

## Phosphate Sorption Characteristics in Some Soils of Ganges Tidal Floodplains

### Abstract

A laboratory experiment was carried out with four representative soil series named Bajoa, Dumuria, Jhalakati, and Ghior which are collected from the Ganges tidal floodplain in Bangladesh where the main cropping pattern is rice-vegetables to determine the phosphorus adsorption. The selected physical and chemical properties of the soils were estimated in triplicate using standard methods. The highest phosphate sorption was found in Jhalakati soil using the Freundlich adsorption isotherm, in Bajoa soil using the Langmuir adsorption isotherm, and in Dumuria soil using the Temkin adsorption isotherm. The experiment revealed that the Langmuir equation provided the best fit for phosphorus adsorption data across the soils compared to the Freundlich and Temkin models. The good fit of the Langmuir model suggests that the phosphorus sorption affinity of the soils remained constant as surface saturation increased.

**Keywords:** Soil series, phosphorus adsorption, adsorption isotherm, sorption affinity, surface saturation.

### Introduction

Phosphorus (P) retention by soils is a crucial factor for assessing soil fertility and determining the environmental behavior of phosphorus. The P adsorption capacity of soils or sediments is typically evaluated through batch experiments, where soils or sediments are equilibrated with solutions containing varying initial P concentrations. Several models, such as the Langmuir, Freundlich, and Temkin equations, have been used to describe the relationship between the amount of P adsorbed and the equilibrium concentration of P in solution (Nair et al., 1984). Phosphorus is a key nutrient for sustainable cropping systems in Bangladesh, and its sorption

by soil is essential as adsorbed P influences the concentration of soil solution P, which is the direct source of phosphorus for plant uptake. Phosphate sorption isotherms provide critical parameters, including concentration, capacity, and quantity, that help characterize soil behavior. Effective management of phosphate fertilizers is becoming increasingly important for economically and environmentally sustainable agriculture. The sorption and desorption of phosphorus are closely linked to factors such as clay content and type, the presence of hydrous oxides of aluminum and iron, inorganic and organic ions, soil pH, and reaction kinetics (Hedley et al., 1995). In Bangladesh, calcareous soil occupies about 19% territory of the country. Not much research has been done on the phosphate sorption qualities of the soils which are calcareous in nature. Consequently, an examination was embraced to research the impacts of calcareousness on the phosphate sorption properties of three calcareous soils and a non-calcareous soil from the Ganges Tidal Floodplain. Bajoa soils series are developed in tidal floodplain basins. They are seasonally shallowly to tolerably profoundly overwhelmed, ineffectively depleted soils create in tidal stores. They have a dim to olive-dim silty clay topsoil subsoil with moderate to solid blocky structure in B horizon. They have five stages: Highland; medium good country, non-saline; medium high country, saline; medium marsh and medium swamp, flood danger (Rahman, 2005). Dumuria soil has high organic matter and darkish gray color and poorly drained. The texture of the soil series is clay (Khan et al., 2018). Ghior has clay textured soils and has high moisture-holding capacity (6.3%). For very low levels of organic matter and low organic carbon content, the color of the soil is lighter (Hasan et al., 2012). Jhalakati have clay textured soil and low level of organic matter (Shil et al., 2016).

More specifically, phosphate sorption indices, including standard phosphorus requirements (SPR) and maximum phosphate buffer capacities (MPBC), were examined alongside other sorption parameters. The MPBC provides insight into the amount of phosphorus fertilizer

needed to maintain a predetermined concentration of P in the soil solution. Several selected soil properties were studied to determine how they influence the sorption characteristics of the soils, particularly in relation to calcareousness. Bangladesh's investigation has given incredible accentuation to agronomic tests estimating the reaction of harvests to P. Notwithstanding, there is currently a critical need to utilize methodological techniques for surveying soil P status that are increasingly applicable to soil-plant considerations. Subsequently, the examination was done to portray the P sorption qualities corresponding to the soil properties of these soils of Bangladesh and to assess the best-fitted adsorption equation for the soils. Soil properties that affect phosphorus adsorption capacity include soil texture (Leclerc et al., 2001), organic matter content (Daly et al., 2001), soil pH (Barrow, 1984), and the calcium carbonate ( $\text{CaCO}_3$ ) content of the soil (Bertrand et al., 2003). Right now, sorption potential is dictated by utilizing levels of P fixations in some representative soils of the Ganges Tidal Floodplain.

### **Materials and Methods**

The experiment was conducted in the laboratory of the Department of Soil Science, University of Khulna, using four different benchmark calcareous and non-calcareous soils of Bangladesh. These included Bajoa (calcareous), Dumuria (calcareous), Jhalakati (non-calcareous), and Ghior (calcareous) soils. Soil samples were collected from a depth of 0-15 cm from various locations in Jhalakati, Bagerhat, and Khulna districts following the composite soil sampling method as recommended by the Soil Survey Staff of the USDA.

The samples were taken from an area of approximately 1 km<sup>2</sup> within a specific soil series and placed in plastic bags. After being transported to the laboratory, the samples were spread out on separate sheets of paper and air-dried at room temperature (25°C) for 7 days. Equal

amounts of the soil (by weight) from different locations were combined to form a composite sample. Once dried, the larger soil aggregates were gently crushed using a wooden hammer, ground, and passed through a 2 mm sieve. The sieved soils were then preserved in properly labeled plastic bags for further physical and chemical analyses. A correlation among the soil series and classification systems is presented in Table 1.

**Table 1.** General information of studied soil

<i>Characteristics</i>	<i>Soil Series</i>			
	Bajoa	Dumuria	Jhalakati	Ghior
Location	Village: Milenmar Upazila: Batiagata District: Khulna	Village: Ghutudia Upazila: Dumuria District: Khulna	Village: Badal Upazila: Kachu District: Bagerhat	Village: Azagara Upazila: Terokhada District: Khulna
Land type	Medium to high land	Medium high land	Medium high land	Medium high land
Land use	Seasame- Fallow- T. aman	Sesame-Fallow- T. aman	Fallow- transplanted aus – t.amon	Boro-Fallow- T.amon
Effervescence	Slightly calcareous	Calcareous	Non Calcareous	Calcareous

**Physical and chemical analysis of the soil samples:** The particle size analysis of the soils was performed using a combination of sieving and the hydrometer method, as outlined by Gee and Bauder (1986). Soil textural classes were determined using Marshall's Triangular Coordinate system. Soil pH was measured electrochemically using a glass electrode pH meter, following the method described by Jackson (1973), with a soil-to-water ratio of 1:2.5. Electrical conductivity (EC) was measured with an EC meter at a soil-to-water ratio of 1:5 and then converted to a 1:1 ratio. Soil organic carbon was determined using the Walkley and Black wet oxidation method (Jackson, 1973), and soil organic matter was calculated by multiplying the percentage of organic carbon by a conversion factor of 1.724.

Available phosphorus was extracted from the soil using 0.5 M NaHCO<sub>3</sub> (Olsen's method) at pH 8.5, and phosphorus was quantified using the molybdenum blue method (Jackson, 1967) and ascorbic acid blue color method (Murphy and Riley, 1962). The cation exchange capacity (CEC) of the soils was measured by extracting the soil with 1N KCl (pH 7.0), followed by replacing potassium in the exchange complex with 1N NH<sub>4</sub>OAc. The replaced potassium was determined using a flame photometer at 589 nm (Jackson, 1967). Free carbonates in the calcareous soil samples were measured using the rapid titration method of Allison and Moodie (1965). Free iron oxides were determined by extracting total or free iron oxides using a citrate dithionite reagent through a rapid titration technique.

**Phosphate sorption experiment:** To estimate the phosphate adsorption characteristics of the soils, phosphorus sorption was evaluated following the method described by Nair et al. (1984). One gram of air-dried, sieved soil was placed into a 50 mL centrifuge tube. Seven initial phosphorus concentrations, specifically 0, 1, 2, 5, 10, 25, and 50  $\mu\text{g mL}^{-1}$  in a 0.01 M

CaCl<sub>2</sub> solution, were added to each centrifuge tube, maintaining a soil-to-solution ratio of 1:20 (w/v). The resulting phosphorus contents were 0, 20, 40, 100, 200, 500, and 1000  $\mu\text{g g}^{-1}$  of soil. The centrifuge tubes were then shaken and allowed to equilibrate for 16 hours. After equilibration, the mixtures were centrifuged, and the supernatants were analyzed for phosphate using the ascorbic acid blue color method (Murphy and Riley, 1962). Phosphorus content was measured using a UV-Vis spectrophotometer at a wavelength of 882 nm. The amount of phosphorus sorbed by the soil was determined by calculating the difference between the initial phosphorus concentration in the solution and the concentration remaining in the solution after equilibration. Each treatment was replicated three times.

***Fitting of phosphorus adsorption data in three equations:*** The phosphate adsorption data were fitted to three equations for evaluating the goodness of fit. The different equations used are described below:

1) The Freundlich equation (1926) for phosphorus adsorption is expressed as:

$$X = K_f C^N,$$

where:

X represents the amount of phosphorus (P) sorbed by the soil ( $\text{mg kg}^{-1}$ ),

C is the equilibrium phosphorus concentration in solution ( $\text{mg L}^{-1}$ ),

$K_f$  is the Freundlich proportionality constant ( $\text{mg g}^{-1}$ ), and

N is the empirical constant related to the intensity of adsorption.

The logarithmic form of the Freundlich equation is:

$$\text{Log } X = \text{log } K_f + N \text{ log } C$$

In this form, a plot of  $\log X$  (on the y-axis) against  $\log C$  (on the x-axis) results in a straight line. The slope of the line represents the constant  $N$ , and the y-intercept is  $\log K_f$ , providing insight into the adsorption characteristics of the soil.

2) The linear form of the Langmuir equation (1918) for phosphorus adsorption is expressed as:

$$C/X = (1/K_L b_L) + C/b_L,$$

where:

$X$  is the amount of phosphorus sorbed by the soil ( $\text{mg kg}^{-1}$ ),

$C$  is the equilibrium phosphorus concentration in solution ( $\text{mg L}^{-1}$ ),

$b_L$  is the adsorption of maximum phosphorus ( $\text{mg kg}^{-1}$ ), and

$K_L$  is the bonding energy constant ( $\text{L mg}^{-1}$ ).

A plot of  $C/X$  (y-axis) against  $C$  (x-axis) produces a straight line. The slope of this line is equal to  $1/b_L$ , and the y-intercept is  $1/K_L b_L$ .

The Maximum Buffer Capacity (MBC) of the soil, which reflects the increase in sorbed phosphorus per unit increase in the final solution phosphorus concentration, is calculated as the product of the Langmuir constants  $K_L$  and  $b_L$  (Holford, 1979). This value provides a measure of the soil's ability to buffer phosphorus concentrations.

3) The Temkin equation (Chu et al., 2021) for phosphorus adsorption is represented as:

$$X = a \log C + b,$$

where:

$X$  is the amount of phosphorus (P) sorbed by the soil ( $\text{mg kg}^{-1}$ ),

C is the equilibrium phosphorus concentration in solution ( $\text{mg L}^{-1}$ ),

a is the slope (intercept), and

b is the regression coefficient.

When plotting X (on the y-axis) against  $\log C$  (on the x-axis), the result is a straight line. In this context, the value of b is considered to represent the phosphorus buffering capacity of the soil, indicating how well the soil can maintain phosphorus levels in the solution despite changes in concentration

**Phosphorus buffering capacity:** The phosphorus (P) buffering capacity of a soil refers to its ability to resist changes in phosphorus concentration within the solution phase (Sui and Thomson, 2000). This buffering capacity is typically calculated using the Temkin adsorption isotherms at a solution phosphorus concentration of  $1 \mu\text{g mL}^{-1}$ . During this process, the phosphate concentration in the solution (referred to as intensity) is measured, while the quantity of phosphate adsorbed by the soil is calculated. The resulting data is summarized through Q/I plots, where the quantity of phosphate adsorbed (Q) is plotted against the intensity of phosphate in the solution (I). When this relationship is observed under constant temperature conditions, it is recognized as an adsorption isotherm (Prutton and Maron, 1953). The ratio between the quantity of adsorbed phosphorus (Q) and the intensity of phosphorus in the soil solution (I) at equilibrium is used to determine the buffering capacity of the soil. This property is crucial as it governs the availability of phosphorus to plants (Holford and Mattingly, 1976), reflecting the soil's ability to compensate for changes in soil solution phosphorus while maintaining a productive concentration. The P buffering capacity may serve as a limiting factor in phosphorus uptake by plants (Nair and Mengel, 1984). Phosphorus buffering capacities are derived from adsorption isotherm plots, as noted by Olsen and

Khasawneh (1980). The buffering capacity (b) can be calculated using the following equation:

$$b = q/c$$

where:

b is the buffering capacity,

q represents the quantity factor (the amount of phosphorus adsorbed), and

c denotes the intensity factor (the concentration of phosphorus in the solution).

This equation quantifies the soil's ability to respond to changes in phosphorus levels, indicating its overall effectiveness in sustaining plant growth.

**Statistical analysis:** Regression curve fitting equations were drawn by the Microsoft Office Excel program. The suitability of different adsorption equations was studied by calculating the R<sup>2</sup> values of the respective equations.

## Results and Discussion

The investigation was conducted to study phosphate sorption in some representative soils of Ganges Tidal Floodplains in Bangladesh. Some selected physical properties are presented in Table 2. and the selected chemical properties are presented in Table 3. of the studied soils.

**Table 2.** Physical properties of the soils

Soil Series	Sand (%)	Silt (%)	Clay (%)	Texture
Bajoa	8	62	30	Silty clay loam
Dumuria	22	37	41	Clay
Jhalakati	28	49	41	Loam

Ghior	21	22	57	Clay
<i>Mean</i>	19.75	42.5	37.75	

**Table 3.** Chemical properties of the soils

Soil Series	PH	EC(dS/m)	Available P( $\mu\text{g/g}$ )	Organic carbon (%)	Free iron oxide	Bicarbonate ( $\mu\text{g/g}$ )	CEC (cmol(+)/kg)
Bajoa	6.97	3.87	15.38	0.96	6742	345.25	20.46
Dumuria	6.76	12.73	35.01	1.31	6161	385.55	17.94
Jhalakati	7.05	14.57	16.68	1.21	5012	296.72	21.13
Ghior	7.44	1.07	22.46	2.23	7183	322.28	28.81
<i>Mean</i>	7.055	8.06	22.38	1.42	6274.5	337.45	22.085

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**Phosphate sorption behavior:** The soils were equilibrated with a 0.01 M calcium chloride solution containing varying concentrations of phosphorus, ranging from 0 to 50  $\mu\text{g mL}^{-1}$ . The changes in the amount of sorbed phosphate were subsequently measured by analyzing the equilibrium solution. All soil samples demonstrated phosphate sorption at different rates and extents, except for the control treatment with 0  $\mu\text{g mL}^{-1}$ , where some desorption occurred across all soil series. Similar findings regarding phosphate desorption at control levels were reported by Afsar et al. (2012).

In this study, phosphate sorption increased gradually with the rise in phosphate application across all soil series. This trend of increased P sorption with elevated phosphate levels in the equilibrium solution aligns with results from other researchers (Afsar et al., 2012). Among the different soil series, the Bajoa, Dumuria, Jhalakati, and Ghior series, which occupy the lower positions in the catena, exhibited the highest phosphate sorption capacity. Conversely, the Sara soil series, located at the highest position in the catena, demonstrated the lowest phosphate sorption. Based on their P sorption capacities, the soils can be ranked in the following order: Ghior>Bajoa>Dumuria>Jhalakati, with respective sorbed phosphate amounts of 432.23, 366.76, 366.28, and 291.20  $\mu\text{g g}^{-1}$  when P was applied at a concentration of 50  $\mu\text{g mL}^{-1}$ .

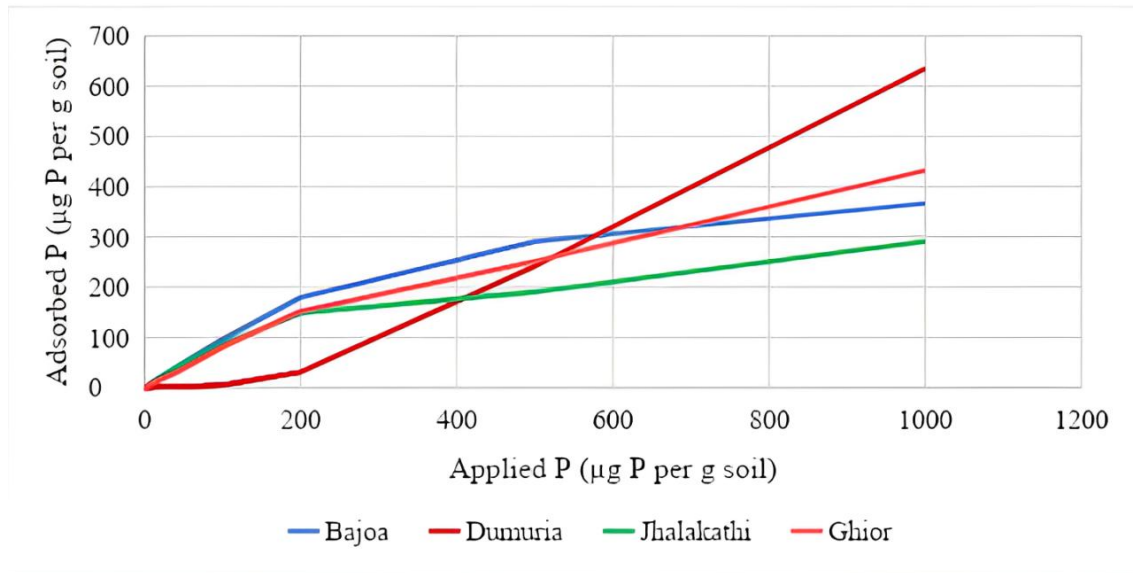


Fig. 1: Phosphate sorption capacity of soils with different soil series as affected by varying rates of phosphorus application

**Freundlich adsorption isotherm:** The Freundlich adsorption isotherm provided a better fit for the soils studied. The  $R^2$  values for the Freundlich equation for the Bajoa, Dumuria, Jhalakati, and Ghior soil series were 0.9166, 0.9599, 0.9911, and 0.942, respectively, with the highest  $R^2$  value of 0.9911 observed in the Jhalakati soil and the lowest value of 0.9166 in the Bajoa soil (see Fig. 2, 3, 4, and 5). The intercepts for the Bajoa, Dumuria, Jhalakati, and Ghior soil series were 1.6261, 1.6522, 1.6077, and 0.9062, respectively. The slopes of the sorption curves varied among the different soil series, indicating differing amounts of P sorbed. Specifically, the slope for the Bajoa soil series was 0.371, for Dumuria it was 0.3421, for Jhalakati it was 0.2926, and for Ghior it was 0.6521. Notably, the highest slope of 0.6521 was observed in the Ghior soil, while the lowest slope of 0.2926 was found in the Jhalakati soil

series. The lower  $R^2$  estimates of the Freundlich equation compared to the Langmuir equation for the Bajoa, Dumuria, Jhalakati, and Ghior soils suggest that the phosphorus sorption affinity in these soils did not decrease logarithmically with increasing surface saturation (Mead, 1981).

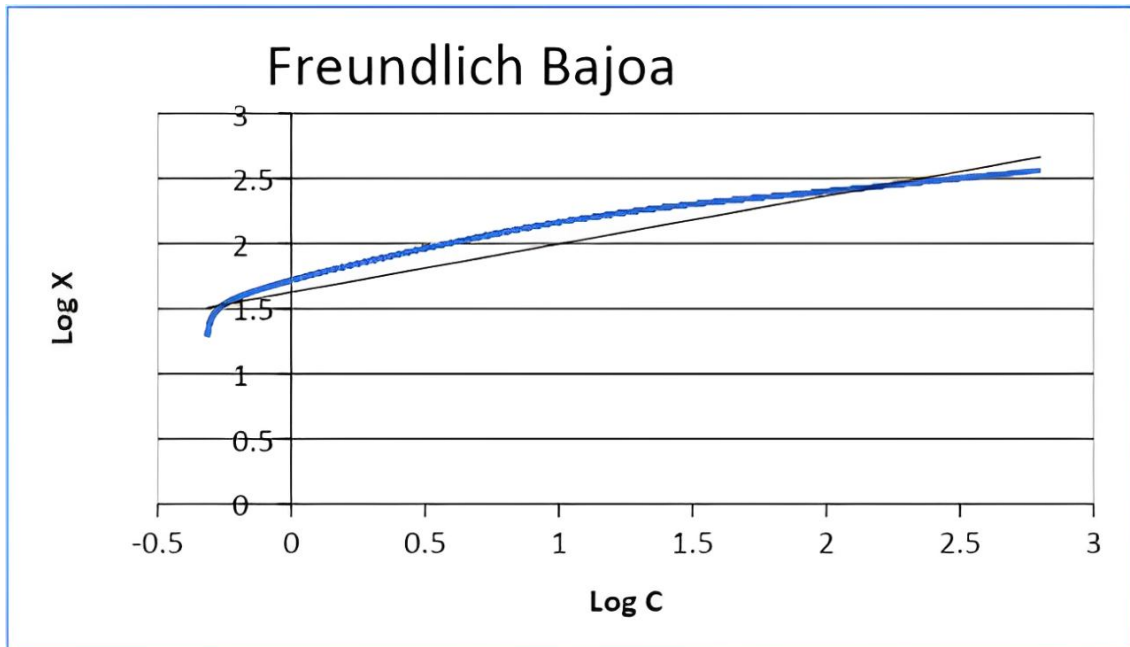


Fig. 2: Freundlich adsorption isotherm for phosphorus in Bajoa soil series

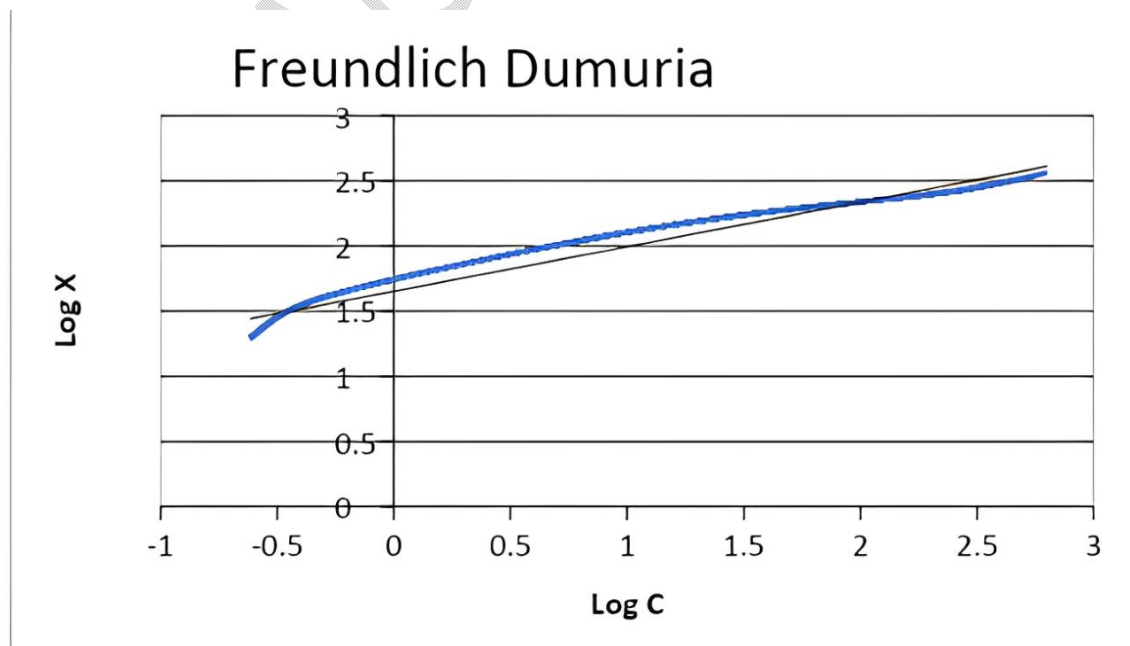


Fig. 3: Freundlich adsorption isotherm for phosphorus in Dumuria soil series

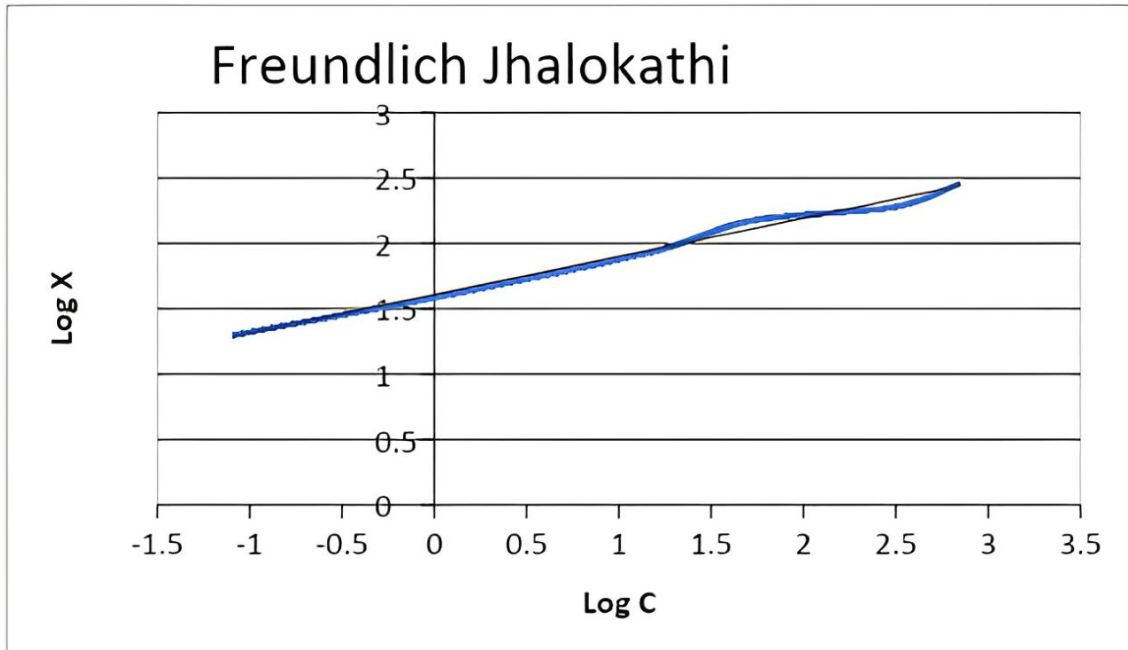


Fig. 4: Freundlich adsorption isotherm for phosphorus in Jhalakati soil series

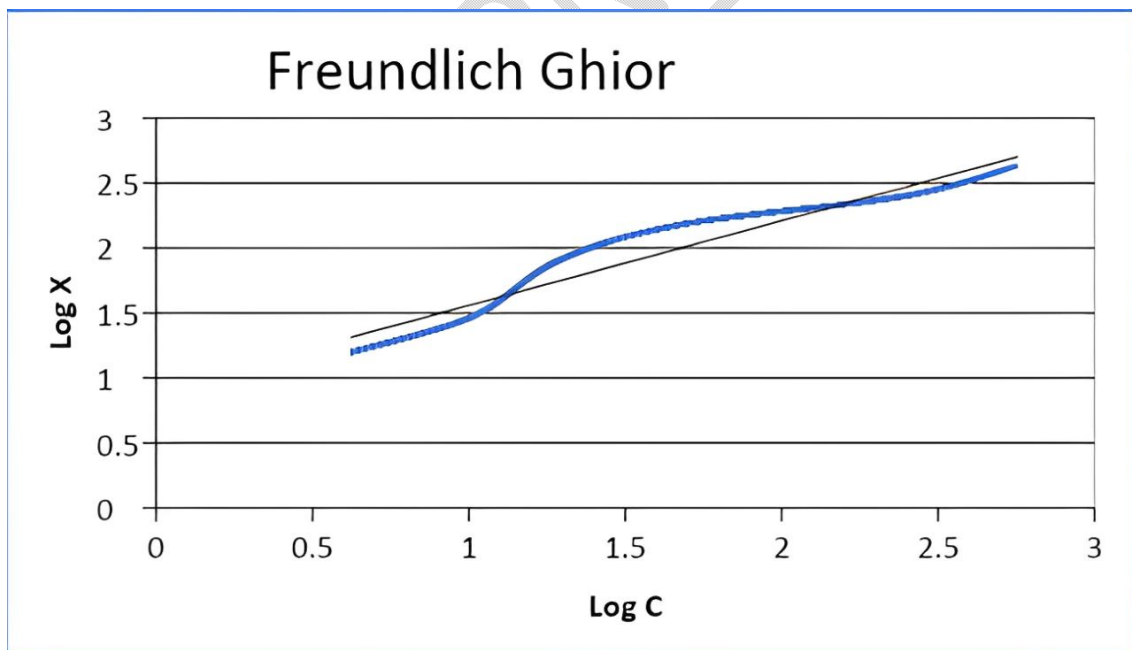


Fig. 5: Freundlich adsorption isotherm for phosphorus in Ghior soil series

**Langmuir adsorption isotherm:** The Langmuir adsorption isotherm effectively describes the adsorption maxima and energy of adsorption. The Langmuir isotherms for the Bajoa, Dumuria, Jhalakati, and Ghior soil series are presented in Figures 6, 7, 8, and 9. This model has been positively associated with P adsorption in various soils. The  $R^2$  values for the Langmuir equation for the Bajoa, Dumuria, Jhalakati, and Ghior soil series were 0.9935, 0.9785, 0.9569, and 0.9018, respectively. The highest  $R^2$  value of 0.9935 was recorded for the Bajoa soil series, while the lowest value of 0.9018 was found in the Ghior soil (see Figures 6 and 9). The intercepts for the Bajoa, Dumuria, Jhalakati, and Ghior soil series were 0.039, 0.0546, 0.1085, and 0.2259, respectively. Notably, the highest intercept of 0.2259 was observed in the Ghior soil series, while the lowest intercept of 0.039 was found in the Bajoa soil series. The slopes of the Langmuir equation for these soil series were 0.0027, 0.0028, 0.0035, and 0.0021, respectively, with the highest slope of 0.0035 seen in the Jhalakati soil series and the lowest slope of 0.0021 in the Ghior soil series. According to Mead (1981), the consistent sorption affinity, even with increased surface saturation, supports the good fit of the Langmuir adsorption isotherm.

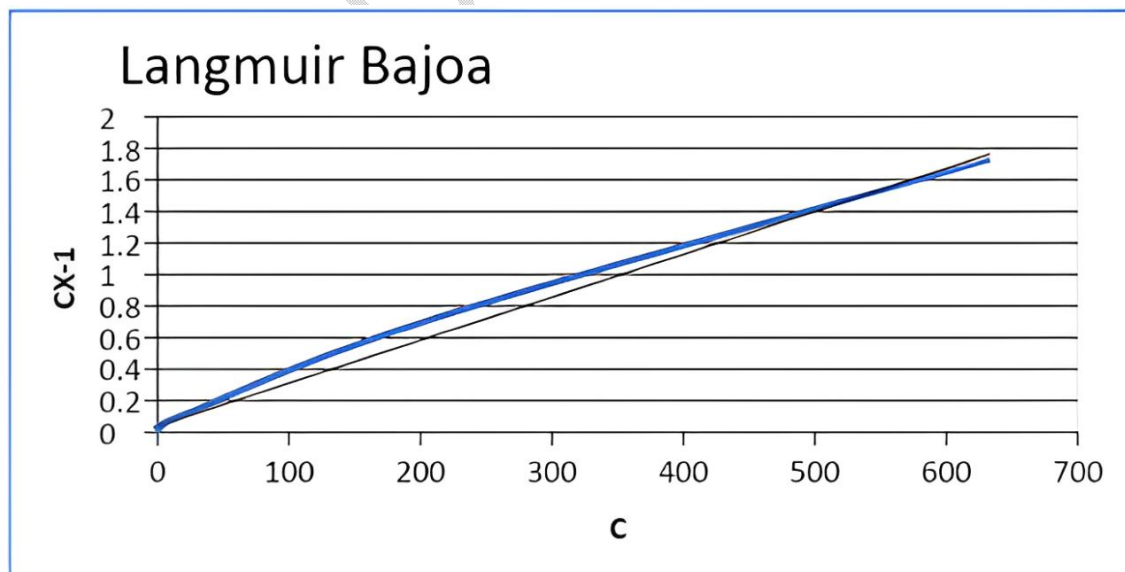


Fig. 6: Langmuir adsorption isotherm for phosphorus in Bajoa soil series

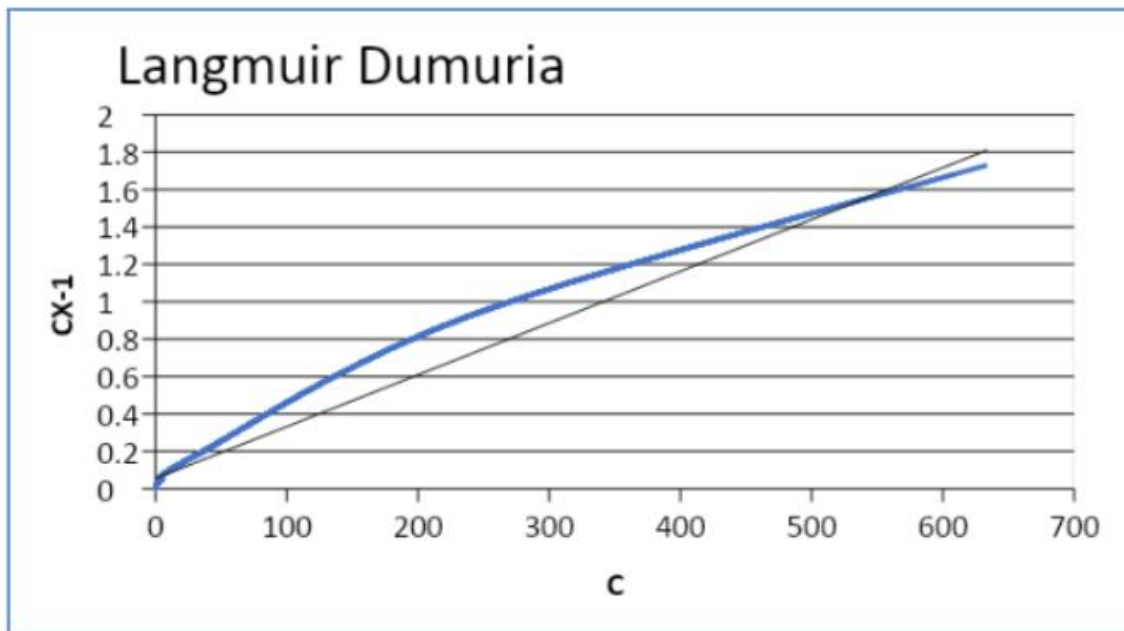


Fig. 7: Langmuir adsorption isotherm for phosphorus in Dumuria soil series

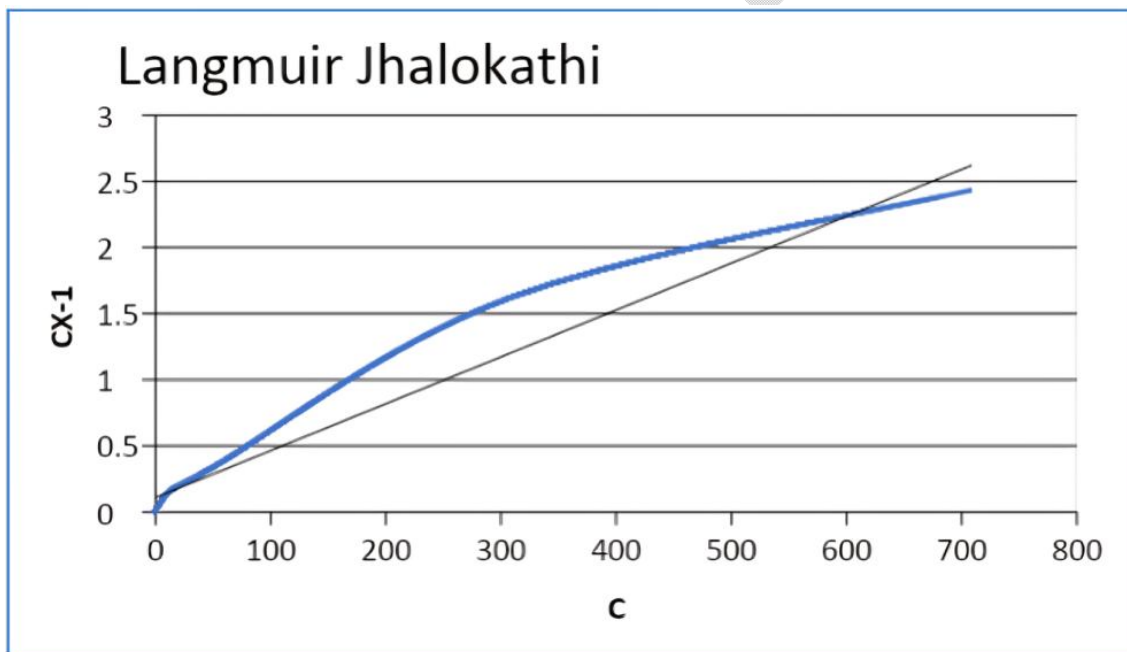


Fig. 8: Langmuir adsorption isotherm for phosphorus in Jhalokathi soil series

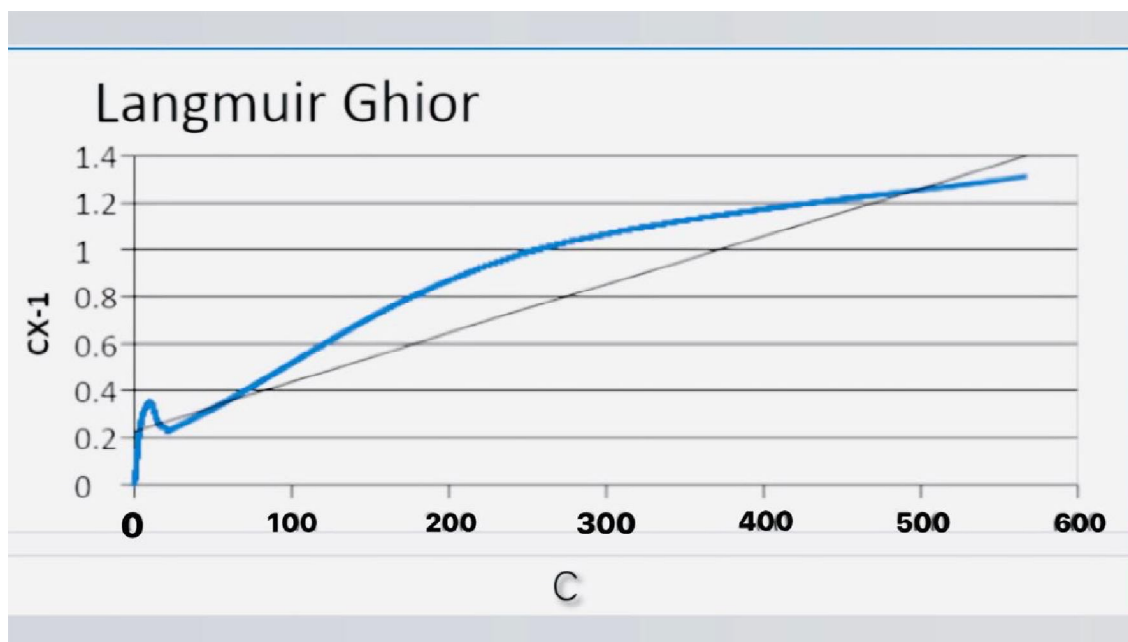


Fig. 9: Langmuir adsorption isotherm for phosphorus in Ghior soil series

**Temkin adsorption isotherm:** According to the Temkin equation the  $R^2$  value of The Bajoa soil series is 0.7706, the Dumuria soil series is 0.8295, the Jhalakati soil series is 0.8035 and the Ghior soil series is 0.5373. The highest  $R^2$  value was seen in Dumuria soil (0.8295) and the lowest value was in the Ghior soil series (0.5373) (Fig. 10, 11, 12, and 13). The slope of Temkin condition of Bajoa, Dumuria, Jhalakati, and Ghior soil series were 61.531, 64.598, 46.34, and 66.952. The highest slope of the Temkin equation was 66.952 for Ghior and the lowest is 46.34 for the Jhalakati soil series. The intercepts of the Temkin equation for the

Bajoa, Dumuria, Jhalakati, and Ghior soil series were found to be 114.09, 102.93, 81.832, and 67.895, respectively. The highest intercept of 114.09 was observed in the Bajoa soil series, while the lowest value of 67.895 was recorded for the Ghior soil series. These results indicate that the soil series exhibited a poor fit to the Temkin adsorption isotherm, suggesting that the adsorption capacities of these soils did not decrease linearly with an increase in surface saturation.

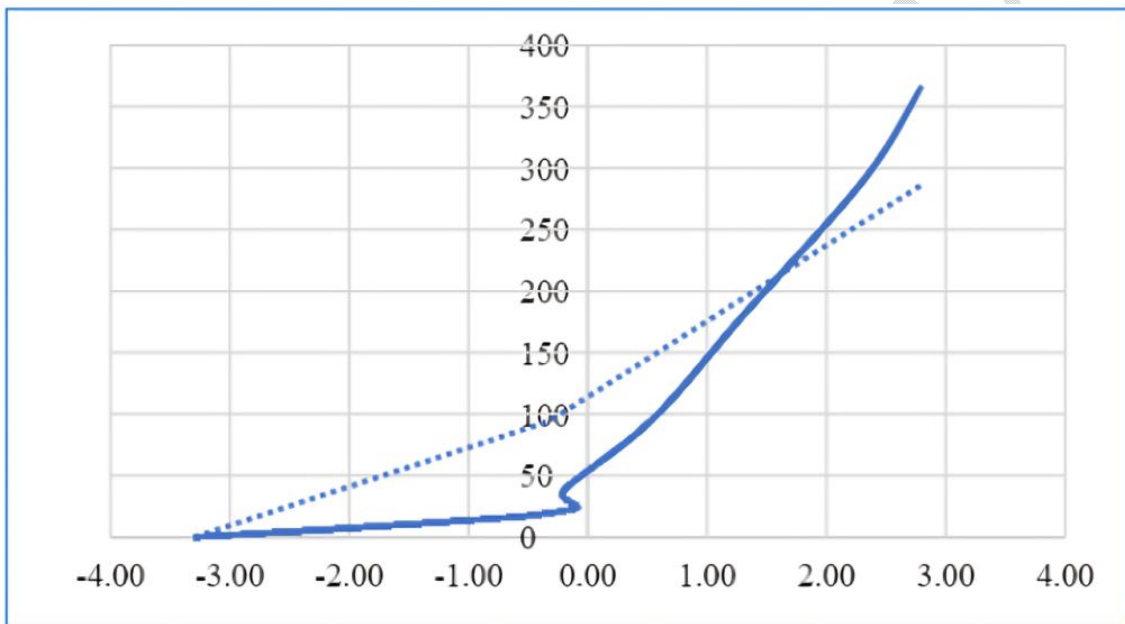


Fig. 10: Temkin adsorption isotherm for phosphorus in Bajoa soil series

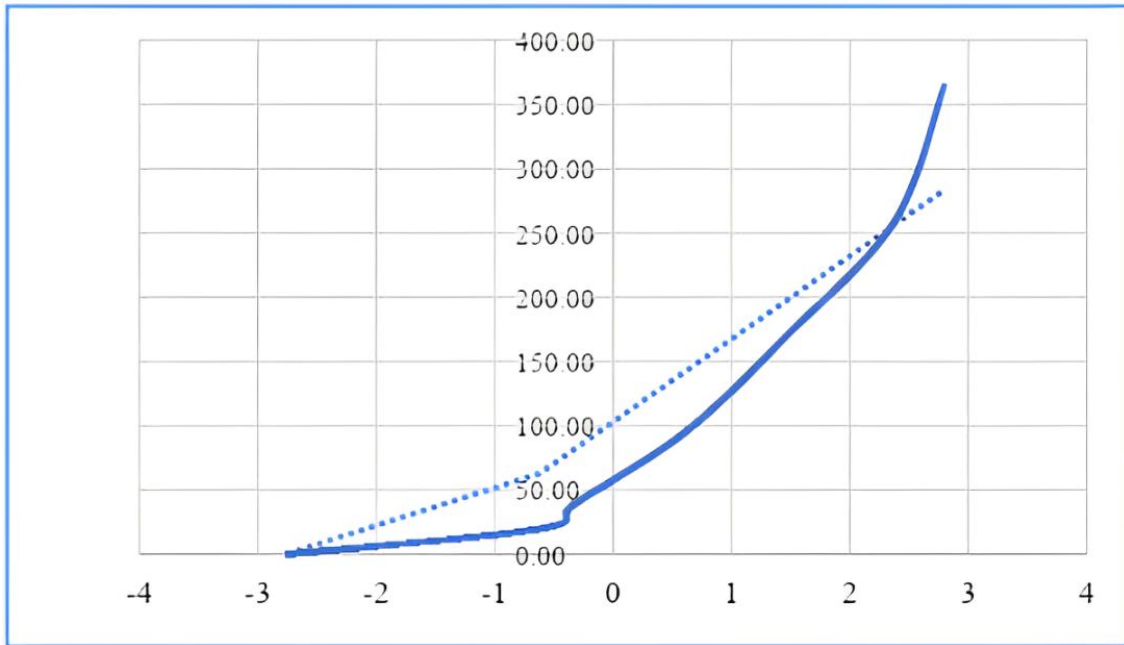


Fig. 11: Temkin adsorption isotherm for phosphorus in Dumuria soil series

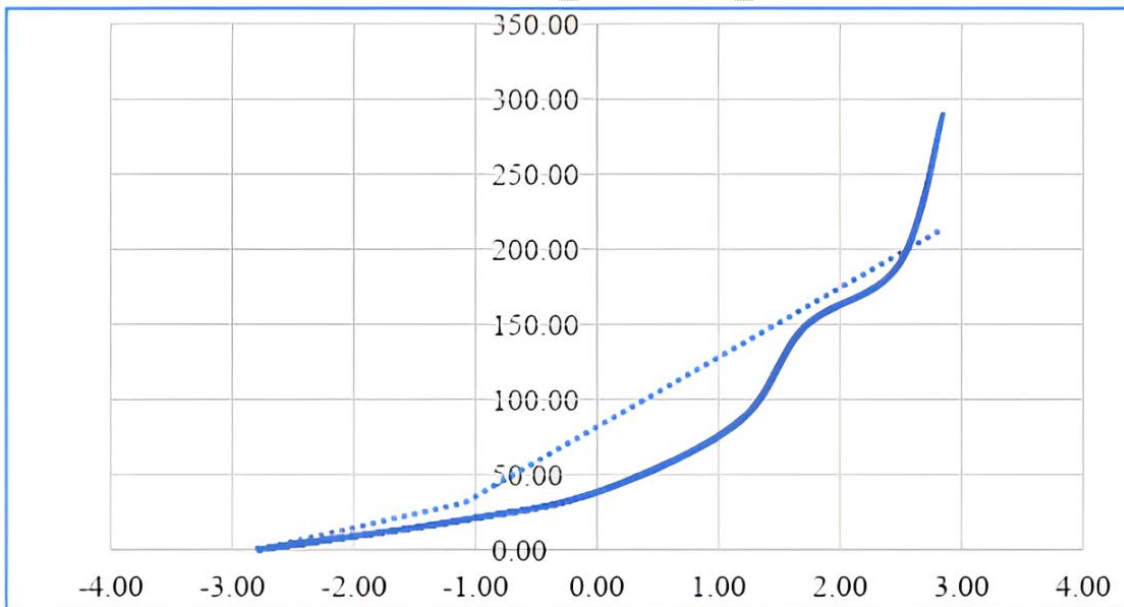


Fig. 12: Temkin adsorption isotherm for phosphorus in Jhalakati soil series

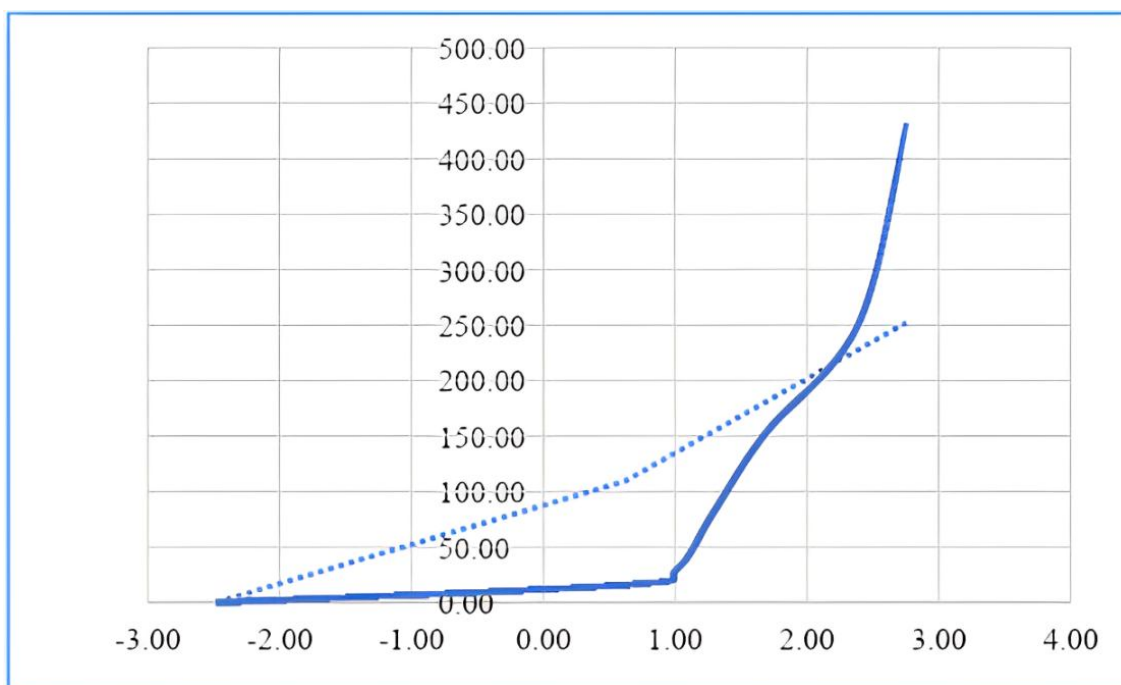


Fig.13 Temkin adsorption isotherm for phosphorus in Ghior soil series

**Multi-point adsorption equations:** The phosphorus (P) sorption values for the four soil series were analyzed and plotted using the Langmuir, Freundlich, and Temkin equations, as summarized in Table 4. Among these three adsorption isotherms, the Langmuir equation demonstrated the best fit for the equilibrium P sorption data, yielding an  $R^2$  value of 0.957. Various phosphate sorption parameters were derived from the three equations and are also presented in Table 4. The Langmuir equation was utilized to estimate the maximum P sorption capacity (BL) of the soils, which were found to be 370.37, 357.14, 285.71, and 476.19  $\text{mg kg}^{-1}$  for the Bajoa, Dumuria, Jhalakati, and Ghior soil series, respectively. This indicates that the Ghior soil series had the highest BL value, while the Bajoa series exhibited the lowest.

An increasing trend in BL values was observed along the catena of the studied soil samples. However, it is important to note that these BL values are more reflective of empirical curve-fitting parameters rather than true sorption maxima, as the input concentrations were

insufficient to fully saturate the soils (D'Angelo et al., 2003). The binding energy constant (KL) values for the Bajoa, Dumuria, Jhalakati, and Ghior soil series were 0.069, 0.051, 0.032, and 0.009, respectively. The Maximum Buffer Capacity (MBC) of the soils, defined as the product of P sorption capacity (or monolayer coverage in  $\text{mol kg}^{-1}$  of soil) and the phosphate affinity constant related to binding strength (Dalal and Hallsworth, 1976), regulates the partitioning of P between the solution and solid phases. The MBC values for the Bajoa, Dumuria, Jhalakati, and Ghior soil series were 25.64, 18.32, 9.22, and 4.43, with the Bajoa series showing the highest MBC and the Ghior series the lowest.

In contrast to P buffering capacity, MBC remains constant regardless of the solution phosphate concentration (Pote et al., 1999). Management practices such as soil conservation measures and manure application have been shown to influence MBC (Majumdar et al., 2004). Additionally, the phosphate sorption data were also adequately described by the Freundlich equation ( $R^2 \sim 0.9524$ ) and the Temkin equation ( $R^2 \sim 0.73$ ). Among the four soil series, the Dumuria series exhibited the highest  $K_f$  value at 44.89, followed by the Bajoa (42.27), Jhalakati (40.52), and Ghior (8.057) series, as determined from the Freundlich equation (Table 4). The Buffering Index (BI) values for the Bajoa, Dumuria, Jhalakati, and Ghior soil series were 370.37, 357.14, 285.71, and 476.19, with the Jhalakati series showing the lowest value and the Ghior series the highest.

**Table 4.** Phosphate's adsorption parameters calculated from the Freundlich, Langmuir and Temkin isotherms

Soil series	Freundlich equation			Langmuir equation			Temkin equation
	N	$K_f$	PBI	$B_L$	$K_L$	MBC	$X = a + b \log C$
Bajoa	0.371	42.277	15.68	370.37	0.069	25.64	$y = 61.531x + 114.09$
Dumuria	0.342	44.895	15.35	357.14	0.051	18.32	$y = 64.598x + 102.93$
Jhalakati	0.2926	40.523	11.86	285.71	0.032	9.22	$y = 46.34x + 81.832$
Ghior	0.6521	8.057	5.25	476.19	0.009	4.43	$y = 66.952x + 67.895$

X: Total sorbed P; C: Equilibrium P concentration in solution;  $K_f$  and N are empirical constants; BI: Buffering index;  $B_L$ : Phosphate sorption maximum;  $K_L$ : P binding strength; MBC: The maximum buffer capacity of the soil; a and b of Temkin equations are constants.

### Conclusion

Results from this sorption study showed that the four soils varied considerably in their phosphate retention capacities. In the investigation, it was noted that Langmuir equation provided the best fit to P adsorption data in the soils compared to the Freundlich and Temkin equations. From the Langmuir plots of soils, the  $R^2$  value was calculated with an average of 0.9576, followed by the Freundlich plots with an average  $R^2=0.9524$  and Temkin plot with an average  $R^2=0.73522$ . From this data, Langmuir equations were able to explain the P behavior in the soils for buffering capacity and P supplying capacity. The Bajoa soil series will retain P better than other studied soils and potentially be the better sink at comparative P-adding rates.

Disclaimer (Artificial intelligence):

We, the authors hereby confirm that no generative AI technologies, such as Large Language Models (ChatGPT, Copilot, etc.), or text-to-image generators were used in the writing or editing of this manuscript.

Thank you for the clarification.

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