What Goes In Must Come Out – Phosphorus Balance on Dairy Farms

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Abstract

Phosphorus (P) stimulates growth of algae in freshwater lakes and streams. The loss of P to surface runoff from fields that contain excess P are typically greater than from fields managed to supply adequate but not excessive P for crop growth. As dairy operations have increased in size, manure application rates of P have often exceeded plant uptake of P, resulting in elevated soil test P. High levels of P in lactating cow diets exacerbates the problem, since P fed in excess of the cow's requirement is excreted in the feces in a largely soluble form. Removing excess P from dairy diets not only reduces P content of manure, but sharply reduces the amount of soluble P excreted, thus reducing risk of surface runoff. Most lactating dairy cow diets can have their P content reduced by 20%. This results in a 25-30% reduction in P content of manure, and a similar reduction in the amount of land required to accommodate the manure.

Introduction

Phosphorus (P) is usually the limiting nutrient for growth of algae in fresh water bodies. Phosphorus from agricultural sources constitutes a large fraction of the P entering our lakes and streams. Dairy operations contribute P from eroded soil particles and from runoff water that solubilizes P from surface applied manure and from P enriched soils. There is considerable P loading of soils in dairy regions. Part of this is due to inadequate crediting of manure P, resulting in over application of fertilizer P and consequent accumulation of soil P. In recent years economic conditions have pushed dairy producers to increase cow numbers, often without a commensurate increase in land available for receiving manure. This has resulted in manure application rates of P that exceed P uptake by crops, leading sometimes to dramatic increases in soil P levels. The problem has been exacerbated by general overfeeding of P to dairy cows. Excess dietary P is excreted in the feces, and in a relatively soluble (and mobile) form. Reducing dietary P is a management tool that can be very effective in reducing environmental risk from dairy manure. This paper will review the relevant issues surrounding P supplementation of dairy cows, and the potential impact that reduction of dietary P can have on reducing environmental risk of manure and the requirement for land to accommodate manure.

Too Much Phosphorus Is Fed To Dairy Cows

There has been much confusion about the P requirement of lactating cows. This is reflected in large differences between feeding standards used by different countries in Europe and North America.[13] Some of the standards differ by as much as three-fold in their estimate of P maintenance requirements, and nearly two-fold in the requirement for milk production. Likewise, large differences exist in estimates of P availability in the gut. It is noteworthy, however, that the standards differ relatively little in their final recommendations for P feeding, as extreme differences in maintenance and lactation requirements tend to cancel each other. The National Research Council (NRC) presents an excellent summary of P utilization by dairy cows, and does much to clarify what has been a murky area in the past.[11]

Literature reports on P utilization and P requirements of lactating cows have been surprisingly consistent. It is in the interpretation of published reports where much confusion has arisen. This confusion has led to feeding of unrealistically large amounts of P in dairy diets. Two surveys,[2,12] plus additional survey information that I have compiled, show that in the United States dairy diets are formulated to contain approximately 0.45-0.50% P (DM basis), an amount that is about 20% in excess of the requirement[11] This over supplementation of P is costing the US dairy industry about $100 million annually, as well as increasing risk of environmental damage through eutrophication of lakes and streams.

How have we come to this point of excessive P feeding? There are at least three factors which have played a role. Perhaps most significant is the notion that increasing dietary P will improve reproductive performance. Nutritionists, veterinarians and producers alike are quick to point out that one reason they recommend feeding high levels of dietary P is the presumed benefit from enhanced reproductive performance. Indeed, there are studies showing improved reproductive performance with P supplementation. It is crucial, however, that we understand the circumstances of these studies, and how this association between P and reproductive performance developed.

Studies in South Africa in the early 1900's demonstrated that supplementing bone meal to beef cows grazing dry season rangeland improved reproductive performance, as well as growth rate and survival rate.[15] Cows grazing this dry season brush country consumed herbage that contained 0.10 to 0.15% P. Typically, supplements were not offered to cattle under these semistarvation conditions when these experiments were conducted. Bone meal was available at that time at a cost that was affordable, and the bone meal had dramatic effect. This series of experiments attracted world-wide attention and established a link between P and reproductive performance. Another study cementing a relationship between P and reproductive performance was conducted in England.[9] This experiment was conducted in the winter of 1949 in England. At that time the English feeding standards called for low amounts of P, lower than the current NRC recommendations for comparable milk production levels. The English study involved 802 dairy cows in 39 private herds.[9] They demonstrated quite convincingly that first service conception rates were higher in those herds feeding 9-18 g P per cow per day in excess of the standard that prevailed in England at that time. Feeding still larger amounts of P did not further improve first service conception rates. The feeding standard in England at that time recommended 10g P per cow per day for maintenance, and 2.3 g per kg milk or slightly over 1 g per lb of milk. Milk production averaged about 27 lb per cow per day (12.2 kg). Using NRC projections for dry matter intake for this milk production level, dry matter intake would be approximately 29 lb/day or 13.2 kg/day.[11] Expressing the P standard at that time in terms of percent of ration dry matter, then the recommendation would be to feed 0.29% P in the ration dry matter. The conclusion of the field study in England was to increase dietary P above this recommended level of dietary P. It is difficult to accurately calculate the increase recommended, but it would bring total dietary P close to 0.39% of ration DM. It is important to remember that in 1949 dairy cows in England were fed primarily weathered hay, some straw and relatively little grain. Vitamin D supplementation was not practiced. It is likely that P availability in the gut was lower under the dietary conditions in England at that time than with modern dairy diets that are supplemented with vitamin D and which contain a higher proportion of grain, which in turn provides a more available form of P than does low quality forage.

In both of these classic studies, dietary P levels were lower than current NRC recommendations, and likely provided insufficient P for maximum rumen microbial growth. Durand and Kawashima suggested the maximum P requirement for ruminal microbes is 4 g P/kg digestible organic matter in the diet.[5] This would be equivalent to less than 0.30% dietary P. Extremely low dietary P can inhibit rumen microbial growth, leading to reduced protein and energy supply to the host animal. It is well known that energy and protein supply can influence reproductive performance. Modern dairy diets never approach the low dietary P concentrations that can result in impaired microbial growth in the rumen. There is no evidence that feeding P in excess of NRC requirements will influence reproductive performance. The studies by Theiler and associates[15] and by Hignett and Hignett[9] were widely recognized, and resulted in much improved P feeding practices. Unfortunately, a mind set was established that related P to reproductive performance. While we work under completely different dietary conditions today than 50-100 years ago, we continue to extend the general conclusion of these classical studies to the conditions of today, and this is inappropriate.

Another factor contributing to the overfeeding of P to dairy cows has been the absence of lactation trials showing the absolute minimum of P required to support high milk production. Without knowing the bare minimum of P needed to support milk production, arriving at a reasonable margin of safety in formulating diets becomes problematic. This uncertainty has led to overly large margins of safety and excessive P in the dairy diet. Information is now available to show that moderate to high producing dairy cows (17,000-28,600 lb milk/lactation) (7,727-13,000 kg) are likely to exhibit beginning signs of P deficiency following long term feeding (1-3 lactations) of diets containing about 0.3% P.[3,16,17,18]

A third factor contributing to overfeeding of P has been aggressive marketing of P supplements. This has probably been less important than the first two factors mentioned.

Figure 1 is a summary of the status of P nutrition of lactating dairy cows producing more than 19,800 lb (9,000 kg) milk/305 d lactation.[17] The bare minimum of dietary P consistent with normal or near normal lactation performance is 0.30% of diet dry matter. At this dietary concentration, signs of P deficiency may begin to occur. At the other extreme of the continuum in Figure 1 is what most dairy producers in the United States are actually feeding. Figure 1 also shows the require-

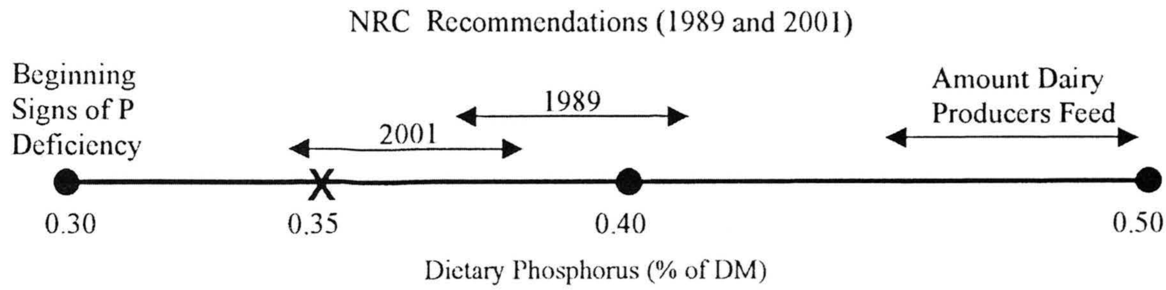

Figure 1. Current status of P nutrition of lactating dairy cows milking > 19,800 lb/305 d of lactation

ments for P as indicated by the NRC.[10,11] For ease of illustration, the NRC requirements are expressed in terms of percent P in the diet. This is based on dry matter intakes suggested by the NRC. The most recent NRC publication has slightly lowered the requirement for P feeding, a change that is fully justified by research results.[11] The NRC presents requirements, and does not include a margin of safety. In calculating the requirement, however, it appears the NRC committee used a conservative estimate for P availability, or the P absorption coefficient. The NRC model used P absorption (availability) coefficients of 64 and 70% for forages and concentrates, respectively.[11] Recent research in our laboratory is suggesting that these values may be low. The long term lactation studies mentioned earlier would confirm that the NRC requirements are more than sufficient, and one might in fact consider the NRC[11] requirement to include a reasonable margin of safety.

It is difficult to determine what a reasonable margin of safety is with regard to P feeding. It will depend upon uniformity of milk production of cows within the feeding group, variability of P content of diet ingredients, and how quickly cows exhibit P deficiency symptoms. Variability in DM intake between animals of comparable milk production will also be a factor. The NRC suggests that Holstein cows weighing 1496 lb, having a body condition score of 3.0, that are 65 mo of age, and producing milk containing 3.5% fat and 3.0% true protein will have a dietary requirement (using a sample diet) of 0.32, 0.35, 0.36, and 0.38% P for milk production amounts of 55, 77, 99 and 120 lb/day, respectively.[11] Certainly grouping cows by milk production level would enable a closer match between dietary P and P requirement.

Based on information in NRC feed composition tables, it appears that the coefficient of variation for P content within a feedstuff listed is about 15%. The new NRC[11] tabular values for P content of feedstuffs appear more accurate relative to the old NRC[10] tabular values, as the older NRC values for P content were systematically lower than recent laboratory analysis.[1] This may be a reflection of increased soil P levels in more recent years, since high soil P can increase plant P content.

Cows lose both calcium (Ca) and P from bone to help supply these elements in early lactation. Ternouth suggested that up to 30% of bone P can be removed during early lactation.[14] Based on this estimate for beef cows, a dairy cow weighing 1320 lb could mobilize 1.3 to 2.2 lb (590-1000 g) of P in early lactation. Phosphorus mobilized from bone would need to be restored in later lactation, but the sizeable bone reserve provides a buffer against short term P deficiencies that might result from

Table 1. Performance of cows fed diets differing in phosphorus content for an entire lactation.[17]

	Dietary P (% of DM)		
Item	0.31	0.39	0.47
Number of cows	10	14	13
Dry matter intake, lb/day	55.0	55.0	54.1
Milk, lb/308 days	28,684	26,200	26,677
Milk fat, %	3.64	3.50	3.64
Milk protein, %	3.16	3.13	3.10
P intake, lb/d	0.171	0.215	0.255
Fecal P excretion, lb/day[1]	0.095	0.145	0.194

[1]Estimated using 68% as the diet DM digestibility, and the means for DMI and fecal P concentrations (0.538, 0.829, and 1.12% for the three treatments, respectively).

underestimating P content of a batch of feed. Also, mobilized bone P reduces the need for elevated dietary P levels in the first weeks of lactation when feed intake lags behind milk production.

With this background, a reasonable approach might be to formulate group rations using NRC[11] recommendations to match the average production level of the top 25% of cows in a feeding group. If this is done, then high production groups in the highest producing herds would have their P requirement met, with a reasonable margin of safety, with diets containing 0.36-0.40% P. This amount of dietary P can be supplied with little or no use of P supplements, and it represents a 20% reduction in P content of the average dairy diet in the United States.

Phosphorus fed in excess of the requirement is excreted, with the vast majority appearing in the feces. Typically cows fed just enough P to meet their requirement will excrete < 1 g P/day in urine. Cows fed P 20-30% in excess of their requirement may excrete 3-5 g P/day in urine.[18] Table 1 contains results from a lactation study where cows were fed diets containing 0.31, 0.39 or 0.47% P for a 308-day lactation.[17] Based on bone P and ash content, cows fed the 0.31% P diet were marginally deficient. Phosphorus fed in excess of the requirement, which in this example was close to 0.31%, was excreted. Referring to Figure 1, reducing P content of average US dairy diets from 0.45-0.50 to 0.36-0.40% represents a 20% reduction in dietary P, and at least a 25% reduction in manure P.

Classical P deficiency symptoms are unlikely to develop in lactating dairy cattle fed high quality feedstuffs typical of modern lactation diets. The feedstuffs utilized today contain P in amounts that will normally meet the P requirement, even without P supplementation. If low quality forages are used in the lactating cow diet, or if vitamin D supplementation is not practiced, it is possible that a P deficiency could develop. Nonspecific symptoms of P deficiency include unthriftiness, inappetance, poor growth and reduced milk production. If P supply is insufficient for maximum rumen microbial growth (possible with diets containing less that 0.3% P), then energy and protein supply to the cow will be reduced.

The normal range for blood plasma P is between 4-8 mg/100ml. Hypophosphatemia (less than 4 mg/100ml blood plasma) may occur if cows are offered diets clearly deficient in P, or on occasion it develops in late pregnancy or early lactation. The latter is usually complicated with concurrent hypocalcemia, hypomagnesemia and possible hypoglycemia.[11] It is not the intent of this paper to review phosphorus disorders, so the reader is referred to an authoritative discussion of this topic,[7,8] but limited discussion in this paper of this condition is warranted.

The onset of lactation draws large amounts of P out of the extracellular pool, drawing down plasma P levels. If the cow is also developing hypocalcemia, parathyroid hormone (PTH) will be secreted, thus increasing urinary and salivary loss of P. According to Goff[8] "plasma P concentrations usually increase rapidly following treatment of the hypocalcemic cow with intravenous Ca solutions. This rapid recovery is caused by reduction in PTH secretion, reducing urinary and salivary loss of P, and resumption of gastrointestinal motility accompanied by increased plasma concentrations of 1,25-dihydroxyvitamin D, which allows absorption of dietary P and reabsorption of salivary P secretions". Goff continues with "some animals developing acute hypophosphatemia do not recover normal plasma P concentration. This is sometimes the case in cows that are classified as 'downer cows'. This syndrome often begins as milk fever, but unlike the typical milk fever cow, plasma P remains low (below 1 mg/100ml) in some of those cows despite successful treatment of the hypocalcemia. Protracted hypophosphatemia in these cows appears to be an important factor in the inability of those animals to rise to their feet, but why plasma P remains low is unclear. In some cases the inability to absorb the salivary phosphate secondary to poor rumen motility may be a cause, but not in all cases. Excessive cortisol secretion could also drive blood P concentration down. How this occurs is unknown. Treatment of cows with phosphate-containing solutions, but not phosphite-containing solutions (orally or intravenously) can effect recovery in some animals. The syndrome does not appear to be caused by low-P diets, because affected cows are often receiving diets containing 0.4% dietary P."[8]

While acute hypophosphatemia in the periparturient cow is relatively uncommon, it can be a serious problem, and demands treatment. Routine feeding of P in excess of requirement, however, is not an appropriate treatment.

Reducing Phosphorus In Dairy Diets Reduces Risk To The Environment

Reducing dietary P concentration not only reduces P content of manure, but it reduces the vulnerability of P in manure from being solubilized in runoff water following field application. Ebeling *et al*[6] obtained manure from lactating cows fed dietary P concentrations of 0.32 or 0.48%. These dietary levels resulted in feces with P concentrations of 0.48 and 1.28%, respectively. This manure was surface applied to field plots without incorporation. Phosphorus load in water run-off from the plots was about ten times greater in plots amended with manure derived from cows fed the high-P diet than manure from cows fed the low-P diet. When these manures were applied at equivalent rates of P (36 lb (16.3 kg)/acre), the high-P manure had P runoff loads about four times that of the low-P manure. A related study was reported recently by Dou *et al.*[4] They measured

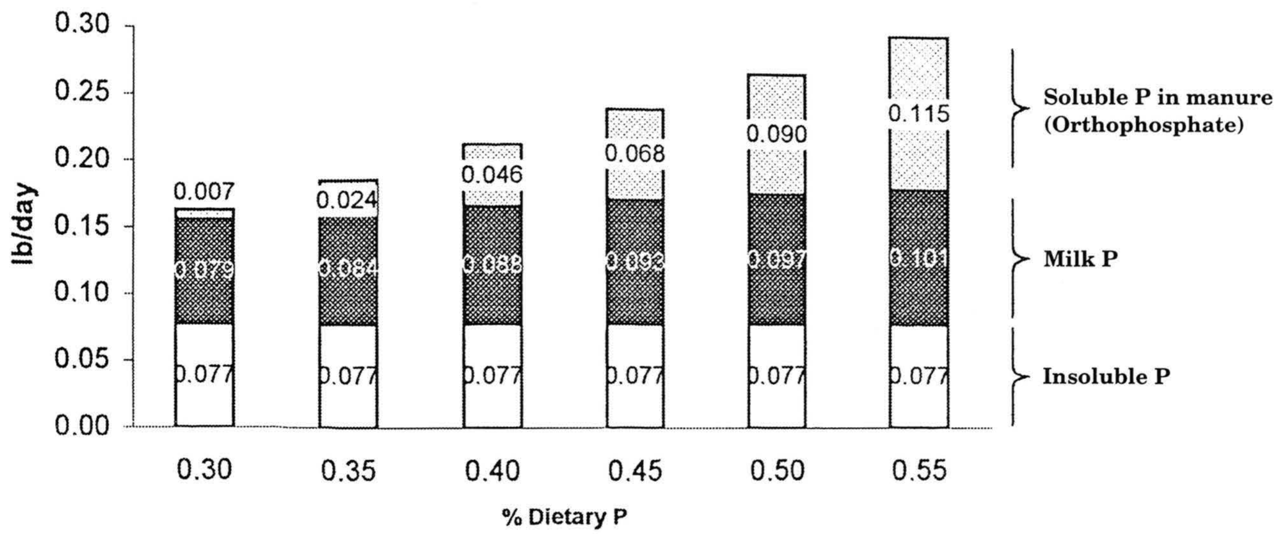

Figure 2. Destination of dietary phosphorus in a dairy cow producing 85 lb milk and consuming 53 lb diet dry matter daily developed from these studies.[4,6,17]

water solubility of P in manure obtained from cows fed different amounts of dietary P. Their study indicated that almost all of the P fed in excess of the cows requirement ended up as water soluble P in the manure. Figure 2 is a composite of results from several studies, and depicts this point.[4,6,17] Increasing dietary P above the minimal requirement (0.3% P in this figure) did not increase P secretion in milk. Dietary P in excess of the requirement was simply excreted in the manure, and largely in water soluble form. Therefore, reducing dietary P not only reduces P content of manure, but can greatly reduce the potential for field runoff of what manure P is applied.

Reducing dietary P can have a very significant effect on the amount of land required to effectively utilize manure P (Table 2). Most lactation diets that are not supplemented with an inorganic P source contain 0.35-0.40% P. This of course depends upon the ration ingredients used. Since this concentration is similar to the P requirement for lactating cows, it follows that essentially all of the supplemental P fed above the requirement will be excreted in the manure. Assuming a crop uptake of 26.7 lb of P/acre/yr, the requirement for land increases proportionally with the increase in manure P. Reducing dietary P to an amount that the lactating cow requires often means complete elimination of mineral P supplements. It can also result in a major reduction in the amount of land required to effectively utilize manure P.

The dairy industry utilizes large amounts of by-product feeds, many of which serve as important sources of protein in the dairy diet. There is a tendency for feedstuffs that are high in protein content to also contain high concentrations of P, but there are significant deviations from this generalization. Table 3 shows the N:P ratio of some common dairy supplements that are often brought into the ration because of their protein

Table 2. Amount of phosphorus fed and excreted by a lactating cow producing 20,000 lb milk in 305 days, and the amount of land required to effectively utilize the manure phosphorus.

Dietary P concentration	Estimated supplemental P	Manure P	Land area needed to recycle manure P	Change in land area
(%)	(lb/lactation)[1]	(lb/lactation)	acres	(%)
0.35	0	34.8	1.3	Base
0.40	7.48	42.2	1.6	23
0.48	19.6	54.3	2.0	53
0.55	30.1	64.9	2.4	83

Assumptions: Cow is consuming average of 49.5 lb (22.5 kg) DM daily, and milk contains 0.09% P. There is no net change in P content of the cow. The cropping area is comprised of 37% corn for grain, 7% corn for silage, 47% alfalfa, and 9% soybeans. Crop yields are typical for the Midwest US, and remove 26.7 lb (12.1 kg) P per acre per year.

Table 3. Protein and phosphorus content of some common feeds.[11]

Feed	Protein content % of DM	N content % of DM	Phosphorus content % of DM	N:P
Bloodmeal	95.5	15.3	0.30	51.0
Soybean meal (48%CP)	49.9	8.0	0.70	11.4
Soybean (roasted)	43.0	6.9	0.64	10.8
Brewer's grains	29.2	4.7	0.67	7.0
Cottonseed	23.5	3.8	0.60	6.3
Corn distillers grains	29.7	4.8	0.83	5.8
Canola meal	37.8	6.0	1.10	5.5
Corn gluten feed	23.8	3.8	1.00	3.8
Wheat midds	18.5	3.0	1.02	2.9
Wheat bran	17.3	2.8	1.18	2.4
Meat and bone meal[1]	54.2	8.7	4.73	1.8

[1]The NRC (2001) does not distinguish between porcine and ruminant meat and bone meal. Some analyses suggest that porcine meat and bone meal tends to have more protein and less P than ruminant meat and bone meal, resulting in a N:P ratio between 2 and 3.

content. Bloodmeal and meat and bone meal represent the extremes in this table. Both feedstuffs are high in rumen undegraded protein content, but bloodmeal supplies a very large amount of protein per unit of P. Meat and bone meal, on the other hand, supplies relatively little protein per unit of P. For dairy producers that are having trouble managing P, choice of a protein supplement or by-product feed can be an important decision affecting P management. A growing number of dairy producers have discontinued using P supplements, but because they utilize large amounts of by-product feeds high in P concentration, overall dietary P content may still be excessive (0.40-0.45%). It is important that least-cost ration formulation programs do not give credit for P content of a feedstuff if the diet does not need P. A significant part of the dollar value of meat and bone meal is associated with its P content. If P is not needed, then meat and bone meal should not be given credit for the P it contributes in excess of the requirement. In fact, a negative value might be appropriately assigned in some cases.

Conclusion

Reducing dietary P in lactating cow diets is perhaps one of the most effective steps that can be taken to reduce the environmental threat of dairy manure. It is a step that reduces cost as well as provides environmental benefits. The P content of most dairy diets can be reduced by about 20%, thus lowering manure P by 25-30%.

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