Strategies to Reduce Phosphorus Losses from Dairy Farms

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Take Home Messages

- Livestock farmers cite meeting environmental regulations as their number one concern as they plan for the future, ahead even of feed and product prices!
- Limits on manure phosphorus (P) application are in place in many states and provinces, and are mandatory in the U.S. for farms receiving certain cost-share funds. All states in the US now have the authority to require these limits, depending on local and regional water quality concerns. These limits on manure P application will dramatically increase the land required to dispose of livestock manure.
- More accurately defining and meeting the P needs of dairy cattle and other livestock (a.k.a. dietary nutrient management) is a powerful, cost-effective approach to reducing the P content of land-applied manure. This will reduce potential P runoff from farms and make it easier for farms to meet P-based regulations.
- Large dairies under P-based regulations with manure P in excess of crop needs may find that treatment of waste to reduce its P content may be cost-effective.

Background

Increased specialization and concentration of livestock and crop production have led to the net export of nutrients from major crop producing areas of the country to areas with a high concentration of animal agriculture. Livestock utilize P inefficiently, excreting 60 to 80% of that consumed. Therefore, the majority of P brought on to the farm in feed stays on the farm, rather than being exported in meat or milk.

Animal manure is typically land-applied to supply nutrients for crop growth, but nitrogen (N) and P are in imbalance in manure relative to crop needs. Land-application of manure to meet the N needs of the crop results in the over-application and accumulation of P in soils. Historically, P contamination of surface water was thought to be associated primarily with erosion. As application of P in excess of crop requirements continues, however, soil becomes saturated and runoff of P can occur independent of erosion (Daniel et al., 1992).

Areas facing the dilemma of an economically important livestock industry concentrated in an environmentally sensitive area have few options. If agricultural practices continue as they have in the past, continued damage to water resources and a loss of fishing and recreational activity are almost inevitable. If agricultural productivity is reduced, however, the maintenance of a stable farm economy, a viable rural economy, and a reliable domestic food supply are seriously threatened. Practices that reduce P losses from farms without impairing profitability must be developed and implemented. Improved understanding of P digestion, absorption, and metabolism in livestock will improve efficiency of P utilization, reducing P excretion and minimizing the imbalance of N and P in manure (Knowlton et al., 2004).

The Role of Animal Agriculture

Concentrated animal agriculture has been identified as a significant source of P contamination of surface water in the United States (median contribution = 7 to 48% of total P loads, depending on watershed; Smith and Alexander, 2000). These losses were calculated with a model using measured stream water quality data and spatial data on sources, landscape characteristics and stream properties. The link between animal numbers, manure application to a limited land area, and P contamination of surface water also was demonstrated in the Lake Okeechobee watershed in Florida. From 1973 to 1988, P concentration in the water of Lake Okeechobee in Florida increased by 250% (Negahban et al., 1993). During this same time period, dairy cow numbers in the three counties surrounding the lake increased by more than 900 cows per year (Boggess et al., 1997), and dairies were identified as the source of about 40% of the P load to the lake (Negahban et al., 1993). The appearance of lake-wide algae blooms led to the imposition of stringent regulations designed to reduce agricultural runoff.

Increasing Regulatory Pressure

Increasing public concern with water quality and increased awareness of the impact of concentrated livestock production has led to the development and implementation of increasingly stringent environmental regulations. Greater pressure on states from the federal government in the last decade to enforce federal clean water regulations has increased significantly the level of regulatory pressure felt by farmers in the USA. Similarly, in Manitoba, Canada, the provincial government has implemented a bill that permanently bans building or expanding animal facilities along the Red River Valley, Southeastern Manitoba and the region between Lake Winnipeg and Lake Manitoba. These regulations were implemented to reduce P loading and contamination of water bodies (MLMMI, 2009).

Limiting manure application to the P needs of the crop is one way to avoid continued accumulation of P in soil, and to minimize potential P runoff and contamination of surface water. Regulations limiting manure application to the P needs of the crop are explicitly allowed in the federal Concentrated Animal Feeding Operation regulations to address water pollution in the U.S. (EPA, 2003). These federal regulations call for site specific decisions on whether N- or P-based manure application limits are needed to protect water quality, and P-based limits are now enforced in several states (e.g., Michigan, Maryland, Virginia, and Florida). Also, some federal cost-share funding is now being linked to the development and implementation of P-based nutrient management plans. Phosphorus-based nutrient management regulations dramatically increase the amount of land required to dispose of manure, and will have a severe, detrimental effect on the agricultural economy in areas of intensive animal agriculture. In Canada, Quebec and Manitoba have introduced regulations that limit manure application. For example Manitoba Conservation (2009) has recently implemented a Livestock Manure and Mortalities Management Regulation, which requires producers to test P content of soil and determine the amount of manure that can be applied based on soil test P.

▪ Precision Phosphorus Feeding

In all species of livestock, P fed in excess of animal requirements is excreted, making reduced overfeeding a powerful tool to reduce the P content of manure. In dairy cows, several studies indicate a direct link between P intake and P excretion (e.g. Morse et al., 1992; Wu et al., 2000; Knowlton and Herbein, 2002). A Florida study was among the first to show this link (Morse et al., 1992). Twelve cows were fed diets containing one of three concentrations of P (0.30%, 0.41%, or 0.56% of dietary DM). Excretion increased linearly with increasing P intake, and accounted for nearly all of the difference in P intake with the highest P diet compared with the low P diet.

Overfeeding of dietary P is common in the field. In the past, P was often fed to dairy cattle 20 to 40% in excess of published requirements (Shaver and Howard, 1995; Sink et al., 2000). A survey conducted by Wu (2003) in Pennsylvania indicated that the extent of overfeeding is less now than was indicated in these earlier surveys. Kebreab et al. (2008) conducted a survey in Ontario, Canada and found that dairy farmers were, on average, using 0.41%

P in the diet. The authors reported that reduction of P to NRC (2001) recommended concentrations would save farmers $20 per cow per year. Moreover, excretion of P would be reduced by 1.3 kt year^{-1} from Ontario dairy farms (Kebreab et al., 2008). Estimates of savings in feed cost assume that the excess dietary P is from purchased mineral sources; if excess P is from inexpensive byproduct feeds, reducing dietary P may increase feed costs.

Why Overfeed?

In dairy cows, the most common explanation for overfeeding of dietary P is the perception that high P diets improve reproductive performance. This perception likely originates from the observation that severe P deficiency impairs reproductive performance in cattle. The original studies that established this belief were primarily with range cattle (Eckles et al., 1932; Beeson et al., 1941), and the dietary P concentrations necessary to induce this impaired reproductive performance were below 0.20% of the dietary DM for lactating cows. This dietary concentration is far below the concentration found in most feedstuffs in modern lactating cow and beef cattle rations even without supplementation, and in all of these studies, reduced P intake was seriously confounded by marked reduction of intake of energy, protein, and other minerals.

Although severe P deficiency may impair reproductive performance, there is no research to suggest a benefit from feeding P to dairy cows in excess of NRC requirements (Brodison et al., 1989; Brintrup et al., 1993; Wu et al., 2000). A review by researchers in Wisconsin summarized thirteen studies with 785 lactating cows fed diets low in P (0.32 to 0.40% P) or high in P (0.39 to 0.61% P; Satter and Wu, 1999). Dietary P had no effect on days to first estrus, days open, services per conception, days to first AI, or pregnancy rate (Table 1).

Table 1. Reproductive performance of lactating cows fed diets low or high in P (summary of 13 trials; Satter and Wu, 1999)

	Low P	High P
Dietary P, % of diet DM	0.32-0.40	0.39-0.61
N	393	392
	mean ± SD[a]	
Days to 1st estrus	46.8 ± 10.9	51.6 ± 13.8
Days to 1st AI	71.7 ± 16.2	74.3 ± 10.6
Days open	103.5 ± 21.4	102.1 ± 13.0
Services per conception	2.2 ± 0.9	2.0 ± 0.5
Pregnancy rate	92% ± 6%	85% ± 5%

[a]Differences between means were not statistically significant for any measured variable.

Two other factors that have led farmers to overfeed P are compensation (safety margin) for suspected undetected variation in the P content of feeds, and inconsistencies between NRC requirements and the nutritional advice farmers receive. Undetected variation in the P content of feeds leads to imprecise ration formulation. Phosphorus content of forages analyzed by the Northeast DHI Forage laboratory from May 1994 through April 1995 was highly variable (Kertz, 1998). The coefficient of variation in P content within forage type was 20 to 25%, and P content was more variable for grasses than for legumes. Despite this variation, wet chemistry analysis of forages for P content is not routinely requested.

Practical feeding recommendations influence P intakes in the field. Inconsistent recommendations from nutritionists, veterinarians, and extension personnel have led many farmers to feed P in excess of the NRC recommendations. Dou et al. (2003) surveyed 612 dairy farms in New York, Pennsylvania, Delaware, Maryland, and Virginia to assess dietary P concentration and to identify critical control points pertaining to P feeding management. Survey responses revealed a wide range of dietary P concentrations for lactating cows, from 0.36 to 0.70 % of DM. The mean was 0.44% of DM, which was 34% above the concentration recommended by the NRC for 27.9 kg milk day^{-1} (Table 2), the mean milk yield in the survey. Higher P concentrations in diets were not associated with higher milk yields but increased dietary P led to higher P excretion in feces. Most producers were feeding more P than cows needed because it was recommended in the rations by consultants. Until the environmental consequences became obvious, overfeeding P was viewed as cheap reproductive insurance. Revisiting the literature makes clear that there is no documented benefit to overfeeding P.

Table 2. Phosphorus requirements for Holstein cows (600 kg BW) with varying DMI and milk yield (NRC, 2001)

	Milk yield, kg day^{-1}						Milk yield, kg day^{-1}					
	30	32	34	36	38	40	30	32	34	36	38	40
DMI, kg d^{-1}	Absorbed P requirement, g day^{-1}						Dietary P requirement, % of diet DM[a]					
21.8	49	51	52	54	56	58	0.35	0.36	0.37	0.39	0.40	0.41
22.5	49	51	53	55	57	58	0.33	0.34	0.35	0.37	0.38	0.39
23.2	50	52	54	56	57	59	0.32	0.34	0.35	0.36	0.37	0.38
23.9	51	53	54	56	58	60	0.32	0.33	0.34	0.35	0.36	0.38
24.6	52	53	55	57	59	61	0.31	0.32	0.34	0.35	0.36	0.37
25.3	52	54	56	58	60	61	0.31	0.32	0.33	0.34	0.35	0.36

[a]Shaded cells indicate dietary P concentrations based on NRC predicted DMI for the specified rate of milk yield.

One final reason P is overfed is the inclusion of feeds in the diet that are naturally high in P. Many byproduct feeds are high in P, most notably the byproducts of corn processing and ethanol production. These are increasingly popular feed supplements for beef and dairy cattle because of the protein and energy they supply. However inclusion of these feeds in higher amounts often increases the dietary P content beyond the animal's requirement. Koelsch and Lesoing (1999) constructed nutrient balances for Nebraska livestock farms and found that producers who used these byproducts had greater imbalances between P inputs and outputs than producers who did not. In their study, the seven beef cattle operations that fed these products imported twice as much P into their farms as they exported in meat, crops, and manure (input:output ratio of 2:1). In contrast, the nine farms who did not feed these products exported nearly as much P as they imported (input:output ratio of 1:1).

It has become uncommon for dairy rations to be supplemented with inorganic P, leaving these byproduct feeds as the primary remaining cause of overfeeding. This challenge of inexpensive high P byproduct feeds will only become more serious in the future with the expansion in ethanol production from various feedstocks and increased use of corn-based sweeteners. From a societal perspective, use of these high P byproducts as livestock feed is positive; the byproducts must be disposed of in some way and recycling them as livestock feed is a better option than land filling them. With time, perhaps technology will be developed to extract P from feeds. In the short term, producers using these feeds should at least remove unneeded supplemental inorganic P from diets. In the long run, however, the true cost of the use of these high P feeds should be carefully considered. If the inclusion of these byproducts will cause significant nutrient imbalance in the livestock operation and lead to difficulty meeting environmental regulations, then these feeds will not be as inexpensive as they appear as feed ingredients.

On-Farm Implementation

Limited work has been published on the impact of reduced overfeeding on herd performance and on-farm nutrient balance. Cerosaletti et al. (2004) conducted a study on four dairy farms to identify feeding strategies incommercial dairy herds to reduce manure P andwhole farm P balance. Monthly, lactating cow diets were evaluated and milk production and herd reproductive performancewere measured. Manure P content was measuredevery 6 months. Reduced P diets wereimplemented in two herds, reducing dietary P intake by 25%. After dietary adjustments in the two herds, fecal P concentrations decreased 33% with no impact on milk yield. Changes in dietary P had no effect on herd reproductive performance measured as heat detection rate, conception rate, pregnancy rate and cows with days open > 150. Reducing dietary P content closer to requirements reduced whole farm P balance by 49%.

Feed Management Software to Reduce Nutrient Surpluses

Feed management software is a useful tool to monitor forage and supplemental feed inventory; facilitate communication between nutritionist, manager and feeder through electronic means; and evaluate the feeder. Comparisons can be made between the amounts of ingredients specified by the nutritionist and the observed amount of each ingredient actually loaded by the feeder.

This software addresses the problem of inaccurate feed delivery, a significant source of variation on farms. Inaccurate feed delivery occurs because scales on mixer wagons are rarely checked for accuracy, mixing consistency is assumed to be constant, and feeders are inadequately trained and monitored. Unfortunately producers overcome many of these obstacles in their feeding program by instituting a substantial safety margin. That is, they overfeed to ensure that the cows' N and P requirements are met.

We have evaluated the impact of improved feeding accuracy on whole farm nutrient balance through the use of feed management software on 18 dairy herds located in Virginia. Herds using feed management software for three years had significantly lower whole farm N balance on a per cow basis. Some herds experienced significant improvements in P balance but these were not consistently observed. The lack of consistent effect of feed management software on whole farm P balance was due largely to increased use of economical but high P byproduct feeds during the study.

Cost Sharing Dietary Nutrient Management?

Environmental best management practices are often encouraged by government and conservation organizations via educational programming, subsidized analysis of soil and manure samples, and cost-share programs to cover a portion of the implementation costs. As the environmental benefits of dietary nutrient management became more well-known, many of these agencies expressed interest in finding ways to 'cost share' this practice as well. We recently wrapped up a three year large scale program offering subsidized feed analysis and incentive payments for precision feeding. 215 herds (29% of all Virginia dairy farms) enrolled with 35,064 cows (35% of all the dairy cows in Virginia). An initial period of feed analysis and data collection indicated that farms averaged ~30% overfeeding. The range in observed feeding rates was from 70% to 215% of the requirement. As the project progressed a greater and greater portion of herds achieved targeted feeding rates for dietary P. The proportion of herds achieving the lowest overfeeding increased to 13% and a total of 70 % of herds (year 2) and 74% of herds (year 3) were feeding within 25% of requirements. Removal of supplemental P sources is the largest contributor to the initial reductions in TMR P content. Additional reductions will require more significant ration modifications, such as ingredient substitution or limited inclusion rates for some ingredients.

▪ Chemical Treatment to Remove P From Manure

Post-excretion treatment of manure to remove or reduce the P content can be achieved physically, chemically, biologically, or through a combination of these processes. These treatments concentrate the bulk of manure P into a smaller volume of solids, facilitating economical transport of manure P to far-flung fields. They also can be used in conjunction to enhance the usefulness of composting systems to export manure P from the farm.

Chemical P removal is a successful and commonly used practice in removing P from municipal wastewater (Metcalf & Eddy, 1991). Commonly used chemicals include aluminum sulfate or alum, aluminum chloride, ferric chloride, and ferric sulfate (Dentel et al., 1993; Metcalf & Eddy, 1991). High removal of P from dairy manure has been shown using these chemicals alone or in combination with polymers (e.g. Zhang and Lei, 1998; Sherman et al., 2000). In general, the literature suggests that Al-based chemicals are more effective than Fe-based or Ca-based chemicals and that polymer effectively increases P removal when used in combination with chemicals.

Full Scale Demonstration of P Removal with Chemicals

A full scale evaluation of batch treatment of manure was conducted at the Virginia Tech dairy complex. Like other institutional dairy farms the Virginia Tech dairy is facing challenges related to loss of farm land due to physical expansion of the university, and the need to increase herd size. This case study is applicable to dairy farms with limited land to apply manure near the central hub of dairy operation but with land farther away, where manure can be applied agronomically based on P limitations.

Lab-scale jar tests were used to identify optimum combinations of chemical and polymer. In “jar tests”, manure is added to calibrated jars and varying dosages of chemicals and polymers are added. Al-based salts outperformed Fe-based salts at all dosages, and we observed that ultra-high molecular weight polymers facilitated higher P removal. The highest P removal and most desirable floc characteristics were achieved by alum + polymer at a 180 mg Al/L dose with 100 mg/L of polymer. Manure with total solids content between 0.87 and 1.7% could be treated with the same amount of chemical and polymer combination.

The aluminum chloride was delivered in bulk by a commercial trucking company and the polymer was delivered in a 1,040 L tote container. The manure in the tank was mixed for 60 minutes and then the chemical was metered directly from the truck into the tank and the mixing continued through both chemical and polymer addition. When visible well-formed flocs were present in the tank the application of polymer was stopped and mixing continued for 2 h. After 24 h of settling the sludge depth was 49% of the total liquid depth. A longer settling time may have improved settling; it was difficult to slow down the large volume of manure liquid after mixing at higher speeds to achieve flocculation and settling.

Treating the manure with chemicals increased the N:P ratio from 5.8:1 in the untreated manure to 15:1 in the supernate. About 80% of the P that was in the tank before treatment was captured in the sludge. These changes made it possible to use more liquid in fields adjacent to the farm with high soil test P, transporting the reduced volume of high P sludge to locations farther away from the farm for application in fields that may be deficient in P. In this experiment, the cost of the chemicals was almost exactly offset by cost savings with reduced manure transport.

Opportunities for Improvement

Although this treatment was successful, approaches to optimize the results in field use were obvious. Key areas for improvement include (1) determining a better way to dilute the polymer and (2) letting treated manure settle for a longer period of time before advancing the supernate liquid and applying the sludge. Chemical P removal may not be a long-term solution for dealing with excess P, but it is a highly effective and immediate solution that could be easily implemented on dairies, without construction of new treatment facilities.

▪ Implications

Phosphorus-based nutrient management regulations increase the amount of land required to dispose of manure, and that will have a detrimental effect on the economy in areas of intensive animal agriculture. Opportunities are now available to reduce P excretion by ruminants by 25 to 40% by more accurate feed analysis and ration formulation, and more precise mixing and feeding of rations to meet the animals' actual dietary P requirements. Reducing the P content of manure through nutrition is a powerful, cost-effective approach to reducing P losses from livestock farms. Chemical removal of manure P is an alternative that may be useful in some situations where manure transport or export is required.

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