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Phosphorus sorption and extractability in Andic soil incubated with plant residues of variable P content

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Abstract

Sodium acetate extractable P and P sorption were measured in a high P-sorbing Andept soil (Mission series) following incubation with Winter wheat (*Triticum aestivum* (L.) *Nugaines*) and red clover (*Trifolium pratense* (L.) *Florex*) plant residue. The effects of plant residue P content, moisture regime, and quantity added were evaluated over a twelve week incubation period. Increased extractable P and decreased P sorption occured when the P content of residue exceeded 0.1% P for both winter wheat and red clover. The extractable P decreased and the P sorbed increased for all treatments and the check as the incubation time progressed. Extractable P increased and P sorption decreased more under air dry moisture conditions than at −0.03 MPa or saturation. Extractable P levels increased and P sorption decreased with increasing amounts of added residue. The effects of the residue additions decreased with increasing incubation time.

Introduction

Although extensive research has been conducted on P reactions with soil constituents, the effects of added organic residues on these reactions have yet to be fully understood. Additions of organic materials to the soil are reported to either increase or decrease P sorption by some soil constituents. Decreased P sorption is generally attributed to organic acids (from organic residue decomposition) that complex with soluble Fe and Al or with sesquioxide surface site and, consequently, block P sorption (Dalton *et al.*, 1952; Gaur, 1969; Olsen *et al.*, 1978). On the other hand, increased P sorption is believed to be a result of microbial assimilation and/or exchange of P for hydroxyl groups at the surface of some organic molecules resulting from the decomposition of added organic residues (Field *et al.*, 1985, Harter, 1969; Lockett, 1938; Sen Gupta, 1969).

White and Ayoub (1983) studied the effect of decomposition of plant residues with varying C:P ratios on the $NaHCO_3$-extractable P content of a soil. Only residues with low C:P ratios (equal to or less than 123) increased the extractable P level in the high P-containing calcareous soil. Singh and Jones (1976) reported that the time of incubation and the P content of residues influenced P sorption by a volcanic ash-derived soil. Decreased P sorption was observed with all the residues after 30 days incubation, while only residues with P contents greater than 0.3% P decreased P sortion after 75 and 150 days incubation. The above studies were limited to the effects of OM on either extractable P or on P sorption. The objective of this study was to investigate both extractable P and P sorption on a volcanic ash-derived soil as affected by incubation with organic residues which differed in total P content. Specific objectives were to determine the effects of (1) the P concentration in organic residues added to the soil, (2) the quantities of added organic materials, (3) the influence of the moisture regime and (4) the effects of the incubation time on P sorption and extractable P in the soil.

Materials and methods

Soil and plant materials

The surface horizon of a Mission silt loam (coarse silty, mixed, frigid Andic Fragiochrept), a

soil with a high P sorption capacity, was used in this study. Soil samples from the Ap horizon were air dried and ground to pass a 2-mm mesh seive. The soil had a pH of 5.7 (saturation paste) and contained 4.1% organic matter, 37.7 mg/kg NO_4-N, 1.7 mg/kg NaOAc-extractable P, and 138 mg/kg NaOAc-extractable K.

Red clover (*Trifolium pratense* (L.) *Florex*) and winter wheat (*Triticum aestivum* (L.) *Nugaines*) were grown for six weeks in silica sand supplied with a complete nutrient solution (Grinsted *et al.*, 1982) containing KH_2PO_4 at concentrations of 1.5, 30, and 300 micromoles of P per liter. The harvested plants for each P level were dried at 60°C and ground in a Wiley mill to pass a 0.25 mm screen to give residues of low, medium, and high P status for each crop. Red clover residues with low, medium and high P contents are represented, respectively, by RCL, RCM, RCH whereas winter wheat residues with low, medium, and high P contents are designated, respectively, by WHL, WHM and WHH. The P contents of the crop residues as determined in a nitric acid digest on an inductively coupled plasma emission spectrometer are given in Table 1.

Incubation studies

Red clover and winter wheat residues with low, medium, and high P contents were each mixed with air dry soil samples at the ratio of 5:100 (w/w) residue:soil. Control soil and treated samples were incubated for twelve weeks in plastic containers. Incubation was begun by adding 50 ml of deionized water to 100 g of soil, providing a moisture level of approximately −0.03 MPa (field capacity) (McDole *et al.*, 1981). Moisture levels were maintained gravimetrically throughout the incubation period. The samples were mixed every sixth day to enhance uniform contact of organic materials with soil. At incubation periods of 0 (9 hours), 2, 4, 6, 8, and 12 weeks, subsamples were taken from the containers, air dried and analyzed for P sorption and extractable P.

Table 1. NaOAc-extractable P ($mg\,kg^{-1}$) in Mission soil incubated with wheat [LSD(0.05) = 1.37] and red clover [LSD(0.05) = 1.42] residues

P content of residue (%)	Incubation time (weeks)					
	0[a]	2	4	6	8	12
Check	2.82	4.58	2.38	3.58	4.12	2.11
Wheat						
0.054 (WHL)	2.84	3.83	2.90	3.15	3.81	2.09
0.081 (WHM)	2.90	4.85	3.50	3.98	4.71	2.23
0.140 (WHH)	5.97	6.45	4.22	4.81	5.63	3.27
Red Clover						
0.089 (RCL)	3.51	3.61	2.76	3.51	3.72	2.14
0.130 (RCM)	5.42	6.33	4.96	5.21	5.58	3.72
0.420 (RCH)	12.37	7.21	5.74	6.84	6.69	5.15

[a] Nine hours of incubation

Phosphorus sorption curves were obtained using a modification of the procedure of fox and Kamprath (1970). Ten-ml aliquots of 5, 10, 30, 50, 80, and 100 mg/l P in 0.01 *M* $CaCl_2$ solution were added to 2-g samples of air dry soil. The soil suspensions were shaken in a 50°C water bath for three hours. The mixture was centrifuged for 20 minutes and P in the supernatant was determined by the method of Murphy and Riley (1962).

Sodium acetate–acetic acid solution (NaOAc) buffered to pH 4.8 (Morgan's reagent) was used to measure the NaOAc-extractable P content of the soils (Grewling and Peech, 1965). Fifty ml of the NaOAc solution was added to 10-g soil samples. The suspension was shaken for 30 minutes and filtered. Phosphorus concentration was measured colorimetrically in the supernatant by the method of Murphy and Riley (1962). Incubations were carried out in triplicate using a completely randomized design. Analysis of variance and LSD values were computed using routines of the Statistical Analysis system (SAS Institute, 1979).

Soil samples to which high P content winter wheat (WHH) residues were added at residue–soil ratio of 5:100 (w/w) were incubated under air dry, −0.03 MPa (field capacity), and saturation moisture conditions to evaluate the effects of moisture regimes. No water was added to the air-dry treatment, −0.03 MPa conditions were provided as described above, saturation conditions were reached by slowly adding deionized water to the soil-residue mixture and mixing thoroughly until a thin layer of water persisted above the soil for about one hour. These moisture conditions were renewed on alternate days throughout a twelve week incubation period. Phosphorus sorption measurements and P extraction were conducted as described above.

Three different OM:soil ratios (1:100, 5:100, 10:100 w/w) were used to evaluate the effects of amounts of residues added to the soil. Only RCH was used in this experiment and the moisture levels were kept at approximately −0.03 MPa during a twelve week incubation period. Phosphorus sorption and NaOAc-extractable P measurements were conducted as described above.

Results and discussion

The NaOAc-extractable P in the Mission soil increased as the P content in the added organic residues increased for both the winter wheat and red clover residues (Table 1). Increases in NaOAc-extractable P over the check were significant for residues with P contents greater than 0.1% P. Other workers have reported 0.2% P as the critical value for the release of P from crop residues (Alexander, 1961; Dalal, 1977; Stevenson, 1982). For winter wheat residues, only WHH, with 0.14% P, resulted in significant increases in the extractable P throughout the twelve-week incubation period and with one exception, at 4 weeks, these increases were found over both the control and the WHL treatment. For red clover residues, both RCM with 0.13% P and RCH with 0.42% P caused a significant increase in the extractable P over both the control and the RCL treatments.

The RCM (0.13% P) and WHH (0.14% P) caused similar effects on the extractable P throughout the incubation period (Table 1). This suggests that the type of organic residues added to Mission soil is not as important as the residue P content in affecting the extractable P levels. The extractable P at the end of the twelve-week incubation period was lower than at the beginning. This may be attributed to both P sorption by the soil and P assimilation by microorganisms. The decrease of extractable P with time of incubation was also found by White and Ayoub (1983) and Field *et al.* (1985). Phosphorus from added organic residues was available to plants over a limited period of time following the addition of residues to soil.

Phosphorus sorption curves on the samples incubated for 2 weeks are shown in Figure 1 for wheat and red clover residues. All the residues, regardless of their P content, caused a lowering of the P sorption curve for the Mission soil during the entire incubation period. The P content of the equilibrium solution at 200 mg kg^{-1} of sorbed P was used to compare the effects of treatments on P sorption over time (Figure 2). As P sorption increases, this solution value will decrease. The soluble P at 200 mg kg^{-1} sorbed P was increased by residues with P contents greater than 0.1% P. The decrease in P sorption by the soil was largest for residues with highest P content. The high P content (WHH) was the only wheat residue to increase the soluble P. Both the medium P content (RCM) and the high P content (RCH) red clover residues caused an increase in the soluble P over the control throughout the incubation period. The effects of all the treatments on soluble P decreased with time. The rate of decrease of soluble P with time was greater for red clover residues than for wheat residues. RCM increased the soluble P at 200 mg $,g^{-1}$ sorbed P more than did WHH up to the fourth week of incubation despite their near identical P contents. Thus, the P content of the residues alone did not account for the differences in P sorption by the soil constituents.

Treatments kept at moisture levels of approxim-

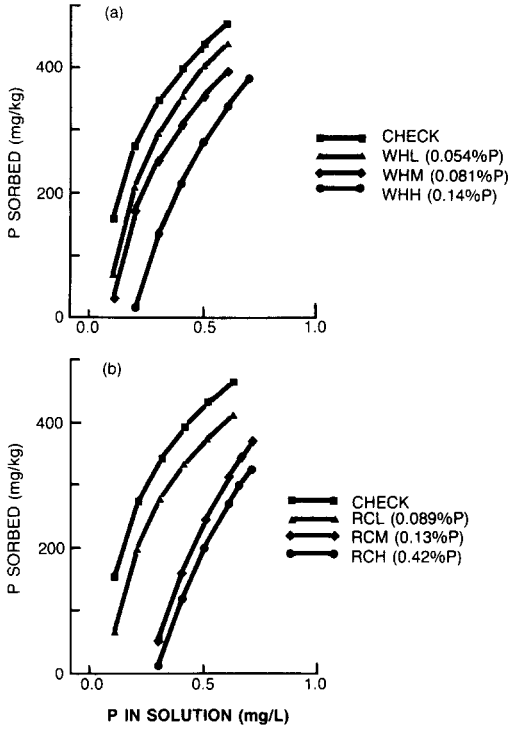

Fig. 1. Phosphorus sorption by Mission soil following incubation with (**a**) winter wheat and (**b**) red clover residues of variable P content for two weeks.

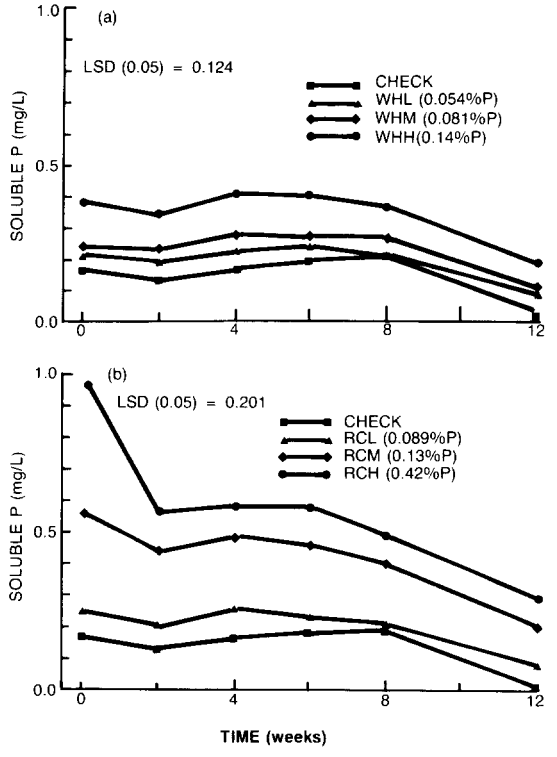

Fig. 2. Soluble P at 200 mg kg^{-1} sorbed P as affected by the addition to Mission soil of (**a**) winter wheat and (**b**) red clover residues with variable P contents over a 12-week incubation period.

ately −0.03 MPa (field capacity) and saturation resulted in similar increases in the NaOAc-extractable P (Table 2). The lack of influence by saturation moisture level indicates easily reducible soil components such as Fe and Mn do not control P extraction from the Mission soil, in agreement with findings of Jones *et al.* (1979). Air dry conditions resulted in a greater increase in extractable P than either −0.03 MPa or saturation moisture levels throughout the twelve week incubation period due to lack of residue decomposition or P mineralization for sorption by the soil under the dry conditions.

Table 2. NaOAc-extractable P (mg kg^{-1}) in Mission soil incubated with high P content (0.14%) wheat residues under different moisture regimes [LSD(0.05) = 1.02] and with varying amounts of high P content (0.42%) red clover residues [LSD(0.05) = 2.25]

	Incubation time (weeks)					
	0[a]	2	4	6	8	12
Moisture						
Air-dry	7.59	8.19	7.08	7.24	6.69	5.63
Saturation	5.90	6.75	4.28	6.35	5.57	3.94
−0.03 MPa	5.97	6.45	4.22	4.81	5.63	3.27
Residue (g kg^{-1})						
0	2.82	4.58	2.38	3.58	4.12	2.11
10	4.05	4.19	3.07	3.53	4.79	2.12
50	12.37	7.21	5.74	6.84	6.69	5.15
100	24.20	11.45	10.53	9.38	8.90	7.45

[a] Nine hours of incubation

The influence of moisture regime on P sorption during incubation was less than its influence on extractable P levels. Incubations under air-dry conditions resulted in the greatest decrease in P sorption followed by saturation and −0.03 MPa moisture levels (Figure 3a). While the differences in P sorption between moisture levels were not large, they were consistent throughout the 12 weeks incubation.

Extractable-P levels increased with increasing amounts of residue (RCH) at the 50 and 100 g kg^{-1} rates (Table 2). The amounts of crop residues

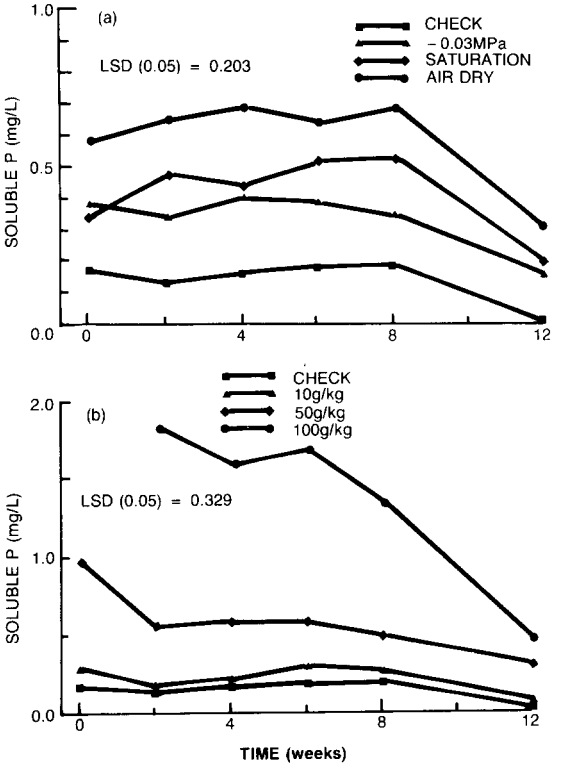

Fig. 3. Soluble P at 200 mg kg^{-1} sorbed P in Mission soil over a 12-week incubation period as affected by (**a**) moisture regimes with high P content winter wheat (WHH) residue and (**b**) variable rates of addition of high P content red clover residues (RCH).

added to the soil had a greater influence on extractable P than did the P content of the residue at the levels used in the study. The effects of residue rate were consistent throughout the twelve-week incubation period, but the differences narrowed with time. The extractable P levels decreased most rapidly with time with the highest residue rate.

Phosphorus sorption curves showed that P sorption decreased with increasing amounts of added residue above the $10\,g\,kg^{-1}$ rate (Figure 3b). This trend remained constant throughout the twelve-week incubation period. However, the equilibrium solution P at $200\,mg\,kg^{-1}$ sorbed P decreased with time at all residue rates. The greatest decrease in soluble P with time occurred at the highest residue level. In spite of the large initial decrease in P sorption by high residue rates, the differences in the soluble P levels at $200\,mg\,kg^{-1}$ sorbed P were small after 12 weeks incubation.

Conclusions

The influences of organic residues on P sorption and extractable P levels in the Mission soil were found to depend upon the P content of the residue, the rate of addition of residue, and moisture content during incubation and the length of incubation of the residue with the soil. Plant residues with P contents greater than 0.1% at rates equal to or greater than 5% (w/w) increased the extractable P and decreased P sorption in the high P-sorbing soil. The effects of the residues were greatest shortly after their addition to the soil. Extractable P decreased and sorbed P increased with increasing incubation time. Dry soil conditions that limited residue decomposition resulted in higher extractable and soluble P levels but saturation moisture level had little influence on the P behavior.

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