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Dairy Diet Phosphorus Effects on Phosphorus Losses in Runoff From Land-Applied Manure

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By Angela M. Ebeling, Larry G. Bundy, J. Mark Powell and Todd W. Andraski

Phosphorus loss in runoff from cropland is an environmental concern because this P often promotes weed and algae growth in lakes and streams. When these weeds and algae die and decompose, dissolved O_2 levels in lakes and streams are depleted, which can lead to odors, death of fish and a general degradation of the aesthetic and recreational value of the environment.

Phosphorus from land-applied manure is one of the major sources contributing to soil P accumulation in Wisconsin, and increasing evidence shows that the amount of P in manure could be substantially reduced by avoiding excess P supplementation of dairy rations. A 1999 study reported that the average dairy diet in the U.S. is supplemented to contain 4.8 g P kg^{-1}, while only 3.8 g P kg^{-1} is needed for optimum milk production and reproductive efficiency. This is a 25 percent over-supplementation of dietary P, based on National Research Council standards. A study in 2000 discussed decreasing P in dairy cow diets without negatively affecting performance and reproductive ability, and cited an earlier study showing that dietary P could be lowered from 6.5 to 4.5 g P kg^{-1} without consistently influencing milk production or reproductive performance. Several studies have shown that decreasing dietary P lowers P excreted in manure.

Phosphorus excretion in manure depends largely on the level of P intake. If P supplementation could be reduced to the minimum concentration needed for optimum production, the amount of P in manure and in applications to farmland would also decrease. The objective of this study was to determine dairy diet P effects on the amounts and forms of P in manure as well as on P losses in runoff from land-applied manure. To relate this work to on-farm manure management practices, we included a manure application strategy simulating an N-based nutrient management approach where manures from two P diets were applied at the same manure rate. In addition, a P-based nutrient management approach was also included where manures from the differing P diets were applied to achieve the same P addition.

Materials and Methods

Dairy diet P effects on P losses in runoff in no-till corn were determined in a field experiment at the University of Wisconsin Agricultural Research Station at Arlington. Four manure treatments, based on two dietary P levels and including a control, were applied to a Ringwood silt loam soil. Phosphorus was determined in runoff from simulated and natural rainfall events.

Dairy manures (feces only, no bedding) with differing P concentrations were hand applied to 2.4-m x 2.4-m plots on May 24, 1999. The site was not tilled in 1999 and residue from the previous year's corn crop remained on the surface. Simulated rain was applied June 1-4, 1999, and again on the same plots on Sept. 30 and Oct. 1, 4 and 5, 1999, after corn silage harvest. Natural runoff was collected from November 1999 to July 2000.

A randomized complete block design with four replications was used in the experiment. The four treatments were: control (no manure, no P addition); low P diet (LPD-56) manure (4.8 g P kg^{-1} manure dry matter) and high P diet (HPD-56) manure (12.8 g P kg^{-1}) applied at 56 wet Mg ha^{-1} to provide 40 and 108 kg P ha^{-1}, respectively; and high P diet manure applied at 21 wet Mg ha^{-1} (HPD-21) to provide the same P addition (40 kg P ha^{-1}) as LPD-56. The LPD-56 and HPD-56 treatments applied equal amounts of manure (same manure rate), but HPD-21 applied less manure than LPD-56 (same P rate).

Feces were collected from lactating Holstein cows involved in a study designed to determine effects of dietary P levels on milk production and reproductive performance. The low P diet group was fed no supplemental P, while the high P diet group had monosodium phosphate added to the low P diet. This resulted in low and high dietary P levels of 3.1 and 4.9 g P kg^{-1}, respectively. The low and high dietary P levels produced manures with average P

concentrations of 4.8 and 12.8 g P kg^{-1}, respectively. These manure P concentrations were used to calculate manure application rates in the field experiments.

Simulated rainfall was applied to experimental treatments. Runoff samples were collected and total runoff volumes were recorded at 30 and 60 minutes. Subsamples of the runoff were analyzed for sediment, dissolved reactive P (DRP), bioavailable P (BAP), and total P (TP) concentrations and loads. P concentration is the amount of P in a given volume of runoff, and P load is the total amount of P leaving (P concentration multiplied by runoff volume).

Corn was planted at a density of 72,000 plants ha^{-1} on all plots following the June rainfall simulation in 1999 and in May 2000. Nitrogen fertilizer was surface applied to all treatments at a rate of 180 kg N ha^{-1} immediately following planting. Glyphosate was used to control weeds. All plants in each plot frame were cut near the base at physiological maturity and weighed, chopped and subsampled to determine plant dry matter yield in 1999. Phosphorus uptake was calculated by multiplying the individual whole plant P concentration by the corresponding dry matter yield.

An analysis of variance was performed for treatment effects on soil moisture, surface residue cover, runoff amount, sediment, DRP, BAP, and TP concentrations and loads in runoff, distilled water extraction, Mehlich III, Bray-Kurtz P-1, ammonium oxalate P, P saturation and silage yield, P concentration, and P uptake. Significant differences among treatment means were evaluated.

Results and Discussion

Manure Characterization — Phosphorus analyses on manures applied in the field experiment showed that all forms of P analyzed were higher in the HPD manure. The addition of monosodium phosphate to achieve the high P diet resulted in more inorganic P in the HPD manure, as shown by the greater than two-fold increase in water-soluble (DI) concentration. BAP concentrations were three times greater and TP concentrations were two times greater in the HPD manure compared with the LPD manure. Water-soluble P and BAP were 40 and 69 percent of TP, respectively, for the HPD manure, and 29 and 43 percent of TP, respectively, for the LPD manure. These results indicate that excessive dietary P supplementation could exacerbate P losses in runoff where these manures are land-applied due to higher TP concentrations and higher proportions of TP in DI and BAP forms. Dry matter content of the high and low P manures was similar.

Site Characteristics — Average time to runoff initiation in the simulated rainfall studies ranged from 5.7 to 7.2 minutes in June and 4.0 to 5.1 minutes in October, and treatments did not significantly affect time to runoff initiation. Treatment effects on soil moisture content in June, seven days following the manure application, differed significantly, ranging from 60 g kg^{-1} for the control to 205 g kg^{-1} for the HPD-56 treatment. The differences in soil moisture content were likely due to water added in the manure and/or decreased soil evaporation from the manured treatments due to their higher surface residue cover. In October, soil moisture content ranged from 110 to 142 g kg^{-1} and was not significantly different among treatments. Soil bulk density measurements taken in October ranged between 1.33 and 1.46 g cm^{-3} and showed no significant differences between treatments. Slope was relatively uniform within the experimental site and did not contribute to treatment effects on P losses.

June — The HPD-56 and HPD-21 treatments increased DRP concentration in runoff relative to the control and LDP-56, and DRP concentration in HPD-56 was nearly 10 times higher than DRP concentration in LPD-56, even though the amount of P applied was only 2.5-fold greater in HPD-56. When the manures were applied at equivalent P rates, DRP concentration in runoff was about four times higher in the HPD-21 than from the LPD-56 treatment. Manure treatment effects on DRP load in runoff were similar to the concentration effects in that loads were significantly higher (≈ 11 times) in the HPD-56 compared with the LPD-56 treatment. The marked differences in runoff DRP concentrations and loads between the LPD-56 and HPD-56 treatments, even when the manures were applied at equal P rates, is likely due to differences in the P composition of the manures.

TP concentrations and loads in runoff in the HPD-56 treatment were significantly higher than in the other manure treatments and the control. The TP load data appear to reflect P contributions from the manure additions and the influence of the manure treatments in controlling sediment loss. Most of the TP load in the control treatment appears to be associated with sediment loss, while a substantial portion of the TP load in the manured treatments is accounted for as DRP.

October — Results from the October simulated rainfall application showed that the higher manure rate treatments (LPD-56 and HPD-56) still had significantly higher surface residue cover than the HPD-21 and control treatments. Runoff amounts and sediment concentrations and loads were substantially higher in October than in June. Higher runoff amounts in fall vs. spring measurements have been reported in previous work, and were attributed to lower infiltration rates due to lower surface residue cover and more extensive soil surface sealing in the fall. The control had significantly higher runoff amounts than both the HPD-56 and the LPD-56 treatments, but the HPD-21 treatment was not significantly different from the other treatments. The control was about two times higher than the high manure rate treatments in sediment concentration and about five times higher in sediment load. This reflects the greater residue cover (as manure) and lower sediment loss in the manure treatments and is similar to the results of two earlier studies.

The DRP concentration in runoff was significantly higher (about four times) in the HPD-56 treatment compared with the LPD-56 and HPD-21 treatments. Manure treatment effects on DRP load in runoff followed a similar trend, except that the HPD-21 treatment was not significantly different from the other treatments. The DRP load in runoff was nearly four times higher in the HPD-56 treatment compared with the LPD-56 treatment.

Treatment effects on BAP concentration were the same as for DRP concentration. Runoff from the HPD-56 treatment was almost three times higher in BAP concentration than from the LPD-56 and HPD-21 treatments, but treatment effects on BAP load were not significant.

In October, treatment effects on TP concentrations and loads were opposite from June. Concentrations and loads of TP in June were higher in the HPD-56 treatment than in the control and other treatments. However, in October, the control had a significantly higher TP load than the LPD-56 and HPD-56 treatments. This probably occurred because TP includes sediment-bound P as well as dissolved P, and sediment losses in October were higher in the control and HPD-21 treatments. The higher sediment losses are consistent with lower surface residue cover in those treatments. Total P loads were about three to five times higher in October than in June except for the HPD-56 treatment. The high June TP load in the HPD-56 treatment was largely due to the relatively high June DRP losses in that treatment. Higher October TP loads in the remaining treatments are consistent with higher runoff volumes and sediment concentrations in October.

Results from the October rainfall simulation show that manures from different dairy diet P concentrations still influenced P concentrations and loads in runoff more than four months after these manures were land applied. This supports the results from the June data indicating that excess P in diets can increase DRP losses runoff when manures from these diets are land applied, and that this effect persists for at least several months. The influence of dietary P levels on TP losses in runoff is complicated by manure treatment effects on runoff volume and sediment loss.

Natural Runoff — Treatment effects on DRP losses in natural runoff support the simulated rainfall results. The cumulative DRP load is consistently higher in the HPD-56 treatment than the LPD-56 treatment and control. Precipitation events varied between 3 and 169 mm and runoff volumes ranged from 0.02 to 10.39 mm. January to March runoff events were primarily associated with snowmelt, and monthly temperatures were above average for this period. May and June had unusually large precipitation amounts, resulting in much larger runoff volumes than in previous rainfall events, and treatment effects on DRP load were accentuated in these cases. There were significant treatment differences in cumulative DRP load at 67 percent of the individual events (12 out of 18 dates). For nine of these dates, the HPD-56 treatment was significantly higher than the LPD-56 treatment and the control; for three of those dates the HPD-56 treatment was similar to the LPD-56 treatment but significantly higher than the control. Overall, the data confirm that higher amounts of DRP are lost from plots amended with high-P diet manure than plots amended with low-P diet manure, and these effects on cumulative DRP loss persist for at least one year.

Soil Analysis — The mean soil test P values for the experimental area indicate a relatively low initial soil P status. At the 0- to 15-cm soil depth, the Bray-Kurtz P-1 soil test P level was 11 mg kg^{-1}, and P additions would be recommended for production of most crops. The October soil test P results show that the HPD-56 treatment usually increased soil test P values at the 0- to 2-cm depth. When the high-P and low-P manures were applied at the same rate, Bray Kurtz P-1 in the high-P treatment (HPD-56) increased more than two-fold compared with the LPD-56 treatment. When the high-P manure was applied at the same P rate as the low-P manure (HPD-21 and LPD-56), Bray Kurtz P-1 tests were not significantly different. This was also true for the distilled water, Mehlich III, and BAP tests, which showed a two- to three-fold increase in the HPD-56 treatment compared with the LPD-56 and HPD-21 treatments.

Corn Analysis — Total aboveground corn dry matter yield and plant P concentration were increased by the manure treatments. These responses are consistent with the application of P to a soil testing low in plant-available P. In addition, total plant P uptake in the manure treatments was significantly greater than in the control. Since a uniform N addition was made to all treatments, these responses are most likely due to P applied in the manures. The possibility of other manure treatment effects on responses cannot be conclusively excluded. Corn yields and total plant P uptake and concentration did not differ among the high- and low-P manure treatments regardless of manure application. This suggests that the lowest P rate added in manure (40 kg P ha^{-1}) supplied adequate P to maximize dry matter yield and plant P concentration.

Conclusions

Phosphorus concentrations in dairy diets influence the forms and amounts of P in manure. Results from this study indicate that when manures from dairy cows fed different dietary P levels are land-applied, a high-P-diet manure contributes more P to runoff than a low-P-diet manure, in both simulated and natural runoff. This effect was seen even when the manures were applied at the same P rate. In June, DRP concentration in runoff from the high-P-diet manure was nearly 10 times higher than the low-P-diet manure when manures were applied at the same manure rate (2.84 vs. 0.30 mg L^{-1}), and four times higher when applied at equivalent P rates (1.18 vs. 0.30 mg L^{-1}). In October, the same comparisons showed that at equivalent manure rates, DRP concentrations were nearly four times higher in the high-P-diet manure treatment (0.89 vs. 0.21 mg L^{-1}) and the same when applied at equivalent P rates (0.21 mg L^{-1}). Dissolved reactive P measurements in natural runoff support the simulated runoff data. These data emphasize the need to avoid excess P supplementation of dairy cow diets to minimize P additions from land-applied manure and reduce P losses to surface runoff and adverse effects on water quality. Regardless of whether an N-based (same manure rate) or P-based (same P rate) manure application strategy is followed, this study indicates that excess P in dairy diets increases the risk of P loss in runoff from land-applied manure. These findings indicate that P in animal diets and its influence on manure P characteristics should be considered when applying the P-index and when implementing nutrient management plans.

Editor's note: Content was adapted from the paper "Dairy Diet Phosphorus Effects on Phosphorus Losses in Runoff From Land-Applied Manure," which was published in Soil Sci. Soc. Am. J. 2002 66, and is courtesy of the authors Angela M. Ebeling, Larry G. Bundy, J. Mark Powell and Todd W. Andraski.

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DIRECTIONS

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Dairy Diet Phosphorus Effects on Phosphorus Losses in Runoff From Land-Applied Manure

August Self-Study Examination

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1. Odor, death of fish, and general degradation of surface water is related to:
   [ ] a. depleted P levels.
   [ ] b. depleted O_2 levels.
   [ ] c. depleted H_2O levels.
   [ ] d. depleted NO_3 levels.

2. Based on National Research Council standards, a 1999 study found dietary P to be over-supplemented by:
   [ ] a. 10%.
   [ ] b. 15%.
   [ ] c. 20%.
   [ ] d. 25%.

3. Studies have shown that decreasing dietary P:
   [ ] a. increases P excreted in manure.
   [ ] b. decreases P excreted in manure.
   [ ] c. has no effect on excreted manure.
   [ ] d. increases dry matter content of manure.

4. Phosphorus load is defined as:
   [ ] a. the concentration of P applied to an area.
   [ ] b. P in a given volume of runoff.
   [ ] c. the dietary supplement given to an animal.
   [ ] d. the total amount of P leaving a field.

5. All forms of P analyzed were:
   [ ] a. higher in the control.
   [ ] b. higher in the low P diet (LPD) manure.
   [ ] c. higher in the high P diet (HPD) manure.
   [ ] d. not consistent in the analyses.

6. In June, TP load in the control treatment appeared to be associated with sediment loss, while a substantial portion of the TP load in the manure treatments was accounted for as:
   [ ] a. sediment loss as well.
   [ ] b. LDP.
   [ ] c. DRP.
   [ ] d. BAP.

7. October rainfall simulation showed that manures from different dairy diet P concentrations still influenced P concentration and loads in runoff more than:
   [ ] a. 4 months after these manures were applied.
   [ ] b. 5 months after these manures were applied.
   [ ] c. 6 months after these manures were applied.
   [ ] d. 7 months after these manures were applied.

8. Overall, the data confirm that higher amounts of DRP were lost from plots amended with high-P diet manure than plots amended with low-P diet manure, and these effects on cumulative DRP loss persisted for at least:
   [ ] a. 1 year.
   [ ] b. 2 years.
   [ ] c. 3 years.
   [ ] d. 4 years.

9. Total plant P uptake in the manure treatments was:
   [ ] a. significantly lower than in the control.
   [ ] b. significantly greater than in the control.
   [ ] c. the same as the control.
   [ ] d. the same as the N uptake.

Over

Nutrient Management Test (continued)

10. When land applied, a high-P diet manure:
[ ] a. contributes more P to runoff than a low-P diet manure.
[ ] b. contributes less P to runoff than a low-P diet manure.
[ ] c. contributes more P to runoff only in simulated runoff.
[ ] d. decreases the risk of P runoff.

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