FACTORS AFFECTING PHOSPHORUS RUNOFF FROM PASTURES

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INTRODUCTION

Non-point source phosphorus (P) runoff from pastures fertilized with animal manures can lead to accelerated eutrophication in lakes and streams. Animal manures tend to have a low N:P ratio and are applied based on nitrogen needs, hence P application is excessive. In pasture systems, manure is generally applied without incorporation, leading to increased levels of P near the soil surface. Continual application of animal manures for several years increases the soil P levels and leads to the threat of losses in surface runoff (Pote et al., 1996). Edwards and Daniel (1993b) have shown that poultry litter applications to pastures result in relatively high P runoff at recommended rates with as much as 90% of the P runoff being in the soluble form. Soluble reactive P is very important due to its direct bioavailability to aquatic plants, whereas particulate P must undergo conversion to inorganic phosphate before becoming bioavailable (Sonzongi et al., 1982). Because P is normally the limiting nutrient for eutrophication, concerns have arisen over animal waste applications (Schindler. 1977).

Sharpley et al. (1993) stressed the importance of emphasizing management practices based on soil P rather than N, particularly for soils susceptible to P runoff. Several researchers have studied the relationship between soil test P and soluble reactive P (SRP) concentrations in runoff. This positive relationship has been observed concluding that the P content of surface soil directly influences the amount of SRP in runoff from that soil (Schreiber et al., 1988; Sharpley et al., 1994, 1995; Pote et al., 1996, 1999). As a result, several states are attempting to determine threshold soil test P levels above which animal manures may not be applied due to increased risk of P runoff.

Perhaps more importantly, is the level of SRP that is applied in animal manures, which is highly susceptible to surface runoff. Sauer et al. (2000) suggested that for plots treated with poultry litter, the main factor affecting P concentrations in runoff is the SRP present in the litter on the soil surface. Several other studies have also shown that SRP concentrations in runoff are higher when runoff events occur after manure is applied to the soil surface (Edwards and Daniel, 1993b; Shreve et al.,1995; Sharpley, 1997). In these studies, rainfall was applied 1 day after litter application to small plots.

Several management scenarios are available to reduce the risk of P runoff. Aluminum sulfate (alum) additions to poultry litter have been shown to reduce SRP concentrations in both litter and runoff (Moore and Miller, 1994; Shreve et al., 1995: Moore et al., 2000). Shreve et al. (1995) reported that alum-treated litter resulted in an 87% reduction in SRP runoff concentrations compared to untreated litter. The addition of phytase enzymes to poultry and swine diets have also been shown to decrease inorganic P levels in the manure (Nelson et al. ,1971; Jongbloed and Kemme. 1990; Beers and Jongbloed. 1992). The use of a low phytate corn variety (Rayboy et al., 1994) has also been used to reduce P levels in manures (HAP, high available P corn). However, Moore et al. (1998) found no statistically significant reduction in P runoff from plots receiving dietary manipulated poultry litter, although HAP corn and HAP/phytase litter lowered P runoff by 22 and 26%, respectively. The timing and frequency of rainfall events have also been shown to effect the quality of runoff water (Westerman and Overcash, 1980; Edwards and Daniel, 1993b; Sharpley, 1997). Sharpley (1997) and Westerman and Overcash (1980) observed a decrease in P runoff with an increase in the length of time between applying manure and a surface runoff event. However, studies conducted on swine manure by Edwards and Daniel (1993a) found little effect on P runoff with time (up to 14 days).

Several different studies have observed various factors affecting P runoff. However, no studies have combined these factors and compared the effect each has on P runoff. The objective of this study was to determine the effects of 1) soil test P; 2) poultry litter application rates; 3)dietary manipulated litter; 4) alum-treated litter; 5) fertilizer type; and 6) weather on P runoff.

DATA AND METHODOLOGY

Seventy-two runoff plots (1.52 x 6.10 m) were established on a Captina silt loam soil (fine-silty, siliceous, mesic Typic Fragiudult) at the University of Arkansas Agricultural Research Station in Fayetteville, Arkansas. The plots were built with a 5% slope and hydrologically isolated from surrounding land with 15 cm metal borders (inserted so that approximately 5 cm of the strips were exposed) on three sides. A 15 cm tall strip was placed into the ground at the downslope edge until the top of the strip was level with the soil surface (silt plate). An aluminum collection trough was then placed at the downslope edge. A flange of the collection trough was placed between the soil in the plot and silt plate to prevent runoff from flowing under the collection trough. After initial construction of the plots were completed, soil test P was augmented on 24 plots. Triple super phosphate (0-46-0) was incorporated to approximately 6-8 inches using tillage at rates of 0, 150, 300, 600, 900, and 1200 lb ac^{-1}. After augmentation of soil test P, all of the plots were seeded with tall fescue (Festuca arundinacea Schreb.) in the fall of 1998.

Beginning in June of 1999, rainfall simulation studies were conducted to determine the effects of the following treatments on P runoff: 1) soil test P; 2) poultry litter application rates; 3) dietary reductions in P using phytase, HAP (high available corn), or a combination of HAP corn and phytase; 4) reducing soluble P in litter with aluminum sulfate; 5) fertilizer type (poultry litter, swine manure, commercial fertilizer); and 6) weather (effect of timing from application until first runoff event). The plot layout consisted of 72 plots with 3 rows of 24 plots. Treatments were applied and blocked by rows.

Row 1 consisted of the soil P augmented plots previously stated. Rainfall was applied two times to the 24 plots before manure was applied. After the second rainfall study, litter was applied at 2.5 tons ac^{-1} with the following treatments: 1) untreated poultry litter; 2) poultry litter treated with 5% alum; 3) poultry litter treated with 10% alum; and 4) poultry litter treated with 20% alum. Each treatment was replicated 6 times, with each treatment being applied once to each of the 6 soil test P levels. Rainfall simulations occurred 1, 16 and 21 days after litter application. Litter used for the study was collected from a poultry (broiler) farm in northwest Arkansas that had six broiler houses, three of which were treated with alum at 10% rates. The 5% alum treatment was made by mixing exactly one-half alum-treated litter and one-half untreated litter. The 20% alum-treatment was made by adding the appropriate amount of alum to the alum-treated litter.

Row 2 consisted of dietary manipulated poultry litter, alum-treated poultry litter, and triple super phosphate. Litter was applied at 2.5 tons ac^{-1} with the following treatments: 1) unfertilized control; 2) untreated litter collected in NW AR; 3) untreated litter collected in DE; 4) phytase litter; 5) HAP litter; 6) HAP + phytase litter; 7) litter treated with 10% alum; and 8) triple super phosphate. Litter of various diets were collected from Delaware and alum-treated litter was collected from same broiler farm in NWAR as previously stated. Triple super phosphate was applied at the same total P rate as applied by poultry litter (70 lb ac^{-1}). Treatments were replicated three times in a complete randomized block design.

The effect of application rates and weather were observed on row 3. Treatments for rates were: 1) 1 ton ac^{-1}; 2) 2 ton ac^{-1}; 3) 3 ton ac^{-1}; and 4) 4 ton ac^{-1}. To evaluate the effect of time after application until a runoff event occurred, rainfall was applied: 1) 1 day; 2) 7 days; 3) 21 days; and 4) 49 days after application of litter. Litter was again applied at 2.5 tons ac^{-1}. All litter used was collected from NW Arkansas. Treatments were replicated 3 times in a complete randomized block design.

After agitating, swine manure was collected from a swine lagoon in central Arkansas undergoing complete cleanout. Since the entire lagoon was agitated and cleaned out, the samples were high in suspended solids and particulate P.

A subsample of manure applied to each plot was taken for analysis of soluble reactive P and total P. Upon return to the laboratory, 20 g of poultry litter from each sample was placed into a 250 ml polycarbonate centrifuge tube and extracted with 200 ml of deionized water for two hours on a mechanical shaker. The sample was then centrifuged at 8,000 RPM for 20 Minutes. Aliquots were filtered through a 0.45 *u*m membrane and acidified to a pH of 2 with HCL for SRP analysis. Swine manure was collected in 250 ml centrifuge tubes in situ and placed directly on a mechanical shaker upon return to the laboratory. The sample was then centrifuged at 8,000 RPM for 20 minutes and filtered through a 0.45 um and acidified to a pH of 2 with HCl for SRP analysis. Soluble reactive P was determined colorimetrically using the automated ascorbic reduction method (APHA, 1992). Total P was determined by digesting oven-dried litter (60 °C) with nitric acid and analyzing the digested sample using ICP (Zarcinas et al., 1987).

After litter application, rainfall simulators were used to provide a 5 cm hr^{-1} storm event sufficient in length to cause 30 minutes of continuous runoff. Runoff samples were collected at 2.5, 7.5, 12.5, 17.5, 22.5, and 27.5 minutes after initial runoff. The six samples from each plot were composited based on flow rates at the time of sampling. Composited runoff samples were filtered through a 0.45 *u*m membrane and acidified to pH 2 with concentrated HCL. Soluble reactive P (SRP) concentrations in the runoff water were determined colorimetrically on the filtered, acidified samples using the automated ascorbic acid reduction method (APHA, 1992).

Soil cores were taken from each plot prior to each rainfall simulation. Composite soil samples consisting of five random cores were taken each for Mehlich III (0-15 cm) and water soluble P (0-5 cm). Cores were dried in an oven for 48 hrs at 60 °C. After drying, the soil was ground to pass a 2mm sieve. Mehlich III P extracts were analyzed using an inductively coupled plasma spectrometer (ICP) after extracting 2 g of soil with 14 ml of Mehlich III solution (Mehlich, 1984). Water soluble P was determined using the automated ascorbic acid reduction method after extracting 2.5 g of soil with 25 ml of deionized water (modified Pote et al., 1996, 1:10 vs. 1:25).

RESULTS

Average soil test P (Mehlich III) levels were 945.9, 737.1, 609.4, 439.2, 318.3, and 232.9 lb ac^{-1} for additions of 1200, 900, 600, 300, 150, and 0 lb ac^{-1}, respectively. Runoff P concentrations were well correlated to soil test P levels as seen by Pote et al. (1999) and Sauer et al. (2000). The first rainfall simulation showed a positive relationship ($r^2 = 0.86$) between SRP and Mehlich III P (figure 1a) as did the second rainfall simulation ($r^2 = 0.52$), which occurred one week later. However, once manure (alum-treated) was applied to these plots, a poor relationship between SRP and soil test P (STP) was found(figure 1b). A poor relationship also existed between total P in the manure and SRP runoff concentrations. However, a good relationship was found between soluble P in the litter and SRP in the runoff water ($r^2 = 0.76$) (figure2). There were no significant differences in SRP runoff concentrations among various soil test P levels after manure was applied. This data agrees with that of Sauer et al. (2000) which shows that manure applications overwhelmed soil test P in runoff concentration. Therefore, it may be concluded that soluble P in manure is one of the most important factors in contributing to SRP in runoff water.

Mean runoff concentrations from the soil P augmented plots after application of alum-treated litter were 26.0, 15.1, 13.4, and 0.88 mg L^{-1} for untreated, litter treated with 5% alum, 10% alum, and 20% alum, respectively. Soluble reactive P concentrations were significantly higher form plots receiving untreated poultry litter while SRP runoff concentrations were significantly lower from plots receiving litter treated with 20% alum. Soluble reactive P runoff concentrations were reduced by 49% and 97% with 10% and 20% rates of alum, respectively. The reduction with 10% alum is less than the 87% that Shreve et al. (1995) found, however, SRP concentrations in the untreated litter used in this study were much lower than that used in their study. Some of the 97% reduction with 20% alum applications may be attributed to the fact of incomplete solublization of alum before litter application.

Commercial fertilizer resulted in higher runoff P concentrations (103.1 mg L-1) than organic fertilizers. Triple super phosphate resulted in significantly higher runoff concentrations than alum-treated litter and untreated litter collected in NW Arkansas. This would be expected since the solubility of commercial fertilizer is much higher than that of organic fertilizers. Plots fertilized with alum-treated litter resulted in the lowest SRP runoff concentrations among fertilized plots. Runoff concentrations for the first runoff event were 15.7 and 10.8 mg L^{-1} for untreated Arkansas liter and alum-treated liter, respectively. Runoff concentrations were lower from alum-treated litter and the NW Arkansas untreated litter for each rainfall event, furthermore; these two treatments also contained the lowest SRP concentrations in the manure. Litter from the diet studies resulted in the highest runoff concentrations among litter applications. Total P concentrations were lower from the diet manipulated litter (figure 3a). However, HAP and phytase diets actually increased soluble P concentrations in the litter therefore increasing SRP runoff concentrations (figures 3b and 3c). Soluble reactive P runoff concentrations were as high as 84.6 mg L^{-1} with phytase litter. The litter had been deep stacked in Delaware for 6-8 months before shipping. Apparently, deep stacking affected the P solubility in the manure. Increasing soluble P concentrations with time for HAP and phytase litter was also observed by Moore et al. (1998) in a growout study. More research is needed to determine what controlled this occurrence.

Phosphorus runoff increased linearly as the phosphorus application rate increased. Runoff concentrations were 33.0, 27.7, 16.6, and 8.8 mg L^{-1} for applications of 1, 2, 3, and 4 tons ac-1, respectively (figure 4). The same positive linear relationship was seen for each rainfall simulation (figure 4). This would be expected if soluble P concentrations in litter is a major contributor to runoff SRP. The mean SRP runoff concentration of 4.75 mg L^{-1} from litter applications equivalent to 1 ton ac-1 after the third rainfall simulation was still higher than that of unfertilized controls. The soil test P levels for these plots and the unfertilized controls were relatively the same. This shows that even after three runoff events, soluble P applied in manure is still a very important factor in regulating P runoff. Although SRP runoff concentrations were positively correlated to total P applications, it was more closely correlated to the amount of soluble P added.

Weather (timing of application) also was another important variable in controlling P runoff. Soluble reactive P runoff was greatly reduced as time increased before a runoff event occurred as seen by Westerman and Overcash (1980). Runoff SRP concentrations were 17.6, 14.3, 8.7, and 3.0 mg L^{-1} for rainfall events occurring 1, 7, 21, and 49 days after litter application, respectively. Soluble reactive P concentrations were significantly lower from plots receiving rainfall 49 days after application. There were no significant differences between plots receiving rainfall 1 and 7 days after litter application.

Mean runoff P concentrations from plots receiving swine manure were 29.7 mg L^{-1} for the first runoff event. Swine application resulted in significantly higher runoff P concentrations than that of alum-treated or untreated poultry litter collected in NW Arkansas. Runoff concentrations were still higher from the dietary supplemented litter and commercial fertilizer applications (figure 5). For the first runoff event, the higher the amount of soluble P applied the higher the amount of soluble P in the runoff water.

CONCLUSIONS

Results from this study show that soil test P levels and manure P solubility are both important factors affecting P runoff from pastures. When no manure has been applied, soil test P values are well correlated to SRP runoff concentrations. However, once manure is applied, SRP concentrations are better correlated to the SRP concentrations in the manure applied. Throughout this study, it was clearly evident that SRP runoff concentrations increased with greater manure P solubility. Lowest runoff concentrations were observed from alum-treated litter which has the lowest SRP concentrations in the litter. Treatments containing the highest P solubility, commercial fertilizer and HAP or phytase litter, resulted in the highest SRP runoff concentrations. Results of this study are being used in the development of a P Index for pastures. This risk assessment will be weighted on both P management in the soil and manure. For example, a farmer with a high P Index rating may use alum or diet manipulation to decrease P solubility. Future studies will observe the results of various combinations of alum and diet manipulation. Since alum decreases P solubility and diet manipulation decrease total P levels, both soluble and total P concentrations may be reduced in manures. However, the hydrology of pasture systems are the most important and least understood aspect. Better understanding of hydrologic behaviors are key in better assessing the risk of P runoff from pastures.

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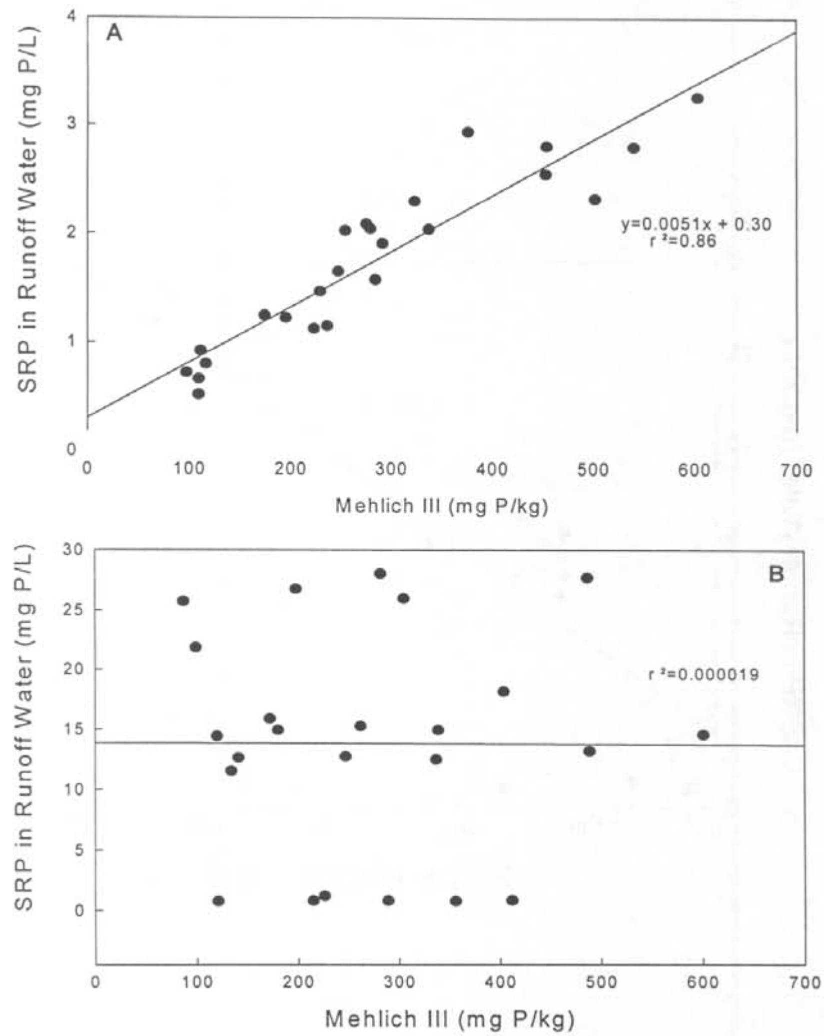

Figure 1. Effect of soil test P on SRP runoff concentrations with (a) no manure applied and (b) manure application.

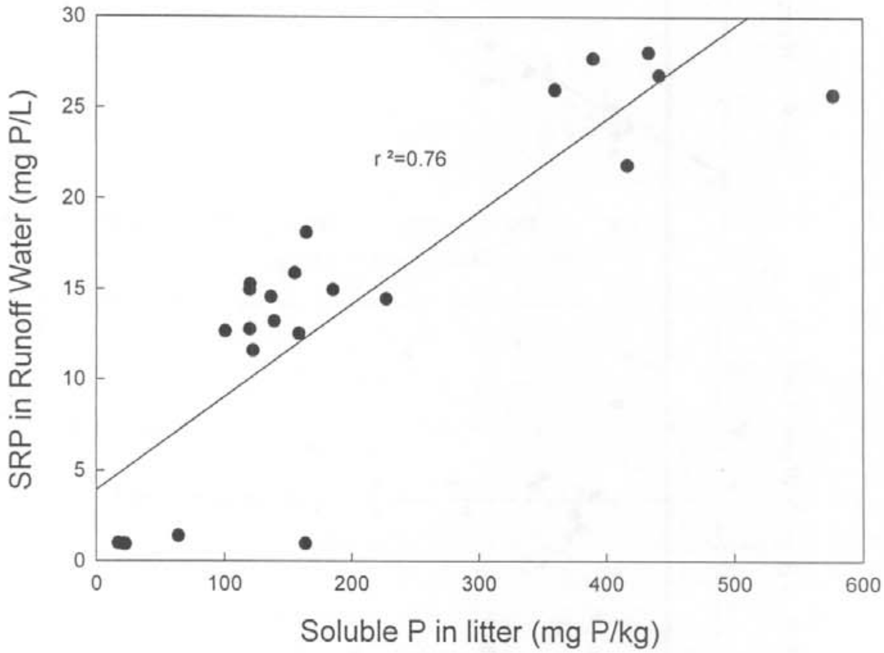

Figure 2. Effect of soluble P in Litter on P runoff.

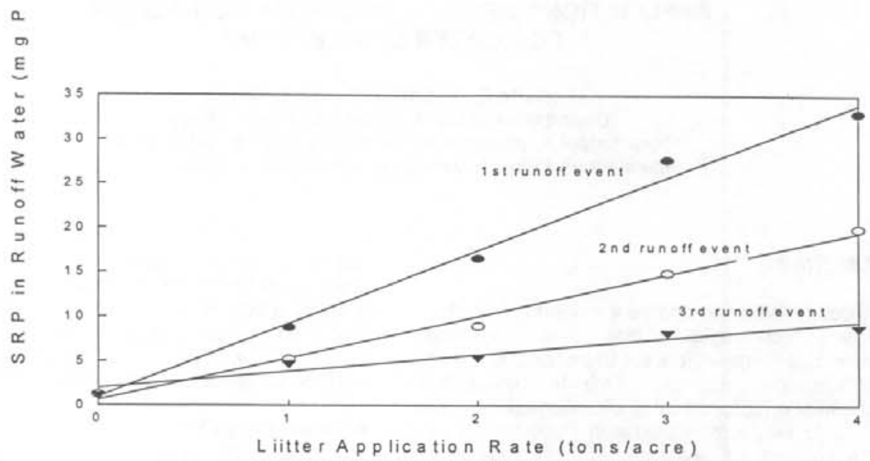

Figure 4. Effect of litter application rates on soluble P runoff.

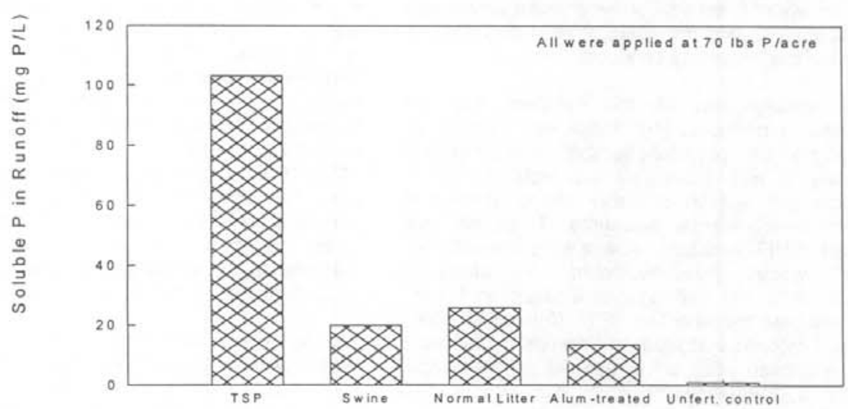

Figure 5. Effect of fertilizer types on SRP runoff concentrations.