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Long-Term Phosphorus Solubility in Soils Receiving Poultry Litter Treated with Aluminum, Calcium, and Iron Amendments[1]

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ABSTRACT

Phosphorus (P) runoff from poultry litter applied to fields can adversely impact water quality. The majority of P in runoff from poultry litter is soluble, so decreasing the solubility of P could lessen the impact of poultry litter on water quality. The objective of this study was to determine long-term P solubility

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[1] Contribution from USDA/ARS.

in soils receiving poultry litter treated with aluminum (Al), calcium (Ca), and iron (Fe) amendments at various soil pHs. Soil pH was adjusted to 4.0, 5.0, 6.0, 7.0, and 8.0 using elemental sulfur (S) or $CaCO_3$ with some soil left at its native pH. The pH-adjusted soil was then incubated with either no litter (control), litter alone (litter control), or litter amended with alum, $Al_2(SO_4)_3 \cdot 16H_2O$, (100 or 200 g/kg), $Ca(OH)_2$ (25 or 50 g/kg), or $FeSO_4 \cdot 7H_2O$ (100 or 200 g/kg). The soil was then allowed to equilibrate in the dark at room temperature for 0, 7, 49, 98, and 294 days. After equilibration, soils were extracted with deionized water and soluble reactive P levels were determined. Water-soluble P levels decreased with time in all treatments, including the control and litter control treatments. Soil pH also affected soluble reactive P levels, with the lowest levels generally observed at pH 8.0. Addition of both unamended and chemically-amended litter to soil significantly increased P concentrations at all combinations of pH and sampling time. Addition of chemically-amended litter to soil significantly reduced soluble reactive P compared to unamended litter. With all treatments, an apparent equilibrium was reached at 98 d after treatment. Amendment of litter with either $FeSO_4 \cdot 7H_2O$ or alum resulted in the lowest soluble reactive P levels after 294 days. Use of chemical amendments to limit P solubility has potential and should be pursued as a

means of reducing eutrophication of sensitive surface waters where poultry litter is applied as a fertilizer.

INTRODUCTION

Poultry litter is typically applied to pasture land at rates dependent on nitrogen (N) requirements for forage production. This practice results in an over application of P to fields and has the potential to create an environmental problem. Schindler (1977) stated that the major nutrient of concern in surface water eutrophication is P, and the importance of P inputs from agricultural runoff has been reported (Sharpley et al., 1992; Sharpley et al., 1994; Daniel et al., 1994), especially in regions where confined animal operations are in proximity to surface waters. For example, Duda and Finan (1983) reported that total P runoff from watersheds with high livestock populations was up to 50 times greater than that from mostly forested watersheds. Recent studies by Edwards and Daniel (1992,1993) have shown very high P concentrations in runoff from fields receiving agronomic rates of poultry litter one day prior to rainfall. More importantly, Edwards and Daniel (1993) report that 80-90% of the P in this runoff water is dissolved reactive P which is the most readily available form of P for algal uptake (Sonzogni et al., 1982).

Because most of the P in runoff from pastures receiving poultry litter applications is in a soluble form, and therefore readily available for uptake, conversion of litter P to less-soluble or less-available forms could effectively reduce potential losses of P in runoff. Moore and Miller (1994) reported that various chemical amendments containing Al, Ca, and Fe effectively decreased P solubility in litter. Shreve et al. (1995) showed two of these litter amendments, alum [$Al_2(SO_4)_3$•

$16H_2O$] and ferrous sulfate ($FeSO_4 \cdot 7H_2O$), decreased P runoff from fescue plots receiving applications of poultry litter by up to 87 and 77%, respectively. Furthermore, application of alum-amended litter significantly increased forage yields compared with application of unamended litter at identical rates. This was probably due to a significantly higher N content in alum-amended litter, a direct result of decreased ammonia (NH_3) volatilization (Moore et al., 1995).

In addition to increasing the N content of the litter, the decrease in NH_3 volatilization that can be achieved by amending litter with alum has important implications for poultry health. Ammonia builds up in poultry houses as a result of using the same litter for several flocks of birds, and can adversely affect bird health and performance (Anderson et al., 1964). Ammonia has been shown to decrease growth rates, feed efficiency, and egg production; damage respiratory tracts; and increase susceptibility to Newcastle disease, incidence of airsaculitis and keratoconjunctivitis, and levels of *Mycoplasma gallisepticum* in poultry (Carlile, 1984).

Research in our laboratory has shown that chemical amendments, such as alum, decreased NH_3 volatilization up to 99% which may provide an economic incentive for producers to utilize them (Moore et al., 1995). Currently, producers increase ventilation to decrease NH_3 levels in poultry houses, but during winter months this becomes impractical due to heating costs.

Use of chemical amendments may, therefore, represent an economical alternative to increased ventilation and may provide an economic incentive for poultry growers to start using alum on a large scale. Such large scale use would be accompanied by the additional environmental benefits of decreased P solubility in litter (Moore and

Miller, 1994) and P runoff from fields receiving poultry litter applications (Shreve et al., 1995). The objective of this study was to determine long-term P solubility in soils receiving poultry litter treated with Al, Ca, and Fe amendments at various soil pHs.

MATERIAL AND METHODS

Approximately 100 kg of Captina silt loam soil (fine-silty, mixed, mesic Typic Fragiudults) was collected from the surface horizon, sieved through a 12.5-mm sieve, and homogenized using a small soil mixer. Ten kg (dry weight equivalent) of soil were weighed into each of six 36-L sealable containers. Appropriate amounts of either elemental sulfur (S) or $CaCO_3$ were added to the soil to achieve pH values of 4.0, 5.0, 6.0, 7.0, and 8.0. One container received no S or $CaCO_3$ so that the native soil pH (5.2) was maintained. To adjust soil to pH 4.0 and 5.0, 1.0 and 0.1 g S/kg soil were required, respectively. Adjustment of soil pH to values of 6.0, 7.0, and 8.0 required 0.04, 0.4, and 2.0 g $CaCO_3$/kg soil, respectively. Soils were moistened with distilled deionized water to bring them to 50% of water holding capacity. Containers were then sealed and soils were incubated in the dark at room temperature for 5 months.

After incubation, the soil in each container was thoroughly mixed and a small subsample was removed for determination of pH and water content. Containers were resealed and incubated for an additional month at room temperature. At the end of this incubation period, 50 g dry weight equivalent of each soil (58.8 g moist) representing the six pH treatments were weighed into 120 brown glass jars and capped.

Litter was obtained from the study reported by Moore et al. (1995). A 0.5 g sample of litter (Table 1) was added to 15 jars at each pH. The litter amendments were 100 g alum/kg, 200 g alum/kg, 25 g $Ca(OH)_2$/kg, 50 g $Ca(OH)_2$/kg, 100 g $FeSO_4$/kg, or 200 g $FeSO_4$/kg, and unamended poultry litter. No litter was added to 15 jars at each of the six pH treatments. Jars were incubated in the dark at 17.6% moisture content and at 25 C for 0, 7, 49, 98, or 294 d. This experimental design provided eight litter treatments, six soil pH treatments, five sampling times, and three replicates per treatment.

At each time point, three jars of each treatment were extracted by adding a 42 mL aliquot of distilled deionized water and shaking for 2 hr on an Eberbach[2] reciprocating shaker (1:1 water:soil). Samples were then transferred to a 250-mL centrifuge tube and centrifuged at 7000 rpm for 20 min in a Sorvall RC5C centrifuge. The supernatant was then filtered through a 0.45 μm membrane filter, acidified to pH 2.0 using concentrated trace metal grade HNO_3 and frozen at -20 C until soluble reactive P (SRP) analyses were performed. Soluble reactive P was determined on the filtered, acidified samples using the automated ascorbic acid reduction method (APHA, 1992).

RESULTS AND DISCUSSION

Litter Characteristics

Soluble reactive P concentrations in the litter were different between litter treatments (Table 1). Litter amended with the high

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[2] Trade names are mentioned in this publication to provide specific information. Mention of a trade name does not constitute a guarantee or warranty of the product by the University of Arkansas, the USDA-ARS, or the University of Kentucky, nor an endorsement over other available products.

TABLE 1. Chemical characteristics[3] of amended poultry litter (adapted from Moore et al., 1995).

Treatment	pH	TKN	NH_4	TP	SOC	SRP	TDP
	--------------	g/kg	--------------			-- mg/kg --	
Control	8.89	26.1	3.72	24.8	27.4	2022	2621
25 g $Ca(OH)_2$/kg	9.09	24.8	3.62	23.3	26.7	1305	1798
50 g $Ca(OH)_2$/kg	9.03	26.3	5.80	21.9	30.3	989	1324
100 g $Al_2(SO_4)_3 \cdot 18H_2O$/kg	8.37	35.7	13.6	22.5	20.7	467	734
200 g $Al_2(SO_4)_3 \cdot 18H_2O$/kg	7.07	41.5	17.6	21.6	22.0	111	261
100 g $FeSO_4 \cdot 7H_2O$/kg	8.37	30.5	12.1	22.3	19.9	748	978
200 g $FeSO_4 \cdot 7H_2O$/kg	8.09	37.5	19.9	21.1	14.6	529	727
$LSD_{0.05}$	0.36	2.7	3.16	NS[4]	3.5	211	295

[3] TKN = Total Kjeldahl N; NH_4 = sum of water soluble and exchangeable NH_4-N; TP = total P, SOC = soluble organic C; SRP = soluble reactive P; TDP = total dissolved P.
[4] NS = Not significant at $p<0.05$.

rate of alum contained the lowest SRP, which was significantly lower than all other treatments. Litter amended with 200 g alum/kg had the lowest pH (7.07) and the highest (41.5 g/kg) total Kjeldahl N (TKN) of all treatments (Table 1). As reported by Moore et al. (1995), this treatment resulted in significantly less NH_3 volatilization than untreated litter.

Moore and Miller (1994) reported lower soluble P in poultry litter with addition of $Ca(OH)_2$ (up to 100% reduction from control litter) than those observed in this study (ca. 50% reduction from control litter). The higher SRP concentrations observed in this study were most likely due to differences in pH. Moore and Miller (1994) reported that addition of $Ca(OH)_2$ raised litter pH to 12.0, whereas in this study, litter pHs of slightly above 9.0 were observed with these treatments (Table 1).

Phosphorus Solubility in Litter-Amended Soils

Phosphorus solubility in the soil which did not receive litter was affected by both soil pH and time (Fig. 1A). Soluble reactive P levels were initially 0.4 mg P/kg at all pHs except 4.0, and decreased to around 0.15 mg P/kg at 294 d. The dashed line in Figure 1 corresponds to 1 mg P/kg soil, an arbitrary reference point. The decrease in SRP with time is most likely due to soil fixation of P liberated from native soil organic matter when the soil was stirred and weighed into the jars. In all soils, receiving all poultry litter treatments, SRP decreased with time and appeared to reach equilibrium at about 98 d.

When unamended poultry litter was added, SRP increased significantly ($p<0.05$) at each sampling time over untreated soil (Fig. 1B). Initially, SRP concentrations were above 20 mg P/kg in soils receiving litter, except for the pH 8.0 soil. Since the pH 8.0 soil had received significant additions of $CaCO_3$, P adsorption to $CaCO_3$ and/or rapid precipitation of calcium phosphate minerals may have occurred (Lindsay et al., 1962; Griffin and Jurinak, 1973). As with untreated soil, SRP concentrations in soil treated with poultry litter decreased with time. The lowest SRP concentrations were observed

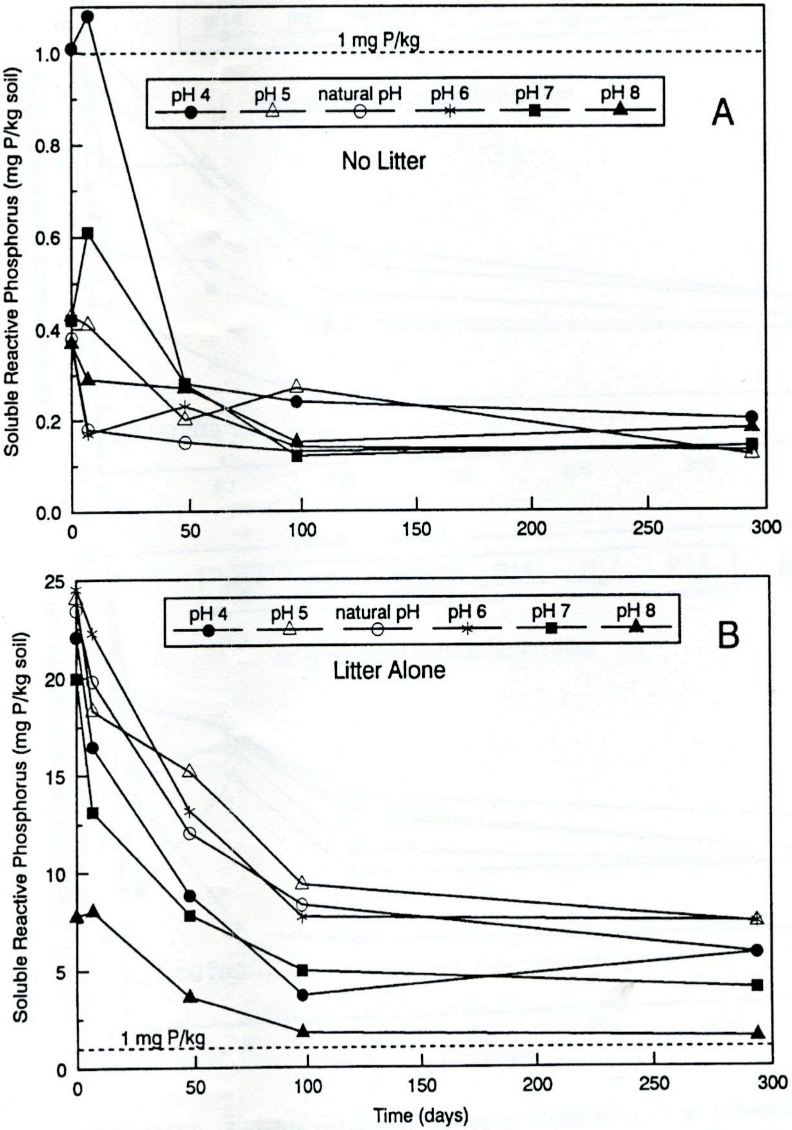

FIGURE 1. Soluble reactive P concentrations in soils as a function of pH and time, receiving (A) no litter and (B) unamended litter.

at pH 8.0 for all sampling times, and the highest observed in pH 6.0 soil at 0 and 7 d and in pH 5.0 soil for later sampling times. At 294 d, the mean SRP concentration of the unfertilized soil was 0.15 mg P/kg (Fig. 1A), whereas addition of poultry litter increased this to around 5 mg P/kg (Fig. 1B), which represents a 30-fold increase.

The high SRP levels observed with poultry litter additions are consistent with those reported by Sharpley et al. (1991). Poultry litter was reported to increase the inorganic P fraction, with accumulation of P occurring in the upper 50 cm of soil, and representing an important source of P to surface runoff waters (Sharpley et al., 1991). Kingery et al. (1994) reported six-fold increases in extractable soil P to a depth of 60 cm with long-term applications of poultry litter. These authors recognized that the buildup of surface soil P represents a potential for negative environmental impact. This threat to surface water quality is potentially greatest in grassland, where most of the P may be transported in soluble rather than in particulate forms, and is more readily available for algal uptake in surface waters (Sharpley and Menzel, 1987).

Soils incubated with litter amended with $Ca(OH)_2$ had significantly lower SRP concentrations through 98 days of incubation when compared to soils treated with litter alone (Fig. 2A&B). There were no significant differences between the two rates of $Ca(OH)_2$ at any combination of pH and time ($p < 0.05$). Final SRP concentrations were significantly lower at soil pH 8.0 (ca. 2 mg P/kg) when compared to all other pH values. Soluble reactive P decreased with time to final concentrations of 3 to 5 mg P/kg at the other soil pHs, which was equivalent to litter alone.

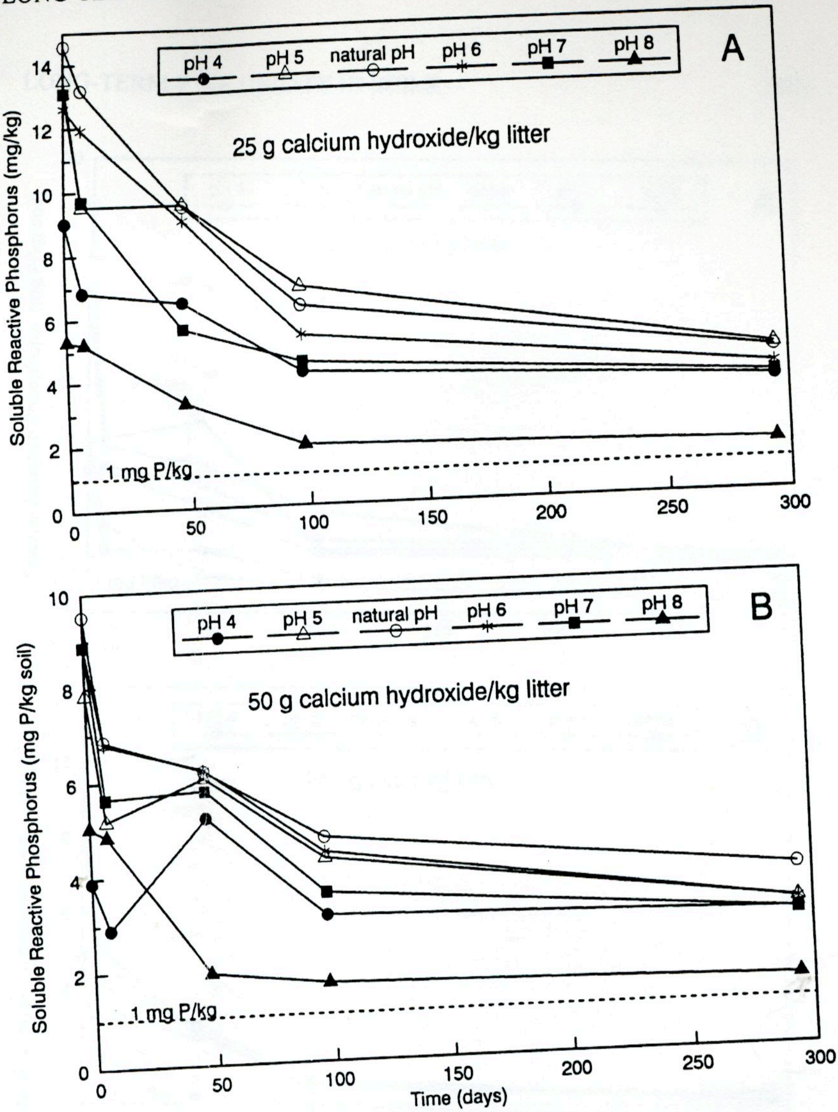

FIGURE 2. Soluble reactive P concentrations in soils as a function of pH and time, receiving litter amended with (A) 25 g calcium hydroxide/kg and (B) 50 g calcium hydroxide/kg.

Soils receiving alum-amended poultry litter had significantly lower SRP concentrations at all pH values and at all sampling times in comparison to the soils treated with litter alone ($p < 0.05$). For the treatment containing 100 g alum/kg litter, SRP in soils ranged from 6 to 18 mg P/kg at time zero and decreased to less than 3 mg/kg by day 294, except for the pH 8.0 soil, which had a final concentration of less than 1 mg P/kg (Fig. 3A). With addition of litter containing 200 mg alum/kg litter, soil SRP decreased from initial concentrations of 4.5 to 11.5 mg P/kg down to approximately 1 mg P/kg at the completion of the study (Fig. 3B). Differences between initial soil SRP concentrations of the two treatments is due to the much lower SRP content of the treated litter itself (Table 1). With the higher rate of alum, no significant effect of soil pH on soil SRP concentrations were observed, but SRP levels of less than 1 mg P/kg were measured in soils with pH of 4.0 and 8.0.

Moore and Miller (1994) reported similar decreases in water soluble P with the addition of alum to poultry litter, and reported that addition of $CaCO_3$ further decreased soluble P levels. The data obtained in this experiment are consistent with that observation, and account for the decreased SRP levels observed in the pH 8.0 soil. Shreve et al. (1995) also reported significantly decreased P runoff from fescuegrass plots with the addition of 200 g alum/kg poultry litter.

Soils which had received litter with 200 g $FeSO_4$/kg litter had significantly lower initial SRP concentrations than soils receiving litter alone (Fig. 4B), whereas soils receiving litter amended with 100 g/kg rate of $FeSO_4$ did not display this decrease (Fig. 4A). Final SRP concentrations were lower (but not significantly lower) in soils

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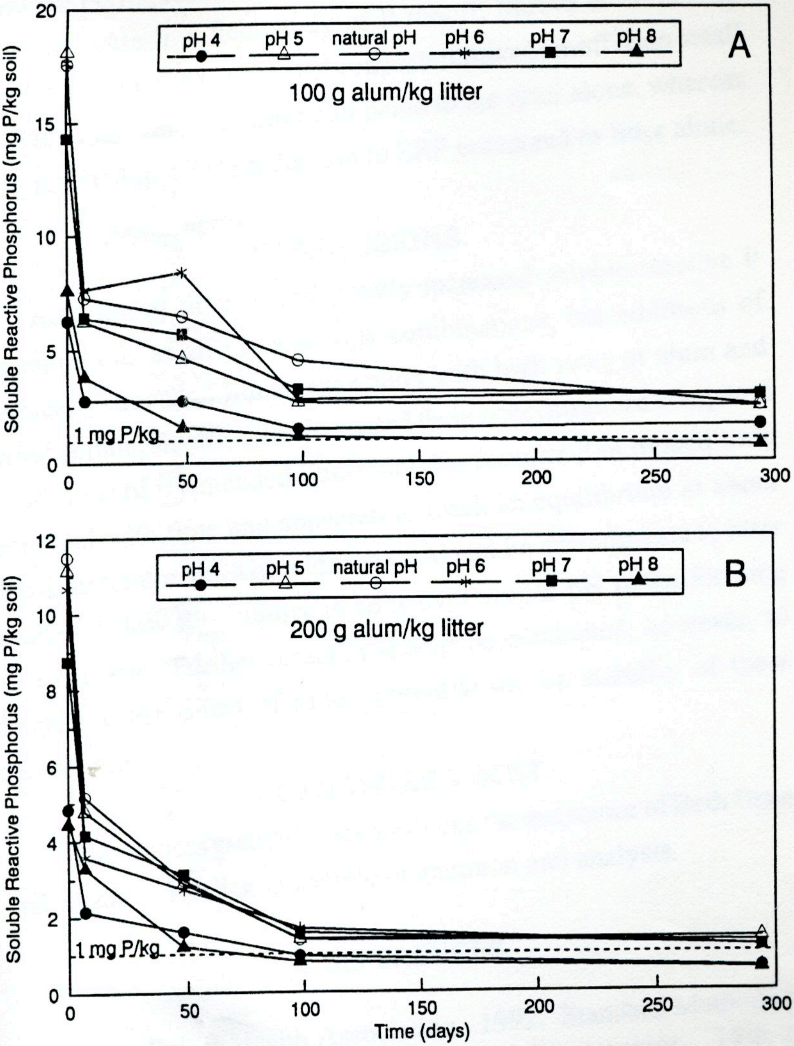
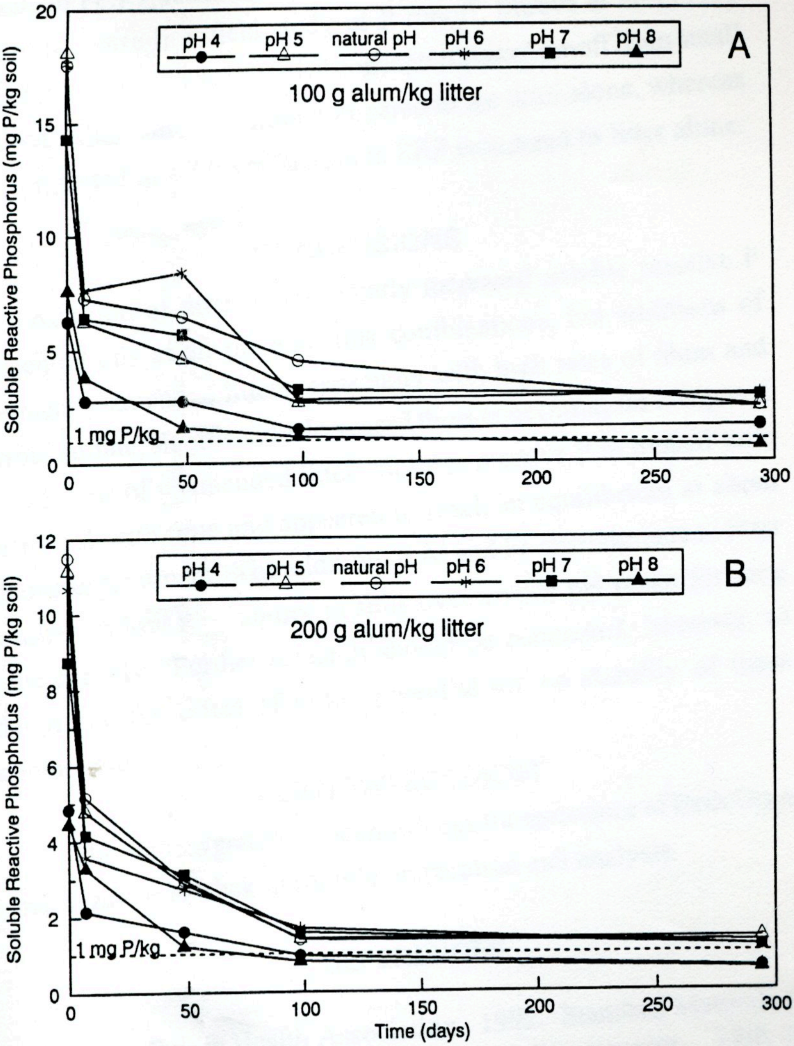


FIGURE 3. Soluble reactive P concentrations in soils as a function of pH and time, receiving litter amended with (A) 100 g alum/kg and (B) 200 g alum/kg.



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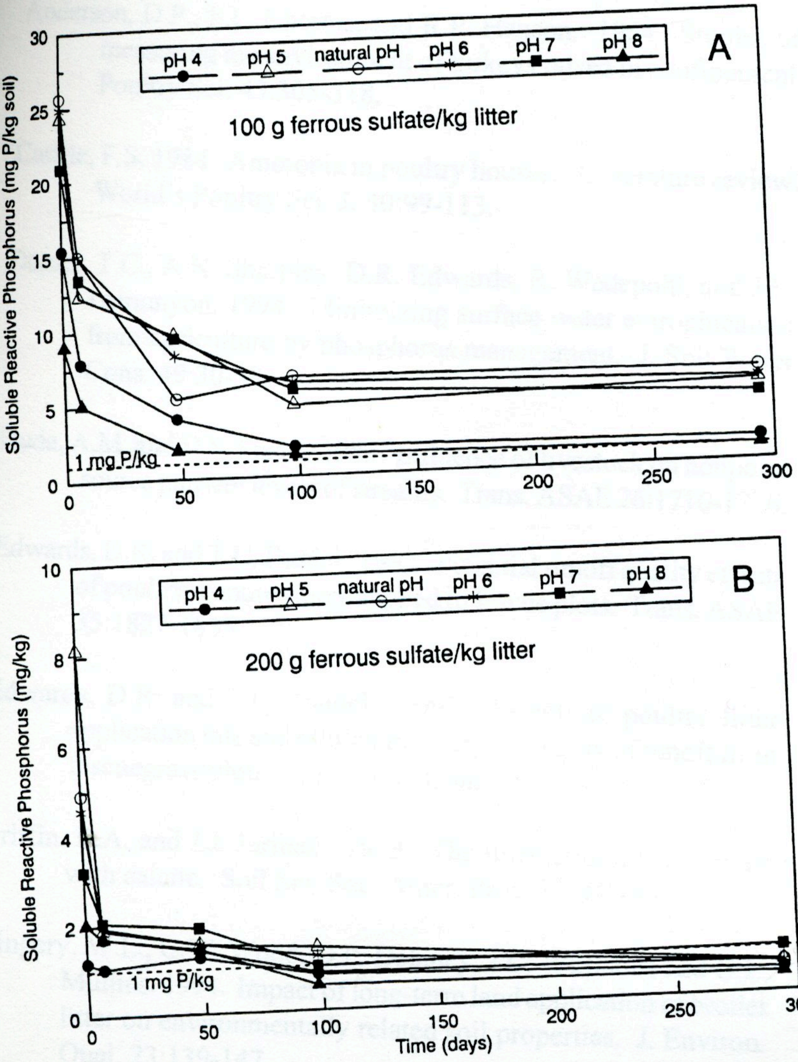

FIGURE 4. Soluble reactive P in soils as a function of pH and time, receiving litter amended with (A) 100 g ferrous sulfate/kg and (B) 200 g ferrous sulfate/kg.

receiving litter amended with 200 g $FeSO_4$/kg than with any other treatment, with values of <1 mg SRP/kg soil at all pH values. The high rate of $FeSO_4$ resulted in lower soil SRP values than alum. This was not the case in a field study of P runoff; Shreve et al. (1995) showed reductions of 87% in SRP concentrations of runoff from small plots with alum amended litter compared to the litter alone, whereas $FeSO_4$ resulted in a 77% reduction in SRP compared to litter alone.

CONCLUSIONS

Addition of litter to soil greatly increased soluble reactive P concentrations at all pH and time combinations, but additions of chemically-amended litters, especially with high rates of alum and ferrous sulfate, significantly decreased these concentrations compared to additions of unamended litter. Soluble reactive P in treated soils decreased with time and appeared to reach an equilibrium at about 98 d after treatment. The addition of Al and Fe amendments to litter resulted in low P solubility in soils over a wide pH range for long time periods. Further research should be conducted, however, to determine the effect of redox potential on the stability of these compounds.

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Effect of pH of Ammonium Oxalate Extracting Solutions on Prediction of Plant Available Molybdenum in Soil[1]

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ABSTRACT

Molybdenum (Mo) is an essential element of plants and animals and is of concern from human nutrition and environmental standpoints. Rational applications to soil of Mo in fertilizers, sewage sludges, or other soil amendments requires information of the concentrations of Mo in soils and plants. Two greenhouse experiments were conducted at Lexington, Kentucky, using surface samples of 12 soils (11 soil types) derived from diverse parent materials in Kentucky with soil pH ranging from

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