Technical Report No.42

The Feeding of Supplemental Phosphorus on Dairy Farms in the Lake Champlain Basin: An Education / Demonstration Project

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for
Lake Champlain Basin Program

April 2003

PUBLICATION SERIES

THIS PROGRAM IS SPONSORED BY U.S.E.P.A. AND THE STATES OF NEW YORK AND VERMONT.

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FINAL REPORT
April 25, 2003

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With Support From:

Lake Champlain Basin Program
US Environmental Protection Agency
Vermont Department of Agriculture, Food, and Markets
US Natural Resource Conservation Service

This report was funded and prepared under the authority of the Lake Champlain Special Designation Act of 1990, P.L. 101-596, through the U.S. Environmental Protection Agency (EPA Grant #EPA X 99177301-2). Publication of this report does not signify that the contents necessarily reflect the views of the States of New York and Vermont, the Lake Champlain Basin Program, or the U.S. Environmental Protection Agency.

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Acronyms and abbreviations

AA	Atomic Absorptions spectrophotometer
Abs Coeff	absorption coefficient
Al	aluminum
ADF	acid detergent fiber
Avg	average
Ca	calcium
CP	crude protein
d	day
DHIA	Dairy Herd Improvement Association (Dairy One Cooperative, Inc)
dl	deciliter (100 milliliters)
DM	dry matter
DMI	dry matter intake
Fe	iron
g	gram
gal	gallon
ICP	Inductively Coupled Plasma spectrophotometer
K	potassium
K_2O	potassium oxide
kg	kilogram
L	liter
lb	pound
mg	milligram
Mg	magnesium
Mn	manganese
MUN	milk urea nitrogen
n	sample size
N	nitrogen
NDF	neutral detergent fiber
NIRS	near-infrared spectroscopy
NRC	National Research Council
P	phosphorus
P_2O_5	phosphorus oxide
RHA	rolling herd average
Std Dev	standard deviation
TMDL	total maximum daily load
TMR	total mixed ration
TMRa	analyzed phosphorus level in a total mixed ration
TMRn	nutritionist calculated phosphorus level in a total mixed ration
U.S.	United States

1. Executive Summary

Introduction

Nutrient balance on dairy farms is becoming more critical in efforts to maintain and improve water quality of the Lake Champlain Basin. Phosphorus inputs onto dairy farms in the form of fertilizers and feeds outweigh the amount of phosphorus leaving the farm in the form of saleable products. Subsequently, excess phosphorus is building up in soils, running off soil or leaching through the soil into the local waterways causing pollution and eutrophication. Much of the excess phosphorus coming onto farms is through purchased feeds. Recent research has shown that a 40% decrease in dietary phosphorus fed to dairy cows, lowered excreted phosphorus by 23% (Morse et al., 1992), and another study reported that reduced dietary phosphorus levels lowered phosphorus excretion by 30% (Metcalf et al., 1996). Reducing dietary phosphorus levels to dairy cattle has the potential to significantly reduce the phosphorus loading of cropland from manure application.

Until recently, many dairy nutritionists, veterinarians, and feed dealers have followed guidelines established by the National Research Council (NRC, 1989) that recommended dairy cow diets contain at least 0.48% phosphorus for cows in early lactation, 0.41% for cows milking 90 pounds/day, and 0.37% for cows milking 65 pounds/day. Fearing that milk production and reproductive performance may suffer when phosphorus intake is low, some dairy producers were feeding phosphorus at levels above NRC-1989 guidelines (Satter and Wu, 1999). A survey of feed consultants operating in Vermont showed recommended phosphorus levels for cows producing 65 lbs/day ranging from: 0.48 to 0.55% from five feed company consultants; 0.44% from an independent consultant;, and 0.37% from the University of Vermont nutritionist (Anderson and Magdoff, 2000). The new NRC 2001 dietary recommendations for phosphorus range between 0.32-0.38% of ration dry matter (DM) for lactating dairy cows. It is clear that at current feeding rates, phosphorus is being fed in excess of requirements, which is contributing to an imbalance of nutrients entering and exiting from dairy farms. Considering these new recommendations, environmental and economic opportunities exist by improving nutrient management through more judicious monitoring of dietary phosphorus levels fed to dairy cows.

Objectives

There are three principle objectives of this project. The first was to conduct a thorough literature review of issues and research concerning phosphorus on dairies, including the updated NRC 2001 phosphorus requirements of dairy animals throughout their various physiological states. This includes a review of phosphorus content of feeds and mineral supplements, providing evidence and supporting materials to be used in educational efforts intended for dairy producers and feed industry personnel. The second objective was to conduct a demonstration trial at the Miner Institute dairy farm, where dietary phosphorus was reduced from 0.48% to 0.40 % for the lactating herd. Milk production, composition and reproductive data was reviewed to determine the efficacy of reducing dietary phosphorus levels. The third aspect was a survey of 30 farms in the Lake Champlain Basin to obtain baseline information about: current phosphorus feeding practices on farms; farmers' understanding of the nutritional requirements for phosphorus; and their attitudes about the economic and environmental importance of phosphorus reduction on dairy farms in the region.

Information and findings of these three papers were prepared for numerous oral presentations to producer and feed industry groups. An informational brochure was created summarizing the findings of these reports that can be distributed for educational purposes as well as being in a format that can be posted on farms for quick reference to producers.

Literature Review

The literature review provides information characterizing the phosphorus cycle on dairy farms, from feed and fertilizer inputs, through the animal and back into the soil. This review includes how the ruminant animal utilizes dietary phosphorus and recycles phosphorus in the form of salivary buffers. Through this process the chemical nature of phosphorus is changed making it a more readily soluble element compared to its original nature in feed particles. The chemistry of phosphorus in feed ingredients is a still relatively unknown issue concerning the efficiency with which animals can absorb phosphorus from various feed sources. With the latest information, NRC 2001 has revised previous recommendations for dietary phosphorus levels downward.

Fears of reduced milk production and reproductive performance when fed reduced dietary phosphorus levels are addressed in the review. Recent research shows no detrimental effects of feeding to the NRC 2001 recommendation of 0.38% dietary phosphorus. Dietary phosphorus reductions are directly linked to commensurate reductions in manure phosphorus levels. Not only is there a significant reduction in the amount of phosphorus in manure but also in the solubility and propensity to leach or flow into ground and surface waters when applied to cropland.

Miner Institute Demonstration Trial

Miner Institute dairy farm records were reviewed for the years of 1997-2000, comparing periods of elevated and reduced dietary phosphorus levels. Prior to December of 1998, dietary phosphorus levels of the high group milking rations averaged 0.48% of dry matter (DM). This level was an industry standard at the time. In December of 1998, a concerted effort to reduce dietary phosphorus levels of the lactating rations was made and the result was an average of 0.40% phosphorus. Records from Dairy One Cooperative, which provides forage quality and dairy management information, were reviewed for the four years and there were no negative effects of reducing dietary phosphorus on milk production, milk composition, or reproduction. Milk production increased during the phase of reduced phosphorus and days to first service decreased (though many management practices were improved independently of the diets that contributed to the positive herd responses during the reduced phosphorus phase). Conclusions are limited due to the lack of negative herd effects of reducing dietary phosphorus rather than a positive relation between reduced phosphorus and improved productivity. Manure phosphorus levels, though, were reduced nearly 30% with reduced dietary phosphorus. This clearly indicates the gains in nutrient management that are possible by reducing the amount of phosphorus cycling on the farm. These results have been used as a demonstration that reducing dietary phosphorus levels can be achieved without adverse effects.

Lake Champlain Basin Farm Survey

Thirty farms located in the Champlain Basin, were chosen from the Miner Institute Farm Report registry to participate in this survey. Selection was random, with weight given to farm size and facility design. Farms varied in size (100-1000 cows), facility structures and management styles from both New York and Vermont (15 from each state). A 10 question survey indicated that farmers were agreeable to reducing dietary phosphorus levels, but not fully aware of the new NRC 2001 phosphorus recommendations or what level of phosphorus they were currently feeding on their farms. Nutritionist's dietary phosphorus formulations were compared with wet chemistry analyses of diets, indicating wide variation between phosphorus levels balanced for nutrition and what was actually being fed. Investigations into this discrepancy points to imprecise measurements of phosphorus in both forages on the farm and feeds sold to the farmer. Individual grain components used to manufacture feeds vary greatly in phosphorus levels and may not be accurately accounted for in ration formulation.

Farm size was shown to be a critical factor in the frequency of forage testing and overall nutrient management. Producers on larger farms were shown to analyze feeds more frequently than smaller farms and had more positive thoughts to the economic savings of reducing dietary phosphorus levels.

Conclusions

This project provides basic information regarding phosphorus nutrition, animal health requirements and reference materials that can be used to educate and facilitate improved phosphorus management in the dairy industry. Further educational efforts include clarifying the nutritional requirements for phosphorus of all dairy animals, including calves and heifers throughout their growth stage as well as the lactating dairy herd. A better understanding of phosphorus levels in grains and by-product feeds that comprise the concentrate portion of dairy diets is needed. Knowing the phosphorus levels in feeds as well as understanding the efficiency by which animals are able to metabolize phosphorus will influence purchases and feeding practices on the farm. By improving the accuracy with which animals are supplied the proper level of nutrients, we can minimize the excesses that not only cost farmers but also contribute to the nutrient loading of soils and waters of the Lake Champlain Basin.

2. LITERATURE REVIEW

Overview

Of all the dietary essential minerals for dairy cattle, phosphorus has the greatest potential risk to water quality if excess is released into the environment. Farm mass nutrient balance models have been used to evaluate phosphorus movement on the farm and account for all farm inputs and outputs with the difference being the mass phosphorus balance of the farm (Figure 1) (Thomas, 1985). Nutrient balance on New York and Vermont dairy farms, including Miner Institute, showed that 50-70% of phosphorus imported onto the farm was not exported (Klausner, 1993; Thomas et al., 1996; Allshouse et al., 1996; Anderson and Magdoff, 2000). Most (65%) of imported phosphorus is from feed and minerals with the remainder from purchased fertilizer (Anderson and Magdoff, 2000). This imbalance results in increased soil phosphorus and therefore increased potential for loss of phosphorus in runoff.

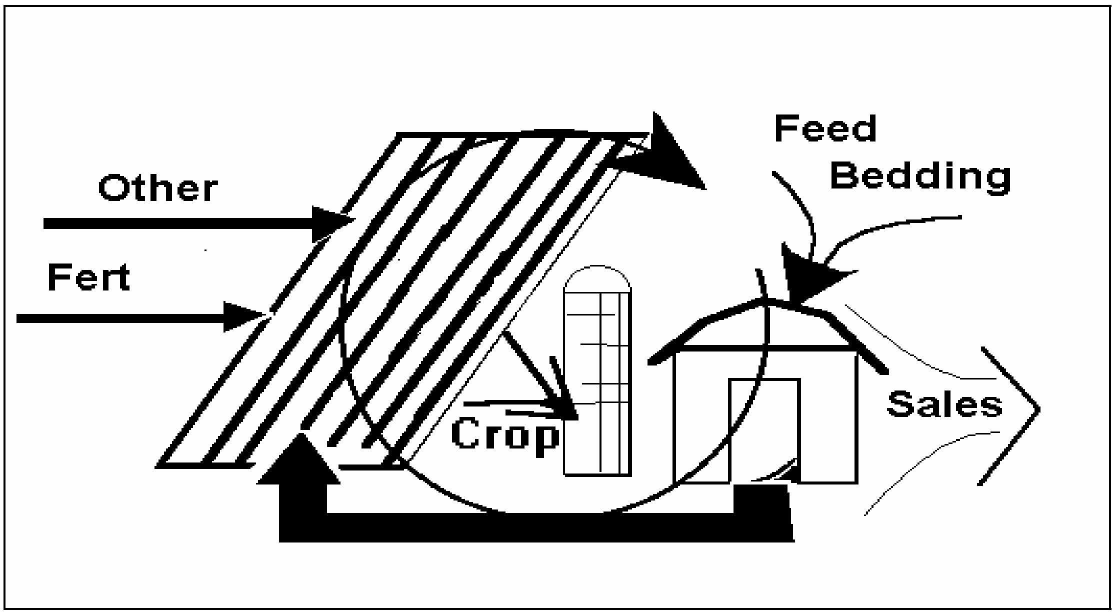


Figure 1. Characterization of phosphorus cycle on dairy farms (Adapted from Lanyon and Beegle, 1993).

Efforts to date have primarily concentrated on farm manure management, from storage to spreading practices, and have played a key role in efforts to reduce phosphorus inputs to the watershed area of Lake Champlain. However, other scientists are examining the prospect of reducing farm phosphorus input based on the logical conclusion that if less phosphorus is imported, there will be less phosphorus runoff from dairy farms. One of the largest sources of phosphorus brought onto dairy farms is through purchased feed concentrate mixes.

Until recently, many dairy nutritionists, veterinarians, and feed dealers followed guidelines established by the National Research Council (NRC) (1989) that recommended dairy cow diets contain at least 0.48% phosphorus for cows in early lactation, 0.41% for cows milking 90 lbs/day, and 0.37% for cows milking 65 lbs/day. Fearing that reproductive performance may suffer when phosphorus intake is low, some dairy producers were feeding phosphorus at levels above NRC-1989 guidelines (Satter and Wu, 1999). Two surveys of Mid-South and Mid-West dairy nutritionists found that phosphorus recommendations averaged 0.51% and 0.48% of dietary dry matter, respectively (Sansinena et al., 1999; Keuning, et al., 1999). A survey of feed consultants operating in Vermont showed recommended phosphorus levels for cows producing 65 lbs/day ranging from 0.48 to 0.55% for five associated with feed companies, 0.44% for an independent consultant, and 0.37% for the University nutritionist (Anderson and Magdoff, 2000). Dairy diets not supplemented with phosphorus typically contain between 0.33 and 0.40% phosphorus, therefore many of the diets with high levels of phosphorus require the purchase of supplemental phosphorus through commercial feeds. Reduction of these purchases will not only result in environmental benefit from reduced phosphorus in the manure, but will also be an economic benefit to dairy producers by reducing the purchased phosphorus used in their dairy rations.

In 2001, NRC re-examined the impact of reducing the level of phosphorus fed to dairy cows without adversely affecting the health and productivity of the animals. Recent research suggests that dietary phosphorus can be reduced to between 0.33 and 0.39% of dietary dry matter without adversely affecting milk yield and reproductive performance (Valk and Ebek, 1999; Knowlton and Kohn, 1999; Wu et al., 2000).

Phosphorus metabolism in the dairy cow

Understanding how the ruminant dairy animal utilizes phosphorus is critical in understanding how best to manage this nutrient. Dietary phosphorus enters the rumen in the form of forage, grain and supplemental mineral. The efficiency with which the dairy cow utilizes phosphorus from each type of feed will vary. In general, dietary phosphorus enters the rumen and supplies the rumen microorganisms with their required phosphorus in order to continue their lifecycle, which involves fermenting fiber, soluble nutrients and generating their own proteins which subsequently supply the cow with microbial protein. Microbial protein is the major source of protein that the cow digests. Maximizing the productivity of the dairy cow requires maximizing rumen microbial activity, which requires meeting the nutritional requirements of the microbes, including their need for phosphorus.

Dietary phosphorus enters the rumen and is either utilized by the microbes or passes through to the lower gastrointestinal tract where most of the absorption of phosphorus takes place. Very little phosphorus absorption occurs in the rumen (NRC, 2001). Phosphorus, based on feed source and chemical form, will be absorbed at varying rates across the wall of the small intestine, enter the blood stream where it is available for tissue growth, production, and other metabolic functions. A major source of phosphorus utilized by the cow is in the form of phosphates that appear in saliva. Rumen fermentation generates large quantities of volatile fatty acids that require buffering in order to maintain constant and favorable pH levels within the rumen. Saliva acts as the primary means of buffering rumen fermentation and is the major source of phosphorus entering the rumen. The cycling of phosphorus through saliva can provide twice the amount of phosphorus to the small intestine than arrives in the diet. Therefore, the ability to absorb this recycled salivary phosphorus is important in minimizing phosphorus excretion. Generally, 68-81% of salivary phosphorus is absorbed in the small intestine (NRC, 2001). As dietary phosphorus increases, thereby increasing the total amount of phosphorus delivered to the small intestine, the efficiency of salivary phosphorus absorption decreases (NRC, 2001).

The efficiency with which phosphorus is absorbed in the dairy cow is affected by numerous factors, including: age (body weight), physiological status (lactating, non-lactating), dry matter intake (DMI), phosphorus intake, Ca:P ratio, dietary Al, Ca, Fe, Mg, Mn, K, and fat, intestinal pH, and source of phosphorus (forage, concentrate, inorganic mineral, saliva). For practical purposes, age, intake and metabolic requirements are the primary factors influencing dietary phosphorus requirement and the efficiency of absorption in the gut.

Feeding phosphorus at the required nutritional levels implies that we have a clear understanding of the minimum and maximum levels of phosphorus required and the potential risks of feeding phosphorus at deficient or excessive levels. The first minimal phosphorus requirement that needs to be established is that of the rumen microorganisms. In vitro studies have shown that 20-80 mg phosphorus/L of rumen fluid is required by bacteria for maximal cellulose digestion and microbial protein synthesis. At a dietary phosphorus level of 0.12% of ration DM, rumen fluid phosphorus levels reach 200 mg phosphorus/L. Clearly, at this level of dietary phosphorus, the rumen microbial requirement for phosphorus is met (Hall et al., 1961; Chicco et al., 1965).

With microbial phosphorus requirements established, defining the animal's dietary phosphorus requirements remains. The animal requirements will include maintenance, growth, pregnancy and lactation. The mathematical expression of dietary phosphorus requirements is the sum of these physiological needs divided by the animals' ability to absorb phosphorus. The denominator term is referred to as the "absorption coefficient", the efficiency rate with which the animal can absorb phosphorus in the gut from various sources. The maintenance requirement for phosphorus has been set at 1.0 g/kg DMI according to NRC 2001. The growth requirement for phosphorus is primarily determined by the deposition of hydroxyapatite in bone development, while soft tissue growth requires minimal phosphorus. The pregnancy requirement for phosphorus is minimal until the third trimester, and is only calculated for fetal growth beyond 190 days of gestation. Lastly, the milk driven requirement for phosphorus is 0.90 g/kg milk. Previous milk requirement for phosphorus, NRC 1989, included an adjustment based on milk fat percentage. Only 10% of milk phosphorus appears in the lipid fraction of milk, and subsequently, this adjustment has been dropped from the requirement calculations in NRC 2001. The phosphorus in milk appears as 20% being esterified with casein, 40% as colloidal inorganic calcium phosphate, 30% phosphate ions in solution and 10% in the milk fat (Jenness and Patton, 1959; Renner, 1983). Though, as milk protein content increases, the requirement for phosphorus also increases. For breeds that produce milk of higher protein content, this becomes a dietary concern. As milk protein percentage increases from 3.0% to 4.0%, the dietary phosphorus requirement increases by about 10% (Wu et al., 2002). For cows of colored breeds, particularly Jerseys, somewhat common in Vermont, this requires dietary consideration. Within a breed, however, increases in milk protein are minimal and difficult to attain. As such, it is milk yield that accounts for the lactation requirement for phosphorus.

Dietary phosphorus requirements of lactating dairy cows

The NRC 2001 committee conducted a review of nine studies looking at a range of phosphorus levels fed to lactating dairy cows. These studies ranged in dietary phosphorus levels, 0.24-0.65% of DM and lasted between eight weeks during early lactation up to three consecutive lactations. Conclusions were drawn that excessive phosphorus levels did not improve DMI or milk production and that milk composition was unaffected by dietary phosphorus levels. Cows fed the 0.24% phosphorus ration showed signs of deficiency with blood phosphorus levels of 3.6 mg/dl, below the normal blood phosphorus range of 4.0-6.0 mg/dl established by Goff 1998a. The NRC 2001 guidelines conclude that feeding diets of 0.32-0.42% phosphorus is sufficient for the entire lactation, and that there are no added benefits to feeding phosphorus greater than 0.42% of the ration DM.

Research conducted at the United States Dairy Forage Research Center in Wisconsin indicates that reducing ration phosphorus to less than 0.40% has no negative impact on milk production (Wu et al., 2002). In addition, a summary of 13 studies involving over 1000 cows revealed no difference in reproductive efficiency of cows fed phosphorus at or slightly below NRC recommendations than those fed in excess of recommendations (Satter and Wu, 1999).

It is important to recognize that the animal has a metabolic requirement for certain mass of nutrient rather than dietary percentage. Balancing rations based on percentages requires accurate estimates of DMI in order to calculate whether sufficient nutrient is being supplied in the diet. This becomes more important the lower the percentage phosphorus is in the diet, approaching minimum levels (0.32%). As for phosphorus deficiencies, forages from soils low in phosphorus, or very mature forages resulting in diets less than 0.25% phosphorus can result in hypophosphatemia. Typically, phosphorus deficiency can be determined when blood phosphorus levels are 2.0-3.5 mg/dl or less. Feeding free choice phosphorus to ensure adequate phosphorus intake does not show consistent success, as cows do not show pica or a specific appetite for phosphorus and did not consume mineral supplement to meet their phosphorus requirement when fed phosphorus deficient diets (Coppock, 1972; 1975). Phosphorus excess is difficult to attain given the strong homeostatic regulation of blood phosphorus levels through excretion, and recycling of salivary phosphorus. Though there are indications that feeding excess phosphorus can exacerbate possible deficiencies of calcium and magnesium. At dietary levels of 0.64% phosphorus, absorption of Ca and Mg can be inhibited, resulting in metabolic deficiencies of these minerals. The absolute maximum level of phosphorus tolerable to the animal is 1.00% of ration DM (NRC, 2001). Concerning the Ca:P ratio that has long been believed to be a nutritional requirement, evidence suggests that ratio only applies when either nutrient is fed at or near a dietary minimum (NRC, 2001).

Dietary phosphorus requirements of calves and heifers

Few nutrition studies have been conducted to determine the level of phosphorus needed in rations to optimize growth in calves and heifers. To estimate dietary phosphorus requirements of young dairy animals, the 2001 NRC committee reviewed and extrapolated numerous studies involving various feeds and mineral supplements with calves and heifers over different growth rates. The conclusion from this review is that normal blood phosphorus concentrations, maximal growth rate and greater bone strength measurements were obtained with diets of 0.30-0.34% phosphorus. This conclusion, however, is in contradiction with the phosphorus requirements listed in Tables 14-12 through 14-16 in NRC 2001. The dietary phosphorus recommendations listed in these tables for growing, bred and non-bred heifers ranges from 0.18% to 0.28%, well below the conclusion that 0.30% may be the requirement for optimal growth. It is apparent that the true dietary requirement for phosphorus of replacement animals needs further study. Given the desire to maximize growth rates, knowing the minimum requirement and optimal level of phosphorus to feed would be beneficial in efficiently managing this nutrient.

Reproduction

There has long been held the belief that feeding extra phosphorus would improve reproductive performance of heifers and cows. A few research trials indicated that feeding supplemental phosphorus with poor quality forages would improve reproductive performance. Hulett (2002) cites a 1951 English study by Hignett and Hignett that is commonly referenced in support of the notion that phosphorus is beneficial to reproductive success. The conclusions of this study have been taken out of context over time and reference is seldom made to the fact that the diets fed in that study were very deficient in phosphorus, 0.10-0.25%. The NRC 2001 guidelines note that diets with less than 0.20% phosphorus result in poor reproductive performance. However, diets deficient in phosphorus will also often be lacking adequate protein and energy. There is evidence that reproductive performance is compromised to a greater extent when both protein and phosphorus are deficient than when phosphorus alone is limiting (Palmer, 1941). There is no evidence to support claims that feeding phosphorus above requirements improves reproductive performance.

A review of seven studies with dietary phosphorus levels ranging from 0.24-0.62%, during early lactation as well as for three consecutive lactations with cows producing between 15-32 kg milk, indicates that dietary phosphorus levels of greater than 0.32% resulted in normal reproductive efficiency parameters. With higher producing cows, 30 kg milk/d, across two lactations and two levels of dietary phosphorus (0.35 vs. 0.45%), days to 1st breeding, days open and services per conception were not affected by phosphorus (Wu and Satter, 2000).

Phosphorus absorption coefficients

The efficiency with which the dairy animal can absorb phosphorus in the lower gut is highly dependent on the feed in which it originates, the animal and numerous dietary factors. The milk fed calf can absorb the phosphorus in milk with 90% efficiency. Thus, the absorption coefficient for phosphorus in milk fed to a suckling calf is 0.90. For various forages and concentrate feeds this value varies. Elaborate feeding trials involving tracer techniques with radioactive phosphorus (P^{32}) are required to determine absorption coefficients, and this has not been done for many feeds (NRC, 2001).

The NRC 2001 committee conducted regression analysis of 20 phosphorus balance trials and found that as the dietary phosphorus level increases from a low of 0.22% to a high of 0.49% dietary phosphorus, the absorption coefficient drops from 1.00 to 0.64. As dietary phosphorus levels increase above requirements, efficiency of absorption decreases. Therefore, a minimum absorption coefficient of 0.64 has been determined. This value is greater than the 0.50 coefficient established by NRC 1989. As this is the most critical factor involved in calculating the dietary requirement for phosphorus, the NRC 1989 value greatly underestimates the ability of the animal to absorb dietary phosphorus and results in overestimation of the dietary feeding requirement. For each gram of absorbable phosphorus required, using the NRC 1989 absorption coefficient of 0.50 results in a dietary recommendation of 2.0 g phosphorus. With the NRC 2001 coefficient of 0.64, the same calculation results in a dietary recommendation of 1.56 g phosphorus. The difference of 0.44 g phosphorus equates to a 28% excess of dietary phosphorus recommended for each gram of phosphorus required by the animal.

The NRC 2001 committee established phosphorus absorption coefficients for forages to be 0.64, and 0.70 for concentrates and grains. Presented in Table 1 are some common mineral supplements with values for nutrient content and absorption coefficient. To note is the varying contribution of absorbable nutrient that each mineral provides. This table serves as a reference to the feed industry to note mineral composition and absorption coefficients that should be used when calculating dietary requirements in order to meet metabolic requirements. It should be noted that each mineral element (Ca, P, K, Mg, etc.) has its own absorption coefficient that will vary between different sources. The phosphorus absorption coefficient for any given mineral source is only relevant for phosphorus, and not any other mineral that may be complexed with phosphorus.

Aguerre et al., 2002, examined phosphorus bioavailability of various concentrates with mid-lactation cows. A base diet of 0.17-0.19% phosphorus was fed for three weeks, then the test diet. The test diet was comprised of the base diet plus the test feedstuff, balanced to a level of 0.30% phosphorus and fed for two weeks. Fecal samples were analyzed to calculate a mass balance of phosphorus absorption. The resulting absorption coefficients for the various feeds were: soy, 0.74; cottonseed, 0.81; corn gluten feed, 0.73; corn distillers grains, 0.83; porcine meat and bone meal, 0.64; and dicalcium phosphate, 0.85. The NRC value of 0.70 underestimates the true biological values obtained in this trial for concentrate feeds, but clearly provides a margin of safety to avoid potentially underfeeding phosphorus. Compared to the NRC 1989 value of 0.50, 0.70 more closely estimates the true absorption coefficient and greatly reduces the potential for overfeeding dietary phosphorus.

Table 1. Calcium and phosphorus content and absorption coefficients for common mineral supplements (NRC, 2001).

Mineral Source	%Ca	Ca Abs Coeff	%P	P Abs Coeff
Ammonium phosphate, dibasic	0.0	0.00	20.6	0.80
Ammonium phosphate, monobasic	0.0	0.00	24.7	0.80
Bone Meal, steamed	30.7	0.95	12.9	0.80
Calcium carbonate	39.4	0.75	0.0	0.00
Calcium chloride	36.1	0.95	0.0	0.00
Calcium phosphate	16.4	0.95	21.6	0.80
Defluorinated phosphate	32.0	0.70	18.0	0.65
Dicalcium phosphate	22.0	0.94	19.3	0.75
Limestone, ground	34.0	0.70	0.0	0.00
Rock phosphate, low flourine	36.0	0.30	14.0	0.30
Sodium phosphate, monobasic	0.0	0.00	22.5	0.90
Sodium tripolyphosphate	0.0	0.00	25.0	0.75
Soft rock phosphate	17.0	0.30	9.0	0.30
Forages		0.30		0.64
Concentrates		0.60		0.70

Dairy manure: Phosphorus output per cow

The dairy cow is a relatively inefficient converter of nutrients into milk and meat. Approximately 62% of the dry matter a cow ingests is digested (Van Horn et al., 1991). However, nutrient utilization is considerably lower; only about 32% of the nitrogen, 35% of the phosphorus, and 24% of the potassium ingested by a dairy cow is accounted for by milk production, fetal development and increased bodyweight (Klausner, 1993, Coelho, 1994). Phosphorous utilization efficiencies are even lower at the whole farm level. Beede and Davidson (1999) estimate that only 20-30% of feed phosphorus is exported off of the farm as animal products, meat and milk, which is similar to other estimates of 20-31% phosphorus efficiency on dairy farms (Morse et al., 1992). Much of the dietary phosphorus ends up in manure.

There is wide variation in the amount of manure produced by a dairy animal, depending upon the age, size, production level, and the relative digestibility of the ration. Older references report manure production in tons per cow, typical for manure from dry handling systems. More recently, with the prevalence of liquid manure systems, units of manure volume commonly reported are gallons or liters per cow. On the average, a 1400-lb Holstein dairy cow produces nearly 14 tons of fecal material per year or nearly 40 tons of manure, combined feces and urine, per year (Van Horn et al., 1994). With the minimum amount of water necessary for handling manure as slurry, annual manure production is 5500 gallons per cow.

The phosphorus content of dairy manure varies even more than the amount of manure produced. Most of what the dairy cow eats is returned to the farm nutrient cycle as feces and urine. The level of phosphorus in manure depends on the ration consumed, the amount and type of bedding in the manure, to what extent urine is retained by the manure handling system, and how much water is added to the system. Solid manure with bedding is about 21% dry matter (Vitosh et al., 1988), and contains approximately 2.4 pounds of phosphorus per ton. Total solid manure nutrient production, therefore, is 43 pounds of phosphorus per cow per year. While the oxide forms of phosphorus (P_2O_5) are used by the fertilizer industry, only the elemental forms of this nutrient are used in this report. The conversions from elemental to oxide forms are: P x 2.3 = P_2O_5. Liquid dairy manure contains 0.008 pounds phosphorus per gallon. Based on this analysis, total liquid manure production is 42.1 pounds phosphorus per cow per year (Klausner and Bouldin, 1983). Figure 1 illustrates the yearly output of phosphorus in manure for an average dairy cow. Efficiency of utilization varies somewhat according to production level and other factors. The situation in countries other than the U.S. is not appreciably better and in some cases considerably worse. For instance, in Holland the efficiency of phosphorus utilization by dairy cows is only 25% (Tamminga, 1992).

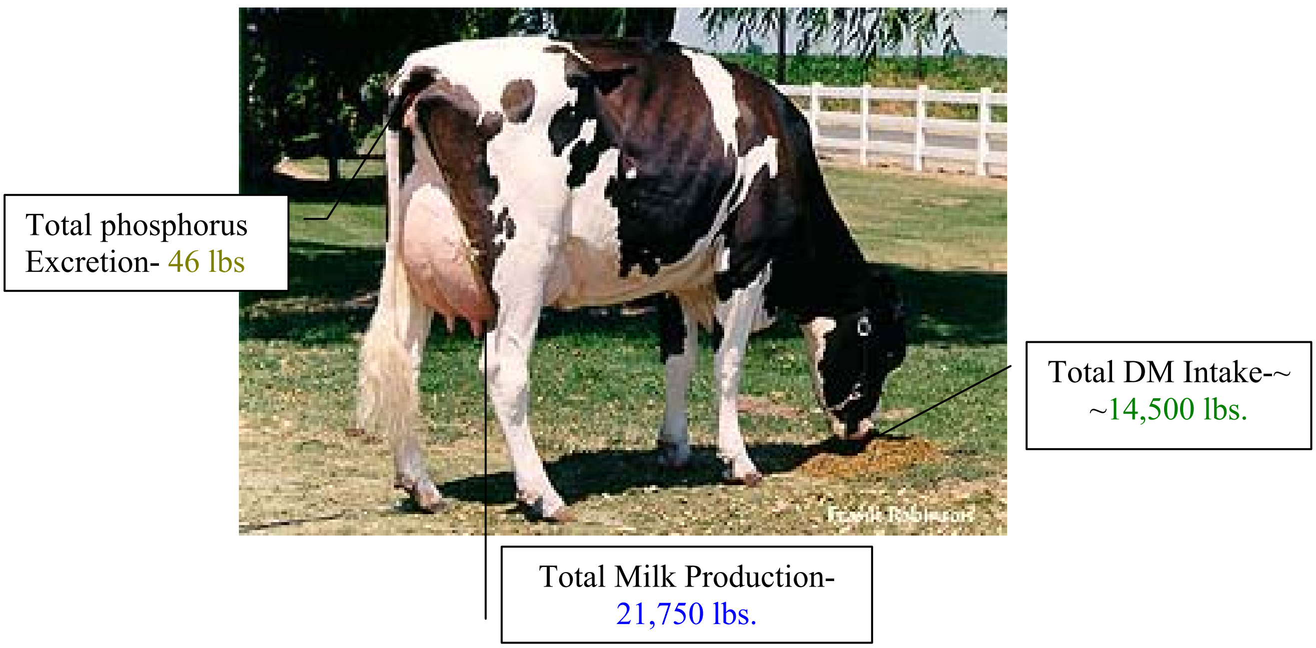


Figure 2. Yearly excretion of phosphorus by 1400 lb Holstein dairy cow fed 0.45% phosphorus diet (Grant, NebGuide).

Nutrient management plans have targeted manure phosphorus as the primary factor in the protection of water quality. The amount of manure spread on cropland and the capacity of soils to recycle phosphorus is under increasing scrutiny. As feed and fertilizer imports on the farm continue, excess phosphorus is building up in the soils of the farm ecosystem, resulting in the increase of phosphorus loss to the local watersheds. Regulations are being adopted that limit the amount of manure that can be spread on soils to the extent that phosphorus is removed in the form of crops. This is an attempt to limit the further buildup of soil phosphorus levels. The allowable rate of manure application to cropland will be determined by the amount of phosphorus being applied. Manure high in phosphorus will need to be spread at a lesser rate than manure lower in phosphorus. Considerations for the field topography, slope, proximity to water and current phosphorus load will be included when calculating the allowable amount of manure that fields may receive. These restrictions will severely limit the ability of a dairy producer to spread all of the manure produced, on that farm. Other outlets off of the farm for manure disposal will be required.

Effects of phosphorus reduction on manure nutrient concentration

The effects of reducing ration phosphorus concentration are well documented. Phosphorus excretion in manure depends largely on the level of phosphorus intake (Ternouth, 1989; Morse et al., 1992; Metcalf et al., 1996; Khorasani et al., 1997). One study has shown that a 40% decrease in dietary phosphorus lowered excreted phosphorus by 23% (Morse et al., 1992), and another study reported that reduced dietary phosphorus levels lowered phosphorus excretion by 30% (Metcalf et al., 1996).

If phosphorus supplementation could be reduced to the minimum concentration needed for optimum production, the amount of phosphorus in manure and in applications to farmland would also decrease. As manure phosphorus levels are reduced, it is desirable to show a subsequent reduction in the amount of phosphorus in runoff from land-applied manure. Research in Florida, showed that reducing ration phosphorus from 0.45% to 0.40% resulted in a decrease in annual phosphorus excretion from 21 to 18 kg/cow (Van Horn, 1990). However, a ration phosphorus of 0.40% is more than is necessary for most lactating dairy cows. Further reductions to 0.35% and, for low-producing/late lactation cows, 0.30%, results in even more significant phosphorus excretion reductions. Grouping cows by production level, and then feeding to the specific phosphorus needs of each group, will achieve the maximum effect on limiting phosphorus excretion. However, there are limits to the amount of phosphorus reduction that can be accomplished by reducing ration phosphorus. Research suggests that the inevitable losses of fecal phosphorus in lactating dairy cows averaged 1.2 g/kg of dry matter. For a high-production dairy cow consuming on average, 20 kg of dry matter per day over 365 days, this represents a fecal phosphorus output of nearly 9 kg per year.

Reducing ration phosphorus concentration will reduce fecal phosphorus output, which has a direct effect on the acres of cropland needed for environmentally acceptable application of this manure. Reducing dietary phosphorus by 0.04% results in approximately 9.1 fewer grams of phosphorus consumed by a dairy cow. If the manure resulting from this reduced-phosphorus ration is applied to land planted to corn that is harvested as silage, for each 100 cows 6.2 fewer hectares will be required for manure disposal (Meyer, 2000).

Powell et al., 2002a, in a survey of 98 Wisconsin dairy farms found that, 32% of the farms had positive field phosphorus balances and that these farms had an average dietary phosphorus level of 0.45%. It is estimated that the adoption of the NRC 2001 dietary phosphorus recommendations would result in a 67% reduction in the number of farms having a positive phosphorus balance and 60% reduction in the amount of land in positive phosphorus balance. If a reduction in manure phosphorus levels is not achieved, farms will require a larger land base for the dispersal of manure.

An added benefit to reducing manure phosphorus levels is that the N:P ratio increases, this will allow more manure to be applied to cropland, allowing more nitrogen to be recycled to the soils and crops. By reducing manure phosphorus content, the resultant increase of the N:P ratio more closely matches the N:P nutrient requirements of the crops (Powell et al., 2002b). This will also relieve some of the expenses for purchased nitrogen fertilizer. By reducing dietary phosphorus levels to 0.32-0.38, marked decreases in manure phosphorus can be realized. Reducing dietary phosphorus from 0.48% to 0.38% resulted in a 25% reduction in manure phosphorus. Reducing the amount of phosphorus in the diet also reduces the amount of phosphorus susceptible to runoff. When manure from cows fed a high phosphorus or low phosphorus diet was applied to soil at an equivalent amount of manure, there was 8-10 times the amount of phosphorus runoff from the high phosphorus diet manure. When those same manures were applied at equivalent amounts of phosphorus per hectare, the high diet manure still had rates of phosphorus runoff 4-5 times greater than the low phosphorus diet (Ebeling et al., 2002; Powell et al., 2002b). Phosphorus fed in amounts greater than 0.38% of ration DM result in not only greater total phosphorus in manure, but also a shift to an increased proportion of water soluble phosphorus in manure. A significant factor in reducing phosphorus runoff is minimizing the water soluble fraction of phosphorus in manure by ensuring that phosphorus is not fed in excess of nutritional requirement.

Noting that the bioavailability of phosphorus sources varies considerably; water-soluble phosphates being highly available (70%), while calcium phosphates have low availability (<40%) (Gueguen, 1977), feeding less of more absorbable forms of phosphorus could reduce manure phosphorus output. Research using highly bioavailable sources of phosphorus minerals found that they resulted in up to one-third less phosphorus in manure. Unfortunately, the feed industry in the U.S. has generally not changed to these higher-priced supplements, and probably will not do so unless requested to do so by farmers.

Dietary phosphorus management: Strategies and responsibilities

Accurate analyses of the feeds and forages fed to dairy animals is paramount in determining whether nutrients supplied in the diet will meet the animals' requirements. The philosophy of "supplementing to requirement," to ensure adequate dietary supply, has resulted in the acceptance of overfeeding nutrients on a regular basis. Accounting for the contribution of nutrients from the various feeds fed in a ration requires sample analyses. The frequency and type of analysis of forages will vary between farms, nutritionists and feed suppliers. Variation in forage quality and composition on a farm warrants the need for fast and frequent analysis. The lag time between forage sampling and return of analyses can be a significant factor in animal production. With the need for fast analyses, near-infrared spectroscopy (NIRS) is the analysis of choice. NIR analysis is very accurate for the basic feed components of DM, protein, ADF, NDF and various protein fractions. Mineral analysis via NIR, however, is very inaccurate. The chemical nature of minerals within the forage material does not allow for accurate calibration of NIRS to mineral composition. Wet chemistry analysis using Atomic Absorptions spectrophotometers (AA) or Inductively Coupled Plasma spectrophotometers (ICP) is required for accurate mineral analyses. These procedures are time consuming and relatively expensive compared to NIR analysis.

In conjunction with the type of analysis, the frequency of forage analysis is important in determining changes in nutrient composition. Whether samples are analyzed weekly, monthly or less often will greatly affect the precision with which all nutrients, not only phosphorus, can be fed on the farm. Assuming a gross error of 0.05 percentage units for phosphorus (0.25 vs. 0.30% phosphorus) of the forage portion of a lactating cow ration, for a cow consuming 25 lbs of forage DM (12 kg), this inaccuracy amounts to 5-6 g of phosphorus. This may be 5-6 g of phosphorus in excess or deficiency based solely on the forage contribution to the diet. The contribution of phosphorus from concentrate sources is much more complex and variable as seen in Table 2.

Farmers do not routinely analyze concentrate feeds unless they are buying them independently as commodities to be fed as an individual ingredient. Even then, the analysis will likely be for DM, protein and fiber levels, not minerals. Feed companies are responsible for providing the nutrient composition of the grains and concentrates that they supply to the farms. Feed dealers routinely analyze grains for DM, CP and fiber levels to feed guaranteed nutrient levels. Mineral composition is unfortunately less often analyzed. For many feed ingredients, a book value of mineral composition is used to estimate the mineral composition of the finished grain mix. However, the mineral composition of grains is extremely variable and can result in great excesses or deficiencies when fed on the farm. An error of +/- 0.10 percentage units phosphorus of a complete grain mix, when fed at 20 lbs/cow can equate to +/- 9.0 g dietary phosphorus. Given the possible cumulative effects of erroneous phosphorus values for forage and grain, (6g + 9g), an excess/deficiency of 15 g phosphorus is possible. With a requirement of 90 g of dietary phosphorus, this equates to a possible 17% over/underfeeding of phosphorus.

Table 2. NRC 2001 feed ingredient phosphorus values.

NRC 2001	samples n	Avg %P	Std Dev	Normal Range Avg +/- Std Dev
Canola Meal	79	1.10	0.20	0.90 - 1.30
Soy 48 solv	256	0.70	0.08	0.62 – 0.78
Wheat Midds	196	1.02	0.20	0.82 – 1.22
Wheat Bran	43	1.18	0.23	0.95 – 1.41
Corn Distillers	649	0.83	0.14	0.69 – 0.97
Dry Brewers	344	0.67	0.06	0.61 – 0.73
Corn grain	1185	0.30	0.05	0.25 – 0.35
Corn silage	1033	0.26	0.04	0.22 – 0.30
Grass silage	4365	0.29	0.08	0.21 – 0.37
Legume silage	8479	0.32	0.06	0.26 – 0.38

Compounding errors resulting from the variation in phosphorus values of various feedstuffs is the phosphorus absorption coefficient used in ration balancing programs and feed mill computer systems. The NRC 2001 change from 0.50 to 0.64 and greater for individual feeds has the greatest effect on decreasing the requirement for dietary phosphorus meeting metabolic requirements of the animal. A metabolic requirement of 60 g of absorbed phosphorus requires 120 g of dietary phosphorus with the NRC 1989 absorption coefficient of 0.50, but only 86 g of dietary phosphorus using the NRC 2001 value of 0.70 for a total ration. This is a difference of 34 g of dietary phosphorus per cow per day. As noted previously, the propensity of phosphorus to runoff and contaminate water systems greatly increases as phosphorus is fed in excess of nutrient requirements.

The importance of proper phosphorus analyses of all feedstuffs, both forages grown on the farm and purchased concentrate feeds cannot be overemphasized. Implementation of the NRC 2001 phosphorus absorption coefficients for all feeds is also a critical step in maximizing the precision with which phosphorus is fed on the farm to meet nutrient requirements.

Fox et al., 2002, present a comprehensive outline of nutrient management concerns and possible future regulations including nitrogen losses through volatilization and total maximum daily loads (TMDL) of phosphorus to impaired water bodies. Overall goals of improving feed management are just part of the larger scheme of whole farm nutrient management, involving the reduction of nutrients brought on to the farm and improving the efficiency of nutrient utilization on the farm. The following is a summarization of just a few of the strategies listed by Fox et al., 2002.

1. Grouping animals according to nutrient demands: heifers, cows by production, one group TMR versus multiple group TMRs. Grouping strategies will allow for greater precision in matching nutrients supplied by the ration with nutrient requirements of the animal.
2. Appropriate feed analysis, frequency, and protocols to improve ration formulation to meet all nutrient demands, not just phosphorus. This may involve increasing the frequency with which feeds are analyzed and require more costly analyses for minerals.
3. Improving feeding accuracy of the formulated ration and the actual ration fed and the ration that is actually consumed by the animals. Mixing errors, changes in DM content, cow sorting of the TMR, can all affect what the animals actually consume.
4. Accurate DMI calculations to ensure grams of nutrients are being consumed to meet nutrient requirements rather than simply supplying ration percentages, (g of phosphorus vs. %P).
5. Timely ration changes. Keeping rations balanced with the changes in forage and feed analyses. This is often difficult given a supply of mineral and grain on hand that may not match accurately with forage nutrient analyses.
6. Maximizing DMI to effectively ensure that nutrients are consumed by the animals, through feed bunk management and feeding frequency.

7. By minimizing milking cow refusals, wasted feed will be minimized and less high phosphorus feed refusals will need to be cycled through heifers that require less phosphorus.
8. Track indicators of proper ration formulation and feed management. Milk production, milk composition and MUN are good short-term indicators of proper nutrition. Body condition scores, heifer growth, lactation persistency and reproductive efficiency are long-term indicators.
9. Manure evaluation can point out rumen health and nutritional imbalances through consistency, particle length, and passage of specific feed particles including fiber and concentrates.

Summary

Reducing the amount of phosphorus entering the farm system through feed ingredients is a very attainable goal. With clearly defined nutritional requirements and improved understanding of the highly variable levels and bioavailabilities of phosphorus in feeds, feeding excessive levels of phosphorus can be minimized. By matching the amount of phosphorus supplied in the diet to the dietary phosphorus requirements of all dairy animals, manure phosphorus levels can be reduced. Subsequently, the amount of phosphorus being applied to cropland will be reduced. This reduction of manure phosphorus will not only reduce the phosphorus load on soils but also reduce the amount of phosphorus susceptible to runoff into water systems. Regulation of phosphorus is mandating that farmers and feed industry personnel take action to reduce the amount of phosphorus entering farm systems. Following NRC 2001 guidelines for phosphorus feeding is both a nutritionally and economically advisable way to begin more strict management of nutrients at the farm level. There is no evidence of reproductive or production losses when animals have been fed according to the current NRC 2001 dietary phosphorus guidelines. The feed industry is the critical point of contact to ensure that accurate mineral content of the feeds they supply to farmers is appropriate for the nutritional needs on the farm.

3. MINER INSTITUTE HERD PRODUCTION RESPONSE TO REDUCED DIETARY PHOSPHORUS LEVELS: A REVIEW OF HERD RECORDS FOR THE YEARS 1997-2000

The over-supplementation of dairy cattle diets with phosphorus is costing the U.S. dairy industry an unnecessary $100 million a year, as well as increasing the risk of environmental damage through eutrophication of lakes and streams (Satter et al., 1999). The reduction of phosphorus in dairy diets is an attainable goal, and would result in a much lower content of phosphorus in manure that must be disposed of by the producer. This reduction will remove some of the pressure from producers to find places to dispose of the excess nutrients. The reduction of dietary phosphorus will not be detrimental to the animals because the current levels of supplementation are higher than recommended and the excess has not been shown to be beneficial to cow health and performance (NRC, 1989; NRC, 2001).

In the U.S., producers are currently feeding an average of 0.48% phosphorus in dairy rations (Satter et al., 1999). The 2001 NRC recommendations for lactating cows range only from 0.32% - 0.38%. Producers, nutritionists, veterinarians, and extension personnel have recommended excessive levels of phosphorus in diets over the years because of a belief that phosphorus had a positive effect on reproductive performance and milk production. Doubts concerning phosphorus requirements and the efficiency of phosphorus absorption in dairy cows have resulted in a philosophy of supplementation in order to avoid deficiencies. It is becoming clear, however, that the relationship between phosphorus and reduced reproductive performance only occurs when phosphorus is at an extreme deficiency level and in conjunction with protein and energy deficiencies (NRC, 2001). In a two-year study at the U.S. Dairy Forage Research Center in Madison, Wisconsin, it was found that dairy animals fed low phosphorus levels (0.38%) and animals fed high phosphorus levels (0.48%) had equal reproductive efficiency over the two years (Wu et al., 2000). This same study also found no difference in lactation performance between the two groups.

Difficulties arise in formulating low phosphorus rations for high producing cows. Diets formulated for high milk production require high levels of energy and protein. Typically, protein supplements and many energy supplements have high concentrations of phosphorus, and when included in the ration can result in exceeding the animal's phosphorus requirement before meeting energy and protein needs. Numerous factors, including dry matter intake and type of feed, can affect the efficiency of phosphorus utilization in dairy cows and subsequently how much passes through in the manure (Morse et al., 1992; Aguerre et al*.,* 2002). Compounding the fact that many protein and energy feeds have high levels of phosphorus is the variability of phosphorus levels within a given feed. The NRC 2001 feed tables clearly show the variability in phosphorus levels of many feed ingredients. This variability leads to a problem with having accurate phosphorus values for ingredients when formulating rations on the farm (Cotanch et al., 2002). When cattle are fed diets with excess phosphorus, there is a decreased efficiency of utilization and an increase in manure phosphorus excretion. With diets that are adequate or low in phosphorus, there is an increased efficiency of utilization and decreased manure phosphorus levels (NRC, 2001). "Cows fed phosphorus at or near the requirement during lactation excrete a large amount of daily intake of phosphorus in their feces, but the amount is less than when excess phosphorus is fed" (Morse et al., 1992). When diet phosphorus concentrations are decreased from 0.48% to 0.38% of ration DM, manure excretion is reduced by 25-30%, which equates to 25-30% less land required for manure disposal in a phosphorus based management system (Satter et al., 1999). It was also found that rations formulated for high milk-yielding cows (25 kg/day or more) result in the most efficient utilization of phosphorus and no excess manure phosphorus (Alocilja, 1998).

Reducing dietary phosphorus levels in lactating dairy cattle rations can reduce the amount of phosphorus appearing in manure and thereby reduce the phosphorus loading of soils receiving manure. The Miner Institute dairy farm undertook reductions in phosphorus inputs on the farm as part of a nutrient management plan and also to serve as a demonstration farm to provide production and reproduction data concerning the effects of reducing dietary phosphorus imports.

Objectives

A review of the Miner Institute farm records for the years 1997-2000 was conducted as a demonstration of herd effects under reduced dietary phosphorus inputs. During this time, dietary phosphorus was reduced from 0.48% to 0.40%. Fertilizer purchases were also reduced, resulting in a net decrease in phosphorus inputs on the farm. Milk production and reproduction parameters were reviewed to determine any detrimental effects of reducing dietary phosphorus and to track reductions in manure phosphorus content. As this paper is a review of historical data, and not a controlled research trial, statistical comparisons between the periods of high and reduced dietary phosphorus levels were not conducted—especially since the time scales for the different data sets are not synchronized as described below. Comparisons in this herd review will be compared to those of published research.

Materials and Methods

The Miner Institute farm records from 1997-2000 were reviewed for diet formulation, feed dry matters, and feeding records. This information was coupled with DHIA records over the same four years. Milk yield and reproductive performance for the herd was compared to phosphorus balance of rations over the four-year period. Monthly milk production and reproductive data were summarized as rolling herd averages. A rolling herd average indicates the average milk and reproductive performance for the last 365 days, with the yearly period ending on the month evaluated. Performance from the month evaluated replaces performance data from a year ago in the calculation. As such these data do not allow for statistical comparisons to be made for the periods of high and reduced dietary phosphorus feeding, because the monthly performance records are not independent of each other. Secondly, since the data review covered four years, the animals involved in producing the data sets were not necessarily the same animals all four years during the high and reduced phosphorus periods. These results were used to characterize the performance of the Miner Institute dairy herd as the dietary phosphorus levels were reduced. This information was used to develop producer and consultant educational materials about phosphorus levels in diets.

Results and Discussion

The Miner Institute lactating dairy herd size on 1/11/97 was 92 milking cows, and on 12/18/00, 160 milking cows. The average number of milking cows on DHIA test 1/11/97-12/18/00 was 127. Milk production for the herd on the 1/11/97 test date was 22,189 lbs rolling herd average (RHA), 816 lbs fat, 728 lbs protein and on 12/18/00 test date was 28,933 lbs RHA, 1089 lbs fat, 887 lbs protein. The average RHA from 1997 to 2000 was 25,461 lbs, 932 lbs fat, 815 lbs protein. Average daily milk production and percent phosphorus in the diet for the entire time period is charted in Figure 3. The reduced phosphorus diet was initiated in December 1998. Milk composition data for percent butterfat and milk protein is displayed in Figure 4.

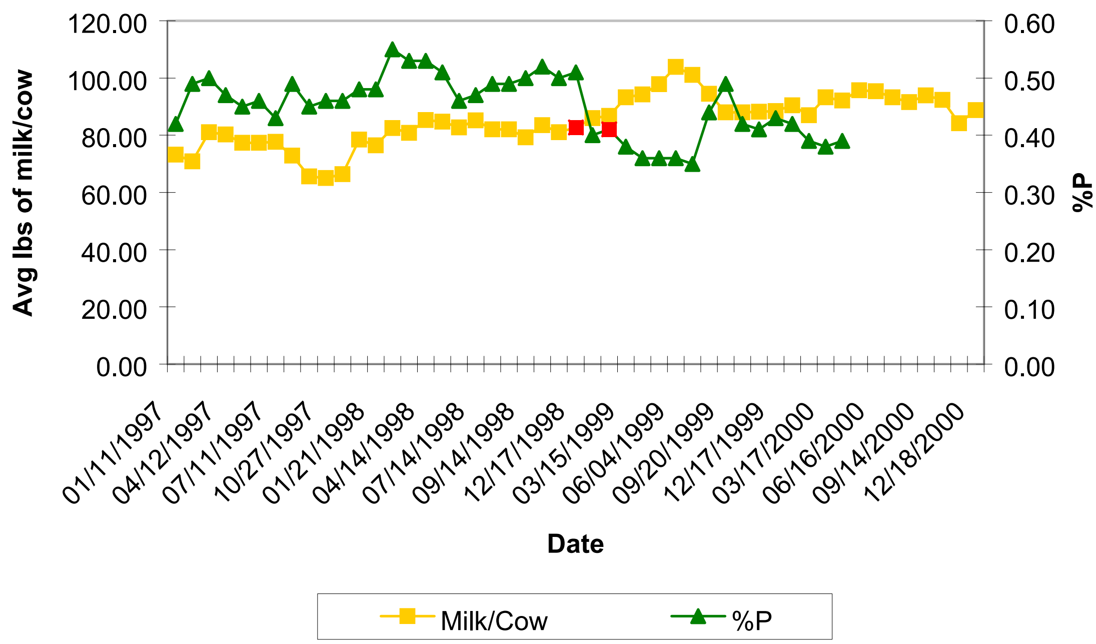


Figure 3. Relationship of %P in rations to milk production per cow 1997-2000.

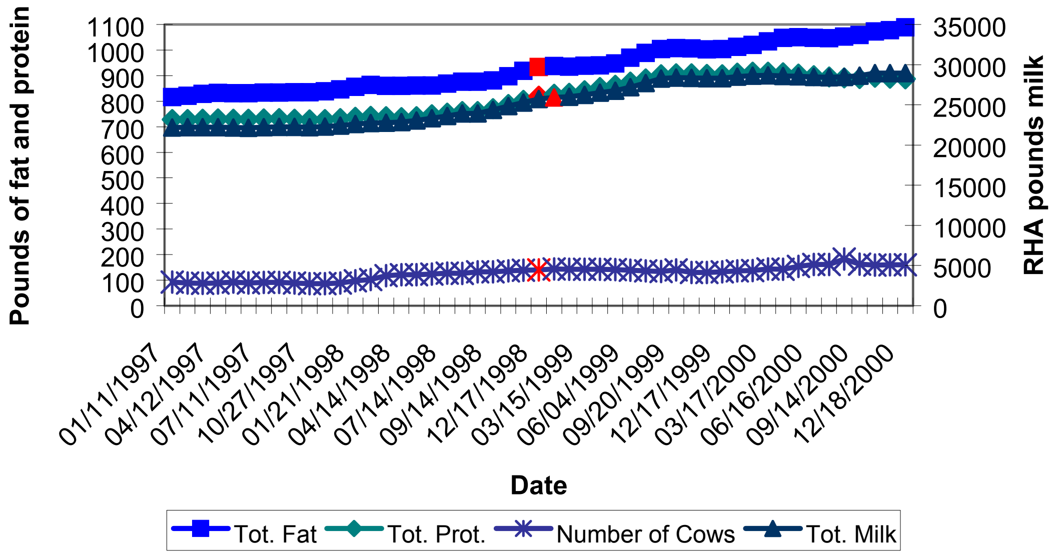


Figure 4. Herd trends for milk, fat, protein production, and number of cows.

The lactating herd at Miner Institute consisted of five groups. This study focused on the rations fed to the high milk production group from 1997-2000. The high group ration averaged 18.3% protein (CP) and 31.2% neutral detergent fiber (NDF), with an average dry matter intake (DMI) per cow of 53.6 lbs (see Table 3). The rather wide range of DMI, %CP and %P resulted from numerous ration formulations due to various research projects during the four years. Some of the nutrition studies conducted in the herd during this time period affected diet formulation resulting in varied dietary phosphorus levels.

Table 3. Average value and range of rations fed to the Miner Institute High Group 1997 – 2000.

	Average	Range
Pounds DM	53.6	51.1 – 59.5
% CP	18.3	16.8 – 18.9
% NDF	31.2	29.5 – 33.6
Pounds P	0.24	0.19 – 0.29
% P	0.45	0.35 – 0.55
Pounds of Milk	91.1	90 – 110

In December of 1998, the lactating cow rations were examined and reformulated to lower dietary phosphorus intake. From November of 1996 to August of 1998 the phosphorus levels in the high group ration averaged 0.48% phosphorus and ranged from 0.42% phosphorus to 0.55% phosphorus. From December of 1998 to August of 2000 the phosphorus levels averaged 0.40% phosphorus and ranged from 0.35% phosphorus to 0.49% phosphorus (Figure 3). No negative effect on milk production was seen in the herd after the changes were made; both RHA and daily milk production per cow had risen even with the reduced phosphorus levels being fed. Interestingly, as herd milk production rose in the later years of the study, so did DMI and the total consumption of phosphorus. Actual intake of phosphorus after reduction of the dietary %P was nearly equal to consumption of the high %P diets, about 0.25 lb/cow/d due to increased total DMI (Figure 5). In conjunction with reduced manure concentrations of phosphorus, these data indicate an improved utilization of phosphorus.

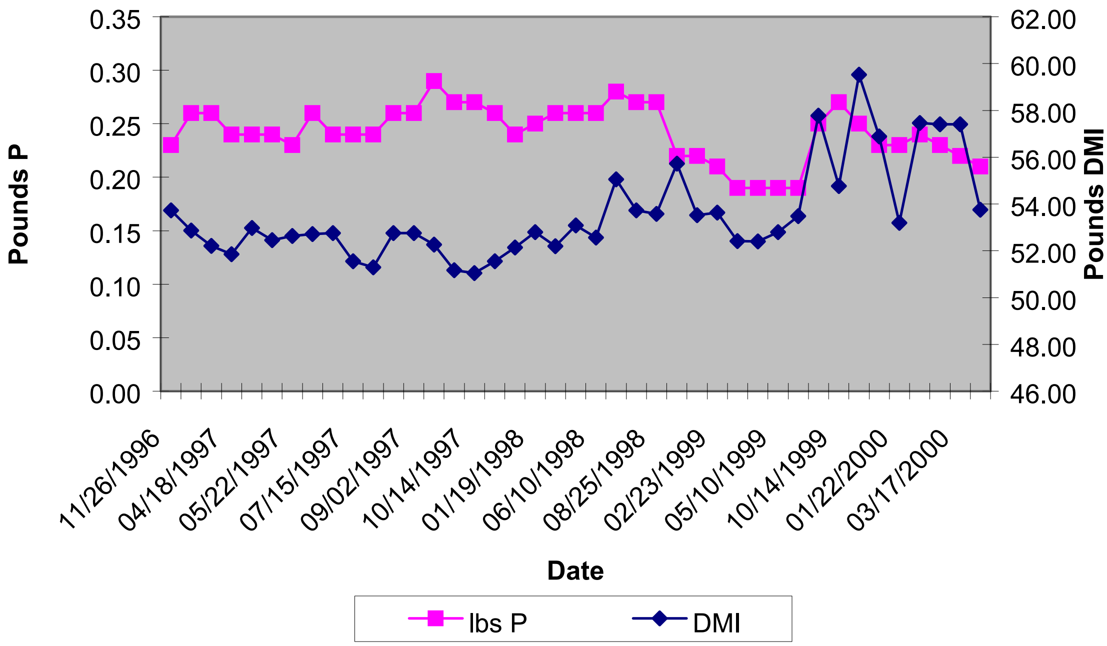


Figure 5. Pounds of phosphorus compared to pounds of DMI 1997-2000.

As previously discussed, a major concern with the reduction of dietary phosphorus levels is the effect, if any, on reproductive performance. In the Miner Institute herd there was a slight trend noticed concerning reproductive performance. The average days to first service from January 1997 to November 1998 was 81 days, while from December of 1998 to December of 2000 the average was 68 days (Figure 6). Though days to first service were reduced during the period of lower dietary phosphorus feeding, this result is likely due to improved reproductive management and elimination of a voluntary wait period for first breeding in the herd. Fears of reduced dietary phosphorus levels resulting in diminished estrous behavior were not realized in this herd. Cows showed signs of heat and were being bred closer to the industry standard goal of 60 days after calving.

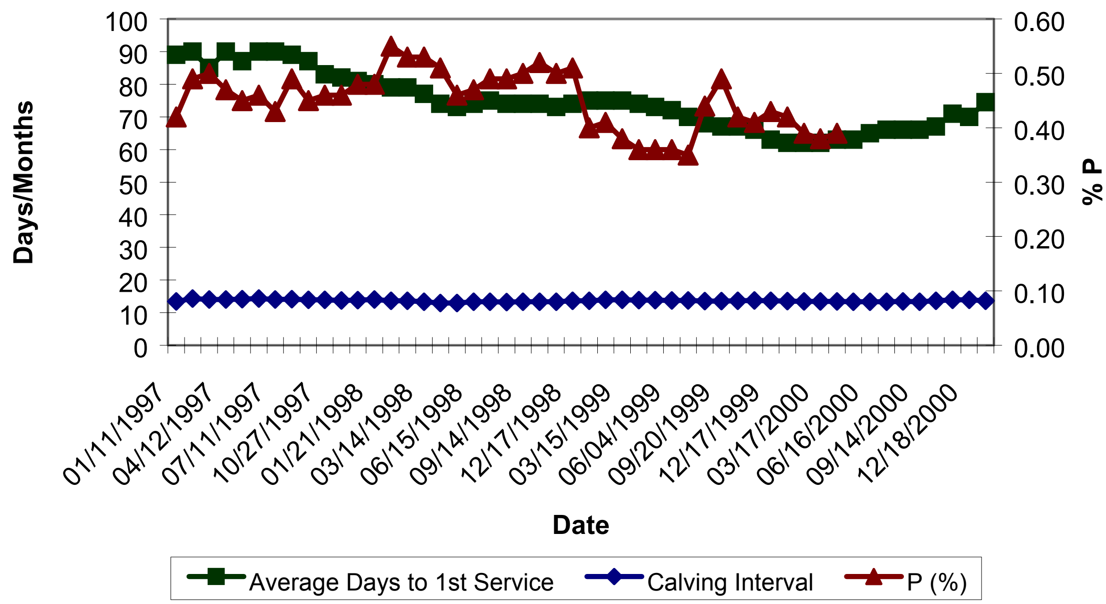


Figure 6. Calving interval and days to 1st service across period of high and low dietary phosphorus.

Manure phosphorus levels were reduced by the reduction in dietary phosphorus. Average manure phosphorus prior to the dietary phosphorus reduction in December 1998 was 1.72% (P_2O_5 basis); following the reduction, manure phosphorus averaged 1.19% P_2O_5. Over the last eight years, the level of phosphorus in manure for the lactating herd has decreased. Table 4 lists the manure analyses for nitrogen, phosphorus, and potassium for the years 1992-2000. Of note is the 27% reduction in manure phosphorus levels subsequent to the dietary phosphorus reduction of December 1998. This immediate reduction of manure phosphorus levels directly corresponds to the reduction in dietary phosphorus levels seen in Figure 3. While there has been a decrease in the total amount of phosphorus applied to the fields at Miner Institute, there was no noticeable change in forage quality over the four crop years. Forage quality parameters of CP, ADF, and NDF were similar between years for the various crop species, legume silage, grass silage, and corn silage (Table 5).

Table 4. Manure analysis at Miner Institute 1992-2000 (dry matter basis).

Date	%DM	%N	lbs P_2O_5/1000gal	$\%P_2O_5$	$\%K_2O$
07/02/1992	9.40	3.60	14.20	1.80	3.70
08/02/1993	8.50	4.30	15.50	2.00	3.70
06/23/1994	6.70	4.50	9.50	1.70	3.40
08/17/1994	7.80	4.30	10.20	1.60	3.00
07/13/1995	10.70	4.00	14.40	1.60	2.90
10/04/1995	7.70	4.40	11.40	1.80	3.30
07/19/1996	5.70	3.80	8.30	1.70	3.60
07/22/1996	5.30	5.00	8.40	1.90	3.60
08/01/1996	6.20	4.10	8.00	1.50	3.00
07/10/1997	7.30	4.56	7.30	1.56	3.25
07/02/1999	9.30	3.78	9.10	1.14	2.27
04/19/2000	7.30	3.52	8.00	1.30	3.00
09/11/2000	9.20	3.68	9.00	1.14	2.77

Table 5. Forage analysis by season and crop 1996-1999.

Season	Forage	Samples (n)	%DM	CP (%DM)	ADF (%DM)	NDF (%DM)	Ca (%DM)	P (%DM)	K (%DM)
1996	Legume	11	32.3	20.1	36.1	48.6	1.24	0.35	2.77
1997	Legume	15	31.1	17.7	36.5	50.0	1.20	0.29	2.65
1998	Legume	18	35.2	19.7	36.5	48.6	1.26	0.33	2.89
1999	Legume	21	35.6	19.6	33.4	45.5	1.30	0.30	2.60
1996	Grass	9	33.9	12.4	38.5	64.2	0.47	0.25	2.33
1997	Grass	9	34.6	14.4	36.4	59.8	0.62	0.26	2.60
1998	Grass	6	42.7	16.5	35.6	57.2	0.54	0.30	2.99
1999	Grass	9	31.9	16.6	32.7	53.6	0.79	0.27	2.25
1996	Corn	11	29.0	8.0	26.6	45.6	0.23	0.25	1.10
1997	Corn	11	32.1	7.9	25.4	44.1	0.26	0.23	1.00
1998	Corn	11	34.6	7.8	25.7	43.7	0.25	0.23	1.07
1999	Corn	32	36.9	8.6	24.4	41.2	0.29	0.21	1.13

A review of the breeding age heifer ration data for the period of March 1996-August 2000 was undertaken to establish a baseline of phosphorus feeding data for these growing animals. The diets had not been modified for reduced phosphorus. The data indicated that phosphorus levels in the rations fed to heifers weighing 649-700 lbs averaged 0.53%. This level of phosphorus is more than twice what is recommended for heifers of this age and size (Table 6). At that rate of excess phosphorus feeding, compared to the NRC 2001 recommendation of 0.23% dietary phosphorus, nearly 20 lbs of excess phosphorus was fed per heifer of that average age, over the course of a year. Heifer nutrition clearly, needs to be investigated further at Miner Institute.

Table 6. Miner Institute heifer rations compared to NRC 2001 recommendations.

	Miner Institute Heifers	NRC 2001 Recommendations
Weight	649 – 750 lbs	660 lbs
Age at 1st Calving	26 months	24 months
DMI	20.3 lbs	15.6 lbs
% CP	17.2	12.3
% P	0.53	0.23

Conclusions

The reduction of dietary phosphorus levels in the rations fed at Miner Institute do not appear to have had any adverse effects on the lactating herd; including milk production, milk composition or reproduction based on graphical inspection. The only reproductive trend observed was a slight decrease in average days to first service, which is likely due to herd management improvements. Manure phosphorus levels were reduced nearly 30% with the dietary reduction in phosphorus. A major area of concern to continue investigating at Miner Institute is heifer nutrition, growth, and reproductive efficiencies with proper protein and phosphorus nutrition and the subsequent effects on nutrient management through heifer manure.

4. PHOSPHORUS SURVEY OF LAKE CHAMPLAIN BASIN FARMS

The agricultural contribution to phosphorus nutrient loading of soils and water through feed and fertilizer imports has been well established. The level of dietary phosphorus (P) feeding nationwide has been to nutritional excess, in many cases averaging over 0.48% of ration dry matter (DM) (Sansinena et al., 1999; Keuning et al., 1999). A survey of Vermont feed representatives showed phosphorus feeding levels ranging between 0.48 to 0.55% for high producing dairy cows (Anderson and Magdoff, 2000). This project involved an evaluation of current phosphorus feeding practices of dairy farms in the Lake Champlain Basin to determine what levels of dietary phosphorus are currently being fed and to establish a baseline measurement of farmers' knowledge concerning phosphorus requirements. Understanding current practices and beliefs of area farmers will facilitate educational efforts in attempts to reduce the amount of phosphorus entering onto farms and potentially reaching the waters of the Lake Champlain Basin.

Students in the Advanced Dairy Management program at Miner Institute for the 2001 and 2002 spring semesters conducted a survey of 30 dairy farms within the Lake Champlain basin, 15 each from Vermont and New York. Farms were randomly selected based on the following criteria for farm inclusion: 1) if possible lactating cows and replacement heifers be fed a total mixed ration (TMR); and 2) calculated/recommended ration nutrient levels of the TMR must be available from the nutritionist/feed representative. Samples of each farms' forages, haylage (hay crop silage), corn silage and TMRs were collected using standard sampling and quartering techniques, then submitted to the University of Vermont Agricultural Testing Laboratory for wet chemistry mineral analysis. The TMR samples were obtained from mixer wagons at feed out. Sub-samples were intermittently taken, as the TMR was discharged from the mixer and composited. The composite was then homogeneously mixed and a sample was taken and submitted to the lab for analysis. Comparison of the nutritionists' calculated phosphorus level of the TMR (TMRn) were made against the actual analyzed phosphorus level of the TMR (TMRa) to identify variation between the predicted/recommended and actual dietary phosphorus levels being fed. These values were then compared to the NRC 2001 dietary phosphorus recommendations for high producing lactating cows of 0.38% phosphorus and for heifers at 0.23% phosphorus. A 10-question survey was conducted to ascertain current feeding and forage testing practices, as well as farmers' beliefs about phosphorus levels affecting reproduction and whether reducing dietary phosphorus would be beneficial to them or the environment.

Survey results

Survey questions appear as they were asked of the farmers. Responses are indicated and where appropriate, further breakdown by response is included to elucidate trends. Percentages are based on the total number of responses for each question. In many cases, not all 30 farmers could answer each question or provide the nutritionist's TMR nutrient specifications. Of the 30 farms surveyed, 28 answered all questions.

Question 1. How many times per day do you feed cows? ____ Heifers?____

Feedings per day	Cows	Heifers
1 x	73%	80%
2 x	27%	20%

Question 2. Do you feed a TMR to all forage consuming animals on the farm?
Yes 75%
No 25%

Question 3. Do you know what level of phosphorus you are currently feeding in your milking rations (Yes/No)?

Response	Cows/milking rations	Heifers
Yes	50%	32%
No	50%	68%

Question 4. Is your nutritionist balancing your rations for reduced phosphorus levels (<0.40% DM)?
Yes 54%
No 25%
Did not know 21%

Response	TMR	Avg %P	Range of %P	% < 0.40
Yes	TMRn TMRa	0.42 0.43	0.30 – 0.46 0.31 – 0.57	27%
No	TMRn TMRa	0.45 0.39	0.38 – 0.50 0.28 – 0.49	20%
Did not know	TMRn TMRa	0.42 0.42	0.30 – 0.45 0.32 – 0.57	20%

Question 5. How accurately do you feel the feeds you are feeding today actually represent what the feeds were at the time the ration was balanced?
Accurate 68%
Inaccurate or did not know 32%

Response	Avg # of forage analyses per month	Avg # of cows
Accurate	2.3	460
Inaccurate or did not know	1.2	180

Question 6. How often are the forages that are being fed analyzed for nutrient content?

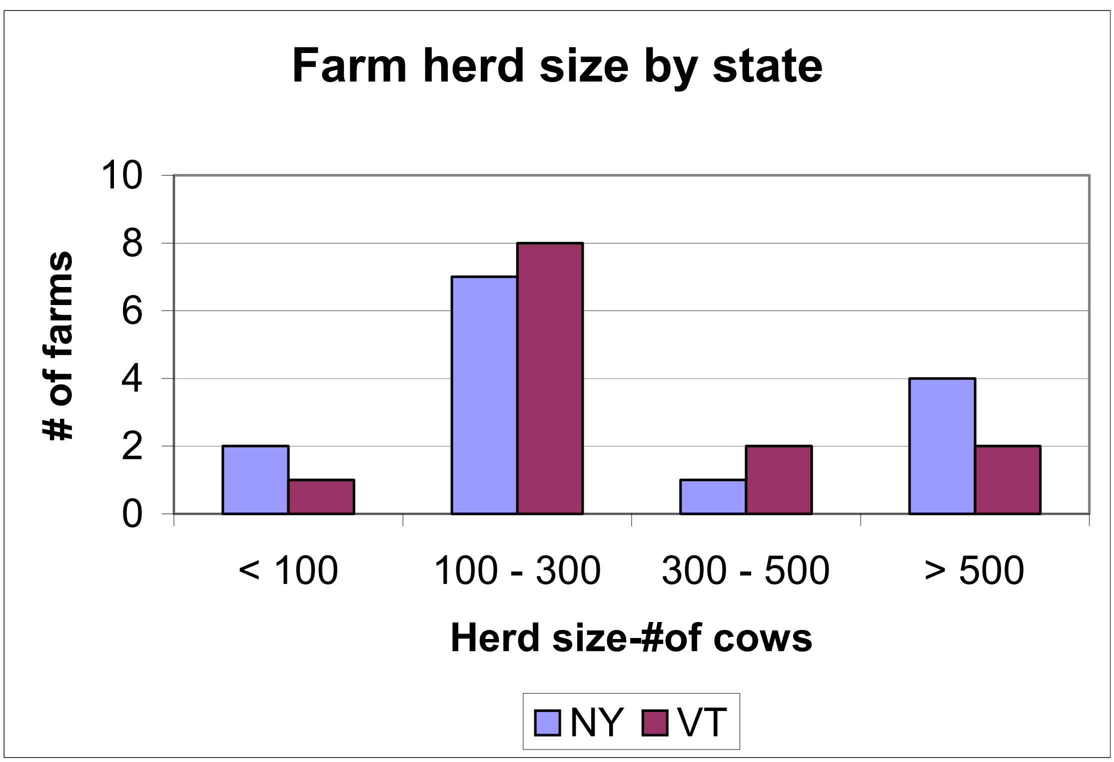
Once per month or less	36%
2x / month	43%
3x / month	4%
4x / month	14%
Did not know	4%

Response	# Farms	Cows
1x/month	8	177
2x/month	12	430
3x/month	1	400
4x/month	4	475
Did not know	1	100
		Heifers
1x/month	2	170 &1200

Question 7. Do you know if the phosphorus levels in your forages are being accounted for in the formulated ration (Yes/No)?

Yes	75%
No	25%

Question 8. What is your current herd inventory? Herd size.



Question 9. Do you feel feeding the recommended phosphorus levels in your milking ration may have a negative impact on the reproductive efficiency of your herd?

Yes	11%
No	71%
Did not know	18%

Question 10. Do you feel that by reducing the amount of phosphorus in your ration to the recommended levels that you will save money and reduce the phosphorus content of your manure?

Yes	54%
No	36%
Did not know	10%

Response	Avg # of Cows
Yes	471
No	295
Did not know	113

Discussion

The distribution of TMRn nutrient specifications for phosphorus indicates that nutritionists/feed representatives are not formulating rations to the NRC 2001 recommendations of 0.38% phosphorus or less. As noted in Figure 7, few nutritionists' nutrient specifications are below 0.40% phosphorus. When farmers were asked if they thought they were feeding reduced phosphorus levels, 54% responded that they were, but only 47% of those that responded yes, also responded yes to knowing their current phosphorus levels. Overall, only 21% of all the nutritionists' recommended TMR phosphorus levels were below 0.40%. These results indicate that many farmers may not know the actual phosphorus level of their rations but trust their nutritionists to make sure they are balanced properly. In most instances farmers are most concerned with the level of protein and energy in their rations. The fact that 54% of the farmers felt they were feeding reduced levels of phosphorus may be indicative of a reduction from previous feeding levels rather than feeding to the NRC 2001 reduced dietary phosphorus recommendation. Though reduced, in this survey, may have been interpreted as a relative term, it was intended to refer to levels of phosphorus <0.40%.

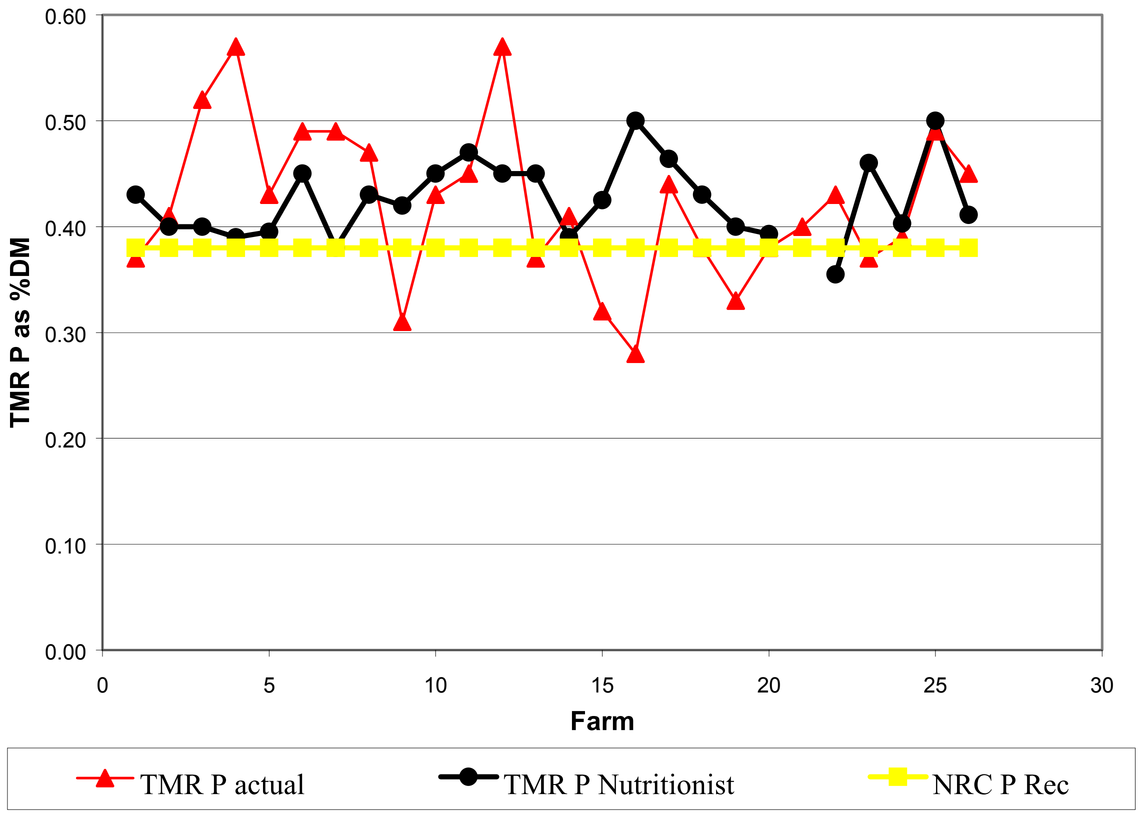


Figure 7. Distribution of actual phosphorus levels of TMR as compared to nutritionist's phosphorus specifications and NRC 2001 recommended 0.38% dietary phosphorus.

Mineral levels up until now have received little attention, which is supported by the results of this survey. Educational efforts pertaining to proper mineral nutrition need to be improved. Of particular importance is the concept of having accurate estimates of DMI to insure that adequate amounts of nutrients, in this case phosphorus, are being fed as opposed to feeding simply percentages. The NRC 2001 guidelines for nutrient percentage requirements are based on assumed DMI values that will differ between herds and animals.

The question remains why nutritionists have not adopted the NRC 2001 phosphorus recommendations of 0.32-0.38%. Farmers' responses to the survey indicate that they are willing to reduce phosphorus levels and that very few of them hold to the myth that reducing phosphorus will adversely effect reproduction. Hesitation and doubt may play a role in the tempered adoption of the new phosphorus feeding guidelines. It may be a matter of wanting first hand experience that no detrimental herd effects occur during a gradual reduction of dietary phosphorus over time. Conversely, it could be that the quick and easy withdrawal of a single phosphorus supplement from rations only reduces TMR phosphorus level to near 0.40%. It is easy to reduce dietary phosphorus if single sources of elemental phosphorus are being fed. Examination of the inclusion rates of supplemental inorganic phosphorus mineral in grain formulations would indicate the feasibility of this quick fix reduction. Grain formulation "recipes" for each farm were not collected as part of this study. Phosphorus, however, is prevalent in all feeds to varying degrees and reducing the use of high phosphorus mineral supplements may not achieve the goal of TMR phosphorus levels in the 0.32 – 0.38% range. Given the variable and sometimes high phosphorus levels in forages and concentrates, feeding less than 0.38% phosphorus in a TMR could be difficult**.** The phosphorus content of the forages for the surveyed farms is listed in Table 7. Depending on the proportions of haylage and corn silage fed, these base forages may contribute significant amounts of phosphorus to the diet before any concentrates or mineral supplements are added. Feed ingredients used to supplement the ration with protein and energy vary tremendously in phosphorus content. Even within a given feed ingredient there is a high degree of variation from the "average" phosphorus value (Table 8).

Table 7. Phosphorus levels (%DM) of forages and TMRs of the surveyed farms by State.

	Avg P Haylage	Avg P Corn silage	Avg TMR P Analyzed	Avg TMR P Nutritionist
Total	0.34	0.20	0.42	0.43
min	0.22	0.04	0.28	0.36
max	0.59	0.33	0.57	0.50
NY	0.33	0.18	0.39	0.43
min	0.23	0.04	0.28	0.36
max	0.59	0.23	0.49	0.50
VT	0.35	0.23	0.46	0.42
min	0.22	0.15	0.37	0.38
max	0.45	0.33	0.57	0.47

Table 8. Average %P and standard deviation of phosphorus content in feed ingredients.*

Feed	Sample Number (n)	Avg %P (DM basis)	Standard Deviation	Normal Range (Avg ± Std Dev)
Canola meal	79	1.10	0.20	0.90 – 1.30
Wheat midds	196	1.02	0.20	0.82 – 1.22
Corn distillers	649	0.83	0.14	0.69 – 0.97
Soybean meal	256	0.70	0.08	0.62 – 0.78
Dry brewers	344	0.67	0.06	0.61 – 0.73
Cottonseed	193	0.60	0.08	0.52 – 0.68
Legume silage	8479	0.32	0.06	0.26 – 0.38
Corn grain	1185	0.30	0.05	0.25 – 0.35
Grass silage	4365	0.29	0.08	0.21 – 0.37
Corn silage	1033	0.26	0.04	0.22 – 0.30

* Data from NRC 2001

The high degree of variation of phosphorus content in feeds in conjunction with the chemical nature of that phosphorus affects the efficiency with which the cow can absorb that dietary phosphorus. Protein supplements such as soy, canola and corn distillers grains have high levels of phosphorus with varying degrees of absorption in the cow (NRC, 2001; Aguerre et al., 2002). These ingredients not only vary in phosphorus but also vary in their functionality in the nutritional program, and they most certainly vary in price. Table 9 charts the phosphorus contribution of a few common feed ingredients fed in the Northeast. The feeds are listed by the grams of phosphorus each contributes when fed at a common feeding rate per cow per day. The NRC 2001 recommendation is that a high producing dairy cow requires about 90 g of dietary phosphorus. Some feeds at high feeding levels will make significant contributions to that requirement, before the cow's total nutritional needs for protein and energy are met. Based on average phosphorus level and feeding rate, this table indicates just a few possibilities for feed substitutions to reduce total dietary phosphorus levels. The considerations for where and when to use these ingredients have long been determined by price, protein, and energy value, not phosphorus content. The use of lower phosphorus ingredients needs to be considered. However, many high phosphorus feed ingredients are the least expensive feeds for their primary nutritional use as either a protein or energy supplements. The replacement of higher phosphorus concentrates with lower phosphorus concentrates may increase the cost of the ration.

Table 9: Phosphorus contribution of common feed ingredients fed in the Northeast.

Feed	%CP	Avg %P (DM)	Feeding Rate DM lbs/cow/d	P contribution Grams/cow/d
Canola meal	38	1.10	6	30
Wheat midds	18	1.02	6	28
Distillers	29	0.83	6	23
Corn meal	9	0.30	15	20
Legume silage	22	0.32	12	17
Soybean meal	54	0.70	5	16
Corn silage	9	0.26	12	14
Grass silage	16	0.29	10	13
Dry brewers	29	0.67	4	12
Cottonseed	23	0.60	4	11

It is important to consider whether current ration balancing programs are using accurate phosphorus analyses of all feed ingredients and what phosphorus absorption coefficients are being used within the program to determine absorbable grams of phosphorus supplied by each feedstuff. The absorption coefficient defines how available a nutrient is for absorption in the gut of the cow. The NRC 1989 guidelines established an overall phosphorus absorption coefficient of 0.50 for all feeds. Using the NRC 1989 recommended value of 0.50 for each gram of phosphorus supplied in the diet, only 0.50 g of phosphorus is absorbed. If an animal requires 60 g of absorbable phosphorus, then 120 g of dietary phosphorus is required, which is then divided by the animal's DM intake to obtain a dietary %P required. The NRC 2001 guidelines have revised the absorption coefficient for feedstuffs based on considerable review of the research. The absorption coefficient for forages has been set at 0.64, and for concentrates, 0.70, and many mineral supplements have higher coefficients that have been more accurately determined. Using the appropriate phosphorus absorption coefficient will substantially reduce the amount of phosphorus "required" in the diet. How ration formulation programs being used by nutritionists and the feed industry are calculating absorbable phosphorus supplied in the diet needs to be verified.

Using the correct absorption coefficient, however, does not explain the variation between the TMRn and TMRa found in this survey. The average of the absolute value of the differences between TMRn and TMRa is 0.067% units of phosphorus, nearly a 17% difference. The distribution of the differences is nearly equal for actual phosphorus values above and below the nutritionists' recommended values. Figure 7 clearly shows the variance between the actual and calculated phosphorus values for the TMRs on each farm. What is accounting for this error? Some of the assumptions that have been made include that the TMRs were mixed properly and homogeneously on the farm, according to the nutritionists' recommendations. These assumptions are accounted for in using standard sampling procedures and the population size of 30 farms. The most likely explanation for this variance is inaccurate phosphorus values for the feedstuffs used to formulate the ration. The use of near infrared spectrophotometry (NIR) analysis for forages is common; unfortunately, NIR is notoriously poor at predicting mineral content. There is a high degree of error between NIR phosphorus values and the actual wet chemistry analyzed phosphorus values. As noted by NIR software manufacturers, the physical chemistry of feed minerals does not allow for precision with NIR analyses. The highly variable phosphorus content of the concentrates and by-product feeds that are used to formulate grain mixes also contribute to the inaccuracy of nutritionists predicted ration phosphorus levels from the wet chemistry analyzed values; see Table 8. Feed manufacturers and nutritionists commonly use book values or periodic averages of phosphorus levels of grain ingredients when balancing rations. Given the degree of variability of mineral content in grains, there can be significant error resulting in under or overestimation of phosphorus in a grain mix. In combination with inaccurate forage phosphorus values, the TMR fed to cows may have very different levels of phosphorus compared to the ration calculated by the nutritionist.

Survey data for the phosphorus levels in heifer rations is limited. Very few farmers had the required TMRn nutrient specifications for the heifer rations of those that were feeding TMRs to their replacement animals. Figure 8 charts the phosphorus levels of the nutritionists and analyzed TMRs fed to heifers in this survey. Clearly, these heifers are being overfed phosphorus according to the NRC recommendations of 0.23%. The average %P of both the TMRn and TMRa phosphorus was 0.40%. The nutritionists' calculated phosphorus value and the analyzed values tend to be closer to each other in the heifer rations than in the lactating rations. Considering that much less grain is fed to heifers, the variance in phosphorus levels resulting from grain is minimized. Heifers are fed primarily forage, haylage being preferable to corn silage, as corn tends to fatten animals. The influence of phosphorus from haylage is likely to set a limit on how low a phosphorus level can be attained in a heifer ration. Haylage tends to average 0.30% phosphorus, which is greater than the NRC recommendation of feeding on average, only

0.23% phosphorus to heifers. Though NRC recommends lower values of dietary phosphorus for growing heifer rations, a realistic goal on farms is to attain 0.30% (Figure 9).

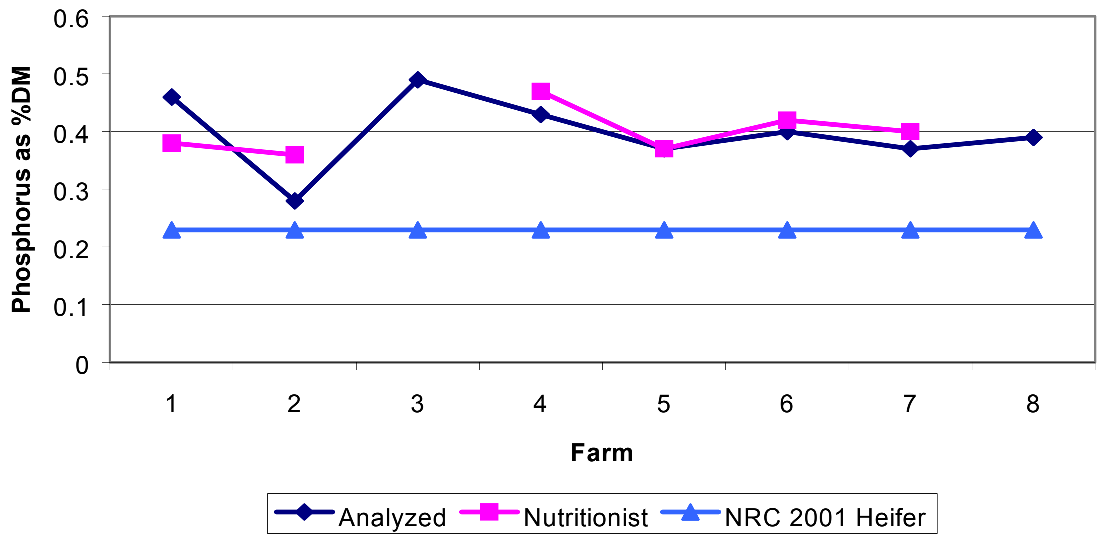


Figure 8. Heifer TMR Phosphorus levels (%DM).

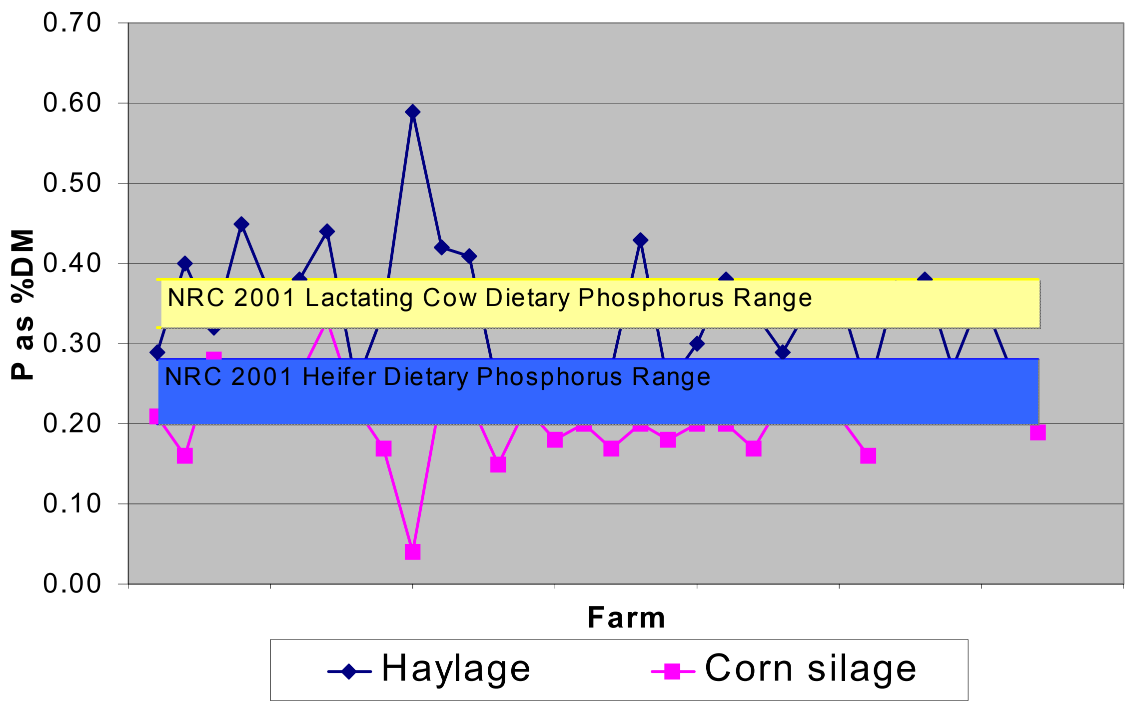


Figure 9. Phosphorus values of haylage and corn silage sampled from surveyed farms (2001-2002) as compared to NRC 2001 guidelines for lactating cows and growing heifers.

The survey responses concerning the frequency of forage testing indicates that larger herds test their feeds more frequently. There is a multitude of possible explanations for this phenomenon: it may be that there is greater concern for monitoring production with greater numbers of cows; greater concern from the feed industry to help manage a larger account; or the ability to more precisely manage nutrients to meet nutritional demands through animal grouping strategies and more frequent reformulation of the grain. Given the greater consumption of grain through greater cow numbers, more frequent deliveries of grain occur on larger farms. Greater frequency facilitates altering nutrient composition of grain mixes to best complement forage quality. As indicated by the survey, smaller herds were less confident that their most recent forage analysis was accurate for the forage they were currently feeding, and the frequency of forage testing was only 1.2x/month compared to larger herds that tested forages on average 2.3x/month.

Concerning the belief that reducing phosphorus would impair herd reproductive performance, only three of 28 respondents felt that was true. Farmers' attitudes towards reducing phosphorus resulting in reduced manure phosphorus and economic savings for them indicated apprehension. The question was poorly worded and should have asked about the economic savings separately. Fifteen farmers responded "yes" to reducing manure phosphorus and saving money by reducing dietary phosphorus. These farms averaged 471 cows and may have a greater awareness for the potential savings that may be possible by feeding lower phosphorus levels. Those responding "no" or "did not know" tended to be smaller farms and questioned whether reducing phosphorus would save them money. Based on their smaller size, they may be less able to take advantage of volume pricing and be more susceptible to pricing effects other than just the phosphorus level. Considering the possible need to make ingredient substitutions to further lower dietary phosphorus levels, predicted economic savings that have been publicized might be over-estimating the potential farm savings of reducing phosphorus levels.

Responses to question 8 indicate that there was a good distribution of farms by herd size. Figure 10 shows the number of feed companies represented in the survey, and the number of farms with each feed company. No one feed company or nutritionist was represented to such an extent as to bias the results. It is clear that the industry has yet to achieve TMR phosphorus levels of 0.32-0.38%. There was no difference with the TMR phosphorus levels for either the nutritionists' or actual phosphorus levels across the two years of data collection. Adoption of the reduced feeding levels may have been more prevalent in 2002 as educational efforts through the media have had more time to be tried and accepted. The average TMRa and TMRn values for 2001 were 0.45% and 0.42%; and for 2002 were 0.40% and 0.43%, respectively.

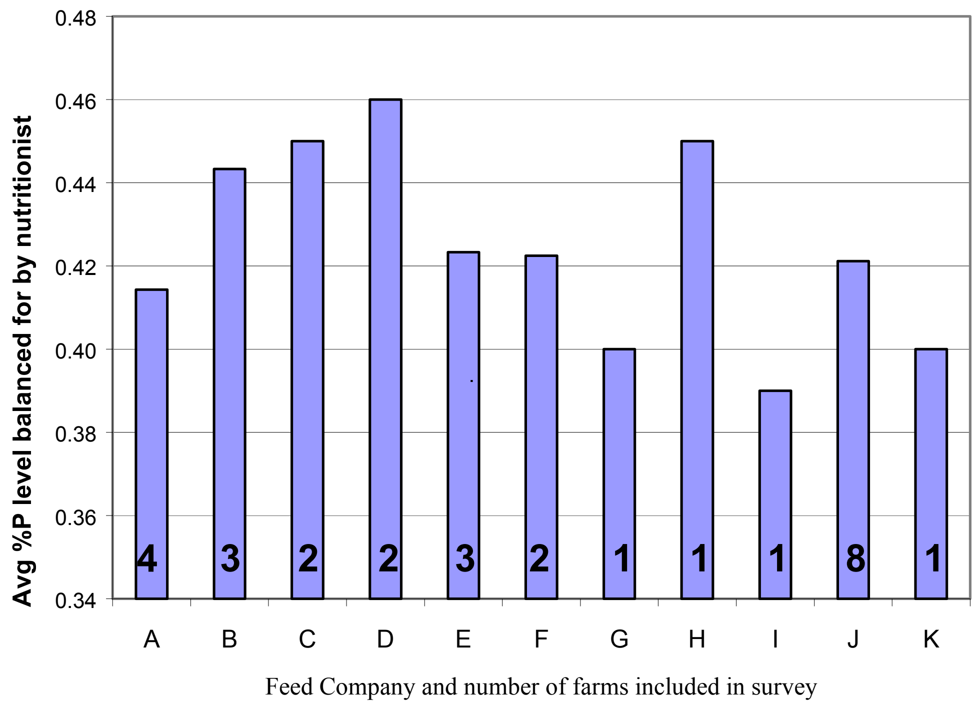


Figure 10. Nutritionist's average formulated phosphorus level by feed company with number of farms represented in survey.

Conclusions

Farmers and feed representatives are aware of the effort to reduce dietary phosphorus levels, though dietary phosphorus levels as formulated by nutritionists are still above the NRC 2001 guideline of 0.32-0.38% phosphorus for lactating cows. Phosphorus levels of analyzed TMR samples greatly differ from the nutritionists' calculated TMR levels. This variation is likely to be a result of inaccurate phosphorus values for both forages and concentrates when calculating dietary levels. Further investigation of what phosphorus levels for concentrates are being used by feed companies, how often concentrates are analyzed for phosphorus, and whether or not they are using the most current absorption coefficients within their ration balancing programs, needs to be conducted. The monitoring of phosphorus in forages also needs to be improved, requiring more frequent analysis and the more expensive wet chemistry analysis for minerals.

Further educational efforts include clarifying the nutritional requirements for phosphorus of all dairy animals, including calves and heifers throughout their growth stage as well as the lactating dairy herd (Table 10). A better understanding of phosphorus levels in grains and by-product feeds that comprise the concentrate portion of dairy diets is needed. Knowing the feeds that not only are high in phosphorus, but also may contribute greater amounts of less absorbable phosphorus will influence purchases and feeding practices on the farm. By improving the accuracy with which we supply animals with the proper level of nutrients, we can minimize the excesses that not only cost farmers but also contribute to the nutrient loading of soils and waters of the Lake Champlain Basin.

Table 10: Generalized Dairy Cow and Replacement Heifer Dietary Phosphorus Requirements based on animal size and production from NRC 2001.

Animal	Dietary Phosphorus (%)	
6 months – 440lbs	0.28	
12 months – 725lbs	0.23	
18 months – 1000lbs (bred)	0.18	
Heifer Close-up	0.30 – 0.40	
Dry Cow Far	0.22 – 0.26	
Dry Cow Close-up	0.30 – 0.40	
Fresh Cow 55lbs/day	Holstein – 0.34 to 0.38	Jersey – 0.40 *
Fresh Cow 77lbs/day	Holstein – 0.37 to 0.42	Jersey – 0.44 *
Lactating Cow 55lbs/day	Holstein – 0.32	Jersey – 0.33 *
Lactating Cow 77lbs/day	Holstein – 0.35	Jersey – 0.37 *
Lactating Cow 99lbs/day	Holstein – 0.36	Jersey – 0.38 *
Lactating Cow 120lbs/day	Holstein – 0.38	

** Breeds of higher milk protein require ~10% more dietary phosphorus than Holsteins for given milk production.*

%Dietary phosphorus = $gP_{required}$/DMI – importance of accurate DMI values for calculating percent dietary phosphorus

5. Educational Programs

Information from the "Feeding of supplemental phosphorus on dairy farms in the Lake Champlain basin: an education/demonstration project" was presented to the following audiences:

September 2001—Vermont Feed Dealers Meeting, Colchester, VT
Audience: 50 people representing the dairy industry, primarily feed industry, in Vermont

November 2001—Poulin Grain Meetings, a series of meetings throughout Vermont
Audience: 30-60 farmers at each meeting

April 2002—New England Dairy Feed Conference, West Lebanon, NH
Audience: 180 dairy farmers and feed industry representatives from Vermont, New Hampshire, Connecticut, Massachusetts and New York

April 2002—Citizen's Advisory Committee, Winooski, VT
Audience: 10 people representing various concerns with the Lake Champlain Basin

April 2002—Citizen's Advisory Committee, Westport, NY
Audience: 10 people representing various concerns with the Lake Champlain Basin

June 2002—Technical Advisory Committee, South Hero, VT
Audience: 15 people representing various concerns with the Lake Champlain Basin

July 2002—American Dairy Science Association and American Society of Animal Scientists, Quebec City
Audience: 75 dairy scientists, industry, research and extension specialists from across North America

July 2002—Lake Champlain Steering Committee Meeting, Chazy, NY
Audience: 25 people representing various concerns with the Lake Champlain Basin

November 2002—Cornell Feed Dealer Meeting, Chazy, NY
Audience: 40 dairy farmers and feed industry representatives from northern NY, Quebec and Vermont

February 2003—Corn Congress at Miner Institute, Chazy, NY
Audience: 150 dairy farmers, feed industry representatives, and crop consultants from northern NY, Vermont, and Quebec

No data are available on audience response to information presented. Individual responses include farmers requesting their feed consultant review phosphorus feeding on their farm and claim reduced manure phosphorus levels. A feed company represented by several farms in the survey project has requested information about which of the farms fed diets formulated by their representatives are out of line with the 2001 NRC guidelines.

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