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DECREASING PHOSPHOROUS SORPTION USING FISHPOND SEDIMENT AND GOAT MANURE IN ACID UPLAND SOIL

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ABSTRACT

Fishpond sediment and fishpond water at Petir village, Darmaga, Bogor, Indonesia have the potential as a soil ameliorant due to the nutrient content needed by crops. This present research sought to evaluate the phosphorus (P) sorption characteristics on acid soil Typic Hapludults Darmaga treated with fishpond sediment, fishpond water, goat manure and their combination, as well as conventional fertilizers. The research was conducted from March to August 2015. The treated soil samples were incubated for 1 week and 2 weeks under room temperature. The experimental design was completely randomized design with three replications. After 1 week or 2 weeks of incubation, soil samples from treatments were subjected to P sorption experiment. The data were simulated by Langmuir and Freundlich equations, wherein data was better simulated by the Freundlich equation. The Freundlich P sorption capacity (K_F) value from the combined fishpond sediment and goat manure treatment was the lowest after 1 week and 2 weeks of incubation. This treatment had a significantly higher n value than that of control after 1 week of incubation, however after 2 weeks incubation, the n value was not significantly different from the other treatments. From the K_F and n values of Freundlich equation, it was suggested that a combination of fishpond sediment and goat manure was the best treatment needed to decrease P sorption capacity. The decrease of P sorption capacity should decrease the rate of P fertilizer applied by farmers.

Keywords: bonding energy, capacity, Freundlich, soil ameliorant

INTRODUCTION

Fresh water flowing from Mt. Salak, Bogor, Indonesia is used by farmers for their agriculture lands and their fishponds containing fresh water fishes (Hartono et al. 2016). This is very typical situation wherein farmers integrate both agriculture and aquaculture in an upstream area. Farmers also raise goats for their cattle. This integrated farming system produces agricultural waste, such as fishpond sediment, fishpond water, and goat manure. Nitrate and phosphate contaminate rivers and accumulate in Jakarta Bay causing algal bloom and death of fishes due to the lack of oxygen (Arifin 2004). Agricultural activities in the upstream contributes to the nitrate and phosphate accumulation in Jakarta Bay. Feeding fish in ponds with pellets and chicken manure may contribute to the accumulation of organic matter, nitrogen (N), and phosphorus (P). Thirty to ninety-five percent of N applied in fishponds accumulate in the sediment (Olah et al. 1994), while most P applied in fishponds also accumulate in sediments (Boyd 1995). One way to decrease nitrate and phosphate contamination in a river is to return them back to agricultural fields wherein they shall be absorbed by crops.

The application of fishpond sediment and fishpond water improved some important chemical properties, including P availability, and increased sweet potato production in Petir village, Darmaga, Bogor (Hartono et al. 2016). Indonesian upland soil consists of about 75% of total land area of the country, with most of them distributed in western Java, Sumatra, and Kalimantan. About 57% of these upland soils are acidic (Subagyo et al. 2000). Acid upland soils in Indonesia in generally exhibit a low nutrient status, which includes P (Hartono et al. 2005). Therefore, P fertilizer application is recommended to overcome low total and available P.

In developing countries like Indonesia, P fertilization efficiencies are absolutely important due to the lack of funding for fertilization, especially in subsistence farmers. P sorption capacity and P bonding energies in acid upland soils were relatively high (Hartono et al. 2005). They were positively correlated to the content of amorphous and crystalline forms of iron (Fe) and aluminum (Al) oxides as reported by other research (Mokwunye 1975, Juo and Fox 1977, Van der Zee and Riemsdijk 1988, Agbenin and Tiessen 1994, Beauchemin and Simard 2000, Dodor and Oya 2000, Dubus and Becquer 2001, Maguire et al. 2001, Henry and Smith 2002, Bertrand et al. 2003, Hartono et al. 2005). These Fe and Al oxides adsorb P in solution making it unavailable to the plant.

The application of soil ameliorants, such as organic matter, decreased soil P sorption maxima and P bonding energies by blocking P sorption sites in the soil (Iyamuremye et al. 1996, Sui and Thompson 2000). Fishpond sediment and fishpond water have clearly improved soil chemical properties, as well as sweet potato production in Petir village, Darmaga, Bogor (Hartono et al. 2016). In oher research, fishpond sediment increased P absorption of morning glory plant (Rachman and Yakupitiyage 2006). However, the effects of fishpond sediment and fishpond water on soil P sorption capacity has not been investigated.

Therefore, it is important to investigate P sorption characteristics of soil together with fishpond sediment, fishpond water, goat manure, and their combination. This research sought to evaluate the decrease in P sorption capacity of acid soil added together with fishpond sediment, fishpond water, goat manure and their combination, as well as conventional fertilizers (Urea, Super phosphate containing 36% P_2O_5, and KCl).

MATERIALS AND METHODS

The study was conducted from March to August 2015. Fishpond sediment, fishpond water, and goat manure were collected from Petir Village, Darmaga, Bogor, Indonesia. Fishpond sediment collected was air-dried, crushed, and sieved using a 2-mm sieve while goat manure was also sieved with a 2-mm sieve.

Fishpond sediment used in this study was the same as the fishpond sediment used in previous research (Hartono et al. 2016). Fishpond sediment pH was 5.10 (slightly acid). Exchangeable Al was not detectable, so Al saturation was undetectable or zero. Organic C was 54.2 g kg^{-1}(very high), total N was 4.20 g kg^{-1} (medium), and available P content (Bray 1-P) was 14.9 mg P kg^{-1} (high). Potential P content or P extracted by 25% HCl (HCl 25%-P) was 32.5 mg P_2O_5 $100g^{-1}$ (medium). The soil cation exchange capacity (CEC) was 21.9 $cmol_c$ kg^{-1}(high). The Ca, Mg, K, and Na were 25.1 $cmol_c$ kg^{-1}, 9.12 $cmol_c$ kg^{-1}, 1.22 $cmol_c$ kg^{-1}, and 1.16 $cmol_c$ kg^{-1}, respectively, with all values categorized as high. The fishpond sediment base saturation was 167% (very high). As for fishpond water, there was 13.1 mg L^{-1} total inorganic nitrogen (TIN) and 0.22 mg PO_4^{3-} L^{-1}. For goat manure, the content of organic C and total N were 102 g kg^{-1} and 171 g kg^{-1}, respectively. Potential P of goat manure extracted by HCl 25%, which was close to total P, was 7,693 mg kg^{-1}.

Soil samples, namely B horizon of Typic Hapludults, were collected in Darmaga, Bogor, Indonesia. Soil samples were air-dried, crushed, and sieved using a 2-mm sieve. Soil property analysis

was conducted as described by Hartono et al. (2005) in the laboratory of the Department of Soil Science and Land Resource, Faculty of Agriculture, Bogor Agricultural University, Indonesia. Soil pH was determined by shaking the soil with aquadest (at a ratio of 1:5) for thirty minutes, then measured it with a pH meter (Eutech Instrumen type pH 2700). Total organic carbon (C) content was measured through the Walkley and Black method. Total soil N was measured using the Kjeldahl method. Available P was determined using the Bray 1 method (Bray and Kurtz 1945). Cation exchange capacity (CEC) was obtained by extraction using 1 mol $L^{-1}NH_4OAc$ at pH 7.0. Exchangeable calcium (Ca) and magnesium (Mg) content were determined by atomic absorption spectrophotometry (Shimadzu type AA-6300), while exchangeable potassium (K) and sodium (Na) content were determined by flame emission spectrophotometry (Corning type 405). Base saturation is the ratio of total exchangeable bases (Ca, Mg, K, and Na) to CEC, and is expressed as a percentage. Exchangeable aluminum (Al) was extracted through 1 mol L^{-1} KCl and measured by titrimetry. Clay content was determined by the pippete method (Sheldrick and Wang 1993). Soil physico-chemical were judged according to Soepraptohardjo et al. (1983).

Incubation experiments were conducted in a completely randomized design with three replications (Stanford and Smith 1972, Saito and Ishi 1987, Sano et al. 2004). Three hundred grams (300 g) of soil (oven-dry weight) was placed in a pot with nothing else added. For other pot set-ups, soil was prepared together with either fishpond sediment, or added with a combination of fishpond sediment and fishpond water, or added with a combination of fishpond sediment and goat manure, or added with goat manure only, or added with conventional fertilizers. Rates of fishpond sediment and fishpond water were based from previous research (Hartono et al. 2016). Rate of fishpond sediment was 33.3 ton ha^{-1}, fishpond water was 1111 L ha^{-1}, and that of goat manure was 8.30 ton ha^{-1}. As for conventional fertilizer, urea was 100 kg ha^{-1}, SP 36 (super phosphate containing 36% P_2O_5) was 100 kg ha^{-1}, and KCl was 200 kg ha^{-1}. Pots were incubated for 1 and 2 weeks at room temperature. Pot water content was maintained at 80% water holding capacity.

After each period of incubation, the sorption experiment was conducted. P sorption data were obtained based from the procedure described by Fox and Kamprath (1970) and Hartono et al. (2005). Duplicate samples weighing 3 g (< 2 mm) obtained from each of the 30 samples were equilibrated in 30 mL of 0.01 mol L^{-1} $CaCl_2$ containing P at various concentrations (0 – 300 mg L^{-1}) in the form of KH_2PO_4 for 6 days at 25° C. The suspension was shaken for 30 minutes twice daily. At the end of the equilibration period, soil suspensions were centrifuged at 1400*G* for fifteen minutes and then filtered (filter paper No. 6, Advantec Toyo, Tokyo, Japan). The amount of P in the supernatant solution was determined based from the procedure described by Murphy and Riley (1962). Absorbance at 693 nm was measured using a UV-VIS spectrophotometer (UV-1280, UV-VIS Spectrophotometer, Shimadzu Corporation, Japan). The amount of P sorbed by the soils was calculated as the difference between the amount of P added and the amount of P remaining in solution. Since P sorption usually varies with pH, experiments were conducted at soil pH values that were naturally-occurring. The P sorption data were fit into the linear form of the Langmuir equation, as described below, to determine the maximum sorption capacity and bonding energy.

$$c/q = c/b + 1/K_L b$$

Where, c = the equilibrium concentration of P in soil solution (mg L^{-1}), q = the quantity of P sorbed per unit mass of sorbent (mg kg^{-1}), b = P sorption maximum (mg kg^{-1}), K_L = a constant related to the bonding energy of sorption (L mg^{-1}).

The P sorption data were also fit into the linear form of the Freundlich equation, as described below, to determine the Freundlich constant.

$$\text{Log } q = \log K_F + 1/n \log c$$

Where, c = the equilibrium concentration of P in soil solution (mg L^{-1}), q = the quantity of P sorbed per unit mass of sorbent (mg kg^{-1}), K_F = a constant related to P sorption capacity, and n = a constant.

Statistical analysis

Statistical analyses was conducted to evaluate the effect of each treatment on the P sorption parameters. Such tests include ANOVA followed by Tukey's test.

RESULTS AND DISCUSSION

Physico-chemical properties of the acid soil

The status of soil physico-chemical properties was judged accordng to Soepraptohardjo et al. (1983), with the criteria presented in Table 1. On the other hand, the physico-chemical properties of the soil and their status are presented in Table 2. Soil pH was very acidic (pH H_2O =3.5). Organic C, total N, and available P were 1.07 mg kg^{-1}, 1.10 mg kg^{-1}, and 6.50 mg kg^{-1}, respectively. All values were catagorized of low status, indicating low soil fertilization. Exchangeable Ca was 1.84 cmol kg^{-1} (very low), exchangeable Mg was 1.53 cmol kg^{-1} (medium), exchangeable K was 0.28 cmol kg^{-1} (low), and Na was 0.38 cmol kg^{-1} (low). Cation exchange capacity was 28.6 cmol kg^{-1} (high) while base saturation was 14.1% (very low). Al saturation was 81.5% (very high). Soil texture was clay because clay content was more than 40%.

Table 1. Criteria of nutrient status of soil fertility (Soepraptohardjo et al. 1983).

Chemical properties	Very low	Low	Medium	High	Very high
Organic C (g kg^{-1})	< 10.0	10.0-20.0	20.1-30.0	30.1-50.0	> 50.0
Total N (g kg^{-1})	< 1.00	1.00-2.00	2.10-5.00	5.10-7.50	> 7.50
HCl 25 %-P (mg P_2O_5 $100g^{-1}$)	< 10.0	10.0-20.0	21.0-40.0	41.0-60.0	> 60.0
Bray 1-P (mg P kg^{-1})	< 4.40	4.41-7.00	7.10-10.9	11.0-15.3	> 15.3
CEC ($cmol_c$ kg^{-1})	< 5.00	5.00-16.0	17.0-24.0	25.0-40.0	> 40.0
Basic cations:					
K ($cmol_c$ kg^{-1})	< 0.10	0.10-0.20	0.30-0.50	0.60-1.00	> 1.00
Na ($cmol_c$ kg^{-1})	< 0.10	0.10-0.30	0.40-0.70	0.80-1.00	> 1.00
Mg ($cmol_c$ kg^{-1})	< 0.40	0.40-1.00	1.10-2.00	2.10-8.00	> 8.00
Ca ($cmol_c$ kg^{-1})	< 2.00	2.00-5.00	6.00-10.0	11.0-20.0	> 20.0
Basic Saturation (%)	< 20.0	20.0-35.0	36.0-50.0	51.0-70.0	> 70.0
Aluminium Saturation (%)	< 10.0	10.0-20.0	21.0-30.0	31.0-60.0	> 60.0
pH (H_2O)	Acid	Slightly acid	Neutral	Slightly alkaline	Alkaline
	4.50-5.50	5.60-6.50	6.60-7.50	7.60-8.50	> 8.50

These physico-chemical properties, as shown in Table 2, indicate that the soil was acidic and low in essential soil nutrients, which are very common in Indonesian acid upland soil. As for P, the low available P content of indicated that P fertilization in this acid soil was low, and it is important to increase P fertilization efficency. The low content of available P in a very acid environment with high aluminum content can also be the cause by the high P fixing capacity of the soil (Hartono et al. 2005).

Table 2. Physico-chemical properties of the soil used and their status.

Soil properties	Values	Status
pH (1:5) H_2O	3.50	Very acidic
Organic C (mg kg^{-1})	1.07	Low
Total N (mg kg^{-1})	1.10	Low
Bray 1-P (mg kg^{-1})	6.50	Low
Exchangeable Ca ($cmol_c$ kg^{-1})	1.84	Very low
Exchangeable Mg ($cmol_c$ kg^{-1})	1.53	Medium
Exchangeable K ($cmol_c$ kg^{-1})	0.28	Low
Exchangeable Na ($cmol_c$ kg^{-1})	0.38	Low
Cation exchange capacity (CEC) ($cmol_c$ kg^{-1})	28.6	High
Base saturation (%)	14.1	Very low
Aluminum saturation (%)	81.5	Very high
Clay content (%)	51.5	-

Effect of different treatments on P sorption characteristics after 1 weeks incubation

After 1 week of incubation, P sorption data was simulated using both Langmuir and Freundlich equations. The R^2 values of Langmuir equation ranged from 0.805 to 0.904, while those from Freundlich equation ranged from 0.914 to 0.999. Thus, the Freundlich equation was better than Langmuir equation to simulate P sorption for this experiment. From linear forms of both Langmuir and Freundlich equations, parameters of P sorption were obtained (Table 3). P sorption maxima from Langmuir (b) for all treatments were the same (5000 mg P kg^{-1}). Thus, there was no significant difference among b values per treatment. Bonding energies based from Langmuir equation (K_L) were not statistically different either. As for P sorption parameters from Freundlich equation (Table 3), treatments containing fishpond sediment, a combination of fishpond sediment and fishpond water, goat manure only, a combination of fishpond sediment and goat manure, and conventional fertilizer had K constants (K_F) from Freundlich equation lower than the control. Decreased K_F values indicate that the P sorption capacity of the soils decreased and had an implication that the addition of P would be more available. Among the treatments, the combination of fishpond sediment and goat manure had the significantly lowest K_F value.

Table 3. Parameters of Langmuir and Freundlich equations after 1 week incubation.

Treatments	Langmuir			Freundlich		
	b (mg kg^{-1})	K_L (L mg^{-1})	R^2	K_F	n	R^2
Control	5000a	0.49a	0.887	1374a	1.35a	0.952
Fishpond sediment	5000a	0.47a	0.891	1331b	1.39ab	0.979
Fishpond sediment and fishpond water	5000a	0.49a	0.904	1319b	1.39ab	0.978
Goat manure	5000a	0.41a	0.837	1253c	1.34a	0.965
Fishpond sediment and goat Manure	5000a	0.52a	0.884	1229d	1.45c	0.982
Conventional fertilizer	5000a	0.56a	0.805	1322b	1.40bc	0.979

Means followed by the same letter within a column have no significant difference (Tukey`s test, $P < 0.05$)

As for the n constant from Freundlich equation (Table 3), treatments consisting of fishpond sediment, a combination of fishpond sediment and fishpond water, goat manure only, a combination of

fishpond sediment and goat manure, as well as conventional fertilizer had an n constant from Freundlich (K_F) equation higher than the control. Higher n values result in a lower P sorption capacity, wherein the combination of both fishpond sediment and goat manure had the highest n value. The combination K_F value and n value resulted in a curve as shown in Figure 1. The Freundlich curve for the combination of both fishpond sediment and goat manure was in the lowest position among the other treatment curves (Fig. 1). Therefore, after 1 week of incubation, the treatment consisting of a combination of both fishpond sediment and goat manure was the best in decreasing P sorption capacity.

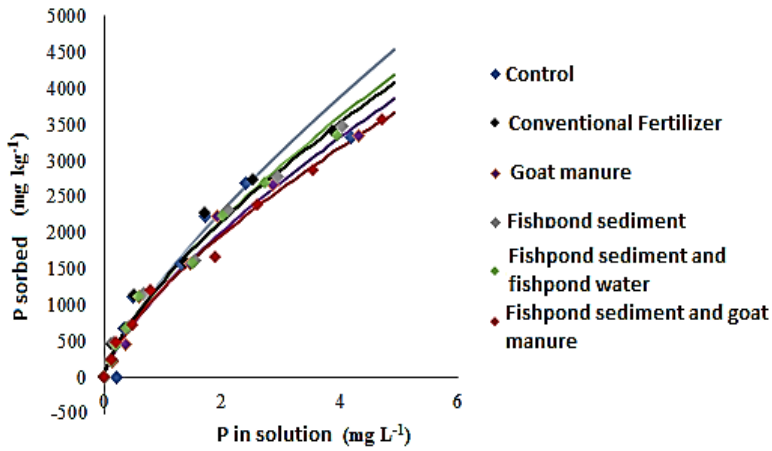
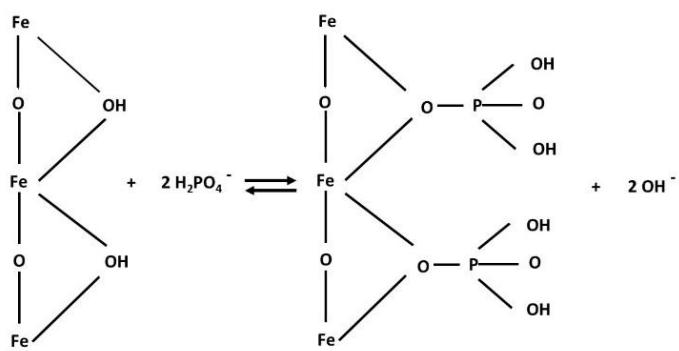


Fig. 1. P sorption data distribution and their Freundlich sorption curves after 1 week incubation.

The decrease of P sorption capacity was due to the anions in fishpond sediment, fishpond water, goat manure, and in conventional fertilizers. These anions, like anions from P, N, and organic acids, block P sorption sites and increase the P content in soil solution (Iyamuremye et al. 1996, Hartono et al. 2005). For example, the anion $H_2PO_4^-$ from fishpond sediment, fishpond water, goat manure or SP 36 fertilizer blocks the P sorption sites of Fe oxide by ligand exchange, as shown below (Bohn et al. 1979):



P sorption sites of Fe oxide were blocked by anions because the added P was in the soil solution, as well as P sorption sites were partly surrounded by anions from the different treatments.

Effect of different treatments on P sorption characteristics after 2 weeks incubation

P sorption parameters from both Langmuir and Freundlich equations after 2 weeks of incubation (Table 4) were compared with from 1 week incubation (Table 3). The bonding energies from Langmuir (K_L) equation after 2 weeks incubation were lower than those values after 1 week of incubation. Although the difference was not statistically significant, treatments containing fishpond sediment, both fishpond sediment and goat manure, and conventional fertilizer tended to decrease

bonding energies for P sorption.

Table 4. Parameters of Langmuir and Freundlich equations after 2 weeks incubation.

Treatments	Langmuir			Freundlich		
	B (mg kg^{-1})	K_L (L mg^{-1})	R^2	K_F	n	R^2
Control	5000a	0.33a	0.858	1354a	1.43a	0.980
Fishpond sediment	5000a	0.29a	0.856	1252b	1.29b	0.944
Fishpond sediment and fishpond water	5000a	0.30a	0.937	1251b	1.43a	0.993
Goat manure	5000a	0.30a	0.958	1250b	1.41a	0.985
Fishpond sediment and goat manure	5000a	0.29a	0.827	1195c	1.40ab	0.972
Conventional fertilizer	5000a	0.29a	0.903	1261b	1.32b	0.944

Means followed by the same letter within a column are not significantly different (Tukey`s test, $P < 0.05$)

Using Freundlich equation, K_F values at 2 weeks incubation were lower than the K_F values after 1 week of incubation. All treatments had K_F values that were significantly lower than the control. The low soil K_F indicated that there was a decrease in P sorption capacity from the soils. Among the treatments, the combination of fishpond sediment and goat manure had the significantly lowest K_F value. After 2 weeks incubation, there was no significant increase in n value among treatments. There was no significant difference in value between the control and the treatment containing both fishpond sediment and goat manure. However, K_F and n values from the combination of fishpond sediment and goat manure had the lowest P sorption curve at 2 weeks of incubation (Fig. 2). Therefore, the combination of both fishpond sediment and goat manure was considered the best treatment in decreasing P sorption capacity at 2 weeks incubation.

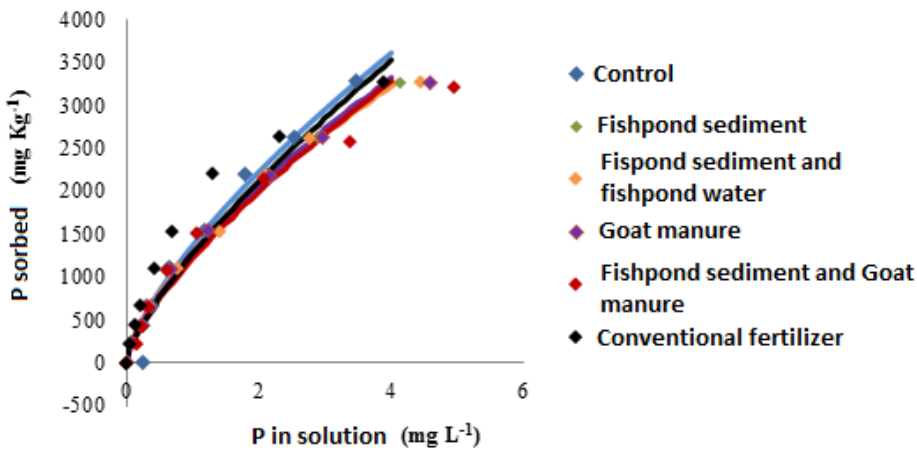


Fig. 2. P sorption data distribution and their Freundlich sorption curves after 2 weeks incubation.

Longer incubation time increased the mineralization of P, N, and organic matter in fishpond sediment, fishpond water, and goat manure, blocking more P sorption sites (Iyamuremye et al. 1996). The blocking of P sorption sites caused the increased P in soil solution.

CONCLUSION

The Freundlich equation presented lower K_F values for treatments that include fishpond sediment, fishpond water, goat manure, and their combinations. This indicates that these treatments decreased P sorption capacity of acid soil Typic Hapludults Darmaga, Bogor. The combination of fishpond sediment and goat manure had the lowest K_F of Freundlich equation. Therefore, this was the best treatment for decreasing P sorption capacity in acid upland soil.

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