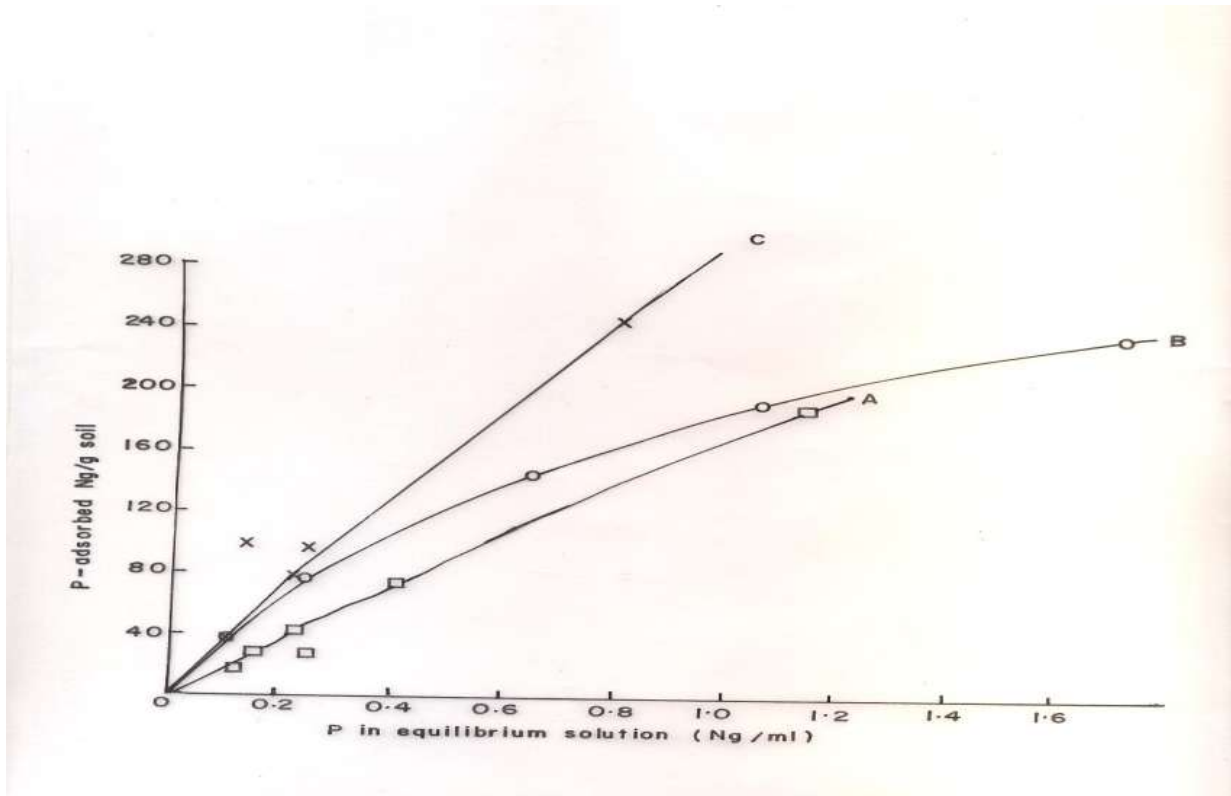


Figure 1: The Adsorption Isotherms of Some of the Soil Series

- A = Gambari
- B = Ondo
- C = Iwo

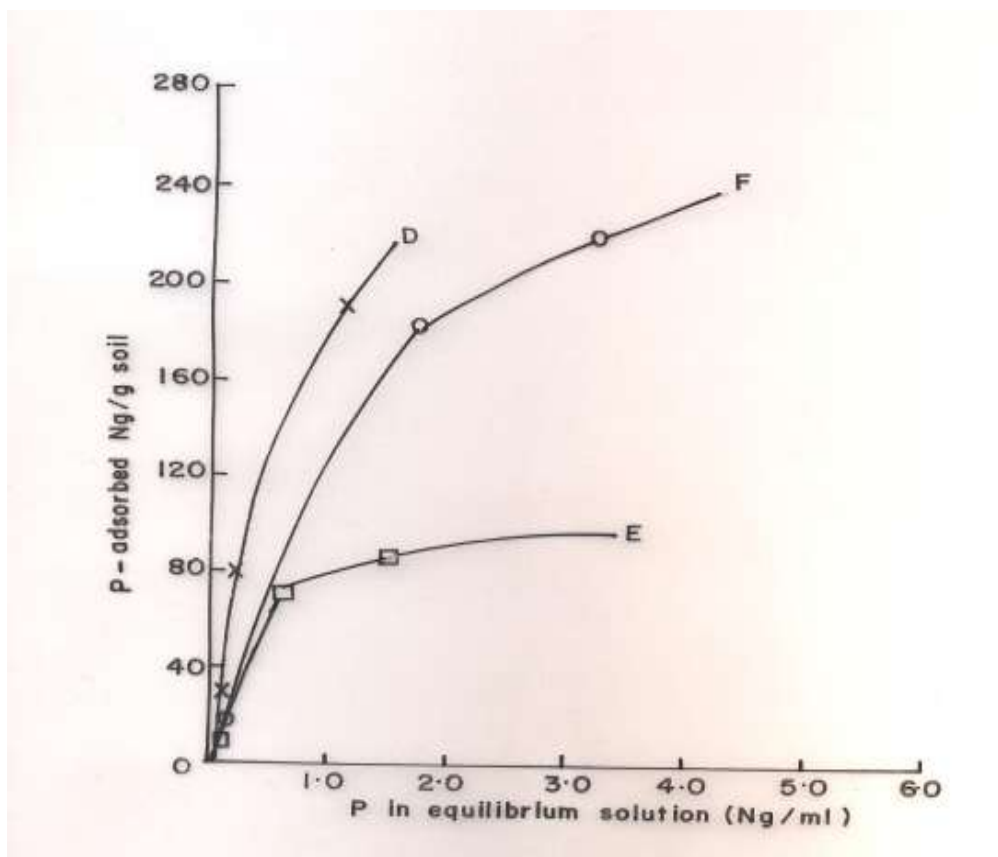


Figure 2: The Adsorption Isotherms of Some of the Soil Series

- D = Egbeda
- E = Itagunmodi
- F = Apomu

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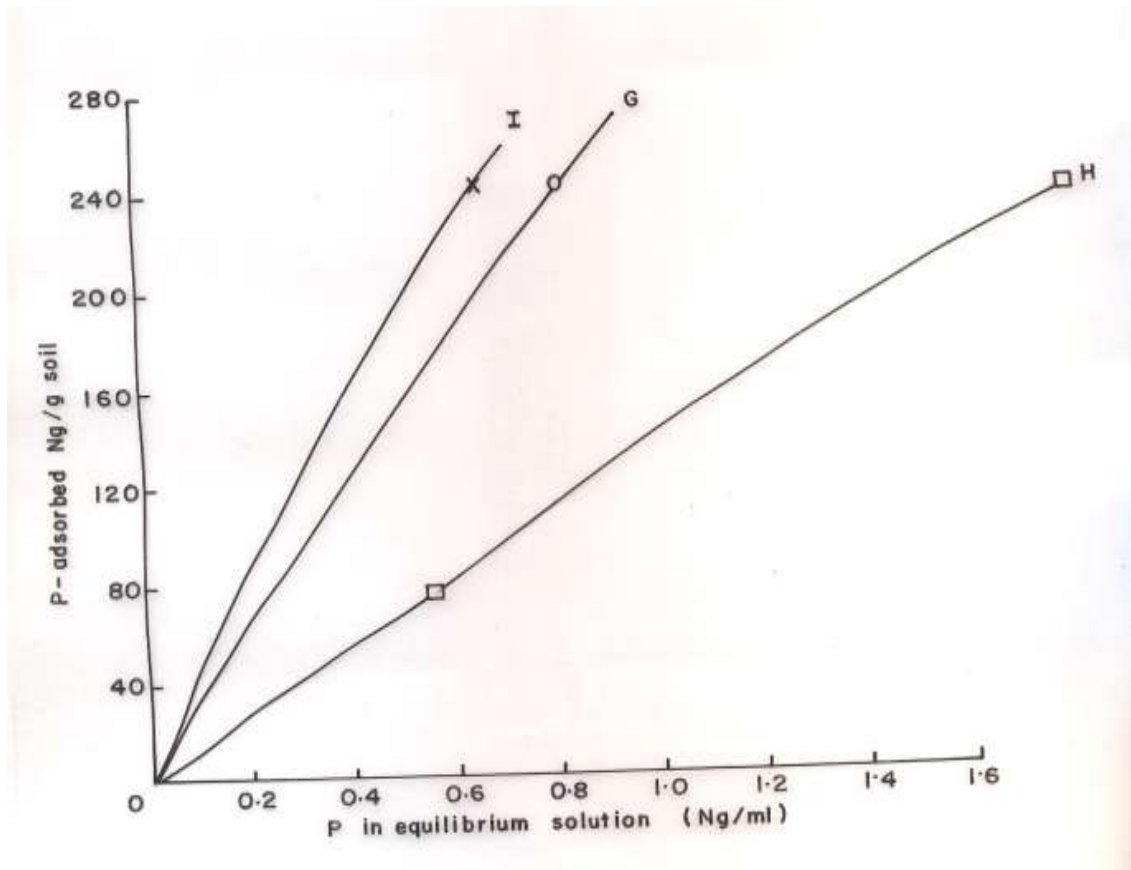


Figure 3: The Adsorption Isotherms of Some of the Soil Series

G = Iwaji
H = Jago
I = Mamu

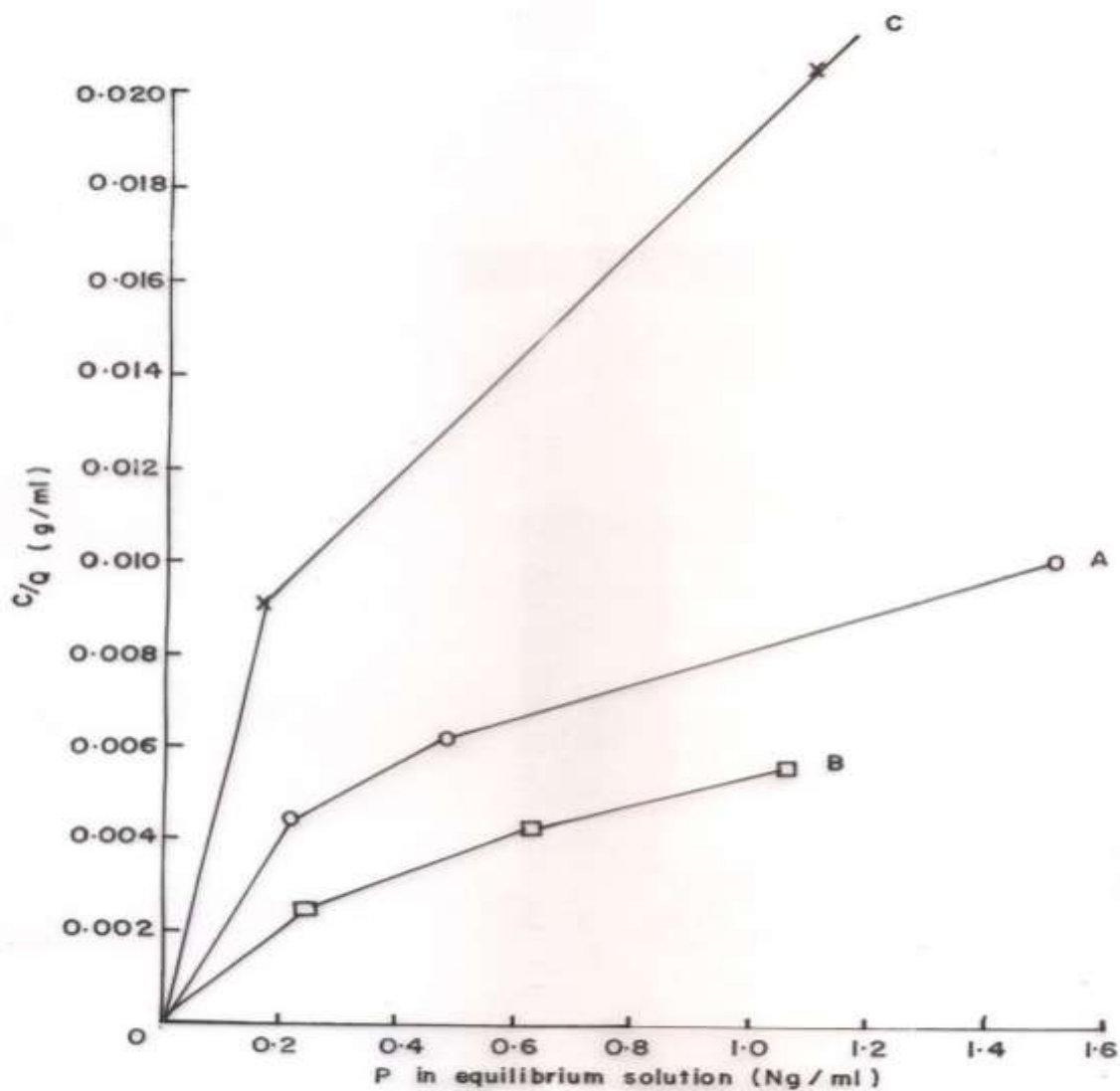


Figure 4: The Langmuir Adsorption Isotherms of Some of the Soil Series

- A = Gambari
- B = Ondo
- C = Iwo

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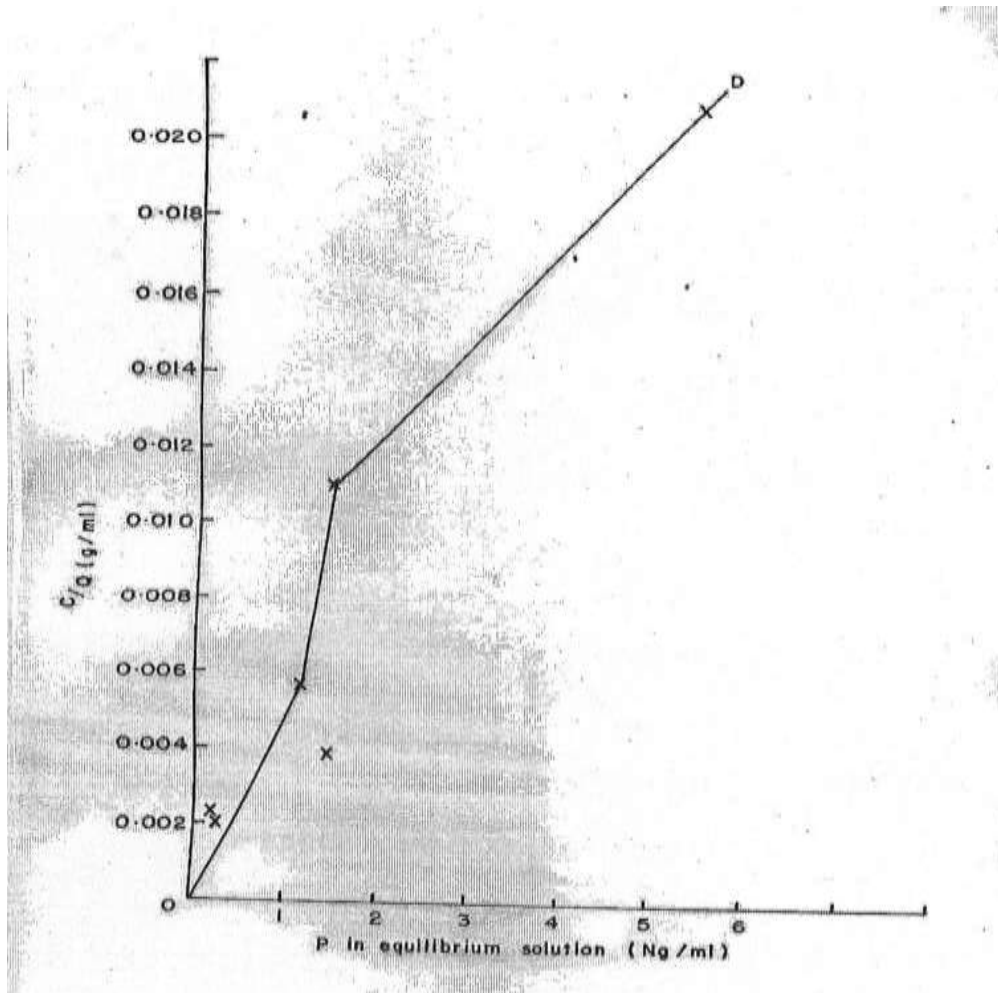


Figure 5: The Langmuir Adsorption Isotherms of Some of the Soil Series

D = Egbeda

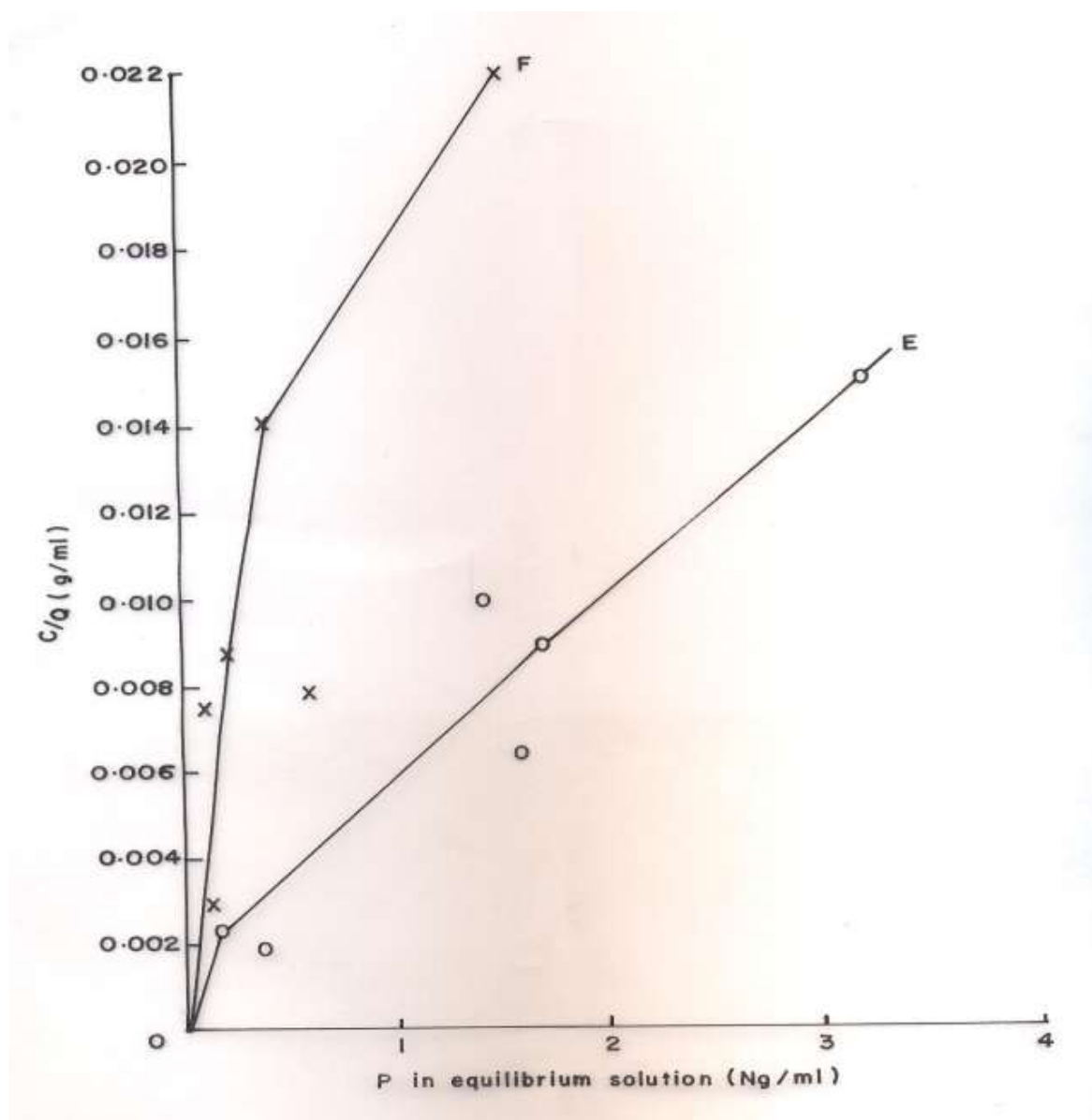


Figure 6: The Lagmuir Adsorption Isotherms of Some of the Soil Series

- E = Itagunmodi
- F = Apomu

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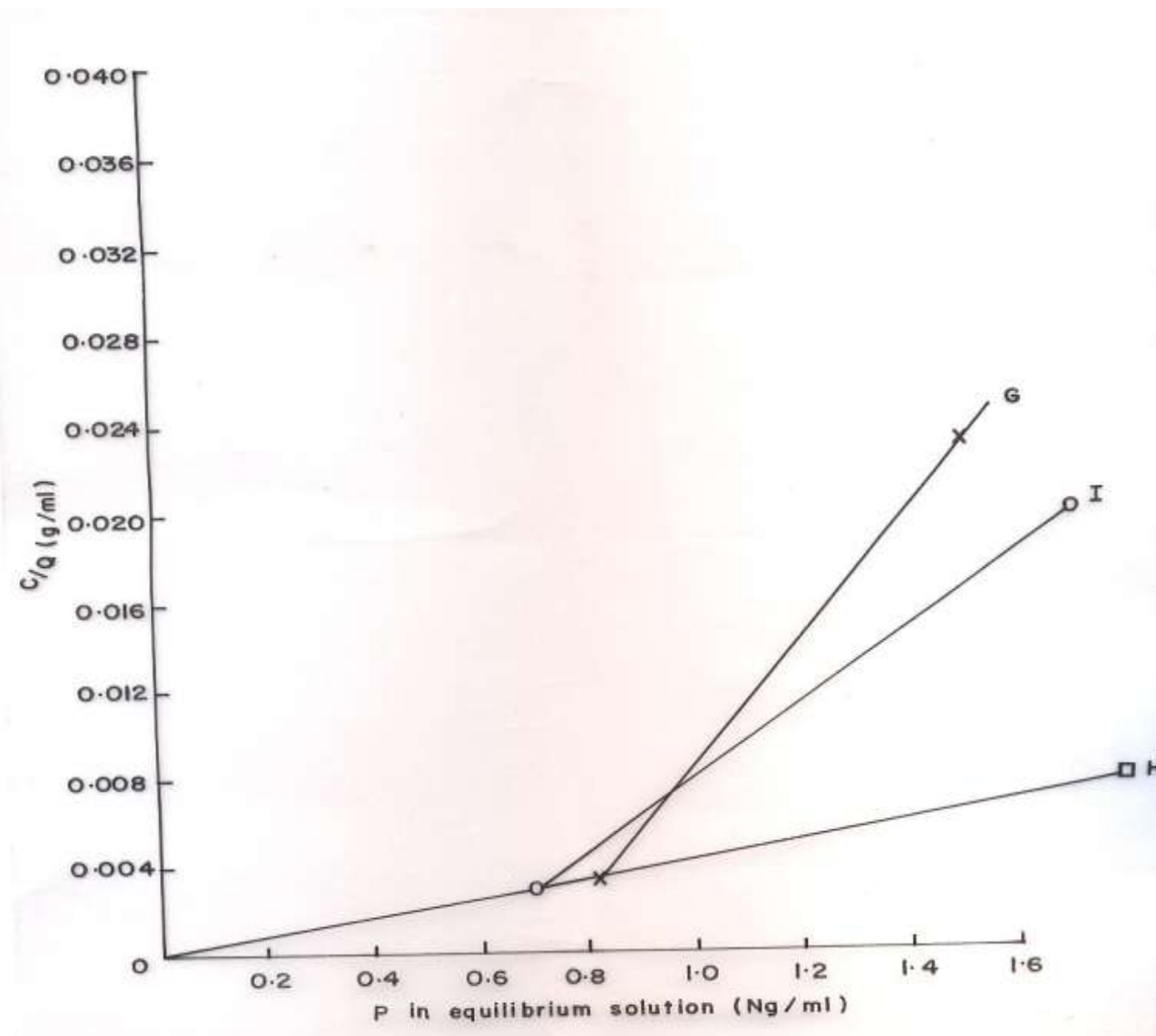


Figure 7: The Langmuir Adsorption Isotherms of Some of the Soil Series

- G = Iwaji
- H = Jago
- I = Mamu

Table 3: The Adsorption Maxima of the Soil Series

Soil series	Iwo	Ondo	Egbeda	Apomu	Itangunmodi	Gambari	Iwaji	Jago	Mamu
	Adsorption Maxima ($\mu\text{g/g}$)								
Bi	19.4	214.29	191.49	22.72	812.5	50	257.14	230.55	257.14
Bii	80.39	214.29	53.57	35.71	224.14	500	72.22		57.69
Biii		316.67	380.43	34.27	250	268.75			
Bi+bii+biii	99.83	630.96	625.49	92.7	1286.64	818.75	329.36	230.55	314.83

Table 4: Adsorption Energy of the Soil Series

	Iwo	Ondo	Egbeda	Apomu	Itagunmodi	Gambari	Iwaji	Jago	Mamu
Binding Energies (ml/μg)									
Ki	1.06	1.00	1.00	0.86	11.38	0.50	1.03	0.99	1.03
Kii	2.41	1.61	0.38	1.33	1.24	7.78	0.61		0.54
Kiii		1.79	1.65	0.65	12.20	2.02			
Ki+kii+kiii	3.47	4.40	3.03	2.84	24.82	10.30	1.64	0.99	1.57

Table 5: Simple Correlation Analysis of Soil Properties with Adsorption Maxima (b) and Adsorption Energy (k)

Soil Properties	B	K
Sand	-0.794*	-0.893**
Silt	0.527	0.607
Clay	0.779*	0.869**
pH (CaCl ₂)	0.525	0.455
SOM (%)	0.516	0.389
Avail. P	-0.811**	-0.659
Extrac. Fe (mg/kg)	-0.402	-0.426
Exch. Al (cmol/kg)	-0.450	-0.528
Exch. H (cmol/kg)	0.069	0.00
TEA (cmol/kg)	-0.279	-0.364
Exch. Ca (cmol/kg)	0.800**	0.615
Exch. K (cmol/kg)	0.448	0.404
Exch. Na (cmol/kg)	0.061	-0.017
TEB (cmol/kg)	0.819**	0.626
ECEC (cmol/kg)	0.839**	0.614

* = significant at 5% probability level

** = significant at 1% probability level

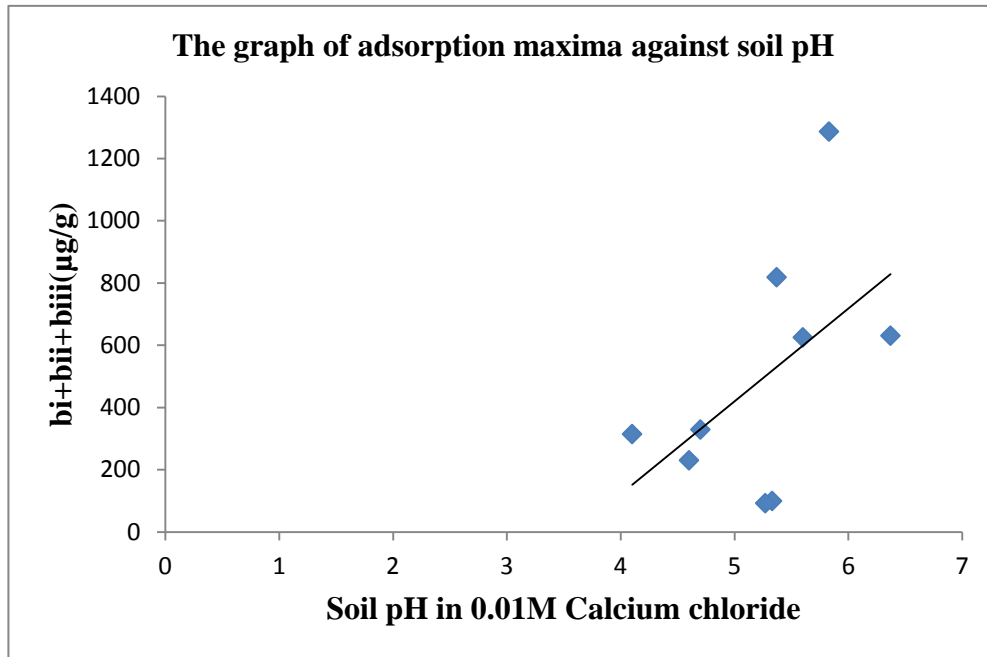


Figure 8: The Relationship between Soil pH and P Fixation

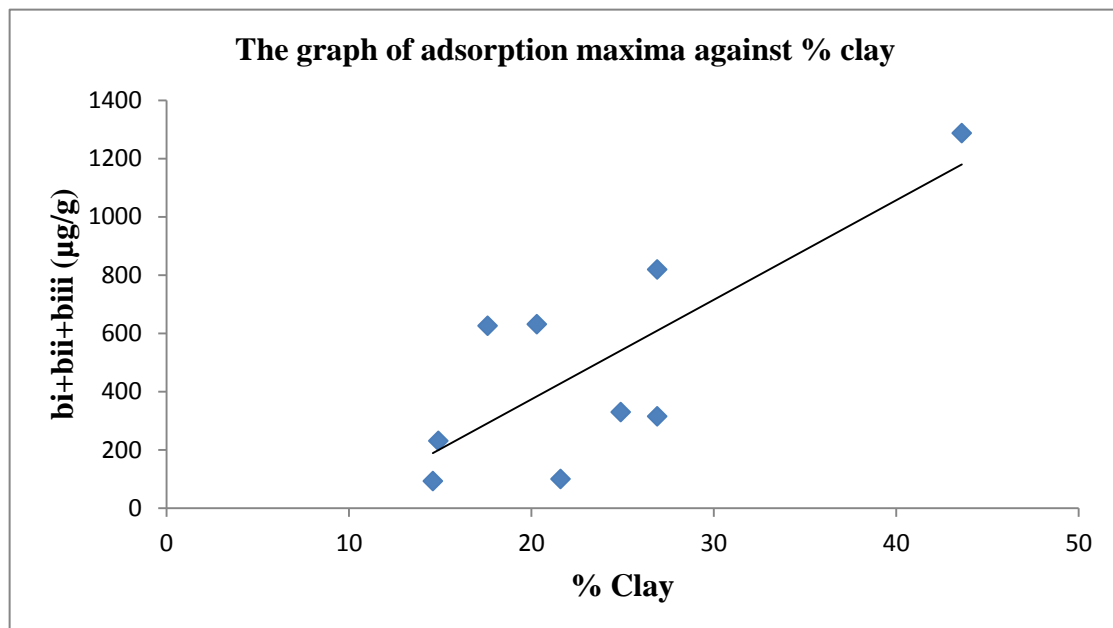


Figure 9: The Relationship between P Fixation and % Clay

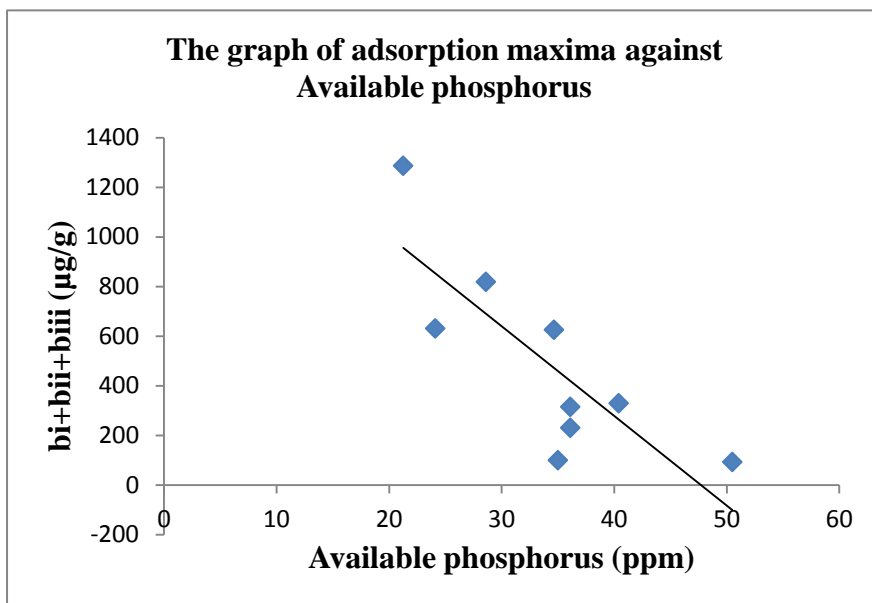


Figure 10: The Relationship between P Fixation and Available Phosphorus

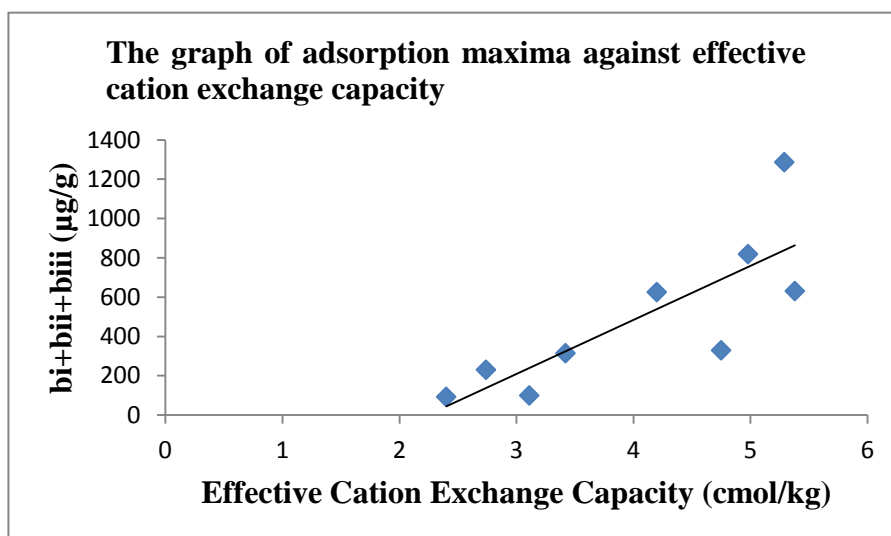


Figure 11: The Relationship between P Fixation and Effective Cation Exchangeable Capacity

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