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Estimation of the Phosphorus Sorption and Saturation in the Eastern Surma-Kusiyara Floodplain and Gopalganj-Khulna Bill Soil of Bangladesh

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Abstract

Annual P application rates should be in equilibrium with the rate of P sorption by soil to ensure enough P in the soil for optimal crop production. So, an experiment was carried out to determine and compare the effect of solution P concentrations on P sorption/desorption in the soils of Eastern Surma-Kusiyara Floodplain and Gopalganj-Khulna Bill. Five samples were collected from cultivated rice fields at 0-15 cm soil depth in each site and analyzed. Phosphorus adsorption isotherms were constructed using standardized phosphorus adsorption isotherm procedure. Phosphorus in solution was analyzed spectrophotometrically using the ascorbic acid method. The sorption phosphorus amount (P_{sorbed}) was calculated as the difference between the initial amount of P added and the amount in the equilibrium solution. Phosphorus desorption happened in 1, 2, 4 µg P ml^{-1} solution whereas phosphorus adsorption found in 16, 25, 50, 100 & 150 µg P ml^{-1} solution. The results show that increasing the concentration of solution P increased P retention onto soil significantly. Maximum phosphorus adsorption capacity (MPAC) (17.24 µg g^{-1}) was found in agro ecological zone 14 soil in respect of adsorption energy. The $P_{saturation}$ of different agroecological zone 14 and agroecological zone 20 soils were 6.33 and 6.10%. The studied sample's phosphorus saturation index demonstrated a far below threshold critical limit of 25. As a result, the application of P fertilizer or manure in our studied soils is environmentally safe.

Keywords: Phosphorus, sorption/adsorption, saturation and Agro-ecological Zones .

Introduction

Efficient nutrient management is one of the key management strategies to achieve the required food production to feed the rapidly growing population in current agriculture. For crop production, phosphorus (P) is the second important nutrient after nitrogen. Crop production has increased in order to feed the world's growing population, and fertilizers have played an important role in this. The nutrients removed from soils by harvested crops encourage the adoption of high-yielding varieties and increase biomass in nutrient-depleted soils, which is replenished with fertilizer.

In developed countries, the use of phosphate fertilizers has decreased since the last decades of the twentieth century. However, Bangladesh as well as in developing countries,their use is steadily increasing, resulting in increased global consumption (Lair et al. 2009). Phosphorus adsorption in the soil is an important factor for creating adsorbed phosphate equilibrates and P in soil solution. This P is immediately available for the plant. The phosphorus adsorption isotherm integrates P intensity with soil capacity and quantity parameters, which can play an important role in controlling the movement of P from soil to growing plant roots. (Hoque et al. 2015). In other countries, the sorption/ desorption reactions of phosphorus in soil have been extensively studied for both agronomic and environmental purposes (Sui and Thompson, 2000). The phosphorus sorption isotherm is widely used to describe P sorption and desorption in soils and to forecast the risk of P loss to fresh water (Zhou and Li 2001).

From the agronomic point of view P is strongly retained by soil makes it less available for plant uptake, which is a major concern. On the contrary, high soil P retention may prevent soluble P losses through runoff and movement to ground water, which is beneficial to the environment. As a result, P sorption and desorption reactions, as well as soil P-buffering capacities, may play an important role in both agronomic and environmental aspects of P management (Islam et al. 2010; Sui and Thompson, 2000). Soil phosphate sorption capacity is a necessary component in the interpretation of soil test value as well as specific fertilizer recommendation (Hoque et al. 2015). The phosphorus sorption capacity of Bangladesh soils in the Asian countries has so far received little attention. Optimum fertilizer application is required to reduce P adsorption and leaching loss, improve an environmental condition, and increase crop production. Keeping this in mind, the goals of this study were to quantify P adsorption/desorption capacities, bonding energy, and other adsorption parameters of the Langmuir model on soils from Bangladesh's Eastern Surma-Kusiyara Floodplain and Gopalganj-Khulna Bill.

Materials and Methods

The sampling sites were located at Eastern Surma-Kusiyara Floodplain and Gopalganj-Khulna Bill in Bangladesh (Figure 1). Five samples were collected from cultivated rice fields at 0-15 cm soil depth in each site and made it composite. The collected soil samples were air-dried and ground to pass through a 2-mm sieve before being combined to form a composite sample. Soil samples were analyzed in a laboratory of Soil Science at Bangladesh Institute of Nuclear Agriculture (BINA), Bangladesh. Particle size (sand, silt, and clay) distributions were done by the laser diffraction method (Microtrac, S3500, Germany). The soil pH was measured by suspending in 1:2.5 soil to water for a designated amount of time and then measured the pH by a glass electrode pH meter (Islam et al. 2014). Soil organic carbon was analyzed using the wet oxidation method (Walkley and Black, 1934). Phosphorus sorption isotherms were constructed through the use of standardized phosphorus adsorption isotherm procedure (Manning et al. 2006). Briefly one gram of the soil sample was taken in 25 mL test-tube with various addition of P (0, 1, 2, 4, 8, 16, 25, 50, 100, 150 ppm) in 20 mL of 0.01M $CaCl_2$ solutions separately. Ultimate the P content was 0, 20, 60, 120, 240, 360, 480, 600, 740, 860, 1100, 1360 and 1600 mg kg^{-1} soil. The samples in test tubes were shaken for 24 h on the horizontal shaker with low oscillation. The suspensions were centrifuged for 30 minutes at 2200rmp, and the supernatants were decanted and filtered. In equilibrium solutions, pH values were recorded.The ascorbic acid method was used spectrophoto-metrically to analyze phosphorus in solution (Murphy and Riley 1962). Sorbed phosphorus amount (P_{sorbed}) was calculated as the difference between the initial amount of P added and the amount at equilibrium. The equilibrium P concentration data were interpreted by the following equation:

The Langmuir adsorption equation is given by:

$$C/(x/m) = 1/kb + C/b$$

where C is the equilibrium P concentration (mg/L); x/m is the mg P sorbed per kg soil; b is the adsorption maxima related to the bonding energy of adsorption. A straight line was produced by the plot of C/(x/m) versus C.

Amount of soil per hectare was calculated the following equation :

Weight of soil (kg/ha) = {Area (cm^2) × Depth (cm) × Bulk density (g/cm^3)}/1000

where, 1 ha = {Area (cm^2) : (10000 cm × 10000 cm), depth= 15 cm}/10000

The data about different parameters was analyzed statistically one way analysis of variance using MSTAT-C software (Gomez and Gomez, 1984).

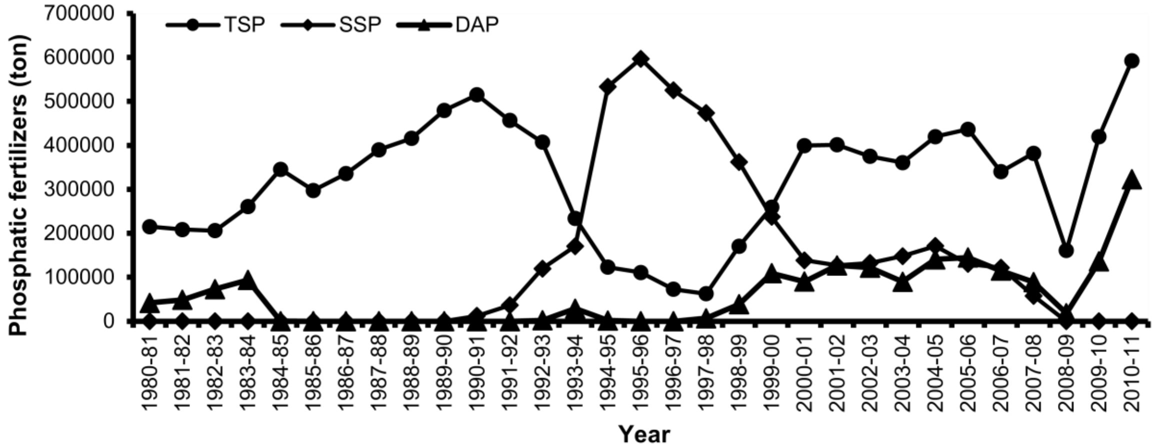


Figure 1. Consumption of phosphatic fertilizers in Bangladesh (FRG, 2012)

Table 1. Physicochemical properties of AEZ 14 and AEZ 20 soils

AEZ	pH	EC (dSm^{-1})	Bulk density (g/cc)	SOM (%)	Available P (ppm)	Sand (%)	Silt (%)	Clay (%)	Textural class
14	4.38	0.017	1.026	22.52	67.20	34.70	55.47	9.84	Silt loam
20	3.98	0.002	1.113	4.03	84.75	7.46	73.69	18.85	Silt loam

Note : AEZ-agro-ecological zone, EC-electrical conductivity, SOM-soil organic matter, P-phosphorus, dS-deci Siemens

Results and Discussion

Soil properties

The physical and chemical characteristics of the studied soils are presented (Table 1). The particle size distribution showed that the texture of the soils were silt loam. Silt fraction was dominated over the sand and clay fractions in the studied soils. Silt contents (55.47 and 73.69%) were found in AEZ 14 and 20, respectively. The lowest particle contents (9.84% for clay and 7.46% for sand) were obtained from AEZ 14 and 20, respectively.

The value of pH was 4.38 and 3.98 in AEZ 14 and 20 soils respectively. The studied soils (AEZ 14 and AEZ 20) were found to be acidic, which can be due to organic matter decomposition and subsequent carbonic acid formation (Islam et al. 2014, 2015). Cations availability increased in soil due to higher soil acidity (Adeniyi et al. 2008; Islam et al. 2014). Organic carbon contents in AEZ 14 soils was 22.52%, which is much more than AEZ 20 soils of Bangladesh (Hoque et al. 2011). Water logging in AEZ 14 soils might slow organic matter decomposition, resulting in higher organic matter concentrations than in Bangladesh's AEZ 20 soils.

Adsorption and desorption isotherms at different concentration of P solution

The P adsorption isotherm results are presented in Figure 2. There was a significant variation among the soils in P adsorption and the application of P largely increased P adsorption. Interaction between the soil and phosphorus was also significant. P sorption ranged from 0.49 to 110.68 mg/L in Eastern Surma-Kusiyara Floodplain soil. P sorption ranged from 0.51 to 110.95 mg/L in Gopalganj-Khulna Bill soil. The highest mean of P sorption (110.95 mg/L) was found in Gopalganj-Khulna Bill soil and the lowest (0.49 mg/L) in Eastern Surma-Kusiyara Floodplain soil.

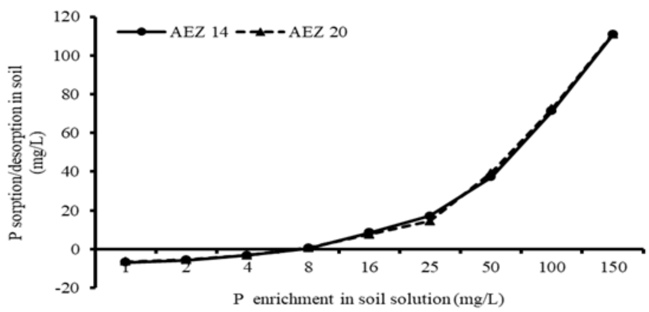


Figure 2. P sorption/desorption isotherms in different agro-ecological zone soils of Bangladesh

Soil pH affected greatly phosphorus adsorption of soils (Rupa et al. 2001). When soil pH increased within the acidic range, the sorption of P decreased(Islam et al. 2007). Some research records show that phosphate sorption decreases with increases in soil pH up to 5.0 - 6.0. Moreover, the difference in the exchangeable Al values of the soils increased it (Lair et al. 2009). The P desorption isotherms results are presented in Figure 2. P desorption from soil is thought to be the inverse of the adsorption process.The P desorption amount was relatively high when the P concentration in the solution was low. P desorption capacity decreased with the increasing P concentration in the solution.The highest amount of P desorption was observed at 6.40 g/mL in AEZ 20 soil when the P enrichment solution was used at 8 g/mL, and the lowest amount of P desorption was 3.28 g/mL in AEZ 20 soil when the P enrichment solution was used at 4.0 g/mLP desorption was not significant when P concentration was 8 µg/ml in the solution. (The desorption capacity of AEZ 14 soils was slightly higher than AEZ 20 soils. Since the importance of immobilized P in the soil becoming available for reuse, and because P discharged from soil can cause environmental concerns, desorption is more significant than adsorption (Wang and Liang, 2014).

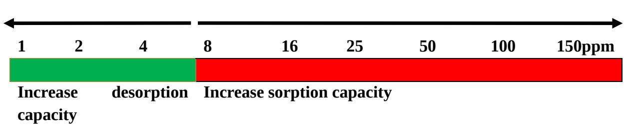


Figure 3. P sorption-desorption trend

Phosphorus saturation

Phosphorus saturation (P_{sat}) was calculated from Olsen extractable P and maximum phosphorus adsorption capacity (MPAC). The P_{sat} of AEZ 14 and AEZ 20 soils were 6.33 and 6.10%. P saturation concept is important because it calculates the degree to which P sorption sites have been filled and indicates the potential desorbability of soil P. (Beauchemin and Simard 1999). A critical DPS (degree of saturation) of 25% has been identified for Dutch soils (Sharpley 1996). The possibility of P losses by leaching and surface runoff above this limit is unacceptable to the Dutch government, and additional manure applications may be forbidden. In our tested samples, none of the soil seems to have P saturation above the critical level of 25%. All of the soils examined have very low P saturation, indicating that applying P fertilizer or manure is environmentally safe.

Maximum phosphorus adsorption capacity

Langmuir adsorption isotherm was used to estimate the maximum phosphorus adsorption capacity (MPAC), which showed that the background of P concentration is responsible for the variation of MPAC in the soil (Figure 2). The MPAC of different soils varied. The maximum P adsorption of 110 to 625 mg/kg for 14 acid piedmont soils of Bangladesh (Islam et al. 2007). Mehadi and Taylor (1988) found that in case of cultivated soil adsorption maxima of 250 mg/kg and 233 mg/kg for virgin soil in the USA.

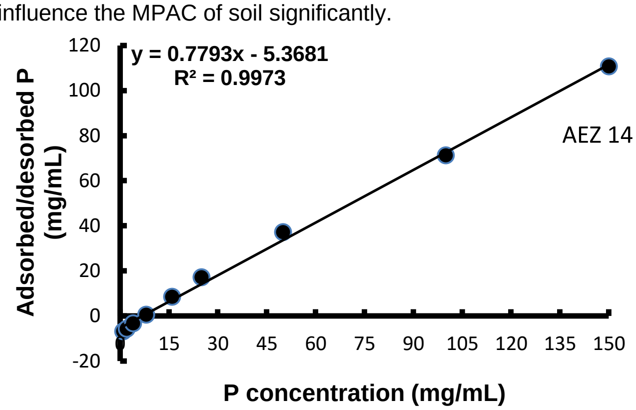
Correlation coefficient

Correlation between P concentration in solution and P adsorption onto Eastern Surma-Kusiyara Floodplain and Gopalganj-Khulna Bill soils results are presented in Figure 4.

Table 2. Correlation between C/X and C, and Langmuir coefficients of AEZ 14 and AEZ 20 soils

Soil AEZ	b ($\mu g\ g^{-1}$)	k ($\mu g\ g^{-1}$)	r
14	17.24	0.026	0.016
20	13.33	0.658	0.039

In Eastern Surma-Kusiyara Floodplain and Gopalganj-Khulna Bill soils, P concentration versus P sorption is positively correlated. It means P adsorption capacity increased with the increase of P concentration.In Eastern Surma-Kusiyara Floodplain and Gopalganj-Khulna Bill soils P concentrations versus P desorption are negatively correlated. It means P adsorption capacity increased with the increase of P concentration. The value of R (0.997) was observed in Eastern Surma-Kusiyara Floodplain and Gopalganj-Khulna Bill soils. The highest adsorption energy was 0.658 µg/g in AEZ 20, and the lowest adsorption energy was 0.026 µg/g in AEZ 14 soil (Table 2). In fact, there was apparently a positive correlation (r = 0.016 for AEZ 14 and 0.039 for AEZ 20 soil) between the energy of adsorption (k) and the maximum phosphorus adsorption capacity (MPAC, b) values observed in the most of the studied soils. Similar findings between the relationship of k and b were reported by (Abedin and Saleque, 1998; Islam, 2003; Islam et al., 2007). In their study, they revealed that the increase of k values decreases the b value. The binding energy required to adsorb phosphorus is expressed as the energy of adsorption. Thus, a soil with lower energy of adsorption showed high P adsorption capacity compared to a soil with high energy of adsorption. Correlation studies showed that soil reaction, organic carbon, and the clay concentration did not influence the MPAC of soil significantly.



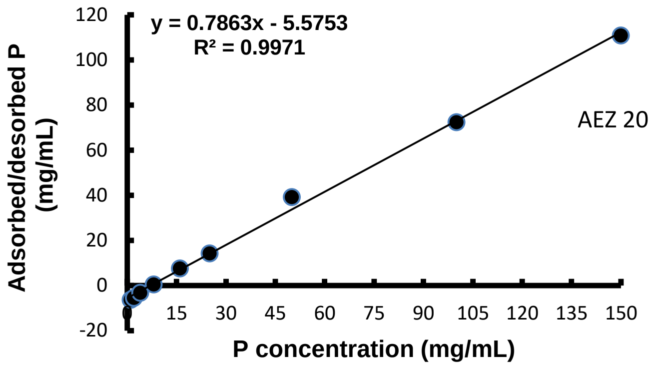


Figure 4. Correlation between P concentration in solution and P adsorbed/desorbed onto soil

Langmuir adsorption isotherm fit in a good way to explain that the sorption affinity of soils remaining constant with increasing surface saturation (Wang et al. 2008). Mehadi and Taylor (1988) also reported that P sorption depended on the energy of adsorption, and might explain the good fit to the linear Langmuir equation. The slope of the Temkin equation ranged from 111.00 (soil 2) to 243.19 (soil 5). The intercept ranged from 521.05 to 761.75. The Temkin adsorption isotherm was found to fit the poorest for Soil 4, meaning to say that the adsorption capacity of the soil did not decrease linearly with the increasing surface saturation (Islam et al. 2007). These findings are consistent with those of Babou et al. (2007) and Nizam et al. (2008).

P fertilizer requirement for optimum crop production and improved soil fertility

Most of the applied P was adsorbed when 8 mg/L P was applied in solution. On the other hand, 4 mg/L containing soil solution desorbed 3.28 mg/L P in Eastern Surma-Kusiyara Floodplain soil. It may be concluded that phosphatic fertilizer was applied equivalent to 4 ppm P that time 3.28 ppm P will reduce from the soil. So, soil fertility will be reduced. Balance method is preferred due to it takes residual P in the soil into account among the methods for calculating the recovery and efficiency of fertilizer P. Total P uptake by the crop as a percentage of the P applied is expressed by it, the difference in P uptake by crops with and without added P as a percentage of the applied P by difference method. The crop taken up P in which partly comes from freshly-applied P and partly from residual P in the soil from previous applications. Replacing the P taken up from residual P (to prevent P mining and loss of soil fertility) is an integral part of the efficient use of an application of P fertilizer. So, among difference methods the balance method is preferable. The amount of soil was 15.39 and 16.70 lack kg soil per hectare in AEZ 14 and 20, respectively. On the other hand, the amount of available P was 103.42 and 141.49 kg in AEZ 14 and 20, respectively. Paddy can uptake 24.39 kg P per each crop (Kamrunnahar et al., 2016).

Phosphorus fertilizers are seldom applied for rice, despite the fact that P removal from the soil continues due to intensive cultivation. According to Ali et al. (1997), available P in many soils of Bangladesh was decreased substantially in 1995 than in 1965. Major plant nutrients significantly influenced nutrient concentration in grain and straw via nutrient uptake. Biomass production is directly related to nutrient uptake. Straw accounted for approximately 87 percent of total K uptake, making it an excellent source of K for rice cultivation.

In extract solution, phosphorus content was 8.43 ppm P when P solution was 6 ppm. On the other hand, 25 ppm solution P at that time of P contains 10.7 ppm P. Rice crop uptake 9 ppm phosphorus on average. So, if we can use the mean value of 40 kg P per is all right for rice production 20 ppm can absorbed

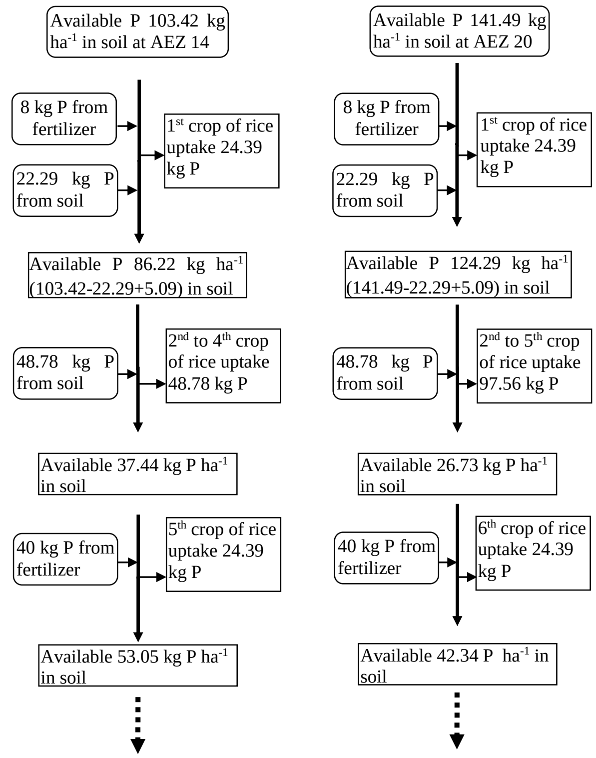


Figure 5. Conceptual model for effective phosphate fertilizer management during rice cultivation

In soil. So, 40 kg P ha^{-1} can get the optimum yield of rice for each season. According to the thumb rule phosphorus use efficiency is 30% for rice production. Paddy can uptake 2.91 kg P from the applied triple super phosphate (TSP) fertilizer, and the rest 5.09 kg P per ha is ready to available for the next crop. Phosphorus saturation indices were demonstrated a far below the threshold critical limit of 25%. As a result, there is no possibility of P losses due to leaching and surface runoff because the critical level has been exceeded.

Conclusion

For the sustainable management of phosphorus, it is important to understand the behavior of P in agro-ecosystems. The results showed that the concentration of P in the solution had a significant impact on P adsorption/desorption. Phosphorus sorption increased significantly as solution P concentration increased (8, 16, 25, 50, 100, 150 µg P ml^{-1}) in both AEZ 14 and AEZ 20 soils. On the other hand, P desorption increased as the concentration of P in the solution decreased. The maximum sorption was obtained in a solution containing 150 µg P ml^{-1}, while the maximum desorption was observed in a solution containing 1 µg P ml^{-1}.

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Conflict of interest

The authors declare there is no conflict of interest.

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