RUNOFF LOSSES OF DISSOLVED REACTIVE PHOSPHORUS FROM ORGANIC FERTILIZER APPLIED TO SOD

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ABSTRACT. *Fertilizers are often applied according to nitrogen requirement; however, recent evidence suggests that phosphorus (P) may pose as much, if not more, of an environmental threat. The objective of this research was to quantify the differences in phosphate-phosphorus losses in runoff from two organic fertilizers (poultry litter and composted dairy manure) and one inorganic fertilizer control, applied at a uniform nitrogen rate (187.3 kg ha^{-1}). The P concentration in the poultry litter (PL) was 2.5%, while the P concentration in the composted dairy manure (CDM) was 0.5%. The fertilizers were applied to run-over troughs filled with Austin clay soil planted with Bermuda grass (*Cynodon dactylon *L. Pers.). Water dispersion devices supplied runoff at a rate equivalent to 125 mm h^{-1}. Runoff was simulated for 30 min every 7 days for a period of 10 weeks. Runoff was analyzed for quantity and PO_4–P concentration. Results from the PO_4–P concentration and load data show that PL had greater loss during the first runoff event, while CDM did not vary significantly ($p > 0.05$) from the control. This pattern continued for the first 4 weeks, but during the following weeks none of the treatments showed a difference. Comparison of cumulative losses over the 10 weeks showed that PL lost a larger proportion of its initial P application than did CDM. Composted dairy manure did not have a greater cumulative loss compared to the control. Poultry litter with its high initial P concentration lost a disproportionately larger amount of PO_4–P in runoff compared to CDM with its low initial P concentrations.*

Keywords. *Animal waste, Composted dairy manure, Grass, Poultry litter, Runoff, Slow release.*

Organic fertilizers are traditionally applied according to the nitrogen (N) requirements of the crop. Organic fertilizers have a narrower ratio between N and phosphorus (P) than inorganic fertilizers, which leads to the over-application of P when applied at rates to meet the N requirements of the crop (Torbert et al., 2005). In the past, it was believed that P was immobile within the soil; thus, over-application of P would not have deleterious effects on the environment (Hart et al., 2004). However, it is now known that P in the soil and in freshly applied organic fertilizers can be lost from the system via leaching and surface runoff (Hart et al., 2004). Surface runoff is considered the primary pathway of loss, with leaching occurring in sandy, organic, and artificially drained soils (Vadas et al., 2005). Phosphorus lost in runoff often makes its way to surface water bodies, where it can cause eutrophication in freshwater systems that are generally P limited (Correl, 1998). Eutrophication can impair water use for drinking, recreation, habitat, and industrial use by producing algal blooms and reducing the dissolved oxygen content of the water (Dougherty et al., 2004).

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Mobilization of phosphorus can be broadly broken down into two categories: physical detachment and subsequent entrainment of particles on which P is bound, and chemical processes in which phosphate ions are released into solution (Dougherty et al., 2004). In grassland systems, physical detachment is limited due to dissipation of raindrop impact by the canopy (Easton and Petrovic, 2004). Thus, the bulk of P transported within grassland systems is in the form of soluble phosphate (Gross et al., 1991; Nash and Murdoch, 1997; Sharpley et al., 1992; Sharpley et al., 1994; Sharpley et al., 2000). When organic fertilizers are surface applied, the first runoff event following application has been shown to contain the largest amount of soluble phosphate followed by a decline with time, but rates remain above background levels for an extended period (Edwards et al., 1994; Heathman et al., 1995; Sauer et al., 1999; Sharpley, 1997).

Runoff concentration of P is controlled by chemical, biological, physical, and hydrological factors (Dougherty et al., 2004). The elapsed time between application of organic fertilizers and runoff has been shown to have little effect on the concentration of dissolved P in runoff from grassland systems (Schroeder et al., 2004). With elapsed times between application and runoff events of 4, 7, and 14 days, no differences were found in dissolved P concentrations (Schroeder et al., 2004). The lack of significant differences was attributed to poor conditions for P adsorption by the soil. The thick canopy of fescue limited contact of the surface-applied poultry litter and the soil (Schroeder et al., 2004).

Initial P concentrations in the soil or organic fertilizer can impact the amount of dissolved P in runoff (Dougherty et al., 2004; Sharpley et al., 2004). Organic fertilizers with high P concentrations lead to greater P concentrations in runoff (Dougherty et al., 2004). High soil test P in the upper 0 to 50 mm of soil is related to elevated concentrations of P in runoff in both non-calcareous soils and calcareous soils (Fang et al., 2002; Pierson et al., 2001; Pote et al., 1999; Torbert et al., 2002).

Organic fertilizers can cause detrimental environmental impacts if not applied according to a nutrient management plan, but they can also provide beneficial effects. Application of organic fertilizers has been shown to reduce soil bulk density, while increasing infiltration rates and nutrient holding capacity (Gaudreau et al., 2002). They also provide farmers with an economical fertilizer source and a cost-effective method of manure disposal.

Organic fertilizers are often applied at rates to meet the N requirements of the crops, leading to the over-application of P. This research compared two organic fertilizers, one with high P concentration (poultry litter) and one with low P concentration (composted dairy manure), to determine how the initial P concentration of organic fertilizers impacted the loss of PO_4−P in runoff when applied at a uniform nitrogen rate in a turf grass system.

Materials and Methods

Three wooden run-over troughs (0.6 m wide × 3.7 m long × 0.3 m deep) were constructed with extended sidewalls that permitted the introduction and containment of overland flow. The troughs were placed in a greenhouse and filled with an Austin clay soil (fine-silty carbonatic, thermic, Typic Haplustolls). The troughs were sodded with squares of commercially available 'Tifway' Bermuda grass (*Cynodon dactylon* L. Pers.) and set at a 5% slope. 'Tifway' Bermuda grass is a dense, dark green, fine-textured grass recommended for use on golf courses, athletic fields, and home lawns. This grass thrives in hot conditions and is considered drought tolerant. It does, however, require regular maintenance, including fertilization and mowing.

The troughs were fitted with water dispersion devices, which provided an even distribution of overland flow equivalent to 125 mm h^{-1}. The dispersion device consisted of a 13 mm PVC pipe installed on the upslope 0.6 m side of the trough. A water supply hose was connected to the pipe, which had 5 mm holes, allowing water to be distributed evenly over the width of the trough. A second PVC pipe that was cut in half was installed under the distribution pipe to dissipate water droplet energy and allow an even flow of water onto the turf. The overland flow was channeled to a 378.5 L (100 gal) storage tank positioned on a 454 kg (1000 lb) continuous-recording floor scale. Prior to fertilizer application, the plots were subjected to a 30 min overland flow event to obtain background nutrient concentrations. No significant ($p > 0.05$) differences in background PO_4−P concentrations by plot were measured (table 1).

Each plot received a single fertilizer treatment at the beginning of the 10-week run in the form of sulfur-coated urea (control), composted dairy manure (CDM), or poultry litter (PL). Nutrient concentrations of the composted dairy manure and poultry litter (table 2) were measured prior to each application to determine the mass of material added. In order to more accurately simulate field conditions, application rates were determined based on the N content of the material. The one-time application rate was equivalent to 187.3 kg ha^{-1} N. Sulfur-coated urea was selected for the control because it provided the same amount of nitrogen as the organic fertilizers, thus providing needed fertilization to the grass while not adding any additional P to the system. The application rates for P are shown in table 2.

Table 1. Background PO_4−P concentrations (mg L^{-1}) from each trough prior to the treatment application.

	Trough 1	Trough 2	Trough 3
18 July 2001 (Rep 1)	0.14	0.29	0.34
10 Oct. 2001 (Rep 2)	0.37	0.28	0.40
17 Apr. 2002 (Rep 3)	0.87	0.61	0.82

Overland flow was simulated every 7 days for a period of 30 min via the water dispersion device located upslope. The simulated irrigation events resulted in a volumetric water depth of 6.35 mm being added each week for 10 weeks. The overland flow source was potable tap water with an average P concentration of 0.047 mg L^{-1}. The application rate of water was such that no fertilizer was washed off the turf. At the conclusion of each overland flow event, the water in the storage tank was agitated and a water sample was collected. The procedure was repeated three times to achieve three replicates. Because the experiment was completed in a greenhouse, the ambient temperature and humidity level were similar for all three runs.

The samples were acidified with HCl and refrigerated at 4°C until analyzed. The samples were filtered through a 0.45 μ membrane and analyzed for PO_4−P using the molybdenum-blue method for P in water (Pote et al., 2001) using a Technicon Autoanalyzer IIC and methods published by Technicon Industrial Systems (Technicon, 1976). After each 10-week run, the troughs were cleaned and new soil and turf were added. The pollutant concentration in the tank and the volume of water collected in the tank were used to calculate a total PO_4−P load. Loads were not corrected for amount delivered in source water.

Statistically significant differences in PO_4−P concentrations, load, cumulative load, and cumulative percent loss of PO_4−P were determined by the mixed model procedure in SAS, taking into account the variation between run-over troughs with the random statement and the covariation associated with repeated readings over time using the repeated statement (Littell et al., 1998; SAS, 1999). Main and interactive effects in response to experimental treatments were separated by a Tukey-Kramer pairwise comparison tests at $p \leq 0.05$.

Table 2. Percentage P in fertilizer source and total P applied to plots.

	18 July 2001 (Rep 1)		10 Oct. 2001 (Rep 2)		17 Apr. 2002 (Rep 3)	
Treatment	% P in fertilizer	kg P ha^{-1} applied	% P in fertilizer	kg P ha^{-1} applied	% P in fertilizer	kg P ha^{-1} applied
Sulfur-coated urea (control)	0.0	0.0	0.0	0.0	0.0	0.0
Composted dairy manure (CDM)	0.55	97	0.44	83	0.50	70
Poultry litter (PL)	2.12	218	2.65	214	2.75	211

Results and Discussion

PO_4–P Concentrations and Load

Comparison of the overall mean concentrations for the fertilizer treatments indicated that PL had the greatest PO_4–P concentration compared to CDM and the control (table 3). The concentration of PO_4–P in the runoff from the PL treatment was more than three times that of the CDM, but the kg ha^{-1} application rate was only two times greater than the CDM treatment. The greatest initial P concentrations in the PL resulted in a greater amount of dissolved P in the runoff, similar to the findings of Dougherty et al. (2004) and Sharpley et al. (2004), who reported that an increase in the initial P concentrations in fertilizers results in greater amounts of dissolved P in runoff.

The PO_4–P concentrations, when compared by treatment and time after application (fig. 1), showed that PL had a significantly greater initial concentration (5.73 mg L^{-1}) than CDM (0.61 mg L^{-1}) and the control (0.23 mg L^{-1}). The PL P concentration in the first week was over nine times that of the CDM and almost 20 times greater than the control. The initial concentration of P in the applied CDM was less than four times that of the initial concentration of P in the applied PL. The concentrations by the end of the fourth week were not significantly different between treatments (fig. 1). The greater concentration of P in the material applied with the PL most likely contributed to the greater concentration in the runoff, especially in the first runoff event. The surface-applied material had little contact with the soil because of the thick canopy of the turf; thus, it was readily dissolved in water and removed by the runoff (Edwards et al., 1994; Heathman et al., 1995; Sauer et al., 1999; Sharpley, 1997).

The orthophosphate loadings for the fertilizer treatments (table 3) showed a similar pattern to the concentration data, with the PL producing a greater loading (1.275 kg ha^{-1}) than CDM (0.392 kg ha^{-1}) and the control (0.044 kg ha^{-1}). Again, when comparing the treatments and time after application, PL had a greater initial load in the runoff, while CDM did not vary significantly from the control (fig. 2). Comparing the treatments, each week the PL was significantly different from the CDM through week 4 and from the control through week 7. A significant decrease in the load from the PL treatment is noted from week 1 to week 2 with additional decreases the following weeks, but none large enough to be significantly different from the previous weeks. The first runoff event following application of an organic fertilizer, particularly one with a high initial P concentration, carries the largest load of soluble P (Edwards et al., 1994; Sauer et al., 1999; Sharpley, 1997). The effect of runoff timing is most pronounced in the first runoff event following application (Schroeder et al., 2004). In this research, 7 days elapsed between application and first runoff, which had the greatest loss of P.

Table 3. Means (n = 3) for each fertilizer treatment over the 10-week study period.[a]

Treatment[b]	Conc. (mg L^{-1})	Average Load per Event (kg ha^{-1})	Cumulative Load (kg ha^{-1})	Cumulative % Loss (%)
Control	0.282 a	0.198 a	1.059 a	--[c]
CDM	0.557 a	0.392 a	2.068 a	2.545 a
PL	1.873 b	1.275 b	9.041 b	4.224 b

[a] Means within columns followed by different letters are significantly different.

[b] Control = sulfur-coated urea, CDM = composted dairy manure, PL = poultry litter.

[c] The control had no intial P added; therefore, no cumulative % loss can be calculated.

Cumulative Load of PO_4–P and Percentage Loss

The mean cumulative loading rate of PO_4–P was significantly greater from the PL treatment than from CDM or the

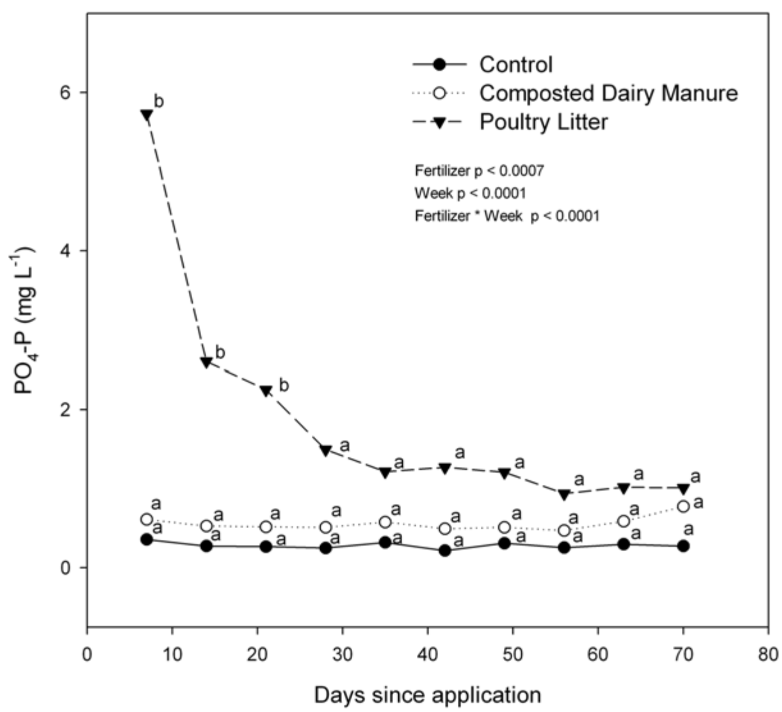

Figure 1. Mean (n = 3) PO_4–P concentrations in runoff water following application. Points labeled with the same letter are not significantly different from the other points on that day.

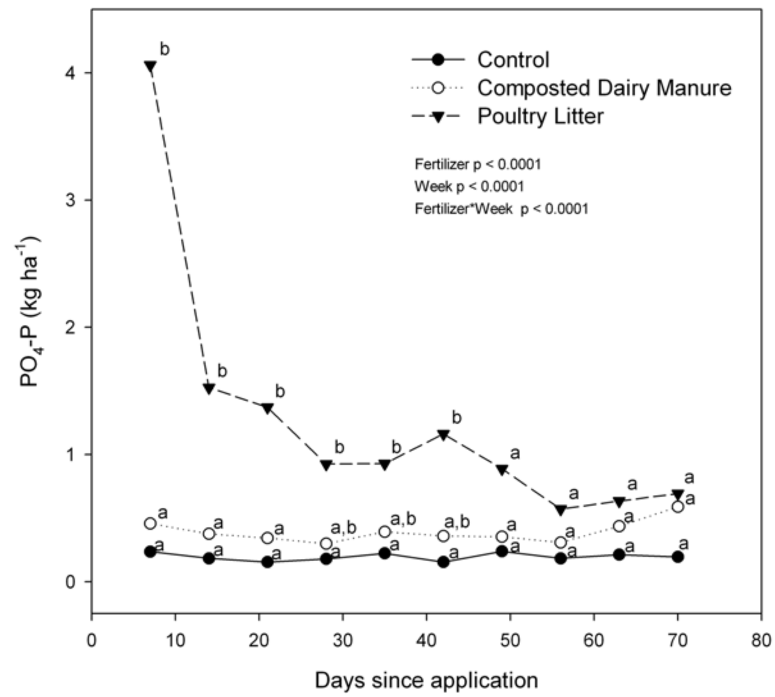

Figure 2. Mean (n = 3) PO_4–P loads by week over the 10-week study. Points labeled with the same letter are not significantly different from the other points on that day.

control (table 3). Poultry litter lost an average of 9.04 kg ha^{-1} (4.2 %) of the 214 kg ha^{-1} of applied P over the 10 weeks compared to 2.07 kg ha^{-1} (2.5 %) of the 83 kg ha^{-1} of applied P for CDM. Composted dairy manure was not significantly different from the control in cumulative losses. However, the adjusted p-values steadily decreased with time, indicating that if the experiment had lasted longer than ten week, there might have been a significant difference between the cumulative load of the CDM and the control (the p-value was 1.0 at week 1 and 0.075 at week 10) (fig. 3). Cumulative losses from the PL treatment exceeded that of CDM and the control throughout the 10-week study period. These results are consistent with other research findings, which showed that higher litter application rates led to greater cumulative losses of P (Schroeder et al., 2004), indicating that losses of P are disproportional to the application rate. Organic fertilizers with greater initial P concentrations will lead to greater cumulative losses.

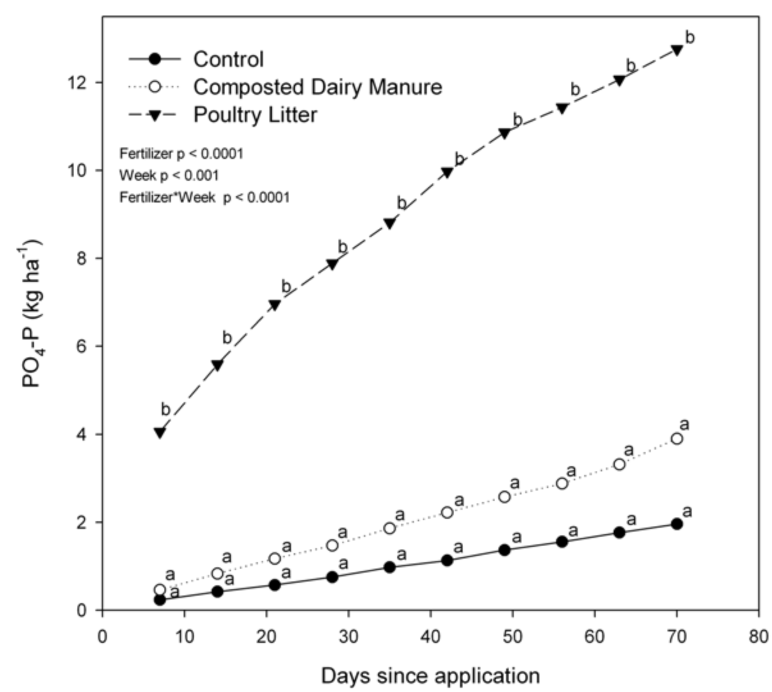

Figure 3. Mean (n = 3) cumulative PO_4–P load over 70 days. Points labeled with the same letter are not significantly different from the other points on that day.

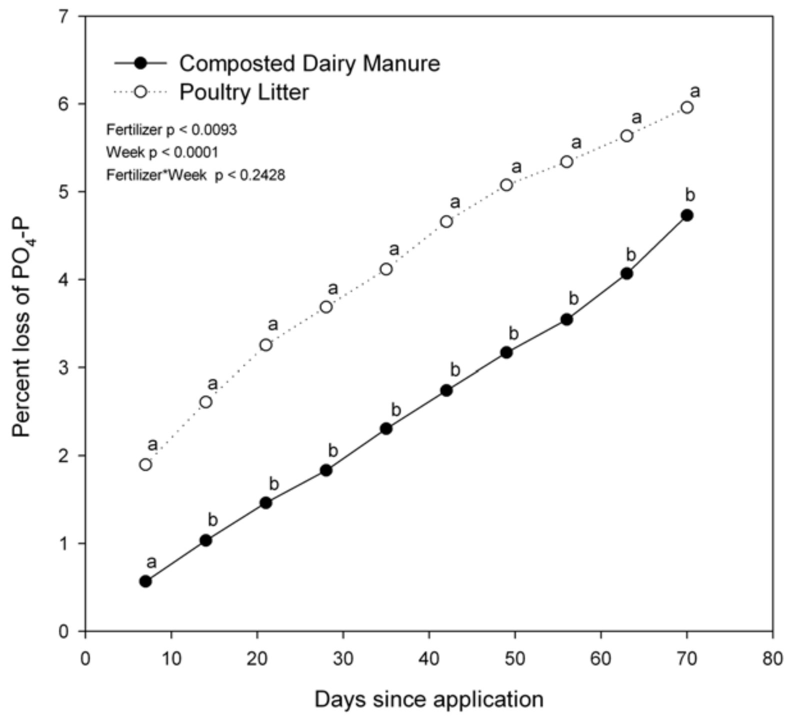

Figure 4. Cumulative percent loss of PO_4–P over the 10-week run. Points labeled with the same letter are not significantly different from the other points on that day.

In comparing the mean cumulative percent loss over the 10-week period, the results show that PL lost a significantly greater percentage of P than did CDM (fig. 4). This suggests that fertilizer sources with a greater percentage of P when applied lose a greater proportion of that P than do applied fertilizer sources with smaller percentages of P. In a turf system, such as the one used in this research, the thatch layer holds the particulate matter in place, but it can increase the interaction of runoff water with the material, thus increasing the loss of P (Torbert et al., 2005).

Summary and Conclusions

Initial P application rate can greatly affect the surface loss of P from a system. Results from this study show that organic fertilizer sources with greater initial P concentrations lose a disproportionately greater amount of P when compared to an organic fertilizer source with a smaller initial P concentration. Organic fertilizers with low initial P concentrations did not exceed the control fertilizer (with no P) in concentration, load, or cumulative load losses of P. Additionally, the results indicate that the first runoff event carried the largest proportion of the cumulative P lost over the 10-week study. When applying fertilizers containing significant amounts of P, it is important to consider the ability of the crop to utilize the phosphorus or the soil to bind the phosphorus. Excess phosphorus under the correct conditions can and will move with runoff.

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