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Effect of manure types on phosphorus sorption characteristics of an agricultural soil in Bangladesh

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Abstract: Manure application changes the phosphorus (P) sorption behavior of soil, which may help release P to surface water. Excess P may result in degradation of quality of receiving water. In this study, effects of dairy, poultry, and goat manure applications on various soil phosphorus sorption indices were estimated for a silt loam Bangladeshi agricultural soil. The soil was incubated with manures for a month, and sorption experiments were conducted using incubated soil. The soil P adsorption isotherms conformed to S-curve shape for the both manure treated and untreated soils. Adsorption data conformed to the isotherms in the order of Freundlich > Temkin > Langmuir for poultry and goat manure treated soils and Langmuir > Freundlich > Temkin for dairy manure treated soil. Manure treatment decreased all the sorption parameters; the highest decrease was observed from dairy manure treated soil. Maximum P buffering capacity and standard phosphate requirement were decreased for all manure treatments, meaning that less fertilizer would be needed to maintain P concentrations in soil solution if manure amendment is used. Results of this study could be utilized for better fertilizer and manure management to reduce the waste of valuable fertilizer and to decrease water pollution.

ABOUT THE AUTHORS

Nureza Hafiz and Shirajum Monira Adity are the two graduate students in the Department of Irrigation and Water Management. They both obtained their bachelor degree in Agricultural Engineering, majoring in irrigation and water management.

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PUBLIC INTEREST STATEMENT

Manures, when applied as a source of plant nutrients, could be a potential non-point source of water pollution. Applied manure interacts with the soil and changes the chemistry between phosphorus (P) and the soil. Long term application of manure in a soil or changes in P chemistry could result in available P in soil solution in excess of plant's requirement. Excess P in soil solution may runoff with rain water and pollute receiving water through eutrophication. This study aimed to estimate such changes in soil in order that optimum level of fertilizer needed could be recommended while maintaining a favorable P concentration in the soil solution for optimum plant growth if manure amendment is used. Results from this study could be used for better fertilizer management to reduce the waste of valuable fertilizer and to decrease water pollution.

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1. Introduction

Livestock manures contain nutrients essential for plant growth and development and when are applied at a proper rate can serve as an important source of plant nutrients. However, land application of manures as a source of nutrients, e.g. phosphorus, often cause environmental problems polluting surface and groundwater.

The transport of P to surface water sensitive to eutrophication has been a worldwide environmental concern for more than 30 years (Sharpley et al., 2003; Sims, Simard, & Joern, 1998). Over use of chemical fertilizers or land application of manures increases bioavailability (dissolved P) of P in surface water through the process of runoff. Accumulation of bioavailable P in surface water leads to algae proliferation, increase in oxygen demand, deterioration of water quality, and loss of recreation values (Indiati & Sharpley, 1995; Lemunyon & Gilbert, 1993; Sharpley, Daniel, & Edwards, 1993; Sharpley, Daniel, Sims, & Pote, 1996). Although movement of P through soil profile to groundwater is not very frequent, there are combination of soil properties, agricultural management practices, and climatic conditions that may result accumulation of P in subsoil and leaching to groundwater (Ciapparelli, de Iorio, & García, 2016; Pizzeghello, Berti, Nardi, & Morari, 2016; Sims et al., 1998). However, not only the bioavailable P is responsible for eutrophication, but particulate P associated with sediment and organic materials also constitutes a source of P in water resources (Dorich, Nelson, & Sommers, 1984; Sharpley et al., 1993).

P occurs in manure in various forms such as inorganic and organic, and the inorganic form is very reactive. When inorganic-P comes in contact with soil, various reactions begin to take place. Those reactions make phosphorus less soluble in water and thereby less available to plants. The rate and product of these reactions depend on include soil pH, texture, moisture, and soil mineralogy (Lindsay, 1979). Phosphorus ions react with soil in two ways; adsorbing into soil particles and chemically combining with calcium, aluminum, and iron by forming their precipitates. These adsorbed and newly formed compounds are slowly released into soil solution and being available to plants. At saturation or over saturation, dissolved phase of P concentration increases in soil solution and is subjected to runoff loss. Some particulate P (adsorbed P) also moves with runoff water when soil particles eroded and reached surface water (Sharpley et al., 1994).

The amount and forms of P in manure varies with the type of animals, age, diet, bedding type, and method of manure handling. 45–95% of manure P is inorganic and the rest is considered to be organic. Over time, organic forms of manure are mineralized to inorganic forms through microbial actions. A few studies compared the concentration of P in manure excreted from different animal species (Barnett, 1994; Sharpley & Moyer, 2000). They noted that total P concentration was highest in swine slurry, followed by poultry and dairy manures. On the other hand, dairy manure had the greatest portion of inorganic water soluble P; whereas, poultry manure had the most stable form of P and swine slurry has intermediate P extractability. Different forms have different availabilities to plants and runoff potential. Storage and handling of manure facilitate microbial activities, which may change the proportion of different forms (Joern, Provin, & Sutton, 1996).

Also, during the decomposition processes, various types of organic acids are produced. The amount and type of organic acids produced from manures are different for different animal species. These organic acids are thought to be, at least partly, responsible for changing soil P sorption strength and capacity (Marshall & Laboski, 2006). Bolster and Sistani (2009) studied the effects of

swine, cattle, and poultry manure extracts on P adsorption in different soil types and observed changes in sorption characteristics. Other studies have shown that when poultry, cattle, and goat manures were applied to highly weathered tropical soil, the P-sorption efficiency and P-buffering capacity decreased with an increasing incubation period (Azeez & Van Averbeke, 2011). Variation in organic products from organic supplements has also been reported to influence sorption (Hue, 1991; Vanden Nest et al., 2016).

Sorption isotherm is an important tool to study the sorption behavior of soils. It also helps understand the processes involved and to summarize many aspects of soil-phosphorus interactions by different parameters (Barrow, 1978). A number of models have been developed (Kinniburgh, 1986; McGechan & Lewis, 2002) to quantify the adsorption, among them the most commonly used sorption models are Freundlich (Russell & Prescott, 1916), Langmuir (Olsen & Watanabe, 1957) and Temkin (Bache & Williams, 1971) equations. A validated model is useful in predicting the effect on nutrient uptake by the plant for different soil and plant parameters (Barber, 1995).

To reduce the environmental impact of P from agricultural soils and better P nutrient management, it is important to understand P sorption behavior of soils. Since soil type varies from place to place, it is needed to establish P sorption characteristics of an area or soil type in question for various manure types. We are not aware any studies that investigated the P sorption behavior of any Bangladeshi soil as affected by different manure types. Therefore, this study aimed to investigate the effects of goat, poultry, and dairy manures on soil sorption behavior of an agricultural soil and to estimate the sorption parameters using sorption isotherm models.

2. Materials and methods

2.1. Soil samples collection and analysis

The experimental soil belonging to the Old Brahmaputra Floodplain (FAO-UNDP, 1988) was silt loam underlain by sandy loam and collected from Bangladesh Agricultural University (BAU) field laboratory site. Soil samples from 0 to 15 cm depth were collected by a core sampler. Soil samples were collected from eight different spots and composited to represent the average soil condition of the field. Upon collection, the soil was air dried for several days and ground and sieved through a 2-mm sieve. The air-dried and sieved soil sample was used for physicochemical analysis and was incubated with manures for sorption experiments.

Particle size analysis of the soil samples was performed using the hydrometer method as described by Day (1965). Soil available P was measured following Olsen method (Olsen, Cole, Watanabe, & Dean, 1954). Organic carbon content of the soil was determined by wet oxidation method (Nelson & Sommers, 1982). Total nitrogen in the soil was determined by semi-micro-Kjeldahl method following digestion with concentrated sulfuric acid in presence of potassium sulfate and copper sulfate catalyst mixture (K_2SO_4:$CuSO_4$· $5H_2O$:Se = 100:10:1) and distillation with 10 N NaOH in presence of boric acid indicator. Soil was extracted with 1 N NH_4OAc and the K concentration in the extract was then determined by flame photometer as described by Knudsen, Peterson, and Fratt (1982). The exchangeable Ca, Mg, and Na were extracted by 1 M CH_3COONH_4 and determined by flame photometer (AOAC, 1990). The available S content in the soil was extracted by 0.01 M Ca $(H_2PO_4)_3$. The extracted S was estimated turbidimetrically and the turbidity was measured by a spectrophotometer at 420 nm wavelength (Page, Miller, & Keeny, 1982). Chemical analyses were performed at Humboldt Soil Testing Laboratory of the Department of Soil Science, BAU. All determinations were done in duplicate.

The experimental soil had silt loam texture with 32.6% sand, 56.7% silt, and 10.8% clay and had a bulk density of 1,200 kg m^{-3}. Other physicochemical properties analyzed for the soil are presented in Table 1. The soil had 1.08% organic matter and 764 and 139 mg L^{-1} of Ca and Mg, respectively. The organic matter content represents the lower range value of Bangladeshi soils, which is found in non-calcareous alluvium (Bhuiya, 1987). The studied soil was slightly acidic with a pH of 6.16 at a soil: water ration of 1:5.

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Table 1. Physicochemical properties of soil															
Treatment	EC, mS m^{-1}	K, meq 100^{-1} mg^{-1}	Total N	OM	S	Na	Ca	Mg	Available P			pH		
		%				mg kg^{-1}								
Untreated	11.5	0.11	0.06	1.08	6.81	127	764	139	26.85			6.16		
Treated									DM	PM	GM	DM	PM	GM
									36.8	10.9	66.3	6.26	6.11	5.96

Notes: OM: Organic matter, DM: Dairy manure, PM: Poultry manure, GM: Goat manure.

2.2. Manure samples collection and analysis

Fresh dairy, goat, and poultry manures were collected from BAU dairy, poultry, and goat farms for the incubation study. The manures were selected as the common alternatives of inorganic P fertilizers. Fresh manure was scrapped from the barn by using a spatula and refrigerated after collection. A portion of the manure was used for physicochemical analysis while the rest was used for sorption experiment. Manure N, P, S, and K were analyzed following standard procedures (Peters, 2003). Fresh dairy, poultry, and goat manures were analyzed to measure the N, P, K, S and pH and the results have been shown in Table 2. Poultry manure had larger amount of N and P than either dairy or goat manure. On the other hand, goat manure had the highest K and S but had the lowest P content. The highest P was observed for poultry manure. Poultry manure typically has two to four times greater concentration of P than manure from other livestock except swine (Kleinman, Wolf, Sharpley, Beegle, & Saporito, 2005), which was also observed in the present study. Compared to other published studies, variation of nutrient concentrations for each manure type was observed, which was likely due to food habit, composition of the diet, age of animal, and time of year (Brown, 2013; Penhallegon, 2003).

2.3. Soil-manure incubation

Air-dried and sieved soil sample (250 g) was taken in a plastic container separately and mixed with a pre-weighed amount of fresh dairy, goat, and poultry manures in each container. The amount of manure used was equivalent to a P treatment level of 100 mg per kilogram of soil. Soil and manure were mixed together with a spatula to incorporate thoroughly. Distilled water was added to bring the incubation mixtures approximately to field capacity of the soil. The mixture was incubated at this moisture content at room temperature for a month. After the incubation, P sorption and availability parameters were estimated for incubated soil samples by P sorption experiment. P sorption experiment was also performed with untreated soil to establish a basis for comparison.

2.4. Phosphorus sorption experiment

P sorption was estimated according to the procedures outlined by Nair et al. (1984). A range of graded P solutions with different concentrations (0–50 mg L^{-1}) were prepared in 0.01 M CaCl$_2$ solution. P solutions with different concentrations were prepared by dissolving required quantities of KH$_2$PO$_4$ in 0.01 M CaCl$_2$ solution. For both manure-treated and untreated soils, 1 gram of soil sample was taken into a 50 ml centrifuge tube. The prepared graded P solutions were added separately into each centrifuge tube to give a soil solution ratio of 1:25 (w/v). A drop of chloroform was added in each centrifuge tube to inhibit the microbial growth during shaking. The centrifuge tube was then shaken and equilibrated for 16 h (Hossain, Hoque, & Osman, 2012). The equilibrated mixture was centrifuged, and the supernatant was analyzed for phosphate following ascorbic acid reduction

Table 2. Chemical properties of fresh manures					
Manure type	%N	%P	%K	%S	pH
Dairy	0.218	0.197	0.3056	0.0891	7.73
Poultry	1.635	0.413	0.5602	0.2033	8.05
Goat	1.613	0.082	0.7639	0.2859	8.16

method (Murphy & Riley, 1962). Phosphate content was measured in a spectrophotometer in 890 nm wavelength. The difference between the concentration of phosphate-P added in the initial solution and the concentration of phosphate-P at equilibrium was used to measure the sorbed P. Duplicate samples were analyzed for sorption experiments.

Standard phosphate requirement of soil (SPR) was determined as amount of P sorbed at a solution P concentration of 0.2 mg P L^{-1} (Fox & Kamprath, 1970). Fitted Langmuir and Freundlich isotherm equations were used to calculate SRP. The sorption efficiency (%) was calculated by

$$\text{Sorption efficiency} = \left[(C_0 - C_{eq})/C_0 \right] \times 100$$

where, C_0 and C_{eq} (mg L^{-1}) are the liquid-phase concentrations of P initially and at equilibrium, respectively.

The adsorption isotherms, which represent the relationship between the equilibrium concentration of adsorbate in the bulk and adsorbed amount at the surface, were constructed by using the data obtained from the sorption experiments. Linearized forms of Langmuir, Freundlich, and Temkin models were used to fit the experimental data. The relationship of P adsorption maxima (B_L) and bonding energy (K_L) values determined by using the linear form of the Langmuir (1918) equation is given as

$$\frac{1}{X} = \frac{1}{B_L} + \frac{1}{K_L B_L C_{eq}}$$

where X = Amount of P sorbed (mg kg^{-1}), C_{eq} = Equilibrium P concentration (mg L^{-1}) in solution, B_L = Adsorption maximum (mg P kg^{-1}), K_L = Bonding energy constant (L mg^{-1} P).

A plot of $1/X$ (Y-axis) against $1/C_{eq}$ (X-axis) will yield a straight line with a slope of $1/K_L B_L$ and a Y-intercept of $1/B_L$. The Maximum phosphorus buffering capacity (MPBC) of the soil (the increase in sorbed P per unit increase in final solution P concentration) was estimated from the product of Langmuir constants K_L and B_L (Holford, 1979).

Freundlich equation (Freundlich, 1926) used is given as

$$\log X = \log K_f + \frac{1}{n} \log C_{eq}$$

where X = Amount of P sorbed (mg kg^{-1}), K_f = Proportionality constant for Freundlich equation, mg kg^{-1}, $1/n$ = Slope of curve log X vs. log C_{eq}, C_{eq} = Equilibrium P concentration (mg L^{-1}) in solution.

Temkin equation (Temkin & Pyzhev, 1940) used is given as

$$X = a + b \ln C_{eq}$$

where X = Amount of P sorbed (mg kg^{-1}), C_{eq} = Equilibrium P concentration (mg L^{-1}) in solution, a, b = Constants.

A plot of X vs. ln C_{eq} will give a straight line with slope b and Y-intercept a.

3. Results and discussion

3.1. Effect of manure incubation on soil chemical characteristics
After a month of manure incubation, pH was increased for dairy manure treated soil and was decreased with poultry and goat manure treated soil (Table 1). The highest decrease in pH was with goat manure treated soil (5.96), whereas dairy manure increased soil pH to 6.26 (Table 1). The higher

pH in manure-amended than unamended soils was attributed to buffering from bicarbonates and organic acids in cattle manure (Whalen, Chang, Clayton, & Carefoot, 2000). On the contrary, for both poultry and goat manures, the values of soil pH were decreased likely due to mineralization of organic matter as well as organic acids that were produced and incorporated into the soil at the beginning of the manure decomposition (Chang, Sommerfeldt, & Entz, 1990, 1991). The available P (Olsen- P) for untreated soil was found 26.85 mg L^{-1}. Increased available P was found for dairy and goat manure treated soils, which resulted in 36.8 and 66.3 mg L^{-1} from dairy and goat manure amended soils, respectively. Poultry manure decreased available P value to 10.9 mg L^{-1}. Addition of poultry manure might have increased the number of sorption sites, causing decreased in available P after incubation (Yu et al., 2013).

### 3.2. Effects of manure types on P-sorption isotherms

The P sorption isotherms of untreated soil is shown in Figure 1a and the same for dairy, poultry, and goat manure-incubated soil are shown in Figures 1b–1d, respectively. In this study, the P adsorption of soil samples increased with increasing P concentration, although different rates of adsorption were observed with varying concentrations in different treatments. A careful observation of the isotherms indicates that all the isotherms conform to the shape of S-curve type, and manure treatment did not change the general shape of the isotherms. S-curvature indicates that the initial adsorption at low concentration was unfavorable and became easier as the concentration was rising.

Researchers observed H-curve type isotherms in several phosphorus sorption studies on soils amended with organic matter and different manures (Azeez & Van Averbeke, 2011; Yu et al., 2013). The forms of sorption isotherms depend on adsorption mechanisms, physical nature of the solute and the substrate surface, and the amount of specific surface area of the substrate (Giles, MacEwan, Nakhwa, & Smith, 1960). Previous studies (Azeez & Van Averbeke, 2011) used P fixing soils (containing large amounts of sesquioxides and kaolinitic clays) and organic materials with varying characteristics, which were different than the present study and the likely causes of different sorption behavior. In those studies, high affinity of P for soil caused high initial slope of the isotherms, which were likely appeared as the H-shaped isotherms. The low initial slopes of the isotherm curves were caused by the low affinity of P for soil and appeared as S-shaped curve as observed in the present study.

3.3. Effects of manure types on model fitting parameters

The P sorption data of untreated soil and three manure-incubated soils were plotted according to the Langmuir, Freundlich and Temkin equations and the resulting fitted parameters are presented in Table 3. Results revealed that, among the 3 adsorption equations, Freunlich equation fitted the best to the equilibrium P sorption data except dairy manure treated soil, where Langmuir equation fitted well to the dairy manure treated soil as evidenced by the high coefficient of determination. The conformity of
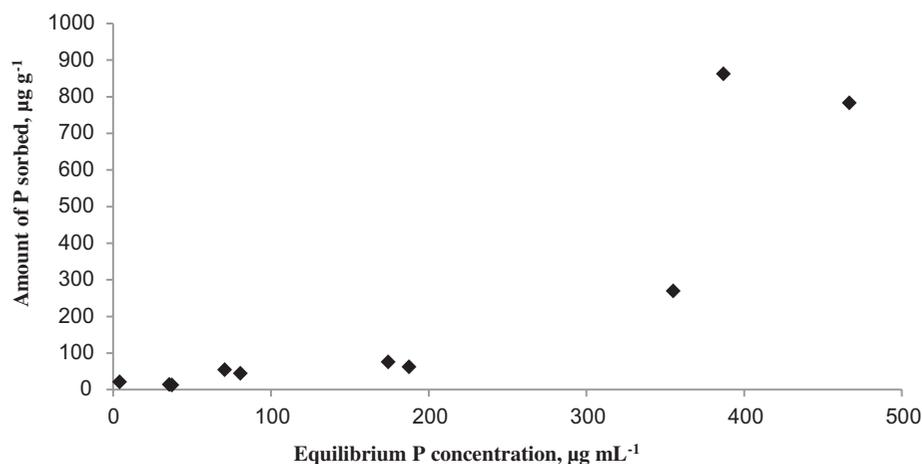
Figure 1a. Phosphorus sorption isotherms derived from untreated soil materials.
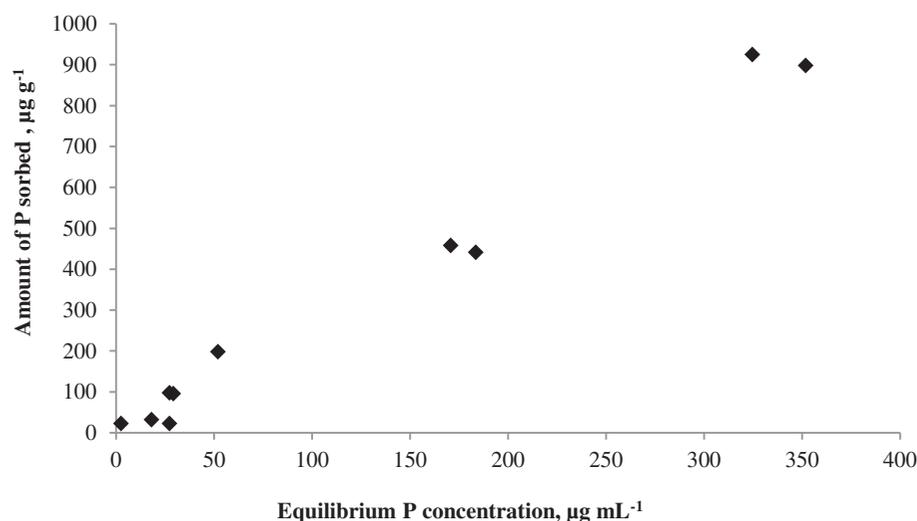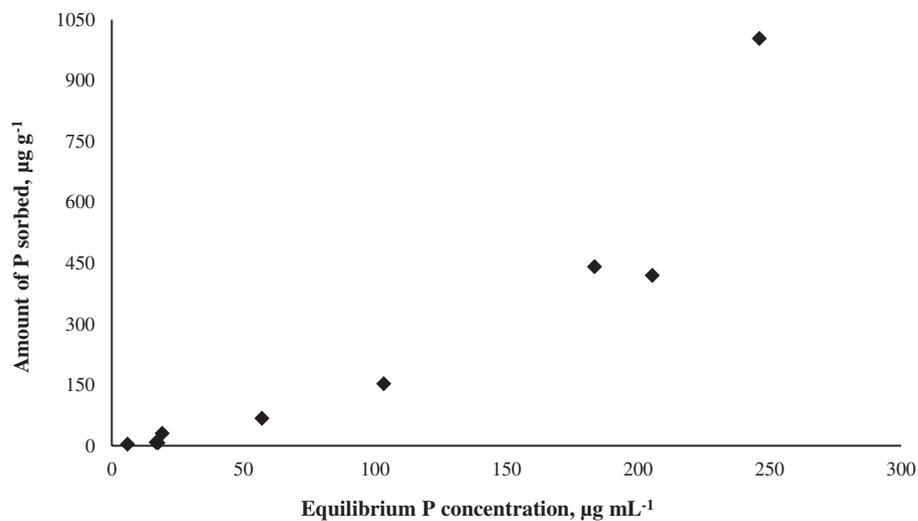
Figure 1b. Phosphorus sorption isotherms derived from soil treated with dairy manure.
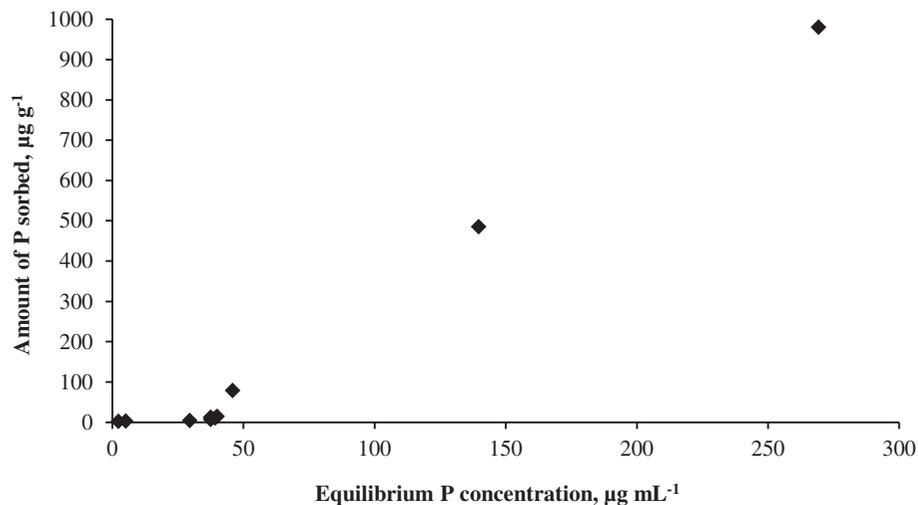
Figure 1c. Phosphorus sorption isotherms derived from soil treated with poultry manure.

Figure 1d. Phosphorus sorption isotherms derived from soil treated with goat manure.

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Treatment type	Langmuir equation				Freundlich equation				Temkin equation			
	$1/X = 1/B_L + 1/B_L K_L C_{eq}$	K_L, L mg^{-1}	B_L, mg kg^{-1}	R^2	$logX = 1/n$ $logC_{eq} + logK_f$	K_f, L kg^{-1}	n	R^2	$X = a + blogC_{eq}$	a	b	R^2
Untreated	$y = 0.0925x + 0.0094$	0.102	106	0.44	$y = 0.8571x + 0.6951$	4.96	1.17	0.85	$y = 446.2x - 449.08$	–	193	0.74
Dairy	$y = 0.9563x + 0.059$	0.062	16.9	0.79	$y = 0.7168x + 0.0042$	1.01	1.18	0.54	$y = 162.47x - 405.46$	–	163	0.48
Poultry	$y = 0.1371x + 0.0222$	0.162	45.1	0.14	$y = 0.8508x + 0.2075$	1.61	1.18	0.66	$y = 335.19x - 443.48$	–	145	0.42
Goat	$y = 0.2367x + 0.0124$	0.052	80.6	0.13	$y = 0.9438x + 0.5106$	3.24	1.06	0.70	$y = 467.14x - 478.94$	–	202	0.58

Table 3. Fitted parameters of Langmuir, Freundlich, and Temkin equations for different manure treated and untreated soil

isotherms to the models as measured by coefficient of determination (R^2) values was Freundlich > Temkin > Langmuir for untreated, poultry, and goat manure treated soils. Likewise, the conformity of isotherm models for dairy manure incubated soil was Langmuir > Freundlich > Temkin. According to Barrow (1978), the good fit of the equations to the data was probably partly due to the limited range of equilibrium concentration. The co-efficient of determination (R^2) for the Langmuir equation was lower than that of Freundlich equation except dairy manure treated soil, which is consistent with the results obtained in many New Caledonian soils, where P sorption data were explained better by the Freundlich equation (Dubus & Becquer, 2001). A few earlier studies with Bangladeshi soils reported good fit of P sorption data to the Langmuir equation (Islam, Saleque, Karim, Solaiman, & Masud, 2007; Masud, Moniruzzaman, Shil, Islam, & Saleque, 2006). However, their studies were limited to untreated soils with specific characteristics. It was also found that the ability of Freundlich model was superior to Langmuir model to describe P adsorption curves for calcareous soil (Rushton, Karns, & Shimizu, 2005; Said & Dakermanji, 1993) which is also consistent with the present study as the soil was calcareous in nature (Table 1). In similar studies of soil amended with cattle, goat, and poultry manures, Temkin equation was found the best fit to describe sorption isotherms (Azeez & Van Averbeke, 2011).

The Langmuir, Freundlich, and Temkin constants determined from the slopes and intercepts of the respective plots are shown in Table 3. The constant B_L in the Langmuir isotherm represents the adsorption capacity, which is useful in comparing performance of adsorption of different adsorbents. Similarly, the value of Freundlich constant K_f indicates the extent of P removal from solution, thus a measure of adsorption capacity as Langmuir B_L. The value of K_f depends on the solution concentration (Kuo & Lotse, 1974).

Temkin adsorption constants are shown in Table 3. Manure treatment increased b for the dairy and goat treated soil and decreased for the poultry manure treated soil. Azeez and Van Averbeke (2011) reported that the effect of the period of incubation on the Temkin adsorption constant was ambiguous, no clearly defined trend was noticed.

Langmuir adsorption maxima (B_L) ranged from 16.9 mg kg^{-1} (dairy manure treated soil) to 80.6 mg kg^{-1} (goat manure treated soil) as shown in Table 3. The adsorption maxima was 106 mg kg^{-1} for untreated soil and decreased for soil amended with all three manure types. The reduction in the adsorption capacity due to the addition of manures might be due to the affinity of organic ligands for the sorption sites. The most ligands are capable of displacing phosphate ions in sites specific to organic ligands such as oxalate, citrate, tartrate and malonate (Bhatti, Comerford, & Johnston, 1998; Huang, 2004; Violante & Gianfreda, 1993). Sharma, Agrawal, and Marshall (2006) reported that the decrease in the adsorption capacity might be occurred due to the possible blockade of P-fixing sites in the soil by soluble humic substances present in manures. Removal of soil organic matter increases the adsorption maxima (Marzadori, Antisari, Ciavatta, & Sequi, 1991), whereas the application of manure into the weathered soils of high P-fixing ability may reduce P-fixation (Azeez & Van Averbeke, 2011).

The Freundlich constant, K_f was found to decrease for all manure treated soil, which followed similar trend as in the Langmuir equation. The reduction of K_f agreed with the results found in other

studies (Azeez & Van Averbeke, 2011; Sharma et al., 2006). The adsorption parameter n in the Freunlich isotherm measures preferential adsorption of the process. According to Desta (2013), the n value expresses the degree of nonlinearity between solution concentration and adsorption. When $n = 1$, the adsorption is linear; if $n > 1$, the adsorption is a physical process; if $n < 1$, then the adsorption is chemical process. High value of n indicates a strong bond between the adsorbent and the adsorbate (Yakubu, Gumel, & Abdullah, 2008). The values found in the present study were over unity for all treatments, indicating that the isotherms' shape could conform to the shape S-curve type.

The energy of adsorption for phosphorus, K_L, was calculated from the Langmuir adsorption isotherms and related to binding energy to sorption sites. Manure treatment decreased energy of adsorption for dairy and goat manure incubated soil and increased poultry manure incubated soil. The sorption strength of poultry manure incubated soil was 0.162 L mg^{-1}, which was the highest among all the treatments. It was thought that the P sorption strength increased likely due to the less phosphate ions' reaction with soil and/or for the short incubation period.

The highest amount of sorption parameter was observed to reduce from the dairy manure treated soil. Dairy manure has the highest percentage of soluble ortho-phosphate compared with total phosphate (ASAE, 2005; Rahman, Rahman, & Cihacek, 2012), and the soil P sorption binding sites were increasingly loaded with ortho-phosphate, which resulted in decrease of sorption ability (Vanden Nest et al., 2016) of the treated soil. Sato and Comerford (2005) and Shaheen and Tsadilas (2013) suggested that an increase in soil-pH can cause a decrease in P sorption strength, which is in agreement by the results of this study where the highest pH increase was with dairy manure treated soil.

3.4. Effects of manure types on phosphorus sorption efficiency

Table 4 shows the phosphorus sorption efficiency of the soil samples as affected by various manure types. It is seen from the table that sorption efficiency of the soil decreased compared to untreated soil after manure amendment for each manure type. The highest P sorption efficiency reduction was 44.8%, which was observed for poultry manure treated soil. The least reduction was observed for goat manure treated soil, which amounted to be 69.9%. Decrease in P sorption efficiency due to manure treatment was also observed in earlier studies (Azeez & Van Averbeke, 2011). The decrease in P sorption efficiency due to manure treatment was likely because of the release of humic acids and other organic substances that consequently participated in the lockage of sorption sites on soil colloids. However, sorption efficiency varies with time of incubation (Azeez & Van Averbeke, 2011); the highest sorption efficiency observed in case of goat manure could have been on its peak.

3.5. Effects of manure types on maximum P buffering capacity

The MPBC as affected by the manure types are shown in Table 4. The maximum P buffering capacity is a product of Langmuir model K_L and B_L. This is a useful index of evaluation of the P supply and immobilization capacity and rates by soils (Holford, 1979). The manure treatments reduced the MPBC for all manure types. The highest reduction was 1.05 L kg^{-1} for dairy manure. Both reduction and increase of MPBC had been observed in earlier studies (Azeez & Van Averbeke, 2011; Yu et al., 2013). The addition of organic matter into soil generated various interactions with soil colloids, which subsequently led to a decrease in the MPBC (Yu et al., 2013). The lower values of MPBC in the present

Table 4. P-sorption efficiency averaged across a range of initial P concentrations, MPBC, and SPR of untreated soil and treated soil with different manure types

Treatment	P-sorption efficiency, %	MPBC, L kg^{-1}	SPR, mg kg^{-1}	
			Langmuir	Freundlich
Untreated	72.4	10.8	2.12	1.25
Dairy	46.9	1.05	0.21	0.32
Poultry	44.8	7.31	1.41	0.41
Goat	69.9	4.19	0.84	0.71

study would mean that a smaller P application rate is needed to for maintaining a desired P concentration in the soil solution (Reddy, Subba Rao, & Singh, 2001).

3.6. Effects of manure types on standard phosphate requirement (SPR)

Standard phosphate requirement for the untreated and manures treated soil are shown in Table 4. It is seen from the table that standard phosphate requirement was decreased for all manure treatments; the highest reduction was observed for the dairy manure treated soil as calculated from both Langmuir and Freundlich isotherm equations. SPR of the soil treated with dairy manure was 0.21 and 0.32 mg kg^{-1} from Langmuir and Freundlich isotherms, respectively. However, the values of SPR vary with the time of incubation. The lower SPR values found in soil after manure treatment indicate that less amount of fertilizer would be needed in this soil to maintain the optimum P fertility level if manure amendment is applied.

4. Conclusions

Manure treatment changed the physicochemical properties of soil and the variation depended on the types of manure. An affinity for P adsorption was observed for the soil, as indicated by the sorption isotherms, which conformed the shape of S-curve type. The sorption experimental data conformed, in general, to the models in the order of Freundlich > Temkin > Langmuir. A definite trend in P adsorption parameters was observed, which was similar for each manure type. Amendment of soil with manure decreased sorption capacity, energy of sorption, P-sorption efficiency, MPBC, and SPR. The reduction of sorption parameters was the highest for soil treated with dairy manure. Decrease of MPBC and SPR would mean that less fertilizer would be needed to maintain a favorable P concentration in the soil solution for optimum plant growth if manure amendment is used. Results from this study could be used for better fertilizer management to reduce the waste of valuable fertilizer and to decrease water pollution.

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