



Changes in Soil Phosphorus From Manure Application

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Sustainable agricultural systems need adequate amounts of plant nutrients, including P, without increasing either environmental nutrient load or loss. Availability of soil P from current and past applications is influenced by a number of soil characteristics. A strong inverse relationship between soluble P concentration and extractable Al and Fe in acid soils, indicating adsorption of P on Al- and Fe-oxides, was demonstrated by studies in 1983 and 1995. Soil P may also form phosphate precipitates with soil Ca, Al or Fe. The availability of soil P and added P is also influenced by soil texture, primarily because of differences in clay content and soil organic C, and initial soil P levels. All of these factors interact to establish equilibrium between soil P pools that vary in plant availability. Because these P pools have different availabilities and are in equilibrium with each other, we do not expect added P to be completely available for plant uptake. The efficiency of added mineral fertilizer P for increasing soil test P (STP) levels is typically <20%. The availability of manure-P and its impact on soil P pools is clearly different from mineral fertilizer P.

Manure P availability is variable and not well understood. The objectives of this research were to (1) compare the effects of mineral fertilizer P (KH_2PO_4) and animal manure P application on soil P concentrations over time and (2) determine the effects of mineral fertilizer P and manure P application rate and initial soil P level on soil P concentration.

Soil used for these laboratory experiments was collected from the USDA-ARS research site in Newport, ME. The sandy loam soil had a particle-size distribution of 61% sand, 29% silt and 10% clay. Selected soil properties include: soil pH = 5.8 (1:1, soil/water); cation-exchange capacity = 3.4 cmol kg^{-1} ; P = 16.5 kg ha^{-1} ; K = 303 kg ha^{-1} ; Mg = 169 kg

ha^{-1} ; and Ca = 1130 kg ha^{-1} . Mehlich-III extractable Fe and Al were 87 and 1435 mg kg^{-1} , respectively.

Beef, dairy, swine and poultry manure were collected from storage structures on local commercial farms. The beef and swine manures contained sawdust-bedding material, and the dairy manure included sand bedding. There was no bedding material in the poultry manure.

Experiment I: Changes in Soil Phosphorus Over Time.

Ten grams of air-dry soil was weighed into 20-mL vials. Four replications of the following treatments were prepared: beef, dairy, poultry and swine manures, and KH_2PO_4 , all applied at 100 mg total P kg^{-1} dry soil, and an unamended control. Samples were destructively sampled 0, 7, 14, 28, 56 and 84 days after amendment. Dry soil and manure were thoroughly mixed, while KH_2PO_4 was dissolved in water and added to soil at the same rates as the manures. Soil water was adjusted to 30% (approximately field capacity), and capped vials were incubated in the dark at 24°C. Extracted P available from manure or KH_2PO_4 at each sampling time was corrected for the unamended soil, and the efficiency of an added P source to alter a soil P pool was determined.

Analysis of variance was used to identify significant effects of time, P source and their interaction on extractable soil P. Changes in soil P over time were evaluated using regression analysis. Both linear and nonlinear models were evaluated. Regression equations from different treatments were identified as significantly different if the 95% confidence intervals around the parameters did not overlap, or if the best-fit form was different (i.e., linear vs. nonlinear). Otherwise, regressions were recalculated using all manure treatments. Where regression did not adequately describe changes in soil P pools over time, fertility sources were compared.

Experiment II: Soil Phosphorus Level and Phosphorus Application Rate.

To evaluate the effects of both initial soil P level and P application rate from different sources, soil P level was adjusted with KH_2PO_4 to achieve varying levels of STP. Phosphorus was added to 1-kg portions of dry soil, assuming that 8 mg P kg^{-1} soil was required to increase STP by 1 mg P kg^{-1} soil. The amount of water applied was calculated to bring soil to 80% field capacity and contained a preweighed amount of KH_2PO_4 to increase soil P to the desired level. Soil was allowed to dry every 20 days and was then rewet to 80% field capacity. This cycle was repeated

five times, and the soil was then stored dry for 150 days before use. The resulting three soils had Mehlich III (M3-P) concentrations of 150, 471 and 732 mg P kg⁻¹ dry soil, and are referred to as Low, Medium and High.

This experiment was designed using a complete factorial arrangement, examining P source, P application rate and soil P level. Air-dried soil was placed in vials. For each soil P level, dried manure (beef, dairy, poultry and swine) was added to quadruplicate vials at rates of 0, 100, 200, 400 and 800 mg total P kg⁻¹ dry soil, and soil and manure were mixed thoroughly. Mineral fertilizer P (as KH₂PO₄) was dissolved in water and added to soil at rates equivalent to those applied as manure. Water to increase soil moisture to field capacity was added to each tube. Vials were capped and incubated at 24 °C, without drying. After 90 days, soil was air dried, and the following extractions were performed: 0.01 M CaCl₂, anion exchange membrane P (AEMP), Mehlich III (M3-P) and modified Morgan (MMP). Total P concentration in all extractions was measured; Al and Fe concentration in M3 were also determined. Response of soil P pools to P application rate was evaluated by linear regression. Comparison of regressions between treatments was accomplished by conducting ANOVA on the regression parameters *a* (*y*-intercept) and *b* (slope or efficiency). Aluminum and Fe extractable by M3 were also used to calculate the degree of P saturation (DSSP_{M3}).

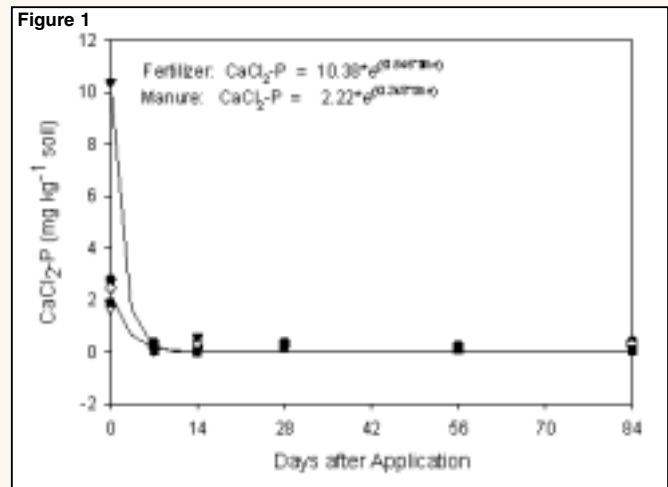
The relationship between DSSP_{M3} and CaCl₂-P was evaluated. The analysis identifies a value for the independent variable beyond which CaCl₂-P increases more rapidly. This value is referred to as the “change point.”

RESULTS AND DISCUSSION

Experiment I: Changes in Soil Phosphorus Over Time.

Analysis of variance indicated that all extractable soil P pools changed over time, and most exhibited significant differences due to P source, time by P source interaction or both. All P fractions declined rapidly after manure or KH₂PO₄ was added to the soil. Water-soluble P and CaCl₂-P (shown in Figure 1), two P fractions essentially immediately available to plants, exhibited similar changes over time. Reduction in P concentration of both of these fractions could be described by a three-parameter exponential decay function (which declines sharply and then stabilizes around some minimum value), with P concentration stabilizing within 14 to 21 days of amendment. This very rapid decline in soluble P, coupled with the fact that both fractions stabilized at <3 mg P kg⁻¹ soil (in other words, <3% of applied P), are indicative of rapid sorption by soil Al and Fe. Changes in these two soluble P pools over time also indicate that effects of KH₂PO₄ and manure were described by different regression equations – the primary difference between KH₂PO₄ and manure P being that KH₂PO₄ had a higher initial solubility in both extractants. This would be expected because this mineral P fertilizer source is completely soluble in water, while the average WSP concentration in the manures was between 18.6% (dairy) and 33.3% (swine) of

total P. Changes in MMP over time were very similar to WSP and CaCl₂-P, with a rapid decline to levels as low as 2.0 mg kg⁻¹ soil. These results demonstrate that all P sources were <5% efficient in altering these soluble P pools. These are much lower than previous estimates of 5% to 30%. However, the soil used here has a high level of extractable Al, indicating the P sorption capacity is high.



The remaining two P fractions, AEMP and M3-P, also declined rapidly after addition to soil, with very little change after 14 days. Also, these two extraction methods were able to distinguish between P sources on most sampling dates, with fertilizer P resulting in higher P concentration than manure. Poultry manure increased M3-P more than dairy manure at most sampling dates, while other manure P sources were similar. The effectiveness of KH₂PO₄ or manure P in increasing these P pools was greater than for those extractants described above. The efficiency of added KH₂PO₄ was 31% to 39% (for AEMP and M3-P, respectively), while manure P efficiency ranged from near zero (dairy manure) to 33% (poultry manure, M3-P), averaging 12.8% for AEMP and 14.7% for M3-P.

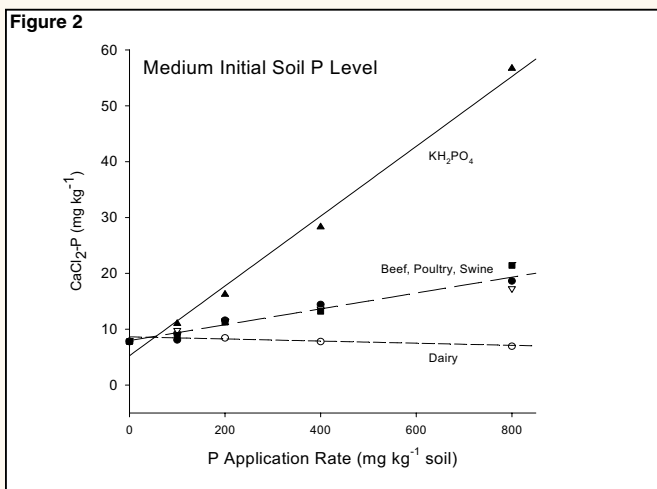
Experiment II: Soil Phosphorus Level and Phosphorus Application Rate.

The three soils with Low, Medium and High levels of soil P clearly differed in P saturation. The DSSP_{soil} of these soils were 0.126, 0.216 and 0.310 mol mol⁻¹ (in other words, 12.6, 21.6, and 31%) for Low, Medium and High levels, respectively. They also showed distinct differences in their ability to adsorb P, which is a function of P saturation. The soils with Low and Medium P levels had the capacity to adsorb P as solution P concentration increased, with the Medium soil having somewhat less capacity to do so. The soil with the High P level, on the other hand, exhibited a net desorption at all solution P concentrations evaluated.

All P fractions were affected by P application rate, P source and soil P level, and interactions were common. In all cases, extractable soil P was a linear function of P application rate.

Results of CaCl_2 extraction across these factors illustrates the interactive effects of the treatment factors, as shown in Figure 2. Fertilizer P increased this P fraction more than manure P. The b values for KH_2PO_4 ranged from 0.015 to 0.105 (that is, efficiency of 1.5% to 10.5%) under Low and High soil P, respectively. Manure P sources generally had slopes between 0.00 and 0.02, although the dairy manure had a negative slope at Medium and High soil P level. The dairy manure originated at a farm that uses sand as bedding material. The sand may have contributed enough soluble Al, Fe or both to adsorb manure-derived P and indigenous soil P. Mehlich-III extractable Fe was not affected by application rate when fertilizer, beef, poultry or swine manures were applied. Increasing dairy manure application rate, however, did increase extractable Fe.

Differences in solubility of fertilizer versus manure P were demonstrated by researchers in 2000. They reported that 53% and 64% of P in poultry and dairy manure, respectively, was soluble by repeated water extraction. The manures used in our research contained on the average only about 25% WSP, as a proportion of total P. Our results indicate that these differences in solubility are evident even after a 90-day incubation in soil, with significantly more of the P from KH_2PO_4 remaining in this soluble P fraction.



An additional trend is that as initial soil P level increases, the slope increases, presumably because the capacity of the soil to adsorb added P is reduced with higher initial soil P level. The amount of fertilizer P needed to increase $\text{CaCl}_2\text{-P}$ by 1 mg kg^{-1} dry soil was 66, 16 and 9.5 mg kg^{-1} soil, for soil with Low, Medium and High soil P level, respectively.

In a comparison of treatment factors, modified Morgan P follows a trend similar to $\text{CaCl}_2\text{-P}$, in two regards: (1) for all P sources, b increases with soil P level, generally doubling or tripling from Low to High soil P level; and (2) there are clear differences between P sources. There are, however, important differences between these two extractants. Specifically, within each soil P level, poultry manure

is more efficient at increasing MMP than any other source. The other manures tended to be similar to each other and generally had greater b values than fertilizer P.

Mehlich-III P was also capable of distinguishing between P sources. At each soil P level, there were no significant differences in efficiency between fertilizer P and poultry and swine manure, ranging from 0.273 to 0.487. These results are considerably higher than the findings of three previous studies. The two ruminant manures used here, beef and dairy, were similar within each soil P level and were less efficient at increasing M3-P than the other P sources. The contrasting results of the MMP and M3-P extractions indicate that, although both of these soil tests are useful for predicting crop response to P, they are extracting different P pools in the soil. Clearly, the F-based Mehlich-III extractant is capable of cleaving Al-bound P, while the modified Morgan extractant is not. Our results suggest, however, that different sources of P contribute to different pools of soil P.

Estimating Soil Phosphorus Saturation using Mehlich-3 Extraction.

Soil P saturation has been suggested as a way to identify critical soil P levels above which soluble P levels increase substantially. A number of different extractants have been used to estimate P saturation, usually using not only extractable P concentration but also extractable Al, Fe or both, because of the important role they play in immobilizing P under acid conditions. The calculations based on M3 have the advantage of using a common soil test extraction. We combined the data from Exp. I and II to assess the relationships between $\text{CaCl}_2\text{-P}$ and P saturation using molar concentrations from M3, in the form $(\text{P})_{\text{M3}}/(\text{Al} + \text{Fe})_{\text{M3}}$.

A study in 2001 successfully used the M3-P concentration to identify what the researchers termed change points in the relationship between soil P level and $\text{CaCl}_2\text{-extractable P}$. The rate of increase in $\text{CaCl}_2\text{-P}$ per unit of M3-P is greater above the change point than below the change point. The change point concept can also be used to identify critical P saturation levels, based on the M3. The change point $(\text{P})_{\text{M3}}/(\text{Al} + \text{Fe})_{\text{M3}}$ is 0.207 mol mol^{-1} . Below this level, $\text{CaCl}_2\text{-P}$ concentration is very low and there is no relationship between P saturation and $\text{CaCl}_2\text{-P}$; that is the slope is zero. This suggests that our earlier interpretation (Exp. I), that applied P is rapidly sorbed by Al in this soil, is correct. Above the change points, the slopes increase to 1.42, indicating that above this level, applied P remains in the more soluble $\text{CaCl}_2\text{-P}$ pool, rather than being sorbed by either Al or Fe in the soil.

Editor's note: Content was adapted from the paper "Changes in Soil Phosphorus from Manure Application," which was published in *Soil Sci. Soc. Am. J.*, Vol. 67, March-April 2003, and is courtesy of T.S. Griffin, C.W. Honeycutt and Z. He.



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Changes in Soil Phosphorus From Manure Application September Self-Study Examination

1. A strong inverse relationship was demonstrated in acid soils between soluble P concentration and extractable:

- a. Zn and Ca.
- b. Zn and Mg.
- c. Al and Fe.
- d. Ca and K.

2. Soil P may form phosphate precipitates with soil:

- a. Ca, Zn, or O.
- b. Ca, Al, or Fe.
- c. O, Ca, or S.
- d. Ca, Al, or K.

3. The efficiency of added mineral fertilizer P for increasing soil test P levels is typically:

- a. <10%.
- b. <20%.
- c. <30%.
- d. <40%.

4. Soil used in the experiment was a:

- a. silt loam.
- b. silty clay loam.
- c. sandy loam.
- d. sandy clay loam.

5. Indicative of rapid sorption by soil Al and Fe were:

- a. the rapid decline in soluble P and the stabilization of water-soluble P and $\text{CaCl}_2\text{-P}$ at $<3 \text{ mg P Kg}^{-1}$ soil.
- b. the rapid decline in soluble P and the stabilization of water-soluble P and $\text{CaCl}_2\text{-P}$ at $<5 \text{ mg P Kg}^{-1}$ soil.
- c. the rapid decline in soluble P and the stabilization of water-soluble P and $\text{CaCl}_2\text{-P}$ at $<7 \text{ mg P Kg}^{-1}$ soil.
- d. the rapid decline in soluble P and the stabilization of water-soluble P and $\text{CaCl}_2\text{-P}$ at $<9 \text{ mg P Kg}^{-1}$ soil.

6. KH_2PO_4 had a higher initial solubility in both water and CaCl_2 extractants. This would be expected because:

- a. mineral P fertilizer is not soluble in water.
- b. mineral P fertilizer is 45% soluble in water.
- c. mineral P fertilizer is completely soluble in water.
- d. manure P is not water soluble.

7. The three soils with Low, Medium, and High levels of soil P clearly differed in P saturation with the DSSP of the soils:

- a. 0.126, 0.216, and 0.310 respectively.
- b. 0.129, 0.225, and 0.330 respectively.
- c. 0.130, 0.230, and 0.335 respectively.
- d. 0.140, 0.240, and 0.340 respectively.



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8. The soils with Low and Medium P levels had the capacity to adsorb P as solution P concentration increased:

- a. at the same level.
- b. with the Low soil having somewhat less capacity to do so.
- c. with the Medium soil exhibiting an ultimate desorption.
- d. with the Medium soil having somewhat less capacity to do so.

9. Extractable soil P:

- a. was an inverse function of P application rate.
- b. was a linear function of P application rate.
- c. did not change with P application rate.
- d. varied only by soil texture.

10. The change point for critical P saturation levels based on the M3 is:

- a. 0.186 mol mol⁻¹.
- b. 0.193 mol mol⁻¹.
- c. 0.200 mol mol⁻¹.
- d. 0.207 mol mol⁻¹.



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