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Adsorption and release of soil P in andisols under organic and conventional vegetable farming system

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Abstract

Phosphorous (P) is strongly adsorbed by soil components, such as soil organic matter and soil amorphous minerals in Andisols, which have been identified as an influential factor in adsorption and release of soil P. The aim of this study was to characterize the pattern of soil P adsorption and release in both organic and conventional vegetable farming systems in Merbabu Mountain area, Indonesia. Soil samples were collected from soil layers (0 cm to 20 cm and 20 cm to 40 cm) in organic and conventional farming systems. The result showed that the highest adsorption rate was found in organic farming systems at a depth of 20 cm to 40 cm. The lowest adsorption rate was found in conventional farming systems with low input of organic matter at a depth of 20 cm to 40 cm. A higher rate of P release was also found in organic farming systems with a low input of organic matter. It can be concluded that vegetable soils in organic farming systems are not only highly capable of adsorbing P but also capable of releasing P rapidly.

INTRODUCTION

Phosphorus is an essential nutrient needed by plants. The total amount of P in mineral soils, on average, is greater than the amount of nitrogen but much lower than that of potassium, calcium, or magnesium (Liu et al., 2017). A low P availability is often found in soils developed from volcanic materials, such as Andisols (Hanudin et al., 2014). If the soluble P source in the form of fertilizer is given to Andisols, P would often be adsorbed strongly by soil particles and clay minerals, and it is difficult to be released back into the soil solution, thereby causing a low efficiency of P uptake by plants (Zhu et al., 2018; Bortoluzzi et al., 2015; Van et al., 2017).

Andisols generally have a high soil organic matter content ranging from 5 – 8% (Yang et al., 2019). A Soil organic matter is also a critical component that affects the adsorption and release of P in the soil through numerous mechanisms (Ahmed et al., 2021). Several researchers have proven that organic matters tend to increase the soil ability to release P, which is then adsorbed by clay particles, Al and Fe cations, and allophane in Andisols (Yan et al., 2013; Gerard, 2016; Wang and Liang, 2014; Wang et al.,2012).

Hiradate and Uchida (2004) reported an increase in the quantity of P adsorbed by the soil when organic matter was removed from Andisols, meaning that the organic matter occupies a site that can adsorb P. However, organic matter also exhibits contradictory effects on the adsorption and release of P in the soil. The results of the research by Debicka et al. (2016) showed that the removal of organic matter could reduce the P adsorption capacity and increase the release of P in most of the topsoil.

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Lately, most vegetable farmers are encouraged to apply organic matter to increase soil fertility and crop yields, and some of them change their vegetable farming into organic farming systems. Organic farming system prioritizes the concept of sustainable ecology using organic matters (Budiasa, 2014). However, the organic matter added to Andisols by farmers varies widely in terms of quantity and quality, which may change the soil P adsorption and release patterns. This study aimed to examine the effects of organic matter addition on soil properties and P adsorption and release patterns in Andisols under organic and conventional (with high and low organic matter input) vegetable farming systems using the P adsorption isotherm curve.

MATERIALS AND METHODS

Study sites, soil sampling, and soil analysis

The study was conducted from July to December 2018. Soil sampling was carried out three days in July 2018, three months after the addition of organic matter, using random sampling method. Soil samples were collected at a depth of 0 – 20 cm and 20 – 40 cm from the three vegetable farms based on their farming systems, which were organic farming (O), conventional farming with high organic matter input (K1), and conventional farming with low organic matter input (K2). Each farming system was represented by five farms located close to each other. Two soil samples as much as 5 kg were taken from each farm to be analyzed for their chemical and physical properties.

The farm with K1 farming system is located in the Magelang Regency area, while the farms with O and K2 farming systems are located in the Semarang Regency, Indonesia. The altitude and the mean temperature of the O, K1, and K2 farms are ± 1402 m asl and ± 23.3°C, ± 1346 m asl and ± 21.5°C, and ± 1378 m asl and 24.8°C, respectively. The common vegetables grown in the farms are cabbage, broccoli, chilies, leeks, green beans, parsley, bok choy, cabbage, tobacco, and tomatoes. The farmers added organic matter into the soil by placing it at a hole of 5 cm at a distance of 7–10 cm beside the plant, then covering it with a small amount of soil. The organic matters added in O farming system were 10 $ton.ha^{-1}$ of cow dung and 25 liter of liquid organic fertilizer four times per year and plant litter for each planting period. The organic matters added in K1 farming system consisted of 7 $ton.ha^{-1}$ of cow dung, 15 liter of liquid organic fertilizer four times per year, plant residue per planting period, and 0.05 $ton.ha^{-1}$ of Urea and NPK (16:16:16) four times per year. Meanwhile, the organic matters added in K2 farming system were 3 $ton.ha^{-1}$ of chicken manure, 0.05 $ton.ha^{-1}$ of ZA, 0.05 $ton.ha^{-1}$ of KCl, and 0.05 $ton.ha^{-1}$ of NPK compound fertilizer (16:16:16), given three times per year.

The physical and chemical properties were observed. Soil samples with a size of 2mm and 0.05 mm were used to analyze pH H_2O, pH KCl, and pH NaF using the electrometric method. The soil organic C analyzed gravimetrically using a muffle furnace, CEC was observed using ammonium chloride method, available P was analyzed using Bray I method, bulk density was observed using pycnometer method, soil texture was analyzed using pipetting method, P adsorption was analyzed using $CaCl_2$ extract 0.01 M (Balai PenelitianTanah 2009), and P release was analyzed using 25 ml NaCl (Yang et al., 2019). Soil samples were analyzed in the Laboratory of Soil Science, Faculty of Agriculture, UGM. The data were analyzed with ANOVA using GenStat 11.1.2008. The data showing a significant difference were then tested using the Least Significant Difference (LSD) test to determine significant treatments.

P adsorption and P release experiment

The experiment of P adsorption and release was carried out following the procedure described by Yang et al. (2019). P adsorption experiment was completed before the P release experiment was done. The P adsorption and P release isotherm were estimated by Langmuir and Freundlich equation. The Langmuir equation is $C/Q = C/Q_m + 1/kQ_m$. The Freundlich equation is $Q = aC^{1/n}$, where Q ($mg.kg^{-1}$) is the amount of P adsorbed at the equilibrium P at C concentration, Q_m ($mg.kg^{-1}$) is the maximum amount of P adsorbed to the soil, and k ($L.mg^{-1}$) is a constant related to the binding strength of P at the adsorption sites. Meanwhile, $k{\cdot}Q_m$ is the maximum adsorption buffering capacity (MBC, $L.kg^{-1}$). Desorption can be described using the Langmuir equation ($C/D = C/D_m + 1/kD_m$) and the Freundlich equation ($D = aC^{1/n}$) (Wang et al., 2011), where D ($mg.kg^{-1}$) is the amount of P desorbed from the soil at the equilibrium P concentration C ($mg.L^{-1}$), k ($L.mg^{-1}$) is a constant related to the desorbing strength, and Dm ($mg.kg^{-1}$) is the maximum amount of P desorbed.

RESULTS AND DISCUSSION

Chemical and physical properties of the soil

There was a significant effect of the farming system on the soil properties ($p \leq 0.05$) in terms of soil porosity content, CEC, and soil organic C content (Table 1). Soils in O and K1 farming systems had soil porosity values that were significantly different between depths, in which the higher values were found at the depths of 0–20 cm. The CEC value is affected by several factors, one of which is organic matter; high organic matter can affect the soil CEC (Zajícová and Chuman, 2019). The addition of organic matter increases the CEC value, which is also in line with the research of Suntoro (2003) stating that the decomposition of organic matter will release organic acids containing reactive functional groups. The difference in the values of soil porosity was suspected to be the effect of organic matter (Herencia et al., 2011).

Total P and available P

The content of available P varied depending on the farming systems, and the highest content of available P was found in the organic farming system (18.29 mg.kg^{-1}) at a depth of 0–20 cm (Figure 1a). In comparison to the content of available P, the highest content of total P in Andisols (Figure 1b) was found in organic farming systems (0.32%) at a depth of 0 20 cm (Oa). The results showed that there was a si nificant difference in the available P between the farming systems at the same depth, in which the K2 farming system showed the lowest available P content. In contrast to the content of available P, there was no significant difference in the total P content of the soils between the farming systems. A lot of Andisols in the agroecosystems contain a very high total P concentration (Stutter et al., 2012; Yang et al., 2019; Velasquez et al., 2016). The high content of total P and available P in organic farming systems is associated with the provision of organic matter, which produces organic acids, such as humic and fulvic acids, which play an important role in binding soil Al and Fe components, so that P becomes more available.

Adsorption and release of soil P

The results showed that the highest adsorption rate of P was observed in O farming system at the depth of 0–20 cm and 20–40 cm (Figure 2a), while the lowest one was found in K1 farming system at the depth of 0–20 cm and 20–40 cm (Figure 2b). It means that in the same amount of the dissolved P,

Table 1. Chemical and physical properties of soil under organic farming systems (O), conventional farming systems with high organic matter input (K1), and conventional farming systems with low organic matter input (K2)

Parameter	Depth (cm)	Farming systems		
		Organic farming (O)	Conventional agriculture with a high organic matter input (K1)	Conventional agriculture with a low organic matter input (K2)
Bulk Density (g.m^{-3})	0-20	0.91 b	0.96 a	0.97 a
	20-40	0.93 b	1.00 a	1.01 a
Porosity (%)	0-20	52.50 a	51.60 a	43.30 c
	20-40	50.70 ab	49.60 b	40.80 c
pH H_2O	0-20	5.00 b	5.20 ab	5.40 a
	20-40	5.10 b	5.20 ab	5.30 a
pH NaF	0-20	10.80 a	10.80 a	11.20 a
	20-40	10.80 a	10.90 a	11.20 a
CEC (cmol (+).kg^{-1})	0-20	24.30 a	21.60 b	20.10 b
	20-40	23.50 a	21.90 b	20.80 b
C organik (%)	0-20	6.71 a	5.70 a	4.27 b
	20-40	6.07 a	5.68 a	4.09 b

Remarks: Means followed by the same letters in the same soil characteristic show no significant difference ($P < 0.05$).

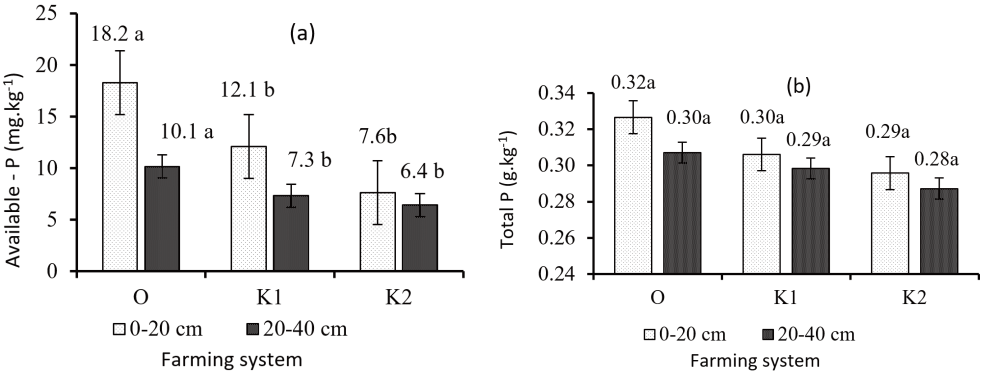

Figure 1. (a) Available P in organic farming systems (O), conventional farming systems with high organic matter input (K1), and conventional farming systems low organic matter input (K2), (b) Total P content in organic farming systems (O), conventional farming systems with high organic matter input (K1), and conventional farming systems low organic matter input (K2).Means followed by the same letters in the same soil property show no significant difference ($p < 0.05$).

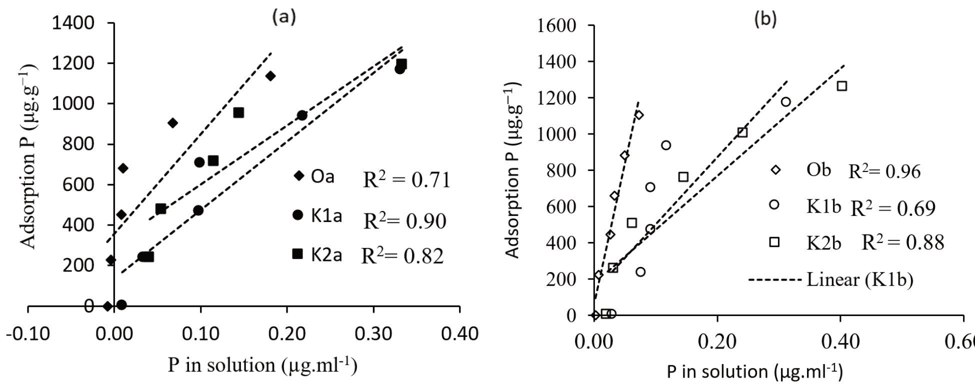

Figure 2. (a) The relationship between P adsorption and P in a solution at a depth of 0–20 cm in organic farming systems (Oa), conventional farming systems with high organic matter input (K1a), and conventional farming systems with low organic matter input (K2a), (b) the relationship between P adsorption and P in a solution at a depth of 0–20 cm in organic farming systems (Ob), conventional farming systems with high organic matter input (K1b), and conventional farming systems with low organic matter input (K2b), the concentration gradient of P was 0, 20, 40, 60,and 100 mg. L^{-1}.

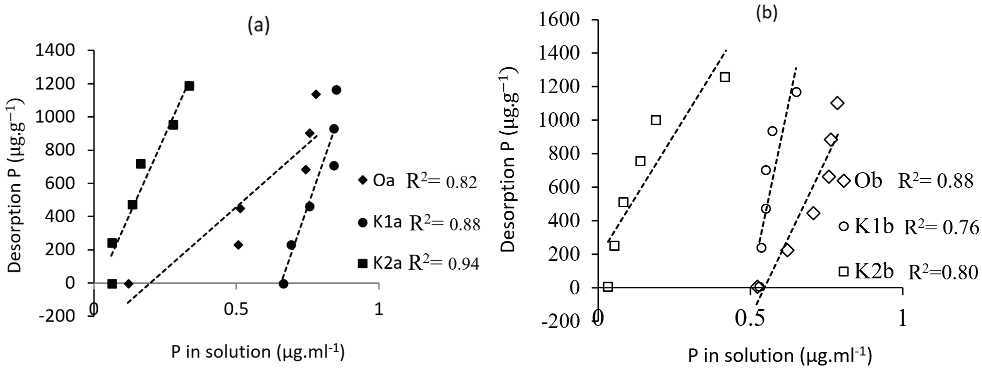

Figure 3. (a) The relationship between P release and P in a solution at a depth of 0–20 cm in organic farming systems (Oa), conventional farming systems with high organic matter input (K1a), and conventional farming systems with low organic matter input (K2a), (b) the relationship between P release and P in a solution at a depth of 0–20 cm in organic farming systems (Ob), conventional farming systems with high organic matter input (K1b), and conventional farming systems with low organic matter input (K2b), the concentration gradient of P was 0, 20, 40, 60,and 100 mg. L^{-1}.

the number of P adsorbed in O farming system was higher than in K1 and K2 farming systems. Compared to the soil in K2 farming system, the soil at the depth of 0–20 cm and 20–40 cm in O farming system showed a higher P release, both on the release axis and P (Figures 3a and 3b). This result means that at the same amount of dissolved P, the amount of P released in the O farming system was higher than in the K1 and K2 farming systems. The lowest P release was found in K2 farming system at the depths of 0–20 and 20–40 cm. Soil organic matter plays an important role in P accumulation in Andisols (Wu et al., 2017; and Dariah, 2014). This study shows a strong relationship between P in solution and a sorbed P. Soil under organic farming systems has the ability to adsorb higher value than P in solution both at the depth of 0–20 cm and 40 cm (Figure 2).

Phosphate adsorption and release equations

The highest maximum adsorption value (Q_m) was found in K2 farming system, followed by a maximum adsorption in K1 and O farming systems (Table 2). The O farming system showed a maximum release value (D_m) at a depth of 20–40 cm, namely 0.82 mg/g with the Langmuir equation (Table 3). From the regression equation in the Freundlich isotherm, it seems that the value of 1/n (slope) indicates the affinity or bond strength (intensity) in the adsorption (Kumari et al., 2017). According to Sukmawati (2011), the smaller bond value indicates the higher bond's energy in the adsorption. The P adsorption in organic farming system at the depth of 0–20 cm

Table 2. Equations of P adsorption in organic farming system, conventional farming system with high organic matter input, and conventional farming system with low organic matter input at different soil depth

Treatment Langmuir equation		Langmuir			Freundlich		
Farming systems	Depth (cm)	$C/Q= C/Q_m + 1/kQ_m$	R^2	Q_m (mg/g)	$Q=aC^{1/n}$	R^2	n
Organic farming	0–20	C/Q= 0.0009C+0.0034	0.97	1122.23	Q =0.0684C^0.2979	0.99	3.36
	20–40	C/Q= 0.0003C+0.00405	0.66	2858.35	Q=0.1935C^0.22766	0.98	4.39
Conventional agriculture with a high organic matter input	0–20	C/Q= 0.0005C+0.1301	0.83	2122.71	Q=0.37014C^0.1786	0.95	5.60
	20–40	C/Q= 0.0005C+0.1111	0.71	2081.03	Q=0.3621C^0.1765	0.87	5.66
Conventional agriculture with a high organic matter input	0–20	C/Q= 0.0004C+0.1840	0.89	2231.96	Q=0.4544C^0.1526	0.93	6.55
	20–40	C/Q= 0.0005C+0.1082	0.99	1861.38	Q=0.3269C^0.1962	0.99	5.10

Remarks: C-Concentration of phosphorus in equilibrium; Q-the amount of P adsorbed on the soil at the equilibrium phosphorus at C; Qm-The maximum phosphorus (P) adsorption capacity.

Table 3. Equations of P release in organic farming system, conventional farming system with high organic matter input, and conventional farming systems with low organic matter input at different soil depth

Treatment Langmuir equation		Langmuir			Freundlich		
Farming systems	Depth (cm)	$C/Q= C/D_m + 1/kD_m$	R^2	D_m (mg/g)	$Q=aC^{1/n}$	R^2	n
Organic farming	0–20	C/Q= 1.2769C+1.2037	0.99	0.78	Q=5.424C^11.3499	0.92	0.09
	20–40	C/Q= 4.0503C+1.2178	0.99	0.82	Q=-9.5680C^14.37	0.97	0.07
Conventional agriculture with a high organic matter input	0–20	C/Q= 1.3038C+11.3416	0.99	0.77	Q=0.0684C^0.2979	0.88	0.05
	20–40	C/Q= 1.4228C+36.665	0.99	0.70	Q=-13.5987C^10.76	0.99	0.09
Conventional agriculture with a high organic matter input	0–20	C/Q= 1.3990C+727.85	0.98	0.71	Q=-6.627C^4.4672	0.97	0.22
	20–40	C/Q= 1.9858C+830.0821	0.78	0.50	Q=-3.1835C^2.739	0.89	0.37

Remarks: Means followed by different letters within a column are significantly different at P < 0.05. Dm-the maximum release capacity of phosphorus (P).

Table 4. Correlation of Dm, Qm, and n with chemical and physical properties of soil under organic farming systems (O), conventional farming systems with high organic matter input (K1), and conventional farming systems with a low organic matter input (K2)

	Q_m	D_m	n	Org-C	CEC	Clay
Q_m	1					
D_m	0.211	1				
n	-0.134	-0.915	1			
Org-C	-0.207	0.776	-0.854	1		
CEC	-0.238	0.610	-0.615	0.921	1	
Clay	-0.202	-0.718	0.396	0.243	-0.196	1

showed the strongest bond energy, with a bond value of 3.36 compared to the conventional farming systems, indicating that organic matter competes with P to occupy the trapping site. The regression equation for Freundlich isotherm for the highest slope value was found in the organic farming system at a depth of 20–40 cm.

There was a very significant but inversely proportional relationship between n releases and the maximum release value with r^2 (-0.854) (Table 4). The smaller the bond value, the higher the bond energy released. There was a very significant inversely proportional relationship between organic C and n release with r^2 (-0.915), showing that the higher the organic matter, the lower the bond release value. This is indicated by the maximum adsorption value, which is higher compared to the maximum release. The rate of P release adsorbed in the soil depends on the chemical properties and strength of the bonds between phosphate and soil components (Guppy et al., 2005; Antelo et al., 2007; Badha et al., 2012).

CONCLUSIONS

Soils in organic farming systems have a higher ability to either adsorb or to release P rapidly by continuously applying organic matter compared to that in conventional farming systems. The organic and conventional farming systems have significant differences in several soil chemical and physical properties. However, the different depths did not exhibit significant differences between the three farming systems planted with vegetables. Based on the correlation between P in equilibrium solution and P adsorption and release (R^2), it is better to use the Freundlich equation in all farming systems. There was a very significant negative correlation between the value of D_m (maximum release) and n (bond energy) release. The higher the value of organic C, the lower the value of n (bond energy) in the release.

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