

Effects of organic-matter application on phosphorus adsorption of three soil parent materials

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Abstract

In this study, poultry manure compost and organic fertilizer were added to soils derived from basalt, granite, and river alluvial deposits for use as soil parent materials. Following incubation periods of 30 or 60 days at 25 °C, the physical and chemical properties and adsorption characteristics of the soils were studied. The results indicated that the application of poultry manure compost or organic fertilizer increased the available phosphorus (P) and organic matter content in all soils; however, the quantity of P and organic matter decreased with an increase in incubation time. The organic materials added via the treatments reduced the strength of P adsorption by the soil derived from basalt. For soils derived from granite and river alluvial deposits, the strength of P adsorption declined after poultry manure compost was added, but increased after the application of organic fertilizer. All soil treatments derived from basalt fitted well with the three adsorption isotherm equations. For soils derived from granite and alluvial deposit as parent materials, the data conformed to the three adsorption models in the order: Langmuir > Freundlich > Temkin. The maximum phosphate buffering capacity (MPBC) and standard P retention (SPR) of soil derived from basalt decreased following the application of poultry manure or organic fertilizer, whereas changes in MPBC and SPR for soils derived from granite and alluvial deposits were dependent on the organic content and incubation time.

Keywords: Soil, parent materials, organic matter, phosphorus adsorption strength, equation-fitting

1. Introduction

Phosphorus (P) is one of the most abundant elements and is essential for plant growth as well as an important component in the developmental processes of agricultural crops (Zhuo *et al.*, 2009a; Withers *et al.*, 2008). Approximately two-thirds of inorganic P and one third of organic P are not available in soil, especially in soils of variable charges. The rate of P use during crop growth is very low. Phosphates fixed by Fe, Al, and Ca in soils is a major cause of low phytoavailability (McBeath *et al.*, 2005), because at least 70–90% of P that enters the soil is fixed, making it difficult for plants to absorb and use (Kou *et al.*, 1999; Lei *et al.*, 2004; Liu *et al.*, 2000). Therefore, research by pedologists and plant nutritionists has primarily focused on the issue of increasing the P use-rate of plants, both at local and international scales. Resolving this issue is fundamental towards the continued development of agriculture.

Organic supplements have been reported to increase P availability in P-fixing soils (Iyamuremye and Dick, 1996; Guppy *et al.*, 2005; Agbenin and Igbokwe, 2006; Gichangi, 2009) and humic substances enhance the bioavailability of P fertilizers in acidic soils (Hua *et al.*, 2008). Decomposition products from manure such as humic acids and citrate were reported to have greater affinity for Al oxides than for PO₄ (Violante and Huang, 1989). Various researchers have investigated the activity of P in soil from the perspective of low-molecular-weight (LMW) organic acids, the incorporation of different organic fertilizers, and soil types. The addition of LMW organic acids activates Al-P and Fe-P in neutral and acidic soils and Ca-P in alkaline soil (Zhuo *et al.*, 2009b; Zhang *et al.*, 2009), causing an increase in the levels of readily-available P for use by plants. Ma *et al.* (2010) reported that the addition of straw during cultivation reduces P adsorption in red and paddy soils, but has a smaller effect on latosol. Bolster and Sistani (2009) studied the effects of swine, cattle, and poultry manure extracts on P adsorption in different soil types. The authors found that the P adsorption capacities of soils were

dependent on the type of organic fertilizer applied and the available soil type. Other studies have shown that when poultry, cattle, and goat manure are applied to highly weathered tropical soil, the P-sorption efficiency of the soil and P-buffering capacity decreased with an increasing incubation period (Azeez and Averbeke, 2011). Variations in organic products from supplements have also been reported to influence P sorption (Hue, 1991).

A number of models have been developed (Kinniburgh, 1986; McGechan and Lewis, 2002) to quantitatively describe the sorption isotherm, the most popular being the Langmuir (Pant and Reddy, 2001; Essington, 2003; Dossa, 2008) and the Freundlich equations (Donald, 2003; Essington, 2003). These studies have highlighted that P sorption can be explained quite satisfactorily by using different isotherm equations, but that no single equation can be considered suitable for all soil types. Little has been reported on the P sorption of soils fertilized with manure for different incubation periods.

In China, the soil of vegetable fields is an important component for the continuation of agricultural development. Due to the over-fertilization of vegetable fields over long periods, the nutritional content of these soils has become highly imbalanced and very different from that of normal agricultural soils. However, only few studies have been conducted on the soils in which vegetable crops are grown. Therefore, in this study, the three typical parent materials (basaltic, granitic, and river alluvial deposits) on which vegetable crops are grown in the Pearl River Delta of China were used as test materials. Through laboratory-based experiments, we studied the effects of adding different organic fertilizers, followed by an incubation period of 30 or 60 days, on the P adsorption activity of the three soil types. The findings of this study are expected to provide a theoretical basis for the rational application of organic fertilizers to these types of soil. Consequently, this

study was conducted to evaluate the effects of two organic fertilizer incubated periods of 30 or 60 days on the P-sorption indices of different parent materials.

2. Materials and Methods

2.1. Test Materials

Soils derived from basaltic, granitic, and alluvial parent materials were obtained from Zhanjiang City in Xuwen County, Guangzhou City in Huadu District, and Foshan City in Nanhai District, respectively. All soil types were composed of 0–20 cm topsoil. The soil samples were air-dried naturally and passed through a 2 mm sieve in preparation for use. The basic physical and chemical properties of the test materials are shown in Table 1. The measurements of pH, organic matter, total phosphorus and alkaline hydrolysable nitrogen were conducted according to the literature (Jackson, 1973). The available phosphorus was determined using the Olsen method (Olsen *et al.*,

1954). The measurement of free iron oxides was conducted with reference to Loppert and Inskeep (1996), and that of amorphous iron oxides, with reference to McKeague and Day (1966).

Two organic fertilizers were tested; specifically, poultry manure (M_1) and commercial organic fertilizer (M_2). The M_1 fertilizer was obtained from farmyard manure in Foshan City of Nanhai District, whereas M_2 (Zhuang Gen Bao refined organic fertilizer) was purchased commercially from the Fertilizer Industry Co. Ltd., Dongguan City. The test fertilizers were air-dried and passed through a 0.25-mm sieve before use. The physical and chemical properties of M_1 were pH = 8.02, total P = 1.65%, and available P = 9.55 g·kg⁻¹. The physical and chemical properties of M_2 were pH = 6.87, total P = 0.66%, and available P = 4.20 g·kg⁻¹. The pH of manure solutions was measured using an Orion combination pH probe (Thermo Electron Corp., Beverly, Mass.). Total P and available P were analysed in triplicate using ICP-OES.

Table 1. Baseline physical and chemical properties of the test materials.

Soil Parent Material	pH	Available		Organic Matter (g·kg ⁻¹)	Alkaline Hydrolysed Nitrogen (mg·kg ⁻¹)	Free Iron Oxide (g·kg ⁻¹)	Amorphous Iron Oxide (g·kg ⁻¹)	Total Amount (%)		
		P (Olsen- P) (mg·kg ⁻¹)	Total P (%)					Fe ₂ O ₃	MnO	Al ₂ O ₃
Basalt	4.50	7.93	0.05	26.62	160.46	10.58	2.18	20.43	0.11	25.43
Granite	6.34	161.81	0.16	30.64	186.76	8.74	2.06	3.00	0.04	17.51
Alluvium	6.19	66.58	0.18	20.48	130.16	8.50	1.48	4.79	0.02	10.70

2.2. Experimental Method

Treatment by the Addition of Organic Materials

Six samples (300 g each) of the soils derived from the three different parent materials were passed through a 2-mm sieve before being weighed and set aside. The M_1 or M_2 fertilizers were separately added to two samples from each of the three soil groups, with an additional two samples from each of the three soil groups serving as the control, in which no fertilizer was added (CK). Nine grams of M_1 and M_2 was added to each sample. After mixing, deionized water was added until 60% of field capacity was reached, and then the surface was covered using porous plastic films. Water was replenished every other day using gravimetric methods, to maintain the initial level. The samples were incubated at 25 °C for 30 or 60 days. After incubation, the soil samples were air-dried and passed through a 0.25-mm sieve before use.

Adsorption Test

For each soil sample, 1 g was accurately weighed and placed into 100-mL centrifuge tubes. Next, 20-mL of different concentrations of P solution containing 0.01 mol·L⁻¹ CaCl₂ was added, which served as a supporting electrolyte. The P concentration gradient was 0, 10, 20, 40, 60, 100, and 140 mg·L⁻¹. The samples were shaken for 24 h (180 r.p.m.) at a constant temperature of 25 °C, and then centrifuged and filtered. The P concentration of the supernatant was determined (Murphey and Riley, 1962), followed by the calculation of P-adsorption rates resulting from the different treatments. Adsorption isotherms were then plotted and fitted to the Langmuir, Freundlich, and Temkin equations. The experimental set was repeated three times. The Langmuir equation is given by $C/Q = 1/(kb) + C/b$. The Freundlich equation is given by $\log Q = 1/n \log C + \log k$ and the Temkin isotherm is applied in the following form $Q = A + B \ln C$.

2.3. Data Analysis

All data obtained from the experiments were analysed using SAS 6.12 statistical software. Significant treatments means were identified using the least significant differences (LSD) value at the 5% level of probability.

3. Results and Discussion

3.1. Changes in the Physical and Chemical Properties of the Test Materials

Table 2 shows the soil pH, Olsen-P, and organic matter content of the three soil types used in the different treatments, followed by 30- or 60-day incubation periods.

The pH of soil derived from basalt was significantly higher in the M_2 groups compared to the CK groups and the pH of soil derived from basalt was higher after the 60-day incubation than that after the 30-day incubation. For soils derived from granite and alluvium, the soil pH of the M_2 groups was significantly different to that of the CK groups. For both of these soil types, soil pH decreased significantly following M_2 treatment and 30-day incubation. After 60 days of incubation, the pH of soil from granite was significantly lower than that in the CK groups, whereas that from alluvium was significantly higher. The addition of M_2 followed by 30 or 60 days of incubation significantly increased the pH of both soil types.

The results show that addition of M_2 followed by 30 or 60 days of incubation increased the pH of soil derived from basalt. Furthermore, soil pH was higher after 60 days than after 30 days of incubation. The basalt-derived soil was strongly acidic; thus, the addition of the neutral and slightly alkaline M_2 partially alleviated soil acidity, but could not achieve neutrality. For soils derived from granite and alluvium, the addition of M_1 followed by 30 days of incubation reduced soil pH, whereas 60 days of incubation increased soil pH.

Table 2. Changes in the physical and chemical indices following organic matter application and incubation.

Soil Type & Treatment	pH		Olsen-P (mg·kg ⁻¹)		Organic Matter (g·kg ⁻¹)	
	30 days	60 days	30 days	60 days	30 days	60 days
Basalt + CK	4.28 f	4.32 e	5.32 e	5.73 e	24.28 d	23.89 d
Basalt + M ₁	4.77 d	4.81 c	76.66 a	72.32 b	29.79 ab	28.70 bc
Basalt + M ₂	5.02 b	5.11 a	24.63 c	21.48 d	27.90 c	30.34 a
F	903.21		5228.20		33.62	
Significance Level	0.0001		0.0001		0.0001	
Granite + CK	6.46 d	6.85 b	259.13 c	238.59 d	31.48 c	30.40 c
Granite + M ₁	6.36 e	6.60 c	425.47 a	361.28 b	37.84 a	35.13 b
Granite + M ₂	6.57 c	6.95 a	257.21 c	245.65 c	37.77 a	34.19 b
F	227.28		259.04		37.74	
Significance Level	0.0001		0.0001		0.0001	
Alluvium + CK	6.34 f	6.78 c	118.33 d	93.30 e	20.53 d	20.43 d
Alluvium + M ₁	6.25 e	6.84 b	260.74 a	227.04 b	24.51 b	22.36 c
Alluvium + M ₂	6.54 d	6.94 a	140.38 c	117.21 d	25.02 a	26.47 a
F	623.71		941.53		25.19	
Significance Level	0.0001		0.0001		0.0001	

Note: Significant differences between treatments at $p < 0.05$ levels are indicated by different lowercase letters within columns.

For all soil types, soil pH increased after the addition of M₂. Soil pH was also higher after 60 days of incubation than that after 30 days. These two soil types are neutral by nature. The high degree of mineralisation during the composting of M₁ produced humic acid and small organic acid molecules, which reduced the soil pH. For M₂, the low degree of mineralisation caused soil pH to either remain neutral or to increase. Overall, changes in soil pH after the addition of organic fertilizers were dependent on the pH of the different soil types, in addition to the pH and extent of mineralisation of the organic fertilizer.

The Olsen P content of the three soils derived from different parent materials was 7.93, 161.81, and 66.58 mg·kg⁻¹, respectively (Table 1). Table 2 shows that for the basaltic CK group, the level of available P decreased after 30 and 60 days of incubation, with a greater decrease after 30 days. This result indicates that between 30 and 60 days of incubation, the amount of available P increased by a small amount. In comparison, between the granitic and alluvial CK groups, the increase was greater after 30 days than 60 days. Although the amount of available P was lower at 60 days than at 30 days, the level was still higher than that in the early incubation period.

This result indicates that P-release was greater than adsorption for soil derived from granite and alluvium in the first 30 days of incubation; however, P adsorption was greater than the release between 30 and 60 days.

After the addition of organic fertilizers, available P was significantly higher in all treatment groups compared to the CK groups, with the exception of granite + M₂. Furthermore, the increase was greater in the M₁ compared to the M₂ groups. This difference might have been due to the relationship between available P and the different degree of mineralisation of M₁ and M₂. As the incubation time increased, available P decreased, with the decrease in the basaltic group being significantly smaller than that in other soil types. The granite + M₂ exception might have been due to the high base levels of available P in the soil, such that the addition of M₂ might have increased the number of sites, causing insignificant changes in the available P. Nevertheless, a small increase was still observed.

For all three soil types, the organic matter content did not change significantly for the CK groups between the start or after 30 or 60 days of incubation, indicating that soil mineralisation had a relatively small effect without organic material addition. For all treatment groups, there was a significant increase in organic matter content compared to the CK groups after the addition of organic materials at 30 and 60 days of incubation. The M₁ and M₂ groups showed similar increases in organic matter content. With the exception of the granite + M₂ and alluvium + M₂ treatment groups, the organic matter content of all other treatment groups after 30 days of incubation was higher than that after 60 days, which suggests that the mineralisation of organic matter occurs during the incubation process. This process might have lagged in the two treatment groups in which this effect was not recorded.

3.2. Changes in the P Adsorption of the Test Materials

Soil Derived from Basaltic Parent Material

The P-adsorption isotherms of soil derived from basalt

that underwent treatments followed by 30 or 60 days of incubation are shown in Figure 1. Supporting the general adsorption characteristics, the P adsorption of the soil samples increased as the initial P concentration increased at lower P concentrations, and then increased to a lesser extent at higher P concentrations.

The results indicate that adding different organic fertilizers followed by 30 and 60 days of incubation decreased the P adsorption of all soil samples from all treatment groups. Latosol is a typical acidic soil that derives from basaltic parent materials. This soil type is rich in iron and aluminum oxides, which have high degrees of crystallinity and high P-adsorption capacities. However, the addition of organic fertilizers reduces the P-adsorption capacity of latosol. There are several possible explanations for this phenomenon. Firstly, organic acids produced by the mineralisation of organic fertilizers might compete for adsorption with P, thereby reducing adsorption sites for P. Secondly, dissolved organic matter (DOM) produced via the mineralisation of organic fertilizers might cause soil to repulse phosphates more. Thirdly, the combination of organic fertilizers with iron and aluminum oxides in acidic soil might reduce the P-adsorption capacities of the oxides. Fourthly, the enveloping effects of organic fertilizers might reduce the P adsorption of the soil (Ma and Xu, 2010; Shariatmadari *et al.*, 2006; Hunt *et al.*, 2007)

Further investigation is required to confirm whether one of these factors was prevalent or whether several factors acted together. Overall, the addition of organic fertilizers reduced the P-adsorption capacity of soils derived from basalt, but did not affect the basic shape of the adsorption isotherms, i.e. an initial rapid increase in adsorption followed by a smaller increase.

3.3. Soil Derived from Granitic Parent Material

The P-adsorption isotherms of soil derived from granite that underwent treatments followed by 30 or 60 days of incubation are shown in Figure 2. The P adsorption of the soil samples increased as initial P

concentration increased. The adsorption isotherms showed a H-shaped increasing trend, with P adsorption reaching a plateau when the initial P concentration was about 40–100 mg•L⁻¹, but increased further beyond 100 mg•L⁻¹. The results indicate that adding M₁ followed by 30 or 60 days of incubation decreased the P adsorption of soil samples for all treatment groups, whereas adding M₂ followed by incubation led to a smaller increase in P adsorption.

In addition to the relatively weaker P-adsorption capacity of granite-derived soils, Table 1 shows that the granite-derived soils have a lower iron and aluminum oxide content compared to soil derived from basalt. The M₁ fertilizer is composed of organic matter that has been partially mineralised and mainly contains inorganic carbon. Thus, the addition of M₁ led to competition between the organic acids produced through mineralisation and P, thus reducing the P-adsorption capacity of the soil. In comparison, M₂ is mainly composed of non-decomposed organic carbon. Hence, the addition of M₂ increases the adsorption sites in soil, causing an increase in P adsorption. At the same time, mineralisation causes adsorption competition; hence, the magnitude of change is small. These results are consistent with those obtained by Zhao *et al.* (2006).

3.4. Soil Derived from Alluvial Parent Material

The P-adsorption isotherms of soil derived from alluvium that underwent treatments followed by 30 or 60 days of incubation are shown in Figure 3. The adsorption isotherm of the CK group after 30 or 60 days of incubation shows that P adsorption increased as the initial P concentration increased. This trend continued until the initial P concentration reached 60mg•L⁻¹, after which P adsorption decreased. Subsequently, P adsorption once more increased together with an increase in P concentration.

For the M₁ group, the adsorption isotherm was wave-shaped after 30 or 60 days of incubation. In this case, P adsorption rapidly increased as the initial P

concentration increased, then decreased, before once again increasing and decreasing. This might be due to the introduction of external P by the addition of M₁, which, together with the mineralisation of M₁, led to large fluctuations in the dynamic adsorption and desorption of P. For the M₂ group, the adsorption isotherm showed an initial increase in P adsorption as the P concentration increased, which then decreased briefly before increasing further after 30 and 60 days of incubation. This trend was also observed for the CK group.

These results indicate that although the addition of M₁ might have caused a decrease in the P adsorption of soil derived from alluvium, it caused large changes in the shape of the adsorption isotherm. In comparison, although the addition of M₂ did not cause large changes in the shape of the adsorption isotherm, it only produced a small increase in the P adsorption of the soil. This result might be due to the relatively weaker P-adsorption capacities of soil derived from alluvium. The addition of M₁, which has a high degree of mineralisation, increased competition for adsorption sites. In contrast, the addition of M₂ might have increased the number of adsorption sites in the soil, thereby increasing P adsorption.

The P adsorption of soil derived from basalt was higher than that of the other two soil types. This difference is closely related to the soil type, as well as to the physical and chemical properties of the soil. Previous studies have shown that soil pH, together with the iron and aluminum oxide content, significantly affects the P-adsorption capacity of soils. In this study, the different P-adsorption capacities of the soils derived from different parent materials were closely related to soil pH, in addition to iron and aluminum oxide content. Zhao *et al.* (2006) reported that for soils with a pH > 6.0, the organic matter in the soil increased P-adsorption, whereas for soils with a pH < 6.0, the organic matter decreased P-adsorption. Similar results were obtained in this study. Soil derived from basalt is acidic, whereas the other two soil types are neutral, with a pH > 6.0.

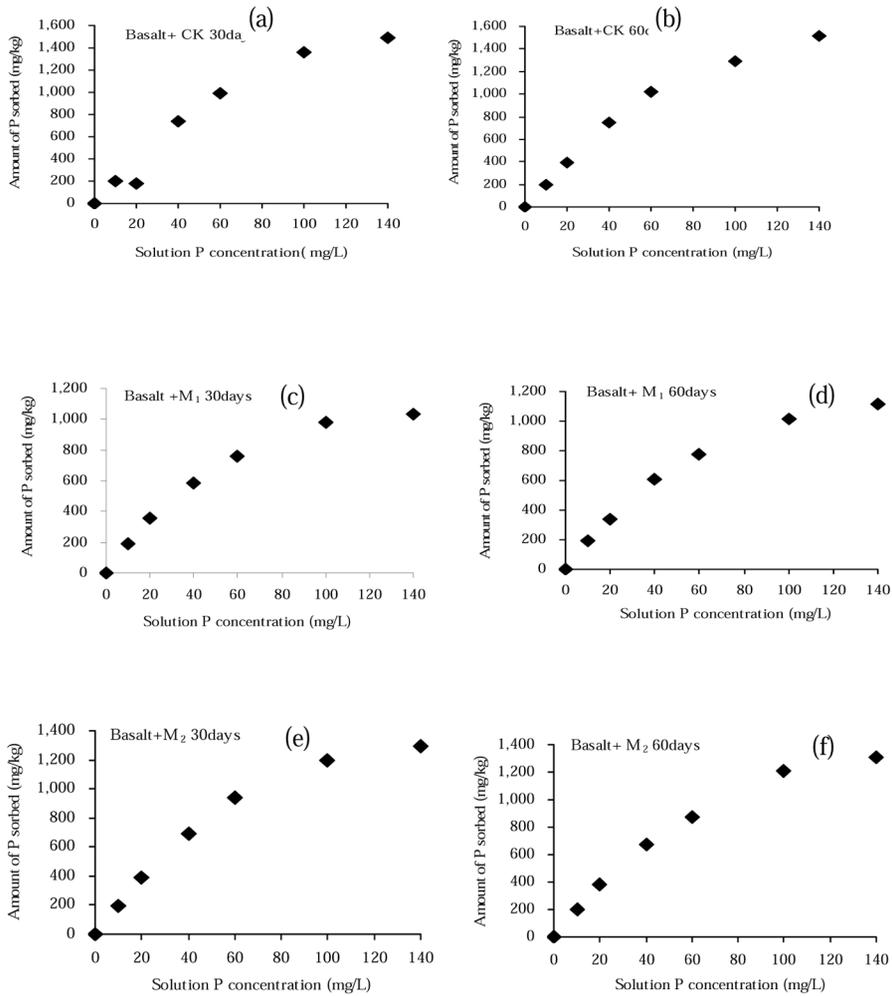


Figure 1. Adsorption isotherms of phosphorus on soil derived from basalt with organic matter application after incubation.

The addition of M₂ decreased the P-adsorption capacity of soil derived from basalt, but increased that of soil derived from granite and alluvium. The addition of M₁ decreased the P-adsorption capacity of all three soil types. This result might have been due to the mineralisation of M₁, causing a large part of

organic matter introduced to the soil to be transformed into organic acids. Adsorption competition from the organic acids was greater compared to the increase in adsorption sites, thereby causing a decrease in overall P-adsorption capacity.

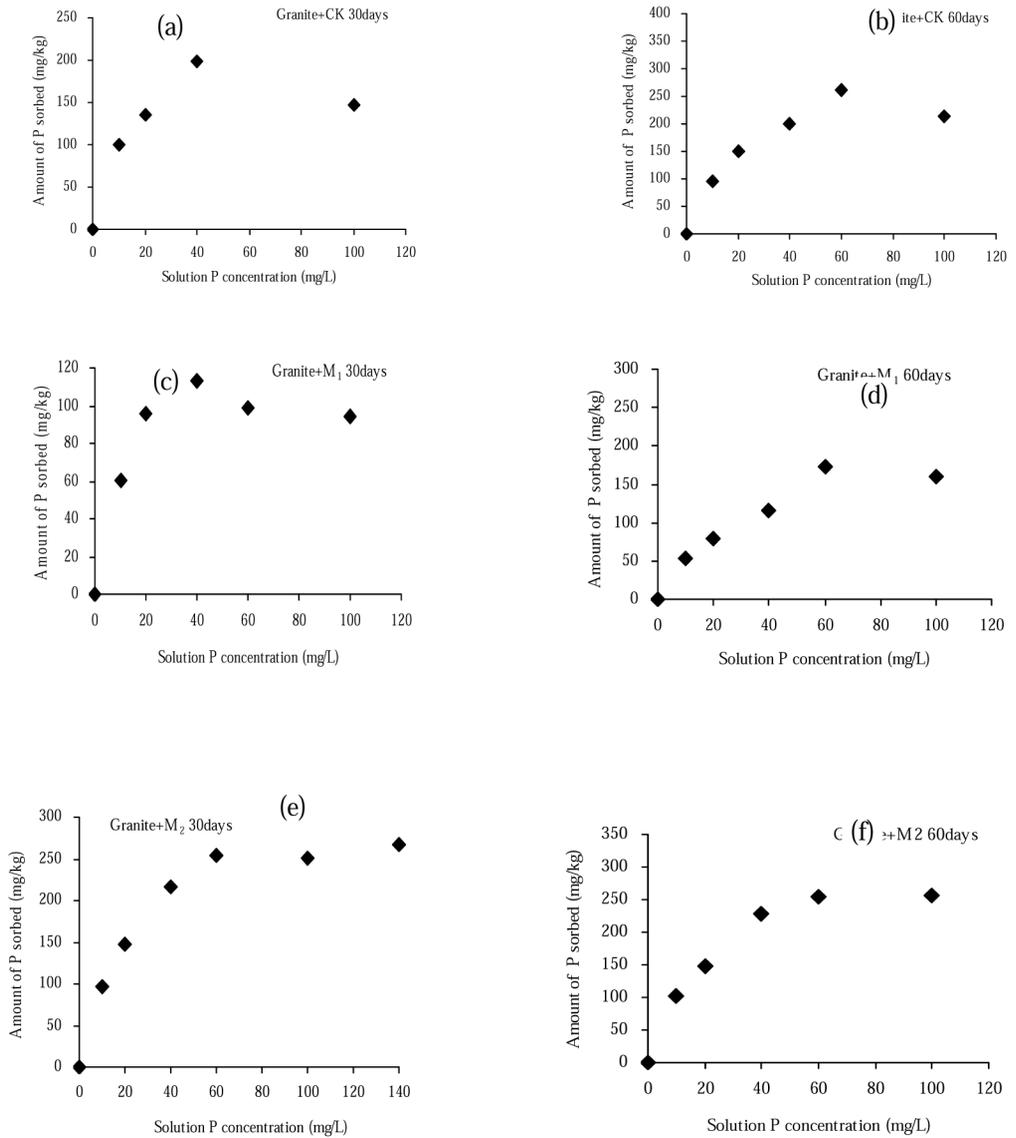


Figure 2. Adsorption isotherms of phosphorus on soil derived from granite with organic matter application after incubation.

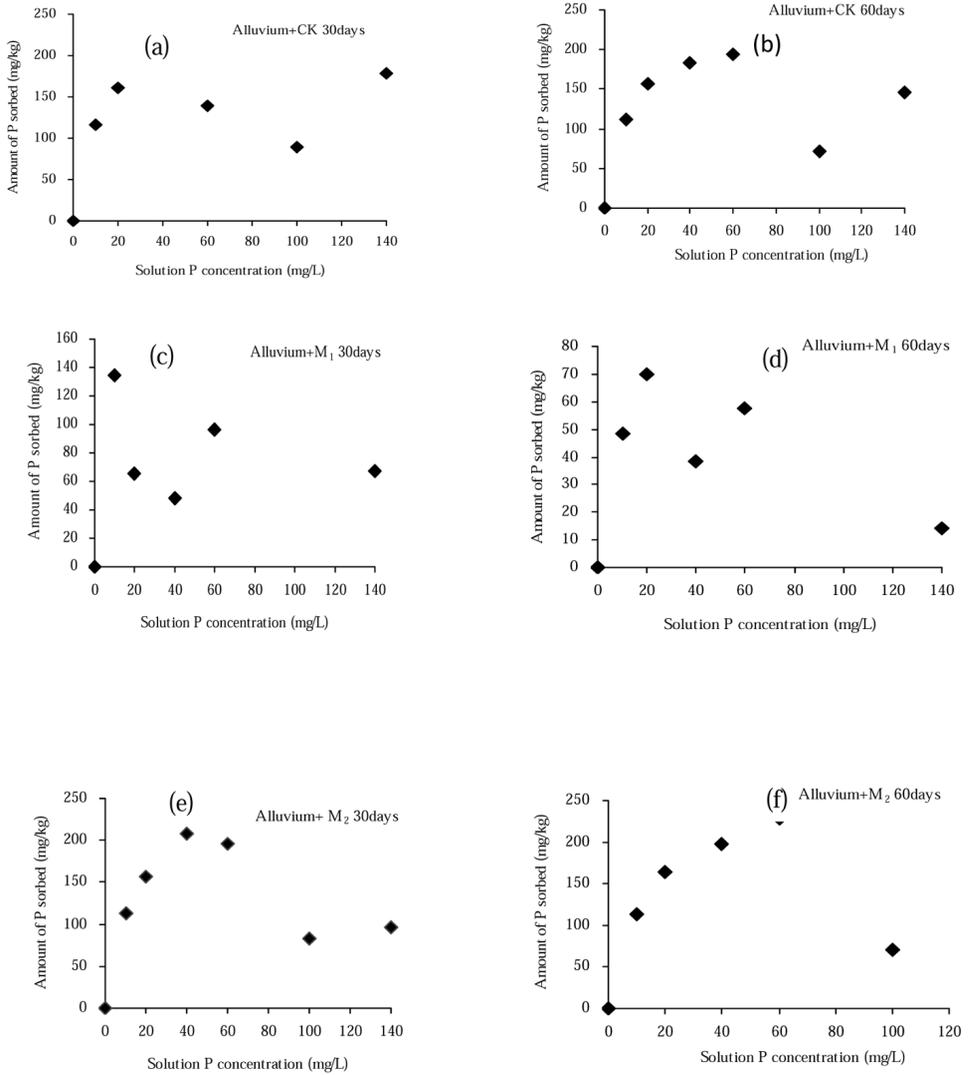


Figure 3. Adsorption isotherms of phosphorus on soil derived from alluvium with organic matter application after incubation.

Table 3. Fitting parameters of adsorption models for the three different soil types

Soil Type & Treatment	Incubation Period (days)	Langmuir Equation			Freundlich Equation			Temkin Equation		
		b ₁ (mg·kg ⁻¹)	k ₁ (L·mg ⁻¹)	R ²	K (mg·g ⁻¹ [L·mg ⁻¹] ^{1/n})	n	R ²	B	A (L·g ⁻¹)	R ²
Basalt + CK	30	1666.67	0.30	0.9932	634.45	4.93	0.9970	123.08	827.92	0.9040
	60	1428.57	0.47	0.9899	587.22	4.33	0.9941	190.79	641.10	0.9798
Basalt + M ₁	30	1111.11	0.16	0.9925	263.88	3.07	0.9898	166.48	266.81	0.9728
	60	1250.00	0.13	0.9914	245.36	2.78	0.9884	188.79	231.00	0.9564
Basalt + M ₂	30	1250.00	0.32	0.9952	405.98	3.43	0.9884	174.18	501.30	0.9746
	60	1428.57	0.22	0.9886	384.33	3.35	0.9928	177.38	468.04	0.9544
Granite + CK	30	149.25	--	0.9868	42.98	2.08	0.4157	142.40	--	0.1824
	60	322.58	0.06	0.8864	59.06	2.91	0.8834	63.48	--	0.8270
Granite + M ₁	30	97.09	6.44	0.9902	52.81	6.22	0.4834	12.54	50.44	0.4428
	60	277.78	0.02	0.8833	19.87	1.99	0.9513	59.76	--	0.8875
Granite + M ₂	30	285.71	0.10	0.9976	63.96	3.12	0.9094	55.34	14.35	0.9405
	60	333.33	0.07	0.9801	63.55	2.95	0.9462	63.38	--	0.9542
Alluvium + CK	30	178.57	0.34	0.9831	114.71	10.49	0.3776	13.87	113.87	0.3404
	60	144.93	--	0.9879	114.26	10.49	0.3283	13.42	114.97	0.2906
Alluvium + M ₁	30	68.49	2.18	0.9536	133.72	--	0.3434	--	135.90	0.4443
	60	13.25	--	0.9197	157.80	--	0.4943	--	87.91	0.4123
Alluvium + M ₂	30	86.96	--	0.9499	177.42	--	0.0772	--	170.30	0.0410
	60	70.42	--	0.8735	165.39	--	0.0141	--	225.35	0.1730

Note: K₁, binding energy; b₁, adsorption maximum; R², coefficient of determination; K and n are empirical constants; A and B are constants.

3.5. Adsorption Isotherm Fitting and Parameter Analysis of the Incubated Soil Samples

The adsorption isotherms of all treatment groups were fitted using the Langmuir, Freundlich, and Temkin equations. The fitting parameters and coefficients of determination are presented in Table 3.

The adsorption isotherms of all treatment groups for soil derived from basalt fitted well with all three adsorption models. For the groups derived from granite and alluvium, the adsorption isotherms of both groups were best fitted by the Langmuir equation, followed by the Freundlich and Temkin equations.

Maximum P buffering capacity (MPBC) is the product of parameters k and b in the Langmuir equation, and is an important index for the evaluation of soil P-fixation capacity and fixation rate. The MPBC values of the three soil types treated with organic matter followed by 30 or 60 days of incubation are shown in Table 4.

The addition of M_1 followed by 30 days of incubation decreased the MPBC of soil derived from basalt, but increased that of soils derived from granite and alluvium.

In contrast, the addition of M_2 caused the MPBC of soils derived from basalt and alluvium to decrease, but that of soil derived from granite to increase. The addition of M_1 followed by 60 days of incubation decreased the MPBC of soils derived from basalt and alluvium, but increased that of soil derived from granite, whereas the addition of M_2 decreased the MPBC of soil derived

from basalt, but increased that of soils derived from granite and alluvium.

The MPBC and the adsorption capacity of soil derived from basalt decreased after the addition of organic matter. As shown by the current study, the addition of organic matter to the soil generated various interactions with soil colloids. This interaction reduced the P-absorption capacity of the soil, which subsequently led to a decrease in the MPBC. For soils derived from granite and alluvium, the addition of organic fertilizers led to unstable changes in the MPBC. Several factors might have caused this phenomenon, including the composition of the introduced organic fertilizers, the soil incubation period and the parent material of the soil. Further investigation is required to obtain a better understanding of the factors relating to this phenomenon.

Table 4. MPBC and SPR of the three different soil types with organic matter application and incubation

Soil Type & Treatment	MPBC (L·kg ⁻¹)		SPR (mg·kg ⁻¹)	
	30 days	60 days	30 days	60 days
Basalt +CK	500.00	666.67	94.34	121.95
Basalt + M_1	181.82	156.25	35.21	30.49
Basalt + M_2	400.00	312.50	75.19	59.88
Granite + CK	–	18.94	–	3.74
Granite + M_1	625.00	6.89	54.64	1.37
Granite + M_2	28.65	22.73	5.62	4.48
Alluvium + CK	60.98	–	11.42	–
Alluvium + M_1	149.25	–	20.79	–
Alluvium + M_2	–	–	–	–

Standard P retention (SPR) refers to the P adsorption of soil when the P solution is $0.2 \text{ mg}\cdot\text{L}^{-1}$. The SPR values for the various treatment groups are shown in Table 4. For all treatment groups of soil derived from basalt, the addition of PM and M_2 followed by 30 or 60 days of incubation decreased the soil SPR. For the groups derived from granite, the addition of both types of organic matter followed by 30 days of incubation increased the soil SPR; however, the soil SPR decreased after 60 days. For the groups derived from alluvium, PM treatment followed by 30 days of incubation increased the soil SPR; however, the soil SPR decreased after 60 days. Treatment with M_2 followed by 30 days of incubation decreased the soil SPR; however, soil SPR increased after 60 days. These differences might have been caused by the effect of long-term fertilization of soils derived from granite and alluvium, which led to a high P content in the soils. Therefore, the negative SPR values calculated from the fitted curves might be due to deviations from the high base P levels in the soils.

4. Conclusions

The addition of M_1 and M_2 followed by 30 or 60 days of incubation increased the availability of P in soils derived from all three parent materials, with available P decreasing with increasing incubation time. The organic matter content of all three soil types was similar to that of available P after the addition of M_1 and M_2 followed by incubation.

In general, the addition of organic matter followed by incubation caused a decrease in the P-adsorption capacity of soil derived from basalt, thereby increasing the risk of P pollution. For soils derived from granite and alluvium, the addition of M_1 followed by incubation decreased the P-adsorption capacity, whereas the addition of M_2 followed by incubation caused it to increase.

The results of equation-fitting showed that soil derived from basalt fitted well with all three equations, whereas soils derived from granite and alluvium fitted the Langmuir equation the best, followed by the Freundlich and Temkin equations.

The addition of M_1 and M_2 followed by incubation reduced the MPBC and SPR of soil derived from basalt. For soils derived from granite and alluvium, different increases and decreases in MPBC and SPR were observed. These differences were due to disparities in the soil parent material and incubation time, as well as differences in the types of organic material. This implied that the amount of P fertilizer needed to be applied to the soil was lowered by the addition of the manure in the soil derived from basalt.

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