Alum and Gypsum Treated Poultry Manure and Fertilizer Phosphorus Losses with Runoff with or without Incorporation into the Soil

Final Project Report to the Iowa Egg Council

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Introduction

This final report summarizes the field and laboratory work for a project conducted from fall 2008 until fall 2011. The goals of the project were to evaluate the effects treating poultry manure with alum or gypsum on different runoff phosphorus (P) fractions, and to compare the results with runoff P loss for inorganic fertilizer and liquid swine manure. The specific objectives were to (1) study how the time of application of poultry manure and of runoff events affects short-term P loss with surface runoff and compare it with P fertilizers, (2) evaluate the treatment of poultry manure with alum or gypsum as ways to reduce P loss with surface runoff, and (3) determine the relationship between the solubility of P in treated manure and effects in soil and runoff P loss. The need and reasons for this research were discussed with detail in the original proposal. Previous research funded by the Iowa Egg Council indicated that the short-term risk of P loss with surface runoff for events occurring immediately after applying manure or fertilizer P is much less for poultry manure than for fertilizer or liquid swine manure. This was true for total P loss but especially for soluble P loss, which is readily available for algae growth in lakes and streams. Alum (aluminum sulfate) or gypsum (calcium sulfate) react with soluble P compounds of the manure and form P compounds of relatively low solubility in water, which may reduce loss of soluble P with surface runoff. Alum can also be used for suppression of manure nitrogen loss through volatilization of ammonia, but this was not an objective of this research. The previous research did not evaluate losses with snowmelt runoff or early spring rainfall runoff for manure applied to frozen or snow-covered ground. Therefore, this new project evaluated the effect of chemical treatments of poultry manure on runoff P loss and compared P losses for a wider range of P application times and runoff events than did the previous research.

Review of Treatments and Procedures

The procedures used were described with detail in the original proposal. Each year we worked on a different field located in Central Iowa (always with soybean residue). The treatments applied differed for the first year and the last two years of the study.

A. First year treatments:

1. Phosphorus sources (five): Egg layer's manure untreated, layer's manure mixed with alum at 32% by weight (as is), layer's manure mixed with gypsum at 27 % by weight (as is), inorganic fertilizer (DAP), and a control with no P applied. One-half of the alum and gypsum were mixed with the manure one week before application to the field whereas the rest was spread immediately after the manure was applied. The P applied was the same for all sources, and was 100 lb total P_2O_5/acre.

2. Time of application (two): The P sources were applied in the fall (October to November) before snow or in early winter (in January).
3. Tillage (two): The fall-applied treatments were applied to the soil surface without incorporation into the soil or were incorporated by disking immediately after the application (also there were no-till and tilled control treatments). The treatments applied during winter were not incorporated into the soil.
4. Timing of runoff event (two): All fall-applied treatments received simulated rainfall within 24 hours of the application, but a different set of plots of treatments without incorporation into the soil received simulated rainfall only 10 days after the application.

B. Second- and third-year treatments: The only difference with the first-year treatments was that we added liquid swine manure as an additional P source without alum or gypsum pretreatment. The swine manure application rate also was 100 lb total P_2O_5/acre, and we used the same time of application, tillage, and timing of runoff event that was used for the other sources.

The experiment each year was not a complete factorial because we did not include all treatment combinations. Some did not make sense (such as P incorporation for the winter application time) and others were not used because of little relevance or to reduce costs (such as a 10-day runoff event for the P sources incorporated by tillage). Therefore, there were 25 treatments in the first year, and 30 treatments in the second and third years of the study. All treatments were replicated three times.

For each site and year, soil samples were taken before applying the P sources and also from selected plots after the final rainfall simulation. Table 1 shows summarized site information.

Table 1. Soil properties for three experiments at a different Central Iowa site each year.

	Soil			Residue		Initial Soil Test Results ‡				
Field	Series	Year	Depth	Cover†	Slope	BP	M3P	OP	OM	pH
			Inches	%	%	------- ppm ------			%	
1	Clarion	2008	0-2	95	3	31	32	14	3.7	7.2
			2-6			18	19	8	3.5	7.1
2	Clarion	2009	0-2	98	3	29	29	17	3.4	6.3
			2-6			16	15	10	3.2	6.3
3	Clarion	2010	0-2	95	3	8	9	4	4.4	5.3
			2-6			5	5	3	3.3	6.0

† Soybean residue.
‡ BP, Bray-P1; M3P, Mehlich 3 P; OP, Olsen P; OM, organic matter.

The first year poultry manure was collected from different egg layer facilities and was analyzed for P and other nutrients. Based on this sampling, for the field study we decided to collect manure from the operation that best represented the egg layer's manure commonly applied in Iowa. We used the same manure source for the three years of the study. The manure was analyzed for moisture content; total N, P, K, calcium, and carbon; water soluble P, and pH; and Table 2 shows summary information.

Table 2. Analysis of the poultry manure used in the study (as-is values).

Year	Moisture	Total Nutrient Concentration †								WSP ‡	pH
		Nitrogen		P_2O_5		K_2O		Ca	C	P_2O_5	
	%	lb/ton	%	lb/ton	%	lb/ton	%	%	%	%	
2008	13.5	60	3.0	79	4.0	72	3.6	8.5	24	17.4	8.6
2009	13.3	64	3.2	78	3.9	48	2.4	9.0	26	16.6	8.4
2010	13.9	57	2.9	68	3.4	48	2.4	9.9	28	3.4	7.5

† Ca, calcium; C, carbon.

‡ WSP, manure water soluble P expressed as percent of the total P.

The field rainfall simulation equipment and procedures were similar to those we used in previous projects. Simulated rainfall was applied at an intensity of 3 inches/hour to get 30 minutes of continuous runoff. The plots that were used for snowmelt runoff measurements differed from other only in that no simulated rainfall was applied in the fall and that a troughs and collection bucket were installed on the down-slope border before snow or soils froze. The natural snowmelt collection was done as it occurred during winter and early spring. After the final snowmelt each year, in early spring, we conducted a final rainfall simulation on the same plots from which we had collected snowmelt.

The surface runoff was analyzed for sediment, dissolved reactive P (DRP), total P, and bioavailable or algal-available P (BAP). The DRP runoff P fraction is readily available for algae growth in streams or lakes, and the BAP fraction is measured by a laboratory chemical analysis (iron-oxide coated filter paper test) that estimates P available immediately to algae plus that becoming available over a few weeks or months depending on the receiving water properties. We measured runoff volume and analyzed the concentration of P in the runoff, and with these data calculated the amount of P loss. It is recognized that field rainfall simulations represent well the concentration of P in runoff that leaves a field when different treatments are evaluated, but do not represent well the actual amounts of P that can be lost at the edge of fields, especially total runoff P loss. Also, comparisons of results for runoff P concentrations and calculated P loads showed similar ranking of the treatments. Therefore, to simplify as much a possible a long and complicated report, we show and refer to only to runoff P concentrations. Also, although the runoff P concentrations showed the expected large year to year variation due to site conditions and manure variation, the ranking of the treatments were consistent across the three years of the study. Therefore, three-year averages are shown and discussed in this report.

Runoff Phosphorus for the Fall Season Rainfall Simulations

Figure 1 summarizes results for untreated poultry manure, P fertilizer (DAP), and no P application treatments when the materials were applied in the fall, and for rainfall events within 24 hours of P application or 10 days after application. One very clear result was that the concentrations of all three runoff P fractions were much greater for fertilizer than for poultry manure for all methods of application (no-till or tillage) and timing of runoff events. Runoff P for manure always was much lower than for the fertilizer and only slightly higher than for the control receiving no P.

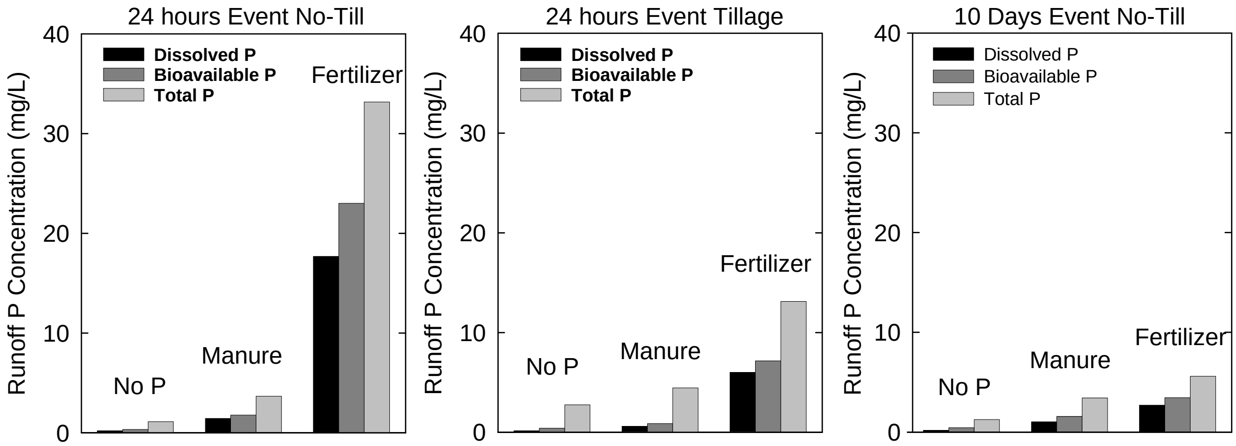

Fig. 1. Runoff P concentration within 24 hours of applying fertilizer (DAP) or poultry manure at 100 lb P_2O_5/acre in the fall with or without incorporation into the soil and also after 10 days of application without incorporation (averages of three years).

This result confirms the results of a previous project funded by the IEC that involved comparisons of runoff P within 24 hours of application for surface-applied fertilizer and untreated manure from egg layers, broilers, and turkeys in several producers' fields. The striking difference with fertilizer is explained by lower immediate P solubility in water of the poultry manure compared with the fertilizer, and also perhaps by the physical properties of manure compared with fertilizer. For example, sometimes the spread manure was in small clumps, and less P may have been extracted by the rainfall. Therefore, the research confirms that the risk of P loss for runoff events shortly after P application without incorporation into the soil is much less for poultry manure of all types than for commonly used P fertilizers.

Another important result shown in Fig. 1 was that incorporation of fertilizer into the soil with tillage and a 10-day delay in the runoff event reduced runoff P to about one-half and one-third or less, respectively, compared with the 24-hour runoff event without incorporation. When manure was applied, however, both tillage and a runoff delay reduced DRP and BAP concentrations but not total P compared with the surface application. The sediment concentration data indicated that tillage increased sediment loss about three-fold compared with no tillage, with no clear differences for fertilizer or manure (data not shown). The fertilizer incorporation offset the sediment loss increase and reduced runoff P loss significantly because all the P is soluble in water and is easily extracted by water runoff.

The fact that even a short 10-day delay in a runoff event significantly reduced runoff P for fertilizer but not much for poultry manure is a very important result. This means that consideration of the probability of a runoff event shortly after P application to the soil surface is a very useful mainly for producers applying fertilizer. For example, it is well known that the probability of a runoff event in Iowa is much less in the fall than in spring. For poultry manure application, however, the risk posed of an immediate runoff event is much less then for fertilizer.

Figure 2 shows alum treatment of manure applied in the fall consistently reduced the P concentration in runoff, but the effect of gypsum was smaller (and more variable across years). As expected, the reduction due to the alum treatment was proportionally greater for the dissolved and bioavailable runoff P fractions then for the total P in runoff. The reduction due to the alum treatment for the 24-hour event without tillage was 81, 71, and 30 % for DRP, BAP, and total runoff P concentrations, respectively. The comparable effects of gypsum addition were only 21, 7, and 23 for DRP, BAP, and total runoff P, respectively. Both the P loss and the manure chemical treatment effects were smaller with tillage or with a 10-day runoff event delay. The decrease in DRP and BAP concentrations in runoff can be explained by precipitation and/or adsorption of P on aluminum and calcium compounds.

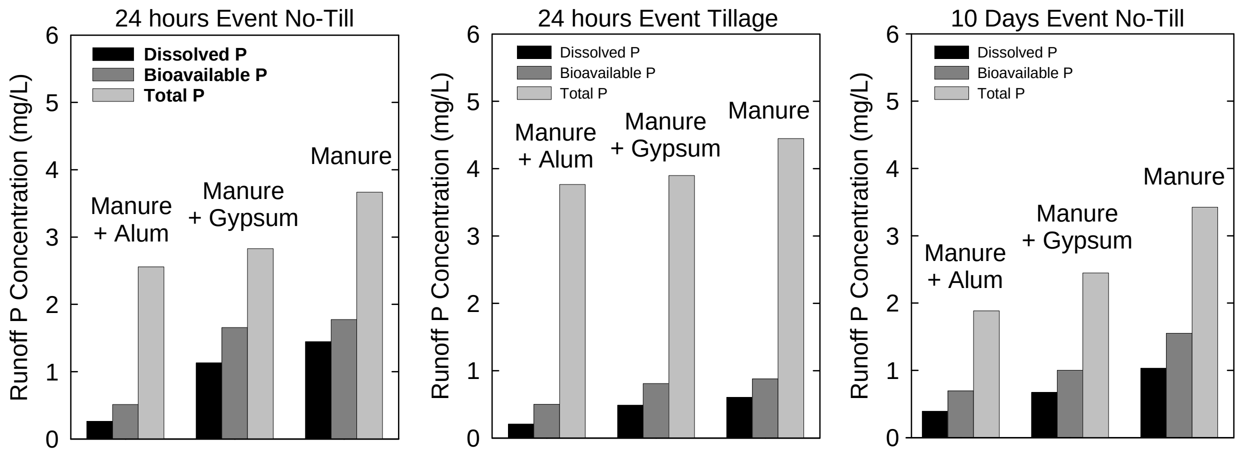

Fig. 2. Runoff P concentration within 24 hours of applying poultry manure untreated or treated with alum or gypsum at 100 lb P_2O_5/acre in the fall with or without incorporation into the soil and also after 10 days of application without incorporation (averages of three years).

The reduction of total runoff P was not entirely explained by the reductions in DRP and BAP, however. Alum and gypsum could have reduced loss of specific runoff P fractions that were not measured, and also both tended to reduce sediment loss slightly compared with all other treatments (data not shown). The delay in runoff and alum effects together resulted in a very large reduction in runoff P loss with surface applied manure. Therefore, treatment of poultry manure with alum and consideration of the probability of a runoff event shortly after manure application to the soil surface are useful factors poultry producers may consider.

Snowmelt and Early Spring Runoff Phosphorus

Figure 3 and 4 summarize results for snowmelt runoff P when untreated poultry manure, treated manure with alum or gypsum, and fertilizer (DAP) were applied either in the fall or in early winter to snow-covered ground (with no runoff event occurring in the fall). The snow cover was 3 to 6 inches thick when the P sources were applied in all years. We could not evaluate effects of application in winter to frozen ground without snow cover because during the three years of the project always there was significant snow cover in central Iowa from the middle of December. The first two years had a record snowfall and duration of snow cover from December to February, and the layer of frozen soil was thinner and lasted a shorter time. The last year was more typical of Iowa winter conditions, and started a hard soil freeze in December and snow cover during January and February. This is important because the manure P reactions with surface soil, retention of soluble P by soil, and the loss susceptibility of dissolved or particulate P could be different depending on these conditions.

Figure 3 summarizes snowmelt runoff P data for untreated manure, fertilizer, and no P treatments were applied either in the fall or in early winter to snow-covered ground. The treatments ranking was maintained compared with the results for rainfall simulations in the fall, but snowmelt runoff P concentrations were lower. The snowmelt P concentration for fertilizer applied in the fall was less than one-half than for fertilizer applied in winter to snow-covered ground. For poultry manure, however, the winter application increased runoff P only slightly compared with the the fall application. The snowmelt runoff P for manure was about one-half than for fertilizer for the fall application time and about one-fifth for the winter application time.

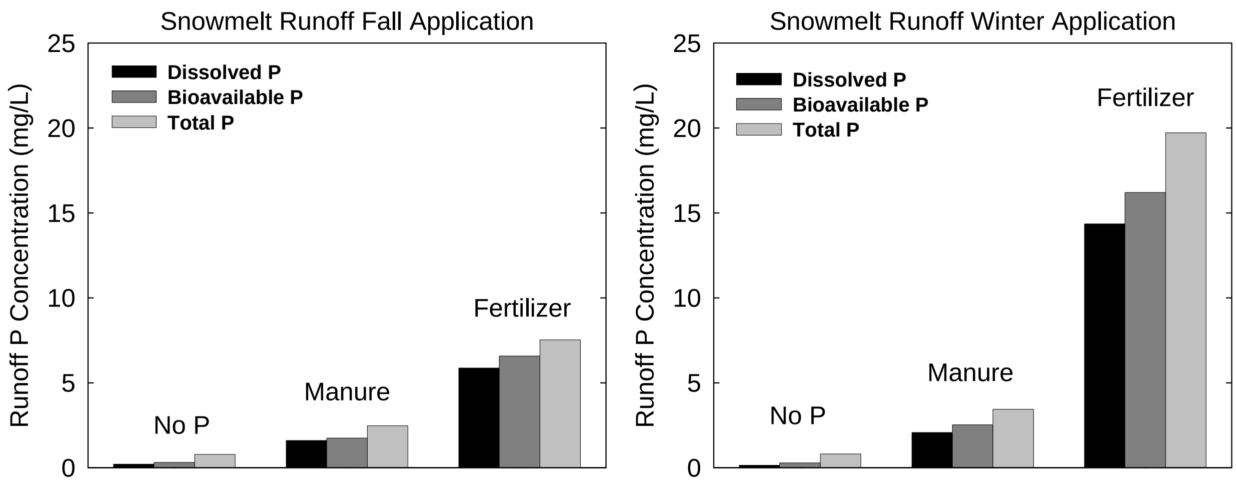

Fig. 3. Snowmelt runoff P concentration after applying fertilizer or poultry manure at 100 lb P_2O_5/acre in the fall without incorporation into the soil or in winter to snow-covered ground (averages of three years).

Another significant result obvious by comparing Fig. 3 and Fig. 1 was that snowmelt runoff P for plots fertilized in the fall was much lower than runoff P from the no-till 24-hour simulation in the fall. The snowmelt P for plots fertilized in winter, however, was only slightly less than for the fall 24-hour runoff event, which indicates P retention by soil during winter. For poultry manure, snowmelt P always was much lower than for fertilizer, and was approximately similar across seasons and times of application. Therefore, the time of P application greatly affected runoff P loss from the fertilized plots but not from plots where poultry manure was applied.

Figure 4 shows that snowmelt runoff P was significantly reduced by the manure pretreatment with alum for applications in the fall or in winter to snow-covered ground. The effect of gypsum at reducing manure P loss was much less than for alum. For the fall application time, alum and gypsum reduced DRP in snowmelt by 65 and 39 %, respectively, and reduced BAP by 58 and 34 %, respectively. The effect of treating manure with alum or gypsum was much greater for the winter application. Alum and gypsum reduced DRP in winter-applied manure snowmelt by 88 and 58 %, respectively, and reduced BAP by 75 and 59 %. The alum and gypsum manure treatments had a small effect on total P in snowmelt runoff, which was mostly accounted for by effects on DRP and BAP.

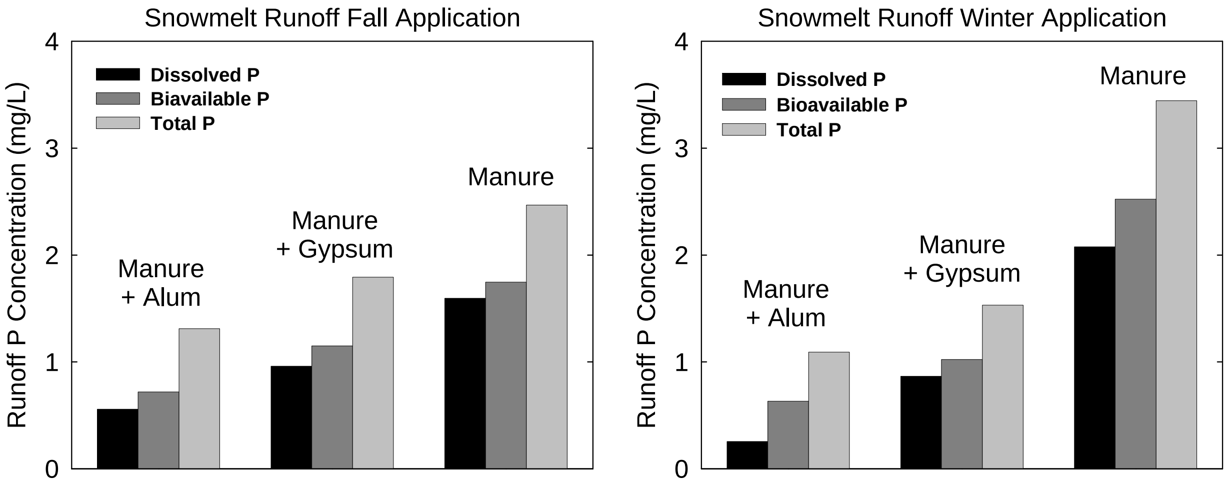

Fig. 4. Snowmelt runoff P concentration after applying poultry manure untreated or treated with alum or gypsum at 100 lb P_2O_5/acre in the fall without incorporation into the soil or in winter to snow-covered ground (averages of three years).

Figure 5 summarizes runoff P concentrations for untreated poultry manure, fertilizer, and no P application for early spring rainfall simulations conducted on the same plots from which we collected snowmelt runoff. These simulations mimicked early spring rainfall on wet soil because were conducted as soon as the soil thawed and moisture was at field capacity. Results show very low runoff P concentrations for all treatments, very small differences between the control and plots receiving P, and essentially no difference between the manure and fertilized plots.

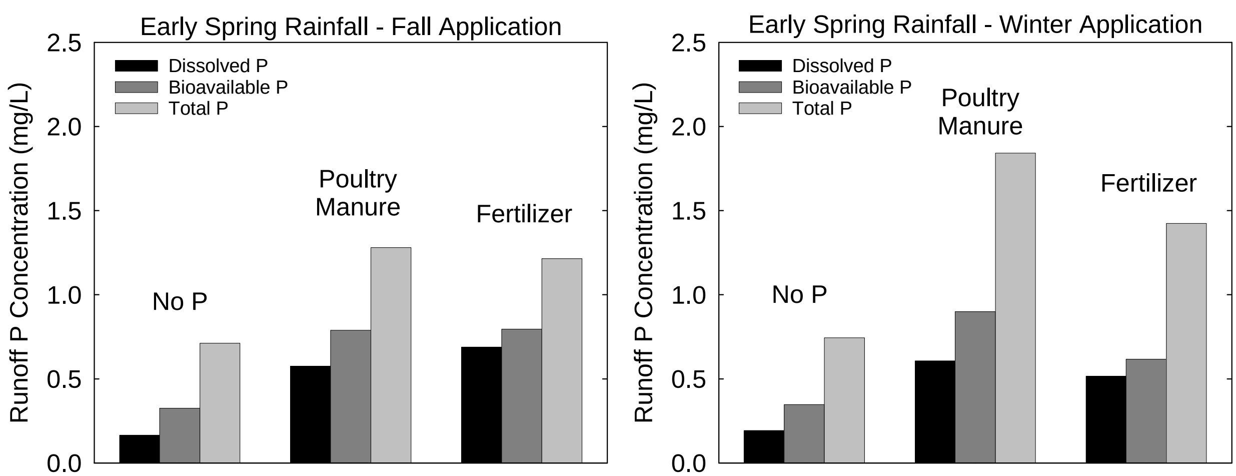

Fig. 5. Phosphorus concentration in spring runoff for plots where snowmelt runoff was collected and untreated poultry manure had been applied at 100 lb P_2O_5/acre in the fall without incorporation into the soil or in winter to snow-covered ground (averages of three years).

Figure 6 compares poultry manure untreated and treated with alum or gypsum for the early spring rainfall simulation. Adding alum or gypsum reduced the P concentration of all runoff P fractions for both times of application, but the effect was greater for DRP and BAP. For the fall application, alum and gypsum reduced DRP in snowmelt by 38 and 30%, respectively, and reduced BAP by 33 and 17%. For the winter application, alum and gypsum reduced DRP 47 and 17%, respectively, and reduced BAP by 35 and 21%. Lower runoff P concentrations and smaller differences between treatments for spring runoff can be explained by further reaction of the P of both fertilizer and manure with the surface soil and to previous P loss with snowmelt runoff.

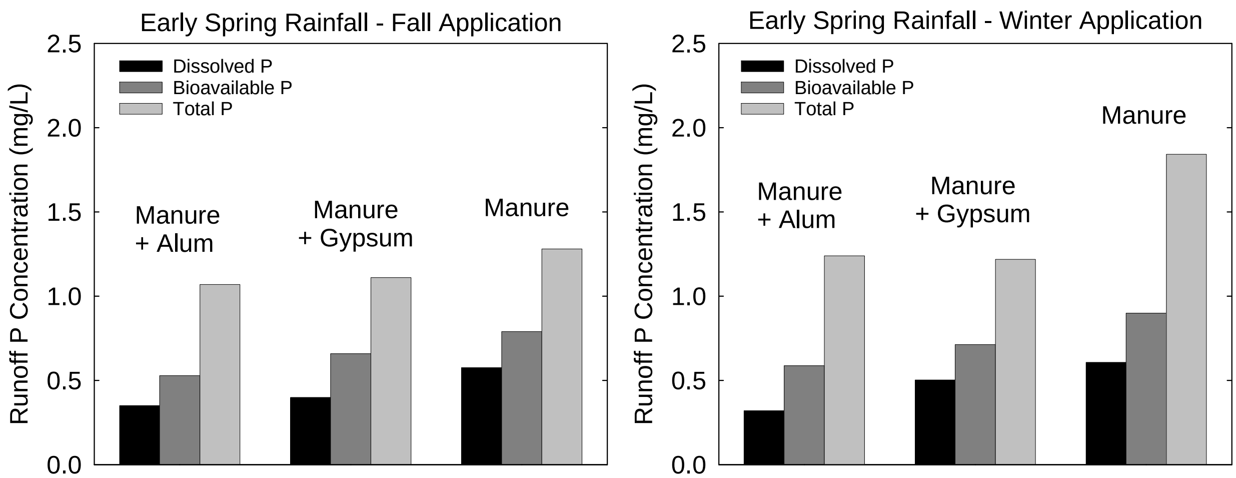

Fig. 6. Phosphorus concentrations in early spring runoff for plots where snowmelt was collected and poultry manure untreated or treated with alum or gypsum had been applied at 100 lb P_2O_5/acre in the fall without incorporation into the soil or in winter to snow-covered ground (averages of three years).

Runoff Phosphorus for Fertilizer, Poultry Manure, and Liquid Swine Manure

The liquid swine manure treatments were applied only in the last two years of the study. Therefore, data for fertilizer and poultry manure shown in this section also correspond to the last two years. Figure 7 shows results for the fall runoff events that occurred within 24 hours of the treatments application in the fall or 10 days later. The runoff P concentrations were highest for fertilizer and were followed by swine manure and poultry manure. This result is in agreement with those of a previous study funded by the IEC that compared runoff P within 24 hours after applying a similar P rate of DAP and manure from beef, poultry, and swine. In that study, runoff P was lowest for the beef and poultry manures.

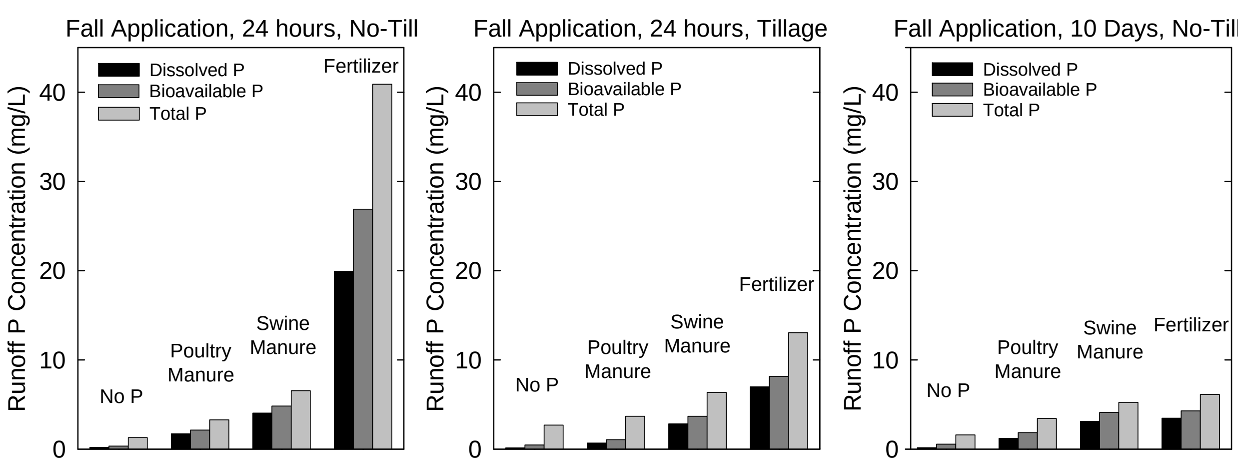

Fig. 7. Runoff P concentration within 24 hours of applying fertilizer, poultry manure, or liquid swine manure at 100 lb P_2O_5/acre in the fall with or without incorporation into the soil and also after 10 days of application without incorporation (averages of two years).

Figure 8 shows P concentrations in snowmelt runoff collected from plots to which the P sources were applied in the fall or in winter to snow-covered ground. Results show much lower runoff P concentrations than for the fall rainfall event, but the treatment ranking was similar. Snowmelt P concentrations for the fall or winter application time were approximately similar, but differences between the manures and fertilizer were smaller for the winter application. Fall application of fertilizer did not reduce P loss much compared with a winter application, but fall application of the manures significantly reduced P loss compared with the winter application.

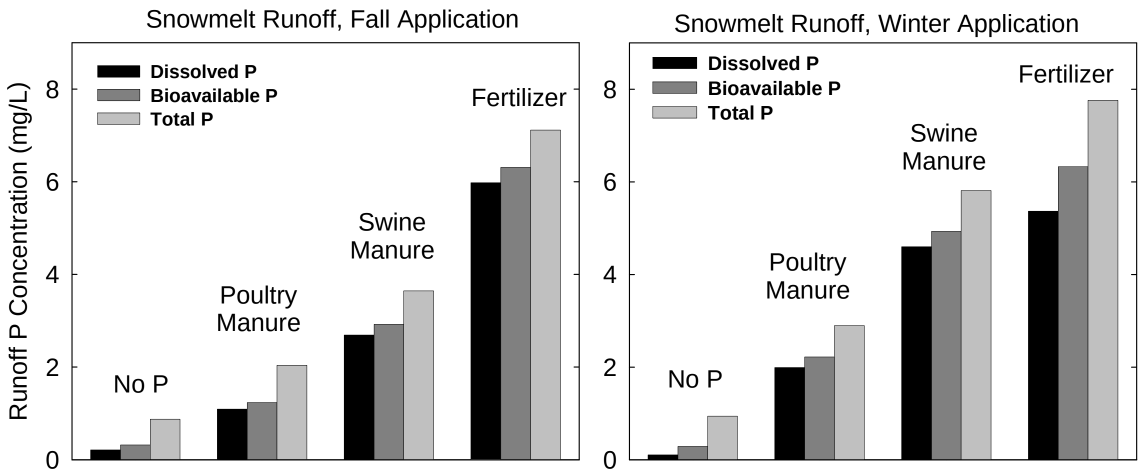

Fig. 8. Snowmelt runoff P concentration after applying fertilizer, poultry manure, or swine manure at 100 lb P_2O_5/acre in the fall without incorporation into the soil or in winter to snow-covered ground (averages of two years).

Figure 9 shows runoff P concentrations with early spring rainfall for the same plots in which snowmelt runoff had been collected. The runoff P concentrations were lower than for snowmelt runoff, which can be explained by further reaction of the P of fertilizer and manure with the surface soil and to previous P loss with snowmelt runoff. Spring runoff P concentrations were highest for liquid swine manure for both times of application, but there were small or no differences between the fertilizer, poultry manure, and control treatments.

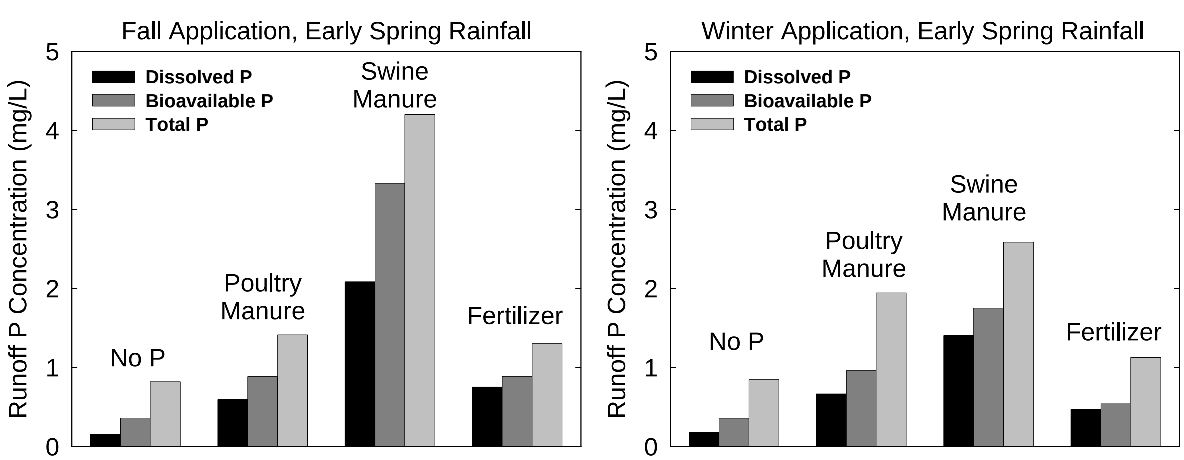

Fig. 9. Phosphorus concentration in early spring runoff for plots where snowmelt runoff was collected and no P, fertilizer, poultry manure, or swine manure had been applied at 100 lb P_2O_5/acre in the fall without incorporation into the soil or in winter to snow-covered ground (averages of two years).

Effect of Treating Poultry Manure with Alum and Gypsum on Soil pH

One possible side effect of treating poultry manure with alum is that long-term alum application to soil may decrease soil pH. The results showed a very small effect of mixing alum with manure compared with untreated manure and pretreatment with gypsum (Table 3). However, the soil pH for the alum-treated manure still was higher than the initial soil pH, because the manure addition increased pH. On the other hand, application of DAP and liquid swine manure slightly decrease pH in the top 2-inch soil layer. The alum effect would be even less when the manure includes significant amounts of eggshells because of higher pH and carbonate calcium concentration. Therefore, the acidifying effects of DAP and liquid swine manure (because of its ammonium-nitrogen) would be more likely and obvious than any possible effects of alum.

Table 3. Effects of phosphorus sources and addition of alum and gypsum to poultry manure on soil pH (averages for three different sites).

Sampling † depth(in.)	Control	Poultry Manure Untreated	Poultry Manure + Gypsum	Poultry Manure + Alum	DAP	Swine manure
0-2	6.29	6.54	6.52	6.32	6.10	6.21
2-6	6.41	6.52	6.58	6.47	6.33	6.47

† Samples were collected in early March, four to five months after treatments application.

Summary of Results

The results confirmed results of previous research funded by the IEC for runoff events within 24 hours of applying poultry manure and inorganic fertilizer without incorporation into the soils, and also of benefits of incorporating poultry manure with tillage that does not increase soil erosion significantly. However, this was the first Iowa study that compared poultry manure, liquid swine manure, and fertilizer concerning application to snow-covered ground; and the first study that evaluated chemical treatments of egg layer's manure to further reduce P loss.

<u>Rainfall runoff P for untreated poultry manure, swine manure, and fertilizer</u>:
There was much less runoff P loss for poultry manure than for fertilizer, and also significantly less than for liquid swine manure. Incorporation fertilizer or swine manure into the soil in the fall or a 10-day delay in the runoff event for a surface application reduced runoff P to one-third to one-half compared with runoff immediately after application without incorporation. For poultry manure the effects of tillage and a runoff event delay were much less, however, in part because the P loss was much less in the first place. Runoff P for poultry manure always was only slightly higher than runoff P for the control without P applied. This result indicates that consideration of the probability of a runoff event shortly after P application to the soil surface is essential for producers applying fertilizer and liquid swine manure, but not as much for poultry producers.

<u>Snowmelt runoff P for untreated poultry manure, swine manure, and fertilizer</u>:
Snowmelt runoff P concentrations for application in the fall without incorporation compared with fall runoff within 24 hours of application without incorporation were one-fourth to one-half for fertilizer and swine manure, but were only slightly less for poultry manure. Snowmelt P for

application in winter, however, compared with fall runoff within 24 hours of application, were one-half to two-thirds for fertilizer and swine manure but about the same for poultry manure. These results show the necessity to apply fertilizer or swine manure as early as possible in the fall and to avoid application to snow-covered ground to minimize P loss with snowmelt runoff, but not for poultry manure. The P loss from poultry manure is much less than for the other two sources, and there was little or no difference in snowmelt runoff P concentration for fall or winter time of application.

Treatment of poultry manure with alum or gypsum:
Treating egg layer's manure with alum consistently reduced the P concentration in runoff with or without incorporation into the soil and even more for the winter application, but the effect of gypsum was smaller and more variable. The reductions were proportionally greater for DRP and BAP runoff P fractions than for total P. The alum treatment reduction for the 24-hour runoff event without incorporation into the soil was 81, 71, and 30% for DRP, BAP, and total P runoff P concentration, respectively. The comparable effects of gypsum addition were only 21, 7, and 23%, respectively. Alum and gypsum additions to manure applied in the fall reduced DRP in snowmelt runoff by 65 and 39%, respectively, and reduced BAP by 58 and 34%, respectively. The P loss and the manure chemical treatment effects were smaller with incorporation or with a 10-day runoff event delay. The chemical treatment effect on snowmelt runoff was greater for the winter application, when alum and gypsum reduced DRP by 88 and 58%, respectively, and reduced BAP by 75 and 59%. Across all rainfall and snowmelt runoff events, alum decreased DRP by 39 to 88% and gypsum decreased DRP 17 to 58%. The results showed that an alum acidification of soil is not a concern because of the manure effect at increasing pH and a slightly lesser increase when alum is added. We believe that approximately similar beneficial effects of alum may be observed for P loss with subsurface tile drainage, although the impact would be less because of lower P loss compared with runoff.

Conclusions

A similar P application rate results in greater runoff P loss for fertilizer and liquid swine manure than for egg layer's manure. Due to much lesser P loss with poultry manure and its properties, application in the fall (as opposed to snow-covered in winter), incorporation into the soil, and avoidance of application during periods with high probability of runoff events are less essential to minimize P loss with poultry manure than with fertilizer or swine manure.

Treating egg layer's manure with alum further reduced P loss with surface runoff, mainly the dissolved and algal-available P fractions. Across all rainfall and snowmelt runoff events, alum decreased DRP by 39 to 88% and gypsum decreased DRP 17 to 58%. The soil acidifying effect by mixing alum with poultry manure was very small, and it was offset by the egg layer's manure application effect at increasing soil pH compared with the initial pH.

This study used only one alum rate and the mixture was prepared by hand one week before the manure was applied to the fields. Therefore, perhaps additional studies are needed to determine the best alum rate to use considering the reduction in dissolved and algal-available P loss, long-term effects on soil pH, and practical issues concerning its mixture with manure.