Effects of Alum and Aluminum Chloride on Phosphorus Runoff from Swine Manure

D. R. Smith,* P. A. Moore, Jr., C. L. Griffis, T. C. Daniel, D. R. Edwards, and D. L. Boothe

ABSTRACT

Phosphorus (P) runoff from fields fertilized with swine (Sus scrofa domesticus) manure may contribute to eutrophication. The objective of this study was to evaluate the effect of aluminum sulfate (alum) and aluminum chloride applications to swine manure on P runoff from small plots cropped to tall fescue (Festuca arundinacea Shreb.). There were six treatments in this study: (i) unfertilized control plots, (ii) untreated manure, (iii) manure with alum at 215 mg Al L⁻¹, (iv) manure with aluminum chloride at 215 mg Al L⁻¹, (v) manure with alum at 430 mg Al L⁻¹, and (vi) manure with aluminum chloride at 430 mg Al L⁻¹. Manure application rates were equivalent to approximately 125 kg N ha⁻¹. Alum and aluminum chloride additions lowered soluble reactive phosphorus (SRP) levels from about 130 mg P L⁻¹ to approximately 30 mg P L⁻¹ at low rates. At high rates, SRP levels in swine manure were around 1 mg P L⁻¹. Soluble reactive P concentrations in runoff were 5.50, 3.66, 3.00, 0.87, 0.87, and 0.55 mg P L⁻¹ for normal manure, low alum, low aluminum chloride, high alum, high aluminum chloride, and unfertilized control plots, respectively. Hence, high alum and aluminum chloride reduced SRP concentrations in runoff by 84% and were not statistically different from SRP concentrations in runoff from unfertilized control plots. These data indicate that treating swine manure with alum or aluminum chloride could result in significant reductions in nonpoint-source P runoff.

The swine industry in the USA is expanding. Swine producers face a potential crisis should important environmental issues be ignored, such as phosphorus (P) runoff from fields fertilized with swine manure. Phosphorus has been identified as the nutrient most limiting to eutrophication (Schindler, 1977). Animal manure applications to pastures have been shown to result in relatively high P runoff, even when manure is applied at recommended rates (Edwards and Daniel, 1992a,b, 1993a,b). Between 80 and 90% of the P in runoff is in the soluble form (Edwards and Daniel, 1993a), which is the form that is most readily available for algal uptake (Sonzogni et al., 1982). Phosphorus runoff from swine and poultry farms has also been implicated in the emergence of Pfiesteria piscicida in waterways on the eastern coast of the USA (Burkholder et al., 1997; Felton and Simpson, 1998). These issues have already become problematic in states such as Oklahoma and North Carolina, where moratoriums have been placed on expansion of the industry until more stringent environmental regulations can be established.

Recent research in our lab has focused on the chemical precipitation of P with metals, such as Al, Ca, and Fe (Moore and Miller, 1994; Shreve et al., 1995; Moore et al., 1998). All of these have been found to be effective treatments to decrease solubility of P; however, Ca and Fe phosphate minerals may dissolve under certain “normal” soil conditions. Calcium phosphate minerals may dissolve under mildly acidic soil conditions (Moore et al., 1998), hence precipitation of P in manure with Ca would probably not be a long-term solution to the P problem. Likewise, Fe(III) in ferrous phosphate minerals may be used in saturated or flooded soils by bacteria as a terminal electron acceptor for respiration, producing more highly soluble ferrous phosphates. Aluminum phosphate minerals are stable under a wide range of physico-chemical conditions (i.e., a wide range in pH and Eh conditions), hence they are stable for long periods of time. The only physico-chemical conditions that would result in aluminum phosphate mineral dissolution under “normal” soil conditions would be extremely low levels of P in the soil solution. Under these conditions, the release of P from the aluminum phosphate would be beneficial in avoiding P deficiency. Therefore, use of Al to precipitate P in manures would be a better choice than Ca or Fe.

Alum additions to poultry litter can decrease P solubility in poultry litter by orders of magnitude (Moore and Miller, 1994). Minerals formed when Al reacts with P are relatively stable, even at very low soil pH. Shreve et al. (1995) found that P runoff from fescue plots fertilized with alum-treated broiler litter was 87% lower than plots fertilized with untreated litter. The fescue plots receiving alum-treated litter had significantly higher yields and higher N contents than untreated litter, indicating that alum had increased N availability in the litter. We hypothesized that the increase in N availability was due to a decrease in ammonia volatilization. This was confirmed in laboratory studies conducted by Moore et al. (1995, 1996), which showed alum amendments to poultry litter could reduce NH₃ volatilization losses by as much as 99% compared with untreated litter. Subsequent work done by Moore et al. (1999) showed that alum applications to poultry litter resulted in significant improvements in broiler performance, due to lower ammonia levels in the production facility.

Preliminary studies were conducted in our lab to determine the effects of addition of alum to swine manure on cumulative NH₃ loss and soluble reactive phosphorus (SRP) (Moore, unpublished data, 1999). These studies indicated that treatment of swine manure with alum could reduce NH₃ losses from swine manure by as much as 95%, and reduce SRP by as much as 99%. However, it was noted in these preliminary studies that high rates of alum application resulted in H₂S odors. Ueki et al.

Abbreviations: SRP, soluble reactive phosphorus; TDP, total dissolved phosphorus.
(1986) indicated that sulfate is commonly used by anaerobic bacteria in liquid animal wastes for decomposition of organic compounds. Sulfate reduction occurs when the Eh is between −100 and −200 mV (Paul and Clark, 1996). Due to the production of H₂S, it was decided that another aluminum compound should be tested to determine if it was comparable with alum in its ability to reduce soluble P in manure and runoff, while reducing the possibility of increased H₂S production. The most obvious choice was aluminum chloride (AlCl₃).

The objective of this study was to evaluate the effect of alum and aluminum chloride applications to swine manure on P runoff from small plots cropped to tall fescue, and tall fescue yield and N uptake.

**MATERIALS AND METHODS**

The runoff study was conducted on 24 small plots (1.52 x 5.96 m, with 5% slope) located at the Main Agricultural Experiment Station of the University of Arkansas on a Captina silt loam (fine-silty, siliceous, active, mesic Typic Fragiudult). Complete details on plot layout and construction may be found in Edwards and Daniel (1992a). The plots had been in continuous fescue production for 7 yr. Soil samples were taken from the surface 15 cm of each plot for Mehlich III-extractable P analysis. Mean Mehlich III P for each block of plots was 135 mg P kg⁻¹ (Table 1).

A total of 2700 L of manure was collected for this study from a commercial swine farm. It can best be described as the “dirty” flush water leaving the house (referred to as afterflush). Total N content of this manure was determined using a LECO (St. Joseph, MI) CNS analyzer, in order to

<table>
<thead>
<tr>
<th>Soil series</th>
<th>Captina silt loam</th>
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<tbody>
<tr>
<td>pH</td>
<td>5.9</td>
</tr>
<tr>
<td>Mehlich III P (mg P kg⁻¹)</td>
<td>135 ± 51</td>
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**Table 1. Soil properties of plots to which swine manure was applied.**

![Figure 1](image.png)

**Fig. 1.** Effect of alum and aluminum chloride on (A) manure pH and (B) total dissolved phosphorus (TDP) and soluble reactive phosphorus (SRP) in swine manure. Different letters indicate significant difference at \( P \leq 0.05 \).
apply 125 kg N ha\(^{-1}\) to each plot. The total N content was 0.12%, indicating that approximately 94.6 L of manure should be applied to each plot.

The experimental design was a randomized complete block design with four replications of six treatments, consisting of an unfertilized control (no manure), untreated swine manure, swine manure treated with alum at a low rate, swine manure treated with aluminum chloride at a low rate, swine manure treated with alum at a high rate, and swine manure treated with aluminum chloride at a high rate. The low rates of alum and aluminum chloride corresponded to 215 mg Al L\(^{-1}\); the high rates were 430 mg Al L\(^{-1}\). The high rate of application resulted in a 1:1 molar ratio of aluminum to total phosphorus as determined by results from preliminary studies. One fertilizer treatment was applied to a block of four plots in a randomized complete block design. Each of the six blocks of treatments had an average of 135 \(\pm\) 51 mg Mehlich III P kg\(^{-1}\).

Prior to treatment of manure with the amendments, the manure was homogenized by pumping for 30 min. For each treatment, 94.6 L of manure was pumped into a container. For the alum treatments, 946 mL of alum was mixed into the appropriate containers for the high treatment rate (1% v/v), and 473 mL of alum was mixed into the appropriate container for the low treatment rate (0.5% v/v). For the aluminum chloride treatments, 726 mL of aluminum chloride was mixed into the appropriate containers for the high rate (0.75% v/v), and 363 mL of aluminum chloride was mixed into the low treatment rate (0.384% v/v). High levels of treatment resulted in 430 mg Al L\(^{-1}\) and low levels of treatment resulted in 215 mg Al L\(^{-1}\) for both alum and aluminum chloride. Each manure treatment (including the control) received enough double deionized (DDI) water to bring the total volume of the amendment (chemical + DDI water) to a volume of 946 mL. Immediately after addition, a 1-m-long PVC pipe was used to thoroughly stir the amended manure. A 500-mL subsample of manure was taken from each container of manure, immediately prior to application, for characterization. The remainder of the manure was applied to the plot.

The subsamples were immediately brought to the labora-
Fig. 3. The relationship between soluble reactive phosphorus (SRP) in runoff water and SRP in manure.

RESULTS AND DISCUSSION

Manure pH

Both alum and aluminum chloride reduced the pH of the manure (Fig. 1A). The pH of the untreated manure was around 8.0. The low rates of alum and aluminum chloride dropped the pH to around 7.3; the high rates dropped it to just below 7.0. Reductions in pH due to alum and aluminum chloride are expected to occur due to hydrolysis by Al.

When alum or aluminum chloride was added to liquid manure, foaming occurred. We suspect that acid produced by these compounds reacted with calcium carbonate in the manure, releasing carbon dioxide in the process. The pH of the foam was about 5.0. We believe that this foam could be valuable in plug–pull or pit-type swine houses. Aluminum chloride could be added to lagoon water. As the pits filled up, foam would form, which may be prohibitive to loss of volatile gases.

Soluble Phosphorus in Manure

Both soluble reactive phosphorus (SRP) and total dissolved phosphorus (TDP) concentrations were significantly reduced by alum and aluminum chloride (Fig. 1B). In the untreated manure, TDP concentrations were about 225 mg P L$^{-1}$ and SRP concentrations were about 130 mg P L$^{-1}$. Low rates (215 mg Al L$^{-1}$) of alum and aluminum chloride reduced these soluble P levels to around 30 mg P L$^{-1}$. High rates (430 mg Al L$^{-1}$) of alum and aluminum chloride reduced soluble P concentrations by two orders of magnitude (near 1 mg P L$^{-1}$). Similar reductions in soluble P have been noticed in
poultry litter when treated with Al, Ca, and/or Fe compounds (Moore and Miller, 1994).

After the addition of alum and aluminum chloride, a visible flocculation of solids occurred, as was expected. This observation suggests that amending swine manure with alum or aluminum chloride may benefit solid separation.

**Runoff Water pH**

The pH of runoff water from plots fertilized with untreated manure was 8.42 (Fig. 2A). Alum and aluminum chloride additions, particularly at the higher rates, significantly reduced runoff water pH. However, the pH was still high with these treatments (7.9–8.2). The pH of runoff from unfertilized plots was significantly lower (7.6) than the other treatments. These pH values were higher than would be expected for natural rainfall events, because the water used was city water from Fayetteville.

**Phosphorus Runoff**

Soluble reactive P concentrations were 5.5 mg P L\(^{-1}\) in runoff water from plots fertilized with untreated manure (Fig. 2B). Significantly lower concentrations of SRP in the water resulted from addition of low rates of alum (3.66 mg P L\(^{-1}\)) and aluminum chloride (3.00 mg P L\(^{-1}\)). The high rates of both alum and aluminum chloride reduced SRP levels in runoff to 0.87 mg P L\(^{-1}\). This represents an 84% reduction in SRP, which is very similar to results reported by Shreve et al. (1995) in poultry litter. The SRP concentration in runoff water from unfertilized control plots was 0.55 mg P L\(^{-1}\) and was not significantly different from SRP levels in runoff water from plots fertilized with swine manure treated with high rates of alum or aluminum chloride. Runoff water SRP was highly correlated with SRP in manure, indicating that SRP in manure determines the amount of P in runoff (Fig. 3).

Although alum can be used to reduce soluble P and
P runoff from swine manure, aluminum chloride is probably a better choice. The problem with adding alum to liquid manure is that there is a slight possibility that hydrogen sulfide (H₂S) gas can form under certain conditions. Anaerobic bacteria can use SO₄²⁻ as an electron acceptor for respiration, reducing it to H₂S. Swine farmers already have odor problems, which do not need to be compounded by amendments that may create more odors. Production of H₂S would not be increased when aluminum chloride is added to swine manure, since it does not contain sulfate. It should be noted that H₂S formation would not occur when alum is added to dry manure, such as poultry litter, because O₂ would be used by bacteria for respiration.

### Tall Fescue Yields and Nitrogen Uptake

Tall fescue yields of plots fertilized with swine manure were significantly higher than the yields of unfertilized control plots (Fig. 4A). However, there was no significant difference in yields from plots fertilized with different types of swine manure. We hypothesized that yields of plots fertilized with manure treated with alum or aluminum chloride would be higher than the untreated swine manure. This was expected as a result of reduced NH₄⁺ volatilization as reported by Moore et al. (1999) and what Shreve et al. (1995) had reported for poultry litter. However, the yields from plots fertilized with untreated swine manure were numerically higher (not statistically higher) than the other treatments.

Relative to the unfertilized control plots, N uptake by tall fescue was significantly higher in plots fertilized with various kinds of swine manure (Fig. 4B). However, as with yields, there were no significant differences in N uptake among the plots fertilized with swine manure. We are not sure why the alum and aluminum chloride additions did not increase N use efficiencies as was seen earlier in studies with poultry litter (Shreve et al., 1995). Weather may have played a role. The manure was applied on 9 Oct. 1998 and the rainfall was applied on 10 October. Yield measurements were made for the following 6 wk, which is a relatively cool time of the year. These cool conditions may have slowed ammonia volatilization for all treatments. Furthermore, manure in this study was amended with alum or aluminum chloride after collection from the swine house, and prior to spreading onto the plots. This procedure would not account for possible reductions in N loss that may occur in the pit if addition of these chemicals were made at the production facility.

Another reason swine manure may have behaved differently than poultry litter may be because it is a liquid. After poultry litter is applied to a pasture, the particles rest on top of the soil and/or on top of the grass. However, most of the swine manure infiltrates the soil, particularly when a rainfall event occurs the day after manure applications. Infiltration of nutrients such as NH₄⁺ may have resulted in increased adsorption to soil particles. Hence, the environmental conditions present in this study may have reduced ammonia volatilization rates enough to negate differences in N concentration between untreated and treated manure.

### CONCLUSIONS

Alum and aluminum chloride additions to swine manure significantly reduced manure pH, which should result in reduced ammonia volatilization. These treatments also reduced soluble P levels in manure. The high rates reduced soluble P levels in manure by two orders of magnitude (from around 200 mg P L⁻¹ to approximately 1 mg P L⁻¹). These reductions in soluble P in manure resulted in lower P in runoff. Soluble reactive P levels in runoff water from plots fertilized with manure treated with the high rates of alum and aluminum chloride were 84% lower than untreated manure. The SRP in runoff from high alum or aluminum chloride treatments was not statistically different from unfertilized control plots. These data indicate that addition of aluminum chloride (addition of alum may increase H₂S emissions) to liquid swine manure may effectively reduce P levels in runoff from swine manure–amended pasture.

These results indicate that further research should be conducted using aluminum chloride in swine houses in an attempt to reduce NH₃ volatilization and soluble P in the manure. Further studies should also focus on possible benefits of the use of aluminum chloride, such as animal performance as measured by weight gains, and feed efficiency.

### REFERENCES


Tillage and Nutrient Source Effects on Surface and Subsurface Water Quality at Corn Planting

Suling L. Zhao, Satish C. Gupta,* David R. Huggins, and John F. Moncrief

ABSTRACT

This study quantified the effects of tillage (moldboard plowing [MP], ridge tillage [RT]) and nutrient source (manure and commercial fertilizer [urea and triple superphosphate]) on sediment, NH$_4$-$\text{N}$, NO$_3$-$\text{N}$, total P, particulate P, and soluble P losses in surface runoff and subsurface tile drainage from a clay loam soil. Treatment effects were evaluated using simulated rainfall immediately after corn (Zea mays L.) planting, the most vulnerable period for soil erosion and water quality degradation. Sediment, total P, soluble P, and NH$_4$-$\text{N}$ losses mainly occurred in surface runoff. The NO$_3$-$\text{N}$ losses primarily occurred in subsurface tile drainage. In combined (surface and subsurface) flow, the MP treatment resulted in nearly two times greater sediment loss than RT ($P < 0.01$). Ridge tillage with urea lost at least 11 times more NH$_4$-$\text{N}$ than any other treatment ($P < 0.01$). Ridge tillage with manure also had the most total and soluble P losses of all treatments ($P < 0.01$). If all water quality parameters were equally important, then moldboard plow with manure would result in least water quality degradation of the combined flow followed by moldboard plow with urea or ridge tillage with urea (equivalent losses) and ridge tillage with manure. Tillage systems that do not incorporate surface residue and amendments appear to be more vulnerable to soluble nutrient losses mainly in surface runoff but also in subsurface drainage (due to macropore flow). Tillage systems that thoroughly mix residue and amendments in surface soil appear to be more prone to sediment and sediment-associated nutrient (particulate P) losses via surface runoff.

The combination of intensive cultivation and the presence of surface and subsurface drainage in southern Minnesota has been implicated in water quality degradation of the Minnesota River, the upper Mississippi River, and the Gulf of Mexico (Payne, 1994; Goolsby et al., 1999). Many soils in the North Central states, including those in southern Minnesota, have low hydraulic conductivity and thus limited drainage capacity (Wheaton, 1977). As a result, artificial drainage is a necessity for profitable crop production in this region. Even when subsurface drainage is enhanced in these soils, problems associated with poor drainage are still not satisfactorily resolved. This is because the landscape is relatively flat (<2% slope) and has many small depressions (pot holes) where water stands after snowmelt and heavy rainfall. Standing water hinders the timeliness of farm operations and is also deleterious to planted crops. To overcome these problems, farmers have installed surface tile inlets that drain water from these depressions to subsurface tile drains. These tile inlets allow transport of sediment and surface-applied chemicals to subsurface tiles, which ultimately flow to surface waters.

In addition to being wet, the soils in the upper Midwest are also cold during early spring, which delays corn planting, shortens the growing season, and thus reduces crop yield (Olsen and Schoeberl, 1970). To overcome problems associated with wet and cold soil conditions during early spring, farmers often moldboard plow in the fall to enhance soil drying and warming the following spring. One consequence of fall moldboard plowing, however, is the lack of surface residue cover during spring when soils are most vulnerable to detachment by spring rains.

Beef, hog, and dairy farming are also an important part of the economy in the area, and thus land application of manure is a common practice. Consequently, additional loading of nutrients and organic matter can occur both in surface runoff and in subsurface drainage. Possible methods to lower nutrient, herbicide, and organic matter loading of the Minnesota River include practices such as ridge tillage, which minimizes soil disturbance while preserving crop residues at the soil surface. Ridge tillage provides substantial residue cover from fall harvest to early spring when ridges are left undisturbed. At planting, surface cover is reduced in the planted row, but overall soil disturbance is minimal. Reestablishment of ridges in late June results in shallow mixing of surface soil, while maintaining cover. Surface residue cover in ridge tillage reduces soil erosion while the raised beds enhance soil warming in early spring (Gupta et al., 1990). One unknown consequence of ridge tillage is the effect of limited soil incorporation of

Abbreviations: FWMC, flow-weighted mean concentration; MP, moldboard plow; M, manure; RT, ridge till; U, urea.