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FEEDING MANAGEMENT TO REDUCE PHOSPHORUS LOSSES FROM DAIRY FARMS

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Introduction

Nitrogen and phosphorus (P) contamination of ground and surface water are the leading environmental issues facing livestock farmers in Virginia, Maryland, and Pennsylvania. Increasing specialization and concentration of animal agriculture has led to nutrient imbalances on farms and across watersheds. When total P inputs to a farm or watershed exceed exports, P accumulates in soil, and may runoff, contaminating water resources. Phosphorus inputs to animal production systems include fertilizer, imported feeds (e.g. grains), and dietary mineral supplements, and P is exported in animal products and cash crops. Long term solutions to the problem of P losses from a farm or across a watershed must address this imbalance between inputs and exports.

Most efforts to reduce nutrient losses from farms have focused on manure management: handling nutrients once they accumulated on the farm. Relatively little attention has been paid to the “front end” of the system: management of the herd and feeding program to minimize nutrient excretion. Better understanding of the P requirements of dairy cows, and reducing the P content of diets to true requirements will reduce P excretion, a critical step in addressing this nutrient imbalance. This presentation reviews the current state of knowledge regarding dietary P requirements of dairy cows and focuses on the opportunity farmers and their advisors have to reduce P losses from dairy farms through improved nutrition.

Environmental concerns

Environmental concerns with P are primarily associated with pollution of surface water. Excess P in water, like excess nitrogen, causes algae populations to grow rapidly, or to “bloom”. The subsequent decomposition of the algae consumes dissolved oxygen in the water. Lack of dissolved oxygen is a major factor affecting the growth and reproduction of fish, clams, crabs, oysters, and other aquatic animal life. An algae bloom and subsequent decrease in dissolved oxygen is known as eutrophication, and may be caused by runoff or leaching of P or nitrogen from land.

It is well known that excess application of nitrogen, either as manure or chemical fertilizer, can result in loss of nitrogen to surface water. In contrast, P was thought to be fixed in soil in a relatively stable from, and the conventional wisdom was that excess P would accumulate in soils and only runoff if there was erosion. Management of P on farms was a matter of preventing erosion using favorable tillage and cropping strategies. Recently, however, it has been discovered that with excessive application of P to soils over a period of several years, the soils become saturated with P and runoff can occur even when erosion is controlled (32)

Increased soil test P from excessive application of fertilizer, manure, and crop residues has been linked to greater soluble P in runoff. No till practices, although they reduce soil erosion, may actually make runoff of soluble P worse, because P is kept near the soil surface. Still controversial is the soil test P level at which soluble P becomes a problem and the interaction of soil type with P solubility (33).

Livestock are inefficient in the utilization of P, and typically, more P is imported as feed and fertilizer than is exported in meat and milk. Figure 1 outlines P flows on an example 100 cow dairy farm. We assumed 100 mature dairy cows averaging 19,500 lbs of milk per cow per year, 80 replacement heifers, and 50% digestibility of dietary P. Forages (corn silage, alfalfa hay, and pasture) are grown on the farm, and grains are imported. Phosphorus imports exceed P exports on this farm by 1 ton per year, and this quantity accumulates in the soil.

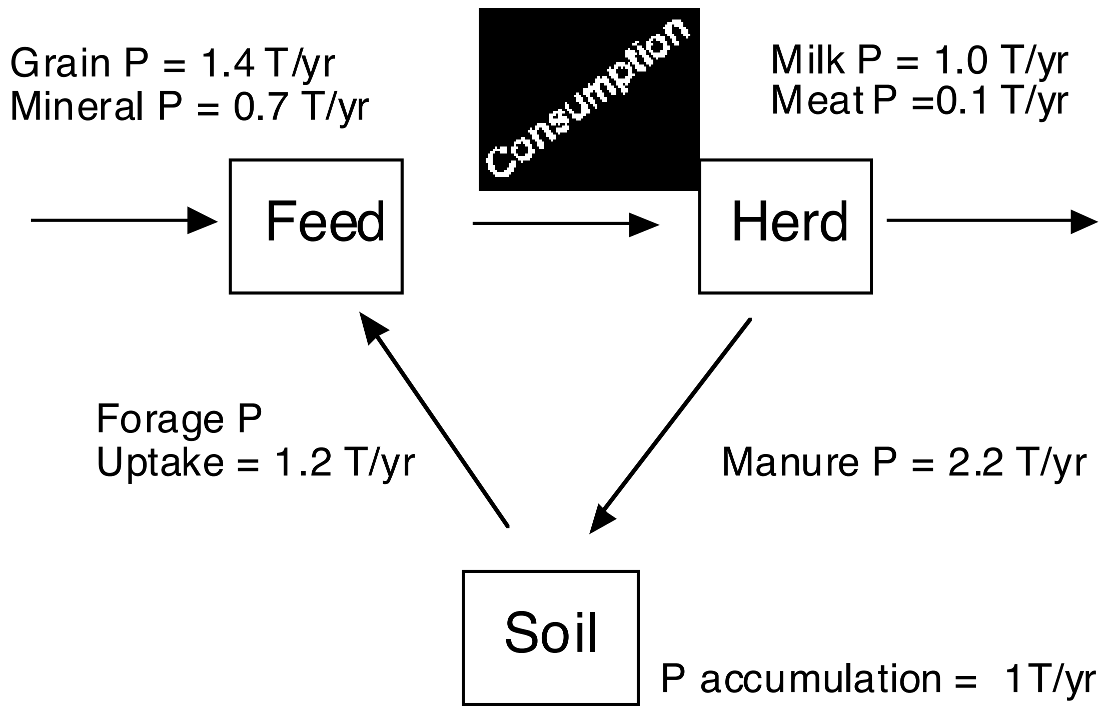

Figure 1. Phosphorus flows on an example dairy farm.

High animal density, application of that manure to a restricted land base, and the resulting soil accumulation of P in the Shenandoah, Potomac, and Susquehanna River watersheds make the Chesapeake Bay particularly vulnerable to nutrient contamination. Rockingham County in Virginia is representative of the challenge facing many counties in the Chesapeake Bay watershed. Rockingham County has the highest population of both dairy cattle and poultry in Virginia, and as many as 20% of the dairy farms in the county also have at least one poultry house. Estimated manure nutrient production in Rockingham county exceeds crop requirements on a yearly basis (29).

There is a clear link between heavy application of manure over time and P accumulation in the soils. Manure phosphate per acre of cropland in Rockingham county increased by 90% between 1978 and 1992, and an analysis of soil tests in 1993 and 1994 indicated that nearly 90% of samples were ranked “high” or “very high” in P (29). Although there is controversy as to the threshold level of soil test P that leads to P runoff, these soils clearly need no additional P, and may not need any more for up to ten years.

This link between cow numbers, manure application to a limited land area, and P contamination of surface water was demonstrated dramatically in the Lake Okeechobee watershed in Florida. From 1973 to 1988, P concentration in the water of Lake Okeechobee in Florida increased by 250% (28). During this same time period, cow numbers in the three counties surrounding the lake increased by more than 900 cows per year (3), and dairies were identified as the source of 40% of the P load to the lake (28). The appearance of massive, lake wide algae blooms led to the imposition of stringent regulations designed to reduce agricultural runoff.

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. If nutrient management regulations cause a displacement of farming activities in exchange for suburban sprawl, nutrient loading to water from septic systems and erosion may actually increase. Practices that reduce nutrient losses from farms without impairing profitability must be developed and implemented.

Reducing the amount of P in manure through nutrition is a powerful, cost effective approach to reducing potential P losses from dairy farms. Concentration of P in the diet of dairy cows has also been shown to have significant impact on P excretion. Several studies indicate a direct link between P intake and P excretion (11, 16, 22). A Florida study shows this link most clearly (22). Twelve cows were fed diets containing one of three levels of P (.3%, .41%, .56% of dietary DM). Excretion increased linearly with increasing intake, and nearly all of the difference in P intake with the high P diet compared to the low P diet was excreted (Figure 2).

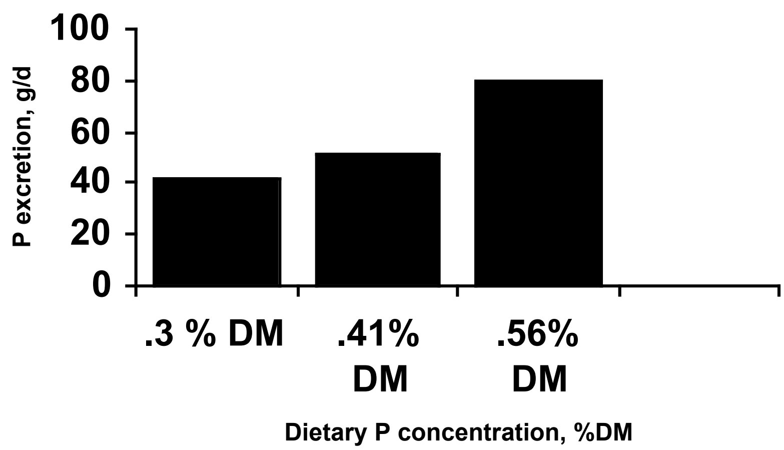

Figure 2. Effect of dietary P concentration on P excretion in lactating cows. (23)

Phosphorus requirements of lactating cows

Phosphorus metabolism by lactating cows

Phosphorus is required by lactating cows for bone formation and maintenance, milk secretion, building muscle tissue, energy metabolism, fatty acid transport, phospholipid synthesis, amino acid metabolism, and protein synthesis. It is a component of nucleic acids involved in cellular metabolism, enzyme systems, and buffer systems.

Regulation of P metabolism is complex, and involves regulation of absorption from the gut, mobilization from bone, and secretion in saliva. Phosphorus is absorbed in the small intestine as phosphate, and this absorption is primarily in response to need – low serum P increases absorption of dietary P (12, 13, 20, 25, 31). Phosphorus in the bloodstream is either retained in meat, milk, or bone, or secreted through saliva back to the digestive tract. Ruminants secrete large quantities of P in saliva, and this is a key mechanism for the regulation of P metabolism. Absorbed P not used for growth, deposited in bone, or secreted in milk is secreted in the saliva and then excreted in the feces.

Phosphorus also enters the bloodstream through mobilization from bone, but there is no direct mobilizing mechanism for P like there is for Ca. Bone mineral is a complex Ca-P salt, so mobilization of bone Ca also results in mobilization of bone P (4). In early lactation cows, Ca is mobilized from bone, and thus P is also released in substantial quantities. In these cows, increased P demands increase P absorption from the gut at the same time that their need for Ca increases P mobilization from bone. This results in a surplus of P in the bloodstream which is then secreted in saliva and excreted. Feeding the early lactation cow to meet her calculated requirements for milk and maintenance may not be necessary and may have no effect on P retention (4). More effort needs to be focused on the best way to meet the requirements of these cows without inadvertently increasing excretion.

Development of published requirements

Table 1 outlines true P requirements for lactating cows according to the current NRC and other nutrient requirement publications from around the world. Published requirements for dairy cattle are based on peer reviewed research in ruminants, including very few studies with lactating cows. The small number of studies is because of the expense involved in conducting and interpreting mineral balance experiments in lactating cows.

Table 1. Published daily P true (net) requirements for dairy cows.*

System	Year	Assumed digestibility of feed P, %	True maintenance req't	True milk req't g/kg milk
NRC	1971	50	14.3 mg/kg BW	1
	1978	55	14.3 mg/kg BW	.9
	1989	50	14.3 mg/kg BW	.99
ARC	1965	55	16.8 g/d for 600 kg	.95
	1980	58	12 mg/kg BW	.905
Netherlands	1983	60	25.2 mg/kg BW	.9
France	1988	70	43.4 mg/kg BW	.875
Germany	1987	60	24 mg/kg BW	1
Germany	1993	70	1 mg/kg DMI	1

* Adapted from (1, 24, 26, 27, 37, 38)

Requirements for P are calculated using a factorial approach. The P requirement for a cow is the sum of the calculated requirement for maintenance based on body weight, the requirement for pregnancy, and the requirement for milk yield based on the P content of milk. True requirements are divided by the efficiency of absorption of dietary P to yield total P requirements, and Table 2 lists current total P requirements for lactating cows.

Table 2. Published daily total P requirements, g/d, for a 600 kg dairy cow*.

System	Year	Assumed digestibility of feed P, %	P intake for maintenance	P intake for maintenance plus varying yields of 4% fat corrected milk, kg/d			
				20	30	40	50
NRC	1971	50	17.2	57.2	77.2	97.2	117.2
	1978	55	15.6	48.3	64.7	81.1	97.4
	1989	50	17.2	56.8	76.6	96.4	116.2
ARC	1965	55	30.5	65.1	82.3	99.6	116.9
	1980	58	12.4	43.6	59.2	74.8	90.4
Netherlands	1983	60	25.2	55.2	70.2	85.2	100.2
France	1988	70	37.2	62.2	74.7	87.2	99.7
Germany	1987	60	24.0	57.3	74.0	90.7	107.3
Germany	1993	70	varies	53.4	67.7	91.4	111.7

* Adapted from (1, 24, 26, 27, 37, 38)

The maintenance requirement for P is currently estimated as 1.43 g/100 kg liveweight/d [Council, 1989 #821]. There is a debate as to whether or not this estimate is appropriate. The maintenance requirement for P is estimated based on minimum endogenous losses of P in the feces and urine. Fecal P is a combination of indigestible P, inevitable endogenous loss, and that excreted as part of a homeostatic regulation (e.g. that consumed in excess of requirements; 18, 35).

In a German study designed to clarify the inevitable endogenous loss of P, two groups of cows of similar body weight were divided into high or low milk yield groups and fed low P diets at different levels of intake (35). Both groups of cows were in zero P balance, so fecal P in these cows was a combination of truly indigestible P and inevitable endogenous losses. With such low P intakes, digestibility of P is typically very high, and the authors ascribed all excreted P to the inevitable endogenous loss category. Fecal P as a proportion of body weight was very different, but fecal P as a fraction of dry matter intake was essentially identical (1.2 g/kg DMI). The link to DMI is logical as salivary P contributes the bulk of endogenous P losses.

The requirement for P for milk yield varies primarily with milk fat content. The current true NRC requirement is .99 g of P/kg 4% FCM (Table 1).

Digestibility

The digestibility of feedstuffs has a dramatic impact on published total P requirements, but is based on relatively few studies (17-19). Digestibility of P declines with age of the animal, and the 1989 NRC requirements for growing animals account for this with P availability declining from 90% in calves to 55% in animals over 400 kg. NRC requirements for lactating cows assume a constant digestibility of 50%. The availability of P in lactating cows from all feeds was reduced from 55% to 50% in the last update of the NRC, apparently in an effort to build an additional safety factor into the published requirements. This change increased the total P requirement for P by 10 to 20%.

If improved P availability allows reduced P intake, the P content of livestock manure can be reduced. The development of phytase additives for monogastric animals is one example of nutritional manipulation of nutrient excretion, but this technology has little potential in ruminant animals because ruminal microorganisms already provide phytase activity. One important implication of this fact is that the natural phytase activity provided by ruminal microorganisms makes the P in grains and forages available to ruminants (8, 11, 22). Thus there is no need to discount the P in grains and forages, but some nutritionists still do.

The assumed digestibility of dietary P has a tremendous impact on the dietary P requirements of lactating cows. If digestibility of dietary P was increased by 5 units allowing decreased P feeding, P excretion could be reduced by about 15% in lactating cows[1]. With roughly 750,000 dairy cows in the Chesapeake Bay Watershed (14), an increase in P digestibility of this magnitude and the appropriate reduction in P feeding would reduce P excretion by 1750 tonnes per year, or the equivalent of 3500 tonnes of P_2O_5 per year. This example makes clear the need to better define the digestibility of P in feedstuffs, and to seek out technologies that may increase digestibility of dietary P in ruminants.

Changes in the NRC requirement for P?

Tables 1 and 2 outline current true (net) requirements and total P requirements (true requirements divided by assumed digestibility) according to the NRC and other nutrient requirement publications from around the world. There is variation among these publications, and published recommendations do change as our base of knowledge expands. Although more data is still needed, it seems apparent that modifications are warranted in the definition of the maintenance requirement for P, and in the bio-availability of P in feeds. Expressing the maintenance requirement of cows as 1.2 g P per kg DMI will increase requirements only slightly (Table 3), but is more biologically sound (35).

Table 3. Impact of expressing the maintenance requirement as a fraction of body weight (1.43 g/kg BW) or of dry matter intake (1.2 g/kg) on P requirement, g/d. Assumes 50% digestibility

MY	BW	DMI	Body weight basis		DMI basis	
Kg/d	Kg	Kg/d	Maintenance P, g/d	Total P, g/d	Maintenance P, g/d	Total P, g/d
25	450	16.9	12.9	62.4	20.3	69.8
30	450	18.7	12.9	72.3	22.4	81.8
35	450	20.7	12.9	82.2	24.8	94.1
25	500	17.5	14.3	63.8	21.0	70.5
30	500	19.5	14.3	73.7	23.4	82.8
35	500	20.1	14.3	83.6	24.1	93.4
25	550	18.4	15.7	65.2	22.1	71.6
30	550	20.4	15.7	75.1	24.4	83.8
35	550	23.7	15.7	85.0	28.4	97.7
25	600	19.2	17.2	66.7	23.0	72.5
30	600	21.0	17.2	76.6	25.2	84.6
35	600	22.2	17.2	86.5	26.6	95.9

[1] Calculations assume lactating cows fed diets to meet current NRC requirement for P. Phosphorus intakes reduced with increasing digestibility of dietary P. Phosphorus excretion calculated as P intake – (milk P + maintenance P). Milk P = .99%* milk yield and maintenance P = .0143*body weight (NRC 1989).

More work to better define the availability of P in a variety of feedstuffs is clearly necessary. There is some reported variation in the bio-availability of P sources for ruminants that has not been fully explored (30, 31), and there is obvious variation in the assumed digestibility of feed P among nutrient requirement publications worldwide. Of these publications, our NRC publication assumes the lowest digestibility of feed P (Table 2). European countries currently assume P digestibility of 58 to 70%, reducing recommended feed levels significantly compared to the U. S. system. Given the environmental and economic importance of P intake, reconsidering the assumption of 55% P digestibility across feedstuffs may be merited. In the long run, a system accounting for variation in availability of P among different feedstuffs would be beneficial.

Overfeeding P

The 1989 NRC P requirement for lactating dairy cows is about .41% of diet DM, but P content of rations in the field typically averages .55% or greater, 30% more P than required (34). Phosphorus is often fed to dairy cattle in excess of published requirements because high P diets are commonly believed to 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 (2, 10), and the dietary P concentrations necessary to induce this impaired reproductive performance were below .25% of the dietary DM. This dietary concentration is far below the concentration found in most feedstuffs in modern dairy rations even without supplementation, and in all of these studies, P intake was seriously confounded with intake of energy and other minerals.

Although severe P deficiency may impair reproductive performance, there is no research data to suggest a benefit from feeding P to dairy cows in excess of NRC requirements. In fact several studies reported no impact of dietary P concentrations of .33 to .35% of dietary DM on days open, services per conception, or calving interval (5, 6, 40). One study did indicate increased services per conception with P at .37% of dietary DM as compared to P at .56% of the diet (36), but cow numbers were much too small in this study (just 16 cows on the low P diet) to assess this parameter accurately.

A recent study by researchers in Wisconsin serves as an example of the studies indicating no effect on reproductive performance of P supplementation (40-42). Forty-eight cows were assigned at calving to low or normal P diets (.35% vs. .5% of dietary DM), and dietary treatments were continued through two lactations. With the data from the first year summarized, milk yield, 4% FCM, and DMI were not affected by treatment. Days to first estrus were 8 days longer for cows on the low P diet ($P < .09$), but days to first service, conception rate, services per conception, and pregnancy rates were not different. These were high producing cows, averaging 65 to 70 pounds of milk through the first year of the study.

Interestingly, one study actually reported depressed milk yield when P was fed at 35% over NRC requirements compared to cows fed at the NRC requirement (7). Forty eight primiparous cows were assigned to high or low energy and high or adequate P diets. Adequate P diets were formulated to contain P at .4% of dietary DM, while the P content of the high P diets were 35% greater than requirements, or .5% of dietary DM. Cows fed the high P diets had reduced milk yield of 1.8 kg/d during the experiment, and produced 816 kg less milk over the course of the first lactation, even though cows were fed a common diet after the first 84 days.

An important point to emphasize is that like other nutrients, the requirement of the cow for P is for quantities, not concentrations. For convenience in balancing rations, P requirements are commonly expressed as a percentage of DM. The actual dietary concentration required to yield the required quantity of P, however, varies with dry matter intake. For instance, the current NRC requirements for a

600 kg cow producing 30 kg of milk with 4% butterfat is 93 g of P per day. The percent of P required in the diet DM for this cow is .49%, .44%, and .40% with DMI of 19, 21, and 23 kg/d.

Again, field observations suggest that most dairy farmers feed diets containing P significantly in excess of these published requirements. Two factors that have led farmers to overfeed P are undetected variation in the P content of feeds, and inconsistencies between NRC requirements and the 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 94 through April 95 was highly variable (15). The coefficient of variation in P content of forages was 20-25% for most forage types, 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.

Both ration balancing programs and field recommendations influence P intakes in the field. Although based on NRC, the DART ration balancing software lists P requirements about 15% higher than NRC for lactating cows (9). This inconsistency, and inconsistent recommendations from nutritionists, veterinarians, and extension personnel have led many farmers to feed P in excess of the NRC recommendations. Until the environmental consequences became obvious, overfeeding P was viewed as cheap reproductive insurance. Revisiting the literature makes clear that here is no documented benefit to overfeeding P. Now that we are realizing the true cost of overfeeding P, we must move aggressively to correct inconsistencies in our recommendations. Phosphorus intakes in the field are now typically in excess of current requirements by 25-40%, giving farmers a tremendous opportunity to benefit both economically and environmentally by feeding at the current published requirements.

Economic impact of reducing P intake, excretion, and losses from the farm system

The impact of reducing P intake on P losses from the farm system can be estimated several ways. One can predict P excretion simply as the difference between P intake, and P in milk, retained in body weight gain, and fetal development (39). Given allocation of manure to crops, and estimated nutrient uptake by those crops, one can calculate acreage required to land-apply manure for changing. Evaluating a dairy farm milking 100 cows with different cropping strategies, we can see the tremendous impact P intake has on acreage required for disposal of manure on a P basis (Table 4). Acreage required to dispose of manure generated by the herd increases by about 60% as P intake increases from .4% to .55%. Alternatively, given a fixed land base and different cropping strategies, we calculated the maximum number of milking cows supported by that land base. As P intake by the herd increases from .4 to .55%, herd size that can be accommodated with P-based manure application decreases by 35%.

The impact on net farm income of P intake depends upon the regulatory conditions affecting the farmer. If the farmer is not under P-based nutrient management, and applies manure without regard to its P content, the only impact of feeding excessive P is on his feed bill (Table 5). A 100 cow herd increases their feed bill by $750 to $850/year by feeding P at .45% of dietary DM vs. .4% dietary DM, depending on milk yield and feed intake. With P at .5% of dietary DM, the feed bill is increased by $1500 to $1700/yr, and at .55%, feed costs are increased by about $2250 to $2500/yr.

There is more and more discussion of mandatory P-based nutrient management, and Maryland has implemented a law requiring farmers to comply with such plans by the year 2004. Most livestock farms produce more manure P than their crops require, and P-based plans will require that the excess manure be exported so that excess P is not applied and allowed to accumulate.

For the farmer under mandatory P-based nutrient management, the costs of excessive P supplementation and P excretion are much greater. These costs include the increased feed bill, the cost of exporting manure in excess of what can be applied to land, and the cost of purchased N fertilizer to meet the needs of his crops because he won't be able to use manure produced on his farm to meet all of the crop N requirements. A study at Virginia Tech examined dairy and dairy poultry operations of different sizes, estimated potential P losses, and simulated net farm income under different policy scenarios (29). One of the policy scenarios was a restriction on P applications to that taken up by the crop harvested.

Table 4. Impact of P intake on manure disposal under P-based nutrient management

	Dietary P concentration			
	.4	**.45**	**.5**	**.55**
Acres required for given herd size and milk yield[1]				
100 cows, 60 lbs milk	91	108	126	143
200 cows, 60 lbs milk	182	217	251	286
100 cows, 80 lbs milk	93	112	132	151
200 cows, 80 lbs milk	186	225	264	303
Maximum cow numbers for given crop acreage				
100 acres, 50% corn 50% alfalfa	93	78	68	60
100 acres, 75% corn 25% alfalfa	93	79	68	60
100 acres, 50% corn 25% alfalfa 25% grass hay	86	73	63	56
100 acres, 50% corn, 25% small grains, 25% alfalfa	73	62	54	47

[1]Assumes cropping program of 50% corn, 50% alfalfa. Dry matter intake predicted from NRC, 1989, and crop nutrient uptakes as in (39)

[2]Assumes milk yield of 60 lb/d, dry matter intake predicted from NRC, 1989, and crop nutrient uptakes from (39)

Table 5. Increase in annual feed costs of a 100 cow herd relative to P at .4% of dietary DM[1]

		Dietary P concentration		
Average milk yield, lbs/d	**DMI, lbs/d[2]**	**.45**	**.5**	**.55**
60	45.6	$754	$1500	$2260
70	48.4	$798	$1603	$2402
80	51.2	$850	$1693	$2542

[1]Assumes increased inclusion of Dicalcium Phosphate, at $350/ton.
[2]Predicted from NRC, 1989

In this study, the policy limiting P application was the only policy with any measurable impact on P losses from dairy and dairy/poultry operations of varying sizes. P losses were reduced by 28 to 43% by this policy, but net farm income was dramatically affected, falling by 11 to 23%. The reduced net farm income was due primarily to the increased cost of purchased nitrogen fertilizer to meet the N requirements of crops (limiting manure application to P removal resulted in under-application of N relative to crop needs). The impacts on net farm income are likely underestimated in this study, as it was assumed farmers could dispose of excess manure off the farm at no charge. If a similar P-based policy were actually enacted, saturation of the market for this manure would likely mean farmers would have to pay to have manure removed from their farms, reducing net farm income still further. While manure obviously has fertilizer value, it is bulky and expensive to transport, and the cost of trucking the material any distance quickly exceeds its fertilizer value.

The economic importance of preventing P losses from dairy farms has been demonstrated in Florida as well. In the 1980's several regulatory and incentive programs were implemented in the Lake Okeechobee watershed in Southern Florida to reduce P losses to surface water (3, 21). Treatment facilities were required to manage wastewater from parlors and holding areas, waterways were fenced, wells were monitored, and farmers were required to meet rigid standards for P application. Noncompliance fines were steep. At the same time a voluntary buyout program was implemented. As a result dairy cow numbers decreased by 26% and milk production decreased by 17% from 1987 (the year of program implementation) to 1993. Despite cost-sharing of 60-70%, dairies remaining in the area faced increased costs of production of more than $1/cwt to implement mandatory and optional management practices and structures to reduce P loss from their farms. When increased culling, labor requirements and variable costs during construction were included, the net expense to producers staying in the area was $568/cow or $600,000 per dairy (21). The total economic impact of these programs in the region between 1987 and 1993 included decreases of 4% in both total income (down $18 million) and job numbers (down almost 500).

Conclusions

Additional research is needed in several areas to better understand the P requirements of lactating dairy cows. Key questions include the availability of P to lactating cows from various sources, and the question of just how low we can go with dietary P in high producing dairy cows without impairing reproductive efficiency. Answering this second question will be difficult because it will require large numbers of high producing cows.

From a policy perspective, perhaps we need to reconsider funding priorities. Most research and cost-share programs for reducing agricultural nutrient loading to water resources have been directed toward agronomic nutrient management and manure handling. However, improving nutrient utilization in the animal with more accurate diet formulation will reduce nutrient losses to the environment, cost less to implement, and may save farmers money compared with traditional approaches.

Most importantly, increased education of producers and their advisors is needed now to reduce overfeeding of P. The perceived impact of P intake on reproductive efficiency far exceeds the actual effect, and overfeeding is not of benefit. For farmers, reducing P intake to published requirements makes sense environmentally and economically. It would be difficult to overstate the economic implications of P-based nutrient management for livestock farms throughout the Chesapeake Bay watershed, and the importance of refining rations to reduce P excretion and subsequent land application of P. Legislation has been passed in Maryland that may outlaw the application of manure to soils that have very high P concentrations. Under this and similar laws, many farmers simply will not be able to apply manure on their farms because of high soil P concentrations. The sooner farmers begin to reduce soil P concentrations to acceptable levels on their farms the better off they will be. Reducing P intake to reduce P excretion is the most powerful, cost effective tool farmers have to achieve this goal.

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