DIETARY MANIPULATION TO REDUCE PHOSPHORUS AND NITROGEN EXCRETION BY LACTATING DAIRY COWS

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INTRODUCTION

Livestock producers, feed suppliers and extension educators are challenged with on-going developments in waste management regulations. In 1972, the Congress passed the Clean Water Act, which established that point sources directly discharging wastes into U.S. waters must obtain a National Pollutant Discharge Elimination System permit. Concentrated animal feeding operations that have 1000 or more animal units must have such a permit. The Clean Water Act also issued Effluent Limitation Guidelines based on the best technology allowable discharges. In 1998, the Clean Water Action Plan was announced, and in response, the U.S. EPA and the USDA jointly developed a Unified National Strategy for animal feeding operations. The strategy called for minimizing water pollution from animal facilities, and set up a national performance expectation that all animal feeding operations should develop and implement technically sound, economically feasible, and site-specific comprehensive nutrient management plans. More recently, EPA was under court order to revise the regulations for concentrated animal feeding operations. Early this year, EPA proposed revisions to the National Pollutant Discharge Elimination System permit program and the Effluent Guidelines. The proposal has gone through public hearings and solicitation of written comments. The final rules will be issued by December 2002, and will take effect immediately for some operations. The proposed new rules require that concentrated animal feeding operations develop and implement a permit nutrient plan. The plan must address manure issues. Manure application rate should be based on the crop needs for phosphorus (P) as well as nitrogen (N). If soil P loss risks are high, application must be P-based. The plan should include soil analyses. All operational records must be maintained for public review. Producers must control the quantity of nutrients entering, leaving, and remaining on the farm. The nutrient content of the manure exported from farms may need to be certified by producers. Feed suppliers and manure dealers may also need to share the responsibility of farm nutrient management.

The time has arrived. We must work to reduce the N and P content of manure. The objective of this paper is to discuss nutritional strategies that can be utilized to reduce N and P excretion by lactating dairy cows, with the goal of reducing the environmental impact and feed cost.

REDUCING NITROGEN EXCRETION

Dairy cows, on average, secrete 25-30% N in milk of the total N they consume, and almost all the remaining N is excreted in feces and urine. Strategies to reduce N excretion include eliminating dietary protein in excess of the requirement, maximizing microbial protein production, and using protected limiting amino acids for reductions in total protein that needs to be fed.

Reducing dietary protein. Typically, research on the protein requirement of lactating dairy cows has been directed toward maximizing milk production with little concern on N efficiency. The NRC (2001) Nutrient Requirements of Dairy Cattle presented a dataset from 82 experiments with 393 treatment means, showing a curvilinear relationship of milk yield and dietary crude protein (CP) content (Figure 1). Milk yield plateaus with 72 lb/d at 23% dietary CP. Few studies included in the dataset were recently conducted using high producing cows. It is likely that milk yield would plateau with a higher production level with modern cows. Despite this, the relationship between milk production and the incremental raising of dietary protein is still a diminished response. The optimal dietary protein level determined from net returns of feeds would be lower than the one that can result in the maximal milk production. Consideration of environmental consequences could also reduce the optimal level.

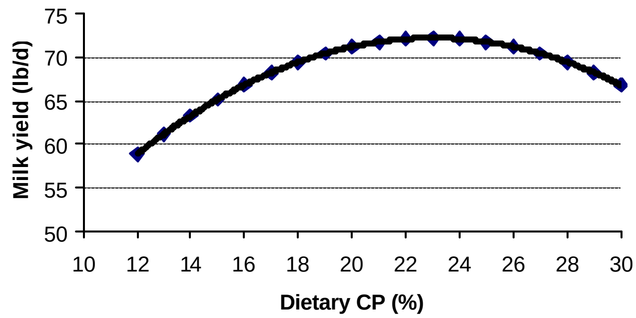

Figure 1. Milk production response to dietary protein (developed from NRC, 2001).

Table 1 lists the protein requirements of lactating dairy cows using some example diets in the NRC (2001). The cow in the example milks 77 lb on d 11 and 99 lb on d 90 of the lactation. Her milk contains 3% true protein for both stages. For d 11 and d 90, she needs 6.7 and 9.5 lb/d of CP, respectively. To provide these amounts of protein, the diet needs to contain 19.5 and 16% CP, with 10.5 and 9.8% from rumen degradable protein (RDP), and 9.0 and 6.2% from rumen undegradable protein (RUP). The higher protein level for d 11 than for d 90 reflects the view that diets for the first weeks of lactation need to be especially condensed in nutrients to compensate for low feed intake.

Table 1. Protein requirements using example diets in NRC (2001).

	Days in milk	
Item	11	90
Milk, lb/d	77.0	99.0
DMI, lb/d	34.3	59.2
Dietary CP		
lb/d	6.7	9.5
%	19.5	16.0
Dietary RDP		
lb/d	3.6	5.8
%	10.5	9.8
Dietary RUP		
lb/d	3.1	3.7
%	9.0	6.2

As mentioned above, few studies have been conducted to determine the lactational response of modern cows to dietary protein level. Three studies (Christensen et al., 1993; Cunningham et al., 1996; Komaragiri and Erdman, 1997) included in the database for Figure 1 utilized cows producing relatively high levels of milk. Diets used RUP supplements to raise the protein content from 16.7 to 19.6% CP on average. Two (Cunningham et al., 1996; Komaragiri and Erdman, 1997) of the studies reported increased milk production, while the third study noted a slight decline in milk production as dietary protein was increased. These studies covered only the first part of lactation, with days in milk averaging 130 at the end of the trials.

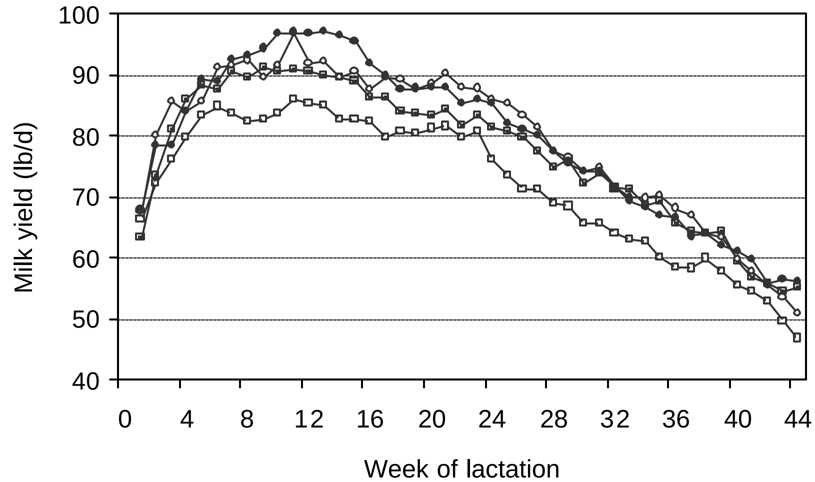

Figure 2. Lactation curves of cows fed diets containing different levels of CP: 15.4% during lactation wk 1 to 16 and 16% during wk 17 to 44 ( ), 17.4% during wk 1 to 16 and 16% during wk 17 to 44 ( ), 17.4% during wk 1 to 16 and 17.9% during wk 17 to 44 (o), and 19.3% during wk 1 to 16 and 17.9% during wk 17 to 44 (•).

Wu and Satter (2000a) reported a study that was conducted for a complete lactation using 58 cows. Treatments were designed to identify the minimum amount of protein needed for the entire lactation. The diets contained 33% alfalfa silage, 22% corn silage, 22-32% finely ground high moisture ear corn, and 10% roasted soybeans. Expeller soybean meal was used at up to 10% as a replacement of high moisture ear corn to increase the dietary protein level. This substitution increased about the same amount of RDP and RUP. The four treatments formed over the entire lactation were as follows: 15.4→16.0% CP, 17.4→16.0% CP, 17.4→17.9% CP, and 19.3→17.9% CP. The change from one level to the other took place at the beginning of wk 17 of the 44-wk lactation. Higher than anticipated protein content of alfalfa silage fed in week 17 to 44 resulted in CP levels slightly higher than intended. All cows were administered bST biweekly starting at wk 9 of lactation.

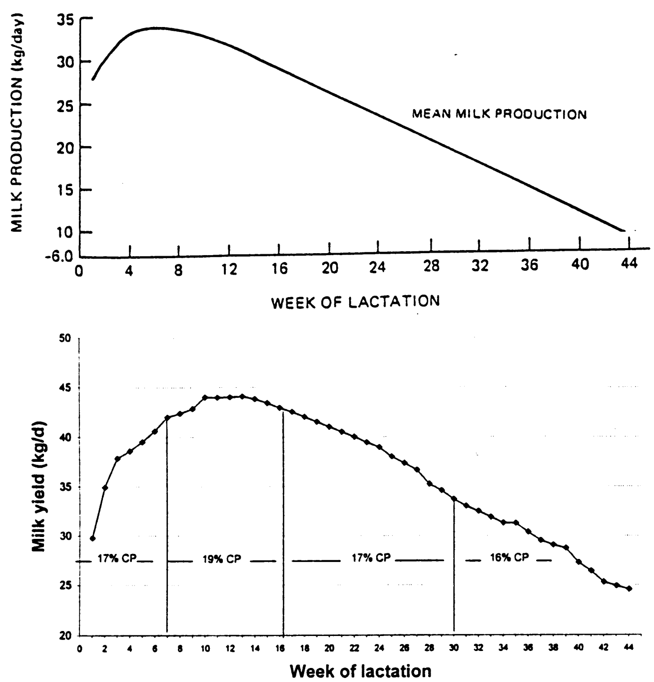

Figure 3. Lactation curve attained with treatments of different dietary protein levels that resulted in the highest milk yields during different stages of lactation in a 2000 study (lower panel) compared to the lactation curve considered typical 15 years ago (upper panel, NRC, 1989).

The lactation curve of the trial (Figure 2) clearly shows that 15.4-16.0% CP was a deficient treatment. The curve for cows fed the highest protein (19.3%) appears to achieve the greatest peak. Furthermore, around the week the dietary protein level was reduced from 19.3 to 17.9% (wk 16 to 18), a dramatic decrease in milk yield occurred for that group. A similar decrease in milk yield was also observed when the dietary CP level was decreased for the cows in the 17.4-16.0% CP group, relative to the group of the cows in the 17.4-17.9% CP treatment. This observation suggests that 16.0% CP was not providing sufficient protein for cows producing about 88 lb/d of milk at wk 17 of lactation. It was not until milk yield had decreased to about 75 lb/d at wk 30 that milk yield of these two groups became similar. Surprisingly, increasing dietary CP from 17.4 to 19.3% failed to enhance milk yield during wk 1 to approximately wk 7 postpartum. All these observations indicated that except for the first few weeks and the late part of the lactation, a high protein diet was beneficial for the majority of the lactation.

The above pattern of milk production and protein requirement is no doubt related to modern cows' production potential and the use of bST. The lower panel of Figure 3 is a constructed composite lactation curve that attempts to reflect the highest milk yields obtained from the top treatments during the different segments of lactation while using the least amount of dietary protein needed to support that maximum production. The synthesized lactation would result in 24,640 lb milk. Compared with the lactation curve considered typical 15 yr ago [upper panel of Figure 3, adopted from NRC (1989)], modern cows receiving bST have broader peak lactation and a more sustained lactation. The use of bST has had the effect of extending the period of peak milk production, and this will sustain the demand for high protein intake over a prolonged period.

Milk yield for the 308-d lactation for the 17.4-16.0% CP treatment was about 1700 lb more than that for the 15.4-16.0% CP treatment, and similar to the yields for the 17.4-17.9 and 19.3-17.9% CP treatments (Table 2). Overall, milk yield averaged 24,240 lb for the 308-d lactation for the three highest protein groups. Estimated N excretion largely reflected N intake. The efficiencies for converting feed N to milk N, ranging from the lowest to the highest dietary protein treatments, were 28.8, 25.9, 24.0 and 24.7%. The lowest protein treatment resulted in the highest efficiency for converting dietary N to milk N, but this treatment was clearly deficient in protein. Based on this experiment, it will be difficult to increase the efficiency of converting feed N to milk N by feeding less protein, when based on total lactation averages, much above 30% and still maintain acceptable milk production levels.

Table 2. Milk yield, intake N, milk N, and manure N of cows fed diets varying in CP content during 308-d lactation.

Item	Dietary CP (%) 15.4-16.0 (n = 15)	17.4-16.0 (n = 15)	17.4-17.9 (n = 14)	19.3-17.9 (n = 14)	SEM
	------------- (lb) -----------------				
Milk yield	22,123	23,830	24,409	24,490	768
Intake N	392	416	470	471	8.8
Milk N	113	108	113	117	3.5
Manure N	278	308	357	355	8.4

This experiment suggests that 17-18% CP is adequate and would allow higher net profit than feeding higher protein. The period that requires the highest protein is not the first few weeks of lactation, as generally thought, but from approximately wk 8 to wk 30. An increase in peak production from feeding more than 17-18% CP is possible, but may not be optimal considering net profit and N excretion. The level can be reduced at around wk 30 to about 16%. Dietary protein level can be manipulated, but the room is quite limited for the most part of the lactation; early and late stages of lactation might provide the best opportunity for reducing the level of dietary protein.

Evidence exists to support the above conclusions. Komaragiri and Erdman (1997) showed that cows fed a diet with 20.9% CP did not produce more milk than cows fed a diet with 17.3% CP during the first 6 wk of lactation, but peaked higher, and sustained milk production at a higher level. Eastridge et al. (1998) summarized the recommendations of four ration formulation programs, and all four programs called for the highest level of dietary protein at d 60 of lactation. The levels of dietary CP recommended by the programs for d 60 ranged from 18.1 to 20.0% for cows producing 120 lb milk daily. However, this level of production is probably higher than the herd averages for most of the farms in the U.S.

Table 3. Cost of reducing N by feeding less protein.

	Dietary CP (%)	
Item	15.4-16.0	17.4-17.9
Milk, lb/308 d	22,123	24,409
Income from milk, \$/308 d[1]	4184	4521
Net income, \$/308 d[2]	2842	3085
Difference \$/308 d	-243	…
Manure N, lb/308 d	278	357
Difference, lb/308 d	-79	…
Cost of reducing manure N, \$/lb	3.09	…
Equivalent of fertilizer N cost[3]	9.0	…

[1]Milk price derived from June 2001 Federal Order One component prices.
[2]Includes management cost = \$1.60/d.
[3]Assuming fertilizer N cost = \$0.35/lb.

Table 3 contains a cost analysis of reducing fecal N using the lowest (15.4-16.0 % CP) and the second highest (17.4-17.9% CP) dietary protein treatments. Yearly total income from milk is calculated from milk component yields and prices. Subtraction of feed and management cost leaves a net income of \$2842 or \$3085 per cow per year for the two groups. Thus, a 2% unit reduction in dietary protein resulted in a net loss of about \$245 per cow per year. The reduction in manure N was about 80 lb per cow per year. The cost for reducing manure N was \$3/lb of manure N reduced, which is about 9 times the cost of commercial fertilizer N based on a fertilizer N price of \$0.35/lb of N. That seems a big price to pay for nutrient management. However, this cost needs to be considered in terms of the disposal of the extra N, either by spreading on land or removal from the farm. If the costs of removing this excess N exceed \$3/lb of N then the producer is better off financially, by reducing the protein content of the ration.

Alfalfa to corn silage ratio. Alfalfa as a N fixing legume is an ideal crop in rotation with corn. Alfalfa and corn silage are complimentary feedstuffs in that alfalfa is high in RDP and corn silage is a good source of fermentable carbohydrate. There may be a ratio at which a mixture of the two can result in the best efficiency of N utilization and milk production. Identifying the optimum blend of the two for feeding can also have significant effects on cropping and field nutrient management. Dhiman and Satter (1997) compared the following three ratios of alfalfa silage to corn silage for lactating cows: 100:0, 67:33, and 33:67. The two forages accounted for 50% of the total diet, and the remaining 50% was from concentrates, with high moisture ear corn and soybean meal as the major components. The protein content of the diets was highest for the 100:0 alfalfa to corn silage diet, being 17.5 and 16.0% in early and late lactation. The level was about 0.8% unit lower for each reduction in alfalfa. The diets were fed to 45 mature cows and 29 first lactation cows for a complete lactation. The 305-d milk yield for the three groups was 21,150, 22,420, and 22,100 lb for mature cows, and 17,910, 18,550, and 18,010 lb for the first lactation cows. While the difference in milk production was modest, the efficiency of protein utilization was increased as more corn silage was fed.

We have started a series of short-term trials to determine the milk production response to dietary protein level under different alfalfa to corn silage ratios. Each trial compared 15.00, 16.25, 17.50, and 18.75% dietary CP using one of the following alfalfa silage to corn silage ratios: 100:0, 75:25, 50:50, and 25:75. The two forages accounted for 50% of the diet on a dry matter basis. The difference in dietary protein content was obtained by varying the amount of roasted soybeans and soybean meal in the diets. Three trials that utilized 100:0, 50:50, and 25:75 alfalfa to corn silage have been completed, and some preliminary data on milk production are presented in Table 4. While it is difficult to make a statistical comparison among trials, it appears that feeding a mixture of alfalfa and corn silage resulted in higher milk yields than feeding alfalfa as the sole forage, which is consistent with the report of Dhiman and Satter (1997). The major objective of these studies was to determine the lactation response to dietary protein level under different alfalfa to corn silage ratios. Results indicated that increasing dietary protein did not increase milk yield or milk protein content under any of the alfalfa to corn silage ratios used in these short-term studies, but resulted in increased milk urea N content. Jonker et al. (1998) suggested that urea N concentrations of 10 to 16 mg/dl are typical under the current protein feeding practices, reflecting protein intake. Milk urea N has begun to be used as a tool for evaluating the efficiency of protein utilization based on its correlation with blood urea N and urinary urea N concentrations. While we have not completed the analyses, N excretion is expected to increase as more protein was fed because milk protein secretion was similar. The observed milk urea N concentrations suggest that this would be the case.

From Table 4 it is possible to see that the various levels of protein did not significantly affect milk production and it would be reasonable to assume that the milk response would influence the profitability of the dairy producer. Figure 4 presents the income over feed costs for the three different forage combinations and four different protein levels. From this graph it is possible to see that the lowest level of protein (15.00%) yielded the highest income over feed costs for the alfalfa and corn silage combinations.

Table 4. Preliminary results of performance of cows fed diets containing different amounts of protein with different alfalfa to corn silage ratios.

	Dietary protein (%)					
Item	15.00	16.25	17.50	18.75	SEM	***P***
Alfalfa : corn silage = 100 : 0						
Milk, kg/d	31.5	32.0	32.2	32.5	0.6	0.69
Milk fat, %	3.85	3.55	3.83	3.72	0.09	0.12
Milk protein, %	3.16	3.12	3.18	3.10	0.03	0.21
Milk urea N, mg/dl	9.8	10.2	11.8	13.3	0.5	0.01
Alfalfa : corn silage = 50 : 50						
Milk, kg/d	37.4	35.5	36.5	36.5	1.5	0.85
Milk fat, %	3.31	3.29	3.31	3.30	0.08	0.99
Milk protein, %	2.79	2.85	2.81	2.82	0.04	0.81
Milk urea N, mg/dl	12.2	13.0	12.6	14.0	0.4	0.02
Alfalfa : corn silage = 25 : 75						
Milk, kg/d	39.3	38.4	39.8	38.8	0.5	0.21
Milk fat, %	3.71	3.51	3.60	3.64	0.09	0.47
Milk protein, %	2.98	3.01	2.99	2.91	0.04	0.40
Milk urea N, mg/dl	11.2	12.7	14.2	15.1	0.3	0.01

Only when alfalfa provided all the forage of the diet did one of the higher protein (17.50%) rations yield more income over feed costs. These results indicate that perhaps reducing the protein content of the ration and adjusting the forage mix can increase the revenue generated by the dairy operation at the same time as reducing N excretion, as cows on low protein rations tend to be more efficient in utilizing protein.

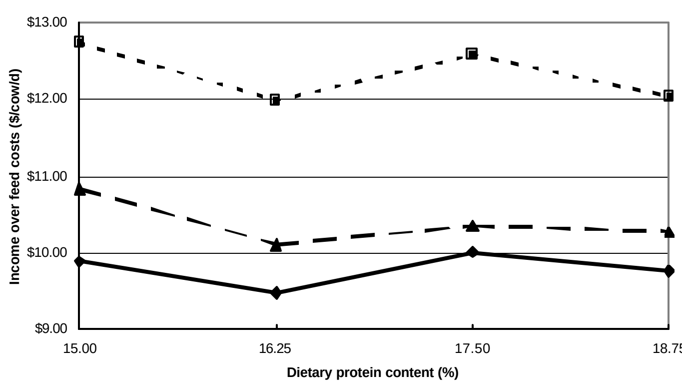

Figure 4: The income over feed costs of cows fed diets containing different amounts of protein with different alfalfa to corn silage ratios (25:75, ¦ ; 50:50, ? ; 100:0, ?).

Increasing microbial production by processing grain. Fine processing of cereal grains, such as steam flaking, can increase starch degradation in the rumen, and thus can stimulate microbial protein production. Numerous studies have obtained responses in milk and milk protein yields to steam flaking of sorghum or corn compared to dry-rolling or steam-rolling of these grains. Theurer et al. (1999) summarized studies using diets containing 34-43% grain and 35-50% alfalfa hay, showing that steam-flaking compared to dry-rolling increased dietary starch digestibility in the rumen (from 35 to 52% for corn; from 54 to 76% for sorghum), in the small intestine (from 61 to 93% for corn; from 74 to 90% for sorghum; both based on starch entry), and in the total digestive tract (from 78 to 97% for corn; from 89 to 98% for sorghum). Total tract starch digestibility was increased as a result of increased proportion of intake starch digested in the rumen and increased digestibility of smaller amounts of starch reaching the small intestine. Microbial protein flow to the small intestine was increased by 10-18% with steam flaking. Urea N recycling from the blood to the gut was nearly doubled in cows fed steam-flaked compared to dry-rolled or steam-rolled corn or sorghum in diets that contained 17-19% CP. In beef studies using steam-flaked grains, most of the blood urea N recycled was transferred into the rumen. This recycling serves as a conservation of N that would otherwise be excreted in urine because the recycled N can be utilized for microbial protein synthesis. This is consistent with increased microbial protein flows to the small intestine with steam-flaked grains. Valadares et al. (1999) reported declined milk urea N concentrations as more dietary concentrate based on high moisture ear corn was fed, suggesting that N utilization increases with more fermentable carbohydrate.

Steam flaking of corn or sorghum has not consistently altered CP digestibility in lactating cows. Most of the studies on steam flaking have been conducted at the University of Arizona, and diets used in these studies contained mostly alfalfa hay. More studies are needed to determine the effect of grain processing on N excretion and on reducing the dietary protein requirement under various forage conditions, such as mixed corn silage, alfalfa silage, and grass silage.

In addition to steam-flaking, high moisture corn has also shown similar advantage over dry corn. Studies at Beltsville (Knowlton et al., 1998; Wilkerson et al., 1997) demonstrated that feeding high moisture corn compared to dry corn, either ground or rolled, increased starch digestibility in the rumen and in the total tract. Fecal N excretion was 10% higher with dry corn than with high moisture corn, and the difference was almost entirely accounted for by increased microbial N excretion. The larger fecal microbial N was related to more microbial activity in the large intestine. Significantly more starch escaped digestion from the rumen and small intestine and was fermented in the hindgut when dry corn was fed. This fermentation stimulated microbial synthesis using urea N recycling from the blood to this site of the gut. Synthesized microbial matter from the large intestine would mostly be excreted in feces. It appears that inefficient digestion of starch in the rumen and the small intestine can result in more starch fermented in the large intestine, forming drainage of N to feces. Feeding corn in a more digestible form can reduce fecal N losses. The same may also be true for P because microbial synthesis would pull P from the blood and carry it to feces.

If recycled urea N is the major source of the increased microbial N in feces when dry corn rather than high moisture corn was fed, less N would be expected to be excreted in urine. A shift of N excretion from urine to feces is considered beneficial because urinary N is more risky to the environment than fecal N. However, urinary N excretion was not changed with corn form as determined using the metabolism unit at Beltsville (Wilkerson et al., 1997). Given the Arizona's observation that increasing ruminal starch digestion resulted in more blood urea N recycled to the rumen, it is possible that dry corn is associated with more urea N recycling to the large intestine while high moisture corn is associated with more urea N recycling to the rumen. The difference in routing could partially explain the lack of difference in urinary N excretion observed in the Beltsville study. Accordingly, the site of starch fermentation is important. Ruminal fermentation would result in N re-utilization, while hindgut fermentation would result in N waste.

In a grazing study (Wu et al., 2001), feeding corn as the primary supplement in cracked dry form or ground high moisture form was compared utilizing late lactation cows. Corn accounted for 75% of the concentrate supplement, which was fed at 20 lb/d (DM) for 13 weeks. Milk yield was about 5 lb/d more (Figure 5) and milk protein content was 0.11% unit higher (3.26 vs. 3.15%) for high moisture corn than cracked dry corn. Result suggests that high moisture corn provided more metabolizable energy and microbial protein than dry corn due to increased starch fermentability.

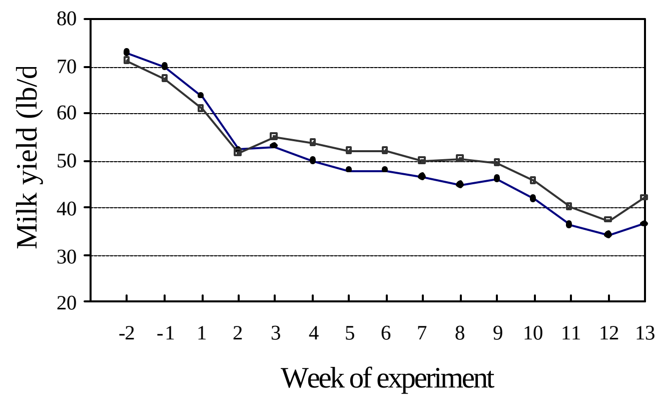

Figure 5. Milk yield of grazing cows supplemented with dry shelled corn (◉) or high moisture shelled corn (¦) for 13 wk (wk 1 to 13). Cows were fed a TMR prior to the grazing period and were adapted to grazing in wk -1.

Use of rumen-protected amino acids. Supplementation of diets with limiting amino acids may provide a means of reducing dietary protein content and manure N excretion. Dinn et al. (1998) compared diets containing 18.3, 16.7, and 15.3% CP fed to early lactation cows. The two lower protein diets were added with rumen-protected methionine and lysine to the same level as the highest protein provided. Although milk yield was not maintained, feeding the amino acid supplemented lower protein diets resulted in decreased excretion of N in feces and urine from 42 to 35 and 31% of the intake N and increased efficiency of converting feed N to milk N from 26 to 29 and 33%, respectively. Krober et al. (2000) also reported reduced urinary N excretion with dietary supplementation of methionine.

Wu et al. (1999) conducted an experiment to determine the effect of supplementation of methionine on reducing the dietary protein requirement. The diet contained 15 or 17%

CP, fed with or without 12 g/d of methionine. Diets used alfalfa and heat processed soy protein sources to result in relatively high intestinal lysine to position methionine as the first limiting amino acid. Methionine supplementation increased milk protein yield by 35 g/d, averaged from the two CP levels. Most of the increase occurred when the 15.2% CP diet was fed. Result indicates that methionine supplementation can upgrade a low protein diet.

Results with supplementation of lysine and methionine have not been consistent. Several studies (Christensen et al., 1994; Piepenbrink et al., 1996) failed to demonstrate that rumen protected amino acids could restore milk yield when added to low protein diets. In these experiments, the low protein diets contained about 14% CP. It would be difficult to restore milk production with such low protein diets. Overall, studies have suggested that fine-tuning of diets with protected lysine and methionine might have marginal benefit in increasing secretion of milk protein, and could facilitate a slight reduction in dietary protein.

REDUCING PHOSPHORUS EXCRETION

The most effective way to reduce manure P excretion is to feed less P. Until recently, almost all dairy rations have been formulated with P levels higher than recommended by feeding standards. Several surveys conducted a few years ago in the Mid-South States (Sansinena et al., 1999), Texas (Goodall et al., 2000), and Wisconsin (Powell et al., 1999) indicated that P was fed at about 30-40% above the NRC (1989) guidelines at the time. Typically, dairy nutritionists recommend that P be fed, on average, at 0.48% of the diet on a dry matter basis (Satter and Wu, 1999). This amount was about 25% higher than the NRC (1989) recommendations.

Reducing dietary P without affecting animal performance has been proven a reality. Several studies (Brintrup et al., 1993; Valk and Ebek, 1999; Wu and Satter, 2000b; Wu et al., 2000, 2001) showed that P fed to lactating dairy cows can be safely lowered compared to the amounts producers had been feeding for many years. These were long-term studies, ranging from one to three years. Figure 6 is the lactation curve of cows fed 0.38% or 0.48% dietary P for two years in one (Wu and Satter, 2000b) of the studies, showing no difference in milk production between the two P groups in either year.

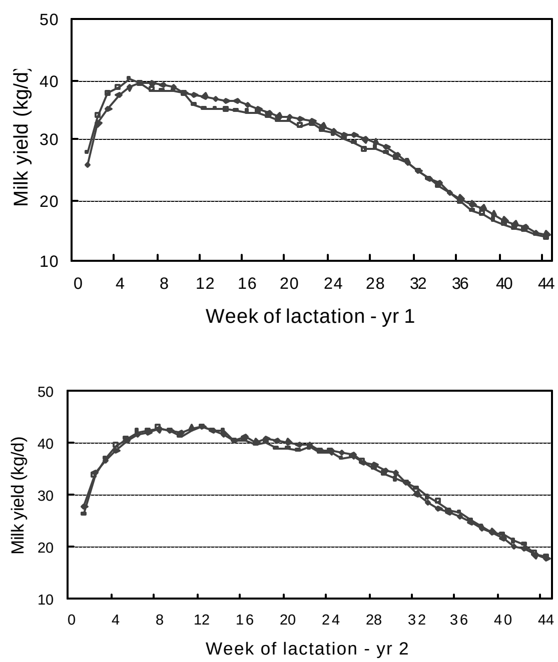

Figure 6. Lactation curve of cows fed diets containing 0.38% (◆) or 0.48% (■) P for two years.

The economics of excessive feeding of P also needs to be questioned. Using the milk production data from Wu et al.

(2000), who fed diets containing 0.31%, 0.40%, or 0.49% P, and current milk prices it is possible to determine the economic impact of feeding P. The low P diet (0.31%) yielded an income over feed cost of $11.01/cow/d over 308-d lactation. Income over feed costs was $11.52/cow/d for the middle level of P (0.40%) and $11.45/cow/d for the high level of P (0.49%). The difference between the 0.40% and 0.49% P diets was due to a slight reduction in milk yield and a higher ration cost for the higher P diet. On a whole farm basis feeding 0.49% P reduced income over feed costs by $0.07/cow/d or $21/cow/yr. Not included in this value is the cost of removing the extra P from the farm system or acquiring the land to spread the extra manure P. Cows on the highest P ration excreted 10 lb more P than did cows on the medium P diet. The dairy producer needs to account for the excess P excreted as well as the loss in income caused by feeding relatively high levels of P.

Table 5. Strength measurements of the 12th rib bone from cows fed diets differing in P content for 2 to 3 years.

	Dietary P (%)			
Item	0.31	0.39-0.40	0.47-0.49	SEM
Number of cows	9	9	11	...
Shear stress, N/mm[1]	26.5	28.1	27.5	2.2
Fracture energy[1], N-m	66.6	60.5	65.0	4.2
Wall thickness, inch	0.20	0.20	0.21	0.01
Bone specific gravity[g]	1.50	1.57	1.55	0.02
Ash, % of dry weight	53.9[c]	56.2[a]	55.6[ab]	0.8
Ash, % of wet weight	46.0[c]	47.4	48.1[a]	0.7
Ash, g/cc, wet bone	0.69[c]	0.74[a]	0.74[a]	0.01
P, % of ash	17.7	17.3	17.9	0.3
P, % of dry weight	9.5	9.7	9.9	0.2
P, % of wet weight	8.1[c]	8.2	8.6[b]	0.2
P, g/cc, wet bone	0.122[c]	0.129	0.133[a]	0.003

[a,b,c]c < a (*P* < 0.06), c < b (*P* < 0.13).

[g]Linear and quadratic (*P* < 0.14) effects.

[1]Area under the force (N) and deformation (m) curve. It is an expression of the amount of the loading force and energy the bone absorbs before fracture.

To ensure that animal health is not compromised with reduced dietary P, Wu et al. (2001) evaluated bone characteristics. They surgically removed a section of the 12th rib at the completion of the second or third lactation from 29 cows that had been fed 0.31, 0.39, or 0.47% P for strength and mineral analyses. The strength test was performed mechanically using a piece of loading equipment . The test showed no difference in bone strength among treatments (Table 5). Bone specific gravity tended to be lower for the 0.31% P treatment than for the other two treatments, with the difference being about 4%. The ash content of the bone, expressed on dry weight, wet weight, or wet bone volume, was slightly lower for the 0.31% P group. The P content of the bone, when expressed on a wet weight or volume basis, was lower for the 0.31% P treatment compared to the 0.47% P treatment. The average decrease in ash and P content was 4.8 and 6.0%, respectively, for the 0.31% group compared to the 0.47% P group. There was no difference in any of these analyses between the other two treatments. Thus, after two to three years of feeding, 0.31% dietary P showed some signs of reduced bone strength and P content, but 0.39% P did not as compared to 0.47% P.

Reproductive performance is a big concern with reducing dietary P. The view has been that supplemental P is very important to reproductive performance of cows. Preston (1977) and McDowell (1992) reviewed the literature and indicated that most of the pioneer studies that established the importance of P to reproduction used beef cattle and sheep fed primarily range or hay. In the early 1900s, cattle and sheep in South Africa, Australia, Ireland, and Latin America were observed chewing bones and exhibiting depraved appetites. The P content of the ranges the animals grazed was only about 0.15% (McDowell, 1992). It was under these conditions that P was shown to be important to the breeding of ruminants. A study conducted in Scotland (Hignett and Hignett, 1951) was also one of the pioneer studies. The study involved several family farms and reported improved conception rates of cows by P supplementation. However, in Scotland in 1951, little or no grain would be fed, and the forage used seemed to be badly weathered. The investigators estimated that 30 g/d of P would be sufficient to meet the requirement for P of lactating cows. This amount is much less (< 50%) than a modern cow receives. It appears that both poor quality roughage and extremely low P were involved in the early observations that established the importance of supplemental P to reproductive performance.

The P need for reproduction does not seem very high. Some early work reported that cows fed P-deficient diets showed depressed appetite, reduced bone P, blood P, and weight gain, but did not show reproductive disorders. In addition to the aforementioned Scotland study, Hignett and Hignett (1952) suggested that 22 g of P per day was sufficient for cows 50 years ago. Noller (1977) suggested that 0.21-0.24% P was adequate. Hurley et al. (1989) compared 0.19, 0.37, and 0.64% P and did not see a difference in mounting activity or hormone concentrations. Milk yield was reduced when dietary P was as low as 0.24% (Call et al., 1987; Valk and Ebek, 1999), but reproductive performance was not affected. It seems that reproductive failures may not occur until after other deficiency signs appear. Modern cows may never be

Table 6. Reproductive measures of lactating dairy cows fed low or high P diets (summary of 8 trials).

Item	Dietary P (%) 0.32-0.40	0.39-0.61	SE
Days to 1st estrus	46	48	4.2
Days to 1st breeding	73	76	3.3
Days open	96	100	4.9
Services/conception	1.8	1.9	0.2
Pregnancy rate	0.87	0.86	0.02

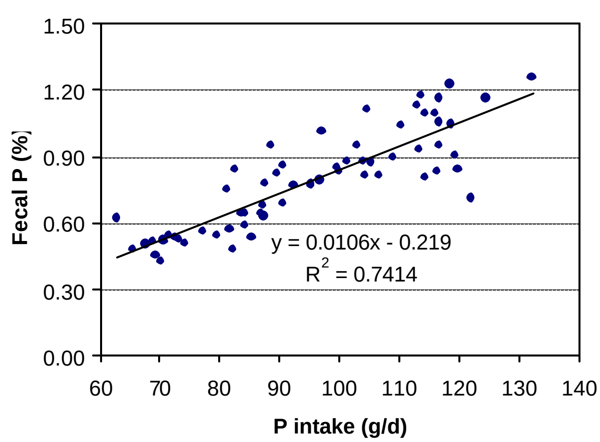

Figure 7. Relationship between P intake and fecal P in lactating dairy cows.

encountered with diets that contain P as low as those suggested by the early studies that would cause infertility. Today, the forages fed are generally of good quality, and diets always contain some protein supplements, which are usually high in P content. A typical lactation diet seldom contains < 0.30% P.

With modern diets, there is little indication that P supplementation improves reproductive performance. Wu and Satter (2000b) summarized 8 studies involving a total of 785 cows. Half of the cows were fed low P ranging from 0.32 to 0.40% and the other half high P ranging from 0.39 to 0.61% of the diet. Means of reproductive measurements (Table 6) show no effect of P level on reproductive performance.

Reducing dietary P can significantly reduce fecal P content. Summarized data from two years of research (Wu et al., 2000, 2001) show a linear relationship between P intake and fecal P excretion (Figure 7). According to this relationship, a reduction in dietary P from 0.48% to 0.38% can result in 30-35% less manure P.

The 2001 NRC adopted research results developed since the release of its previous version (NRC, 1989) and made several modifications in estimating the P requirement of lactating dairy cows. The requirement is calculated as the sum of absorbed P utilized for maintenance, lactation, and pregnancy. Absorbed P is then divided by the coefficient of absorption of feed P from the gut to result in P that needs to be supplied from the diet. This dietary P is expressed as grams per day or as a percentage of the diet on a dry matter basis.

The maintenance requirement is calculated as 1.0 g/kg of dry matter intake, plus a negligible amount to recover urinary P losses (0.002 g/kg of body weight). The 1989 NRC used live weight to calculate the maintenance requirement. The change is made largely as a result of the research by Spiekers et al. (1993), who demonstrated that P excretion in feces of cows fed P just to maintain P balance is a function of dry matter intake rather than a function of body weight.

The 2001 NRC calculates the P requirement for lactation using a rate of 0.9 g/kg of milk, disregarding milk fat content as a factor as used in the 1989 NRC. This is based on several studies, which showed that the P content of milk is relatively constant despite a weak correlation with milk protein content; its relationship with milk fat is even weaker.

The P requirement for pregnancy is significant only in the last trimester. The new NRC uses an exponential equation to calculate the P requirement according to days of gestation. Values estimated range from 1.9 g/d for day 190 to 5.4 g/d for day 280 of pregnancy. Because the last 60 days of pregnancy generally occur during the dry period, only days 190 to 220 of pregnancy need to be considered for lactating animals. The amount of absorbed P required for pregnancy during this period averages 2.5 g/d.

Changes are also made for the conversion of absorbed P to dietary P. The 1989 NRC used 50% as the availability value for dietary P from the gut. The new NRC uses 64% for forages, 70% for concentrates, and various percentages for mineral supplements.

Monosodium phosphate and dicalcium phosphate have availability values of 90 and 75%, respectively.

The new NRC recommends overall lower dietary P amounts than the 1989 NRC. Table 7 lists the amounts of P that needs to be fed calculated from the 2001 NRC based on milk production and feed intake. Milk yields listed include 44 to 132 lb per day, and the dietary P ranges from 0.29 to 0.40 Clearly, feeding 0.40% P is sufficient for any high producing herds that could be possibly found today in the U.S. Realistically, 0.35-0.38% P can cover most of the herds, and can still provide some safety margins.

Table 7. Calculated amounts of P that needs to be fed at different milk yields and feed intakes.

Milk (lb/d)	Dry matter intake (lb/d)	Dietary P	
		g/d	%
44	41	52	0.29
55	45	61	0.31
66	48	70	0.33
77	52	79	0.35
88	56	88	0.36
99	59	96	0.37
110	63	105	0.38
121	66	114	0.39
132	70	123	0.40

A shortcoming of the 2001 NRC is that it failed to address the effect of body P reserves on the P requirement. Lactating dairy cows typically mobilize P from bone in early lactation to support milk secretion, and restore bone P in late lactation. Crediting P released from bone as a source of P and accounting for P that is to be deposited in bone can influence the assessment of the dietary P requirement, making the adjustment of the dietary P level according to stage of lactation a less need, if there is any. The NRC failed to address these issues because there were no data available. This is unfortunate because an accurate estimation of the P requirement is essential for precise feeding to minimize P excretion.

Some producers have adopted the recent research results and reduced P feeding. A recent survey of dairy nutrition consultants and producers in Pennsylvania (Table 8) showed that the most common dietary P level for all production groups of the herd is 0.39-0.44%. These levels are considerably lower than those revealed a few years ago, as mentioned earlier. There are not many herds feeding above 0.50% P. However, even the minimum P (0.35%) used by producers is still equal to the level that can meet the requirement for 77 lb/d of milk (Table 7). Some nutritionists still formulate rations to contain 0.45-0.50% P. Thus, there is still a need for reducing P for the majority of the herds. Needless to say, there is even a bigger need for reducing P for those producers who are feeding above average P levels and yet are reluctant to reduce their amounts (Table 8).

Table 9 lists the P content of some common feeds used for dairy cows in Pennsylvania based on 2000 analyses (Dairy One Co., Inc. Ithaca, NY) in comparison to the NRC (2001) published values. It shows that most of the feeds have a P content larger than that listed in the NRC. Also, there is a wide range of the P content of a given feed. These indicate that feedstuffs need to be analyzed for their P content for ration formulations. If book values are used, the actual P content of the diet would likely be higher than projected. That certainly would not help the farm P balance.

Table 8. Survey on dairy phosphorus feeding in Pennsylvania (2001).

Nutritionists, responded/contacted: 38/80			
Diet P % according to milk production:			
Production group	Min	Max	Ave
High	0.39	0.50	0.44
Medium	0.37	0.48	0.41
Low	0.35	0.45	0.39
Distribution of respondents indicating the most representative P level of formulated diets:			
	0.38-0.42%	0.43-0.47%	0.48-0.52%
Respondent, %	61	34	5
Distribution of respondents in willingness to reduce P to 2001 NRC:			
	Yes	No	
Respondent, %	74	26	
Producers, responded/contacted: 33/200			
Herd P average:			
	Min	Max	Ave
Dietary content, %	0.30	0.51	0.44
Distribution of respondents in willingness to reduce P to 2001 NRC:			
	Yes	No	
Respondent, %	18	82	
Distribution of respondents in thoughts on whether herd is overfed with P:			
	Yes	No	
Respondent, %	9	91	

Table 9. Phosphorus content of Pennsylvania feeds analyzed during 2000 relative to values listed in NRC (2001)[1].

Feed	IFN[2]	N	Average (%)	Ratio to NRC[3]	Low (%)	High (%)	SD
Legume silage	3-07-796	275	0.34	1.06	0.29	0.39	0.05
Legume hay	1-20-648	102	0.29	1.12	0.24	0.33	0.05
Corn silage	3-28-248	1600	0.24	0.92	0.21	0.27	0.03
Shelled corn	4-02-854	34	0.33	1.10	0.27	0.38	0.06
High moisture shelled corn	4-26-265	174	0.31	1.03	0.27	0.34	0.04
High moisture ear corn	4-26-240	52	0.29	1.04	0.26	0.31	0.03
Wet brewers grains	5-00-517	104	0.64	1.08	0.58	0.71	0.07
Whole cottonseed	5-01-614	3	0.86	1.43	0.71	1.15	…
Wheat middlings	4-05-205	10	1.21	1.19	1.00	1.41	0.21
Soybean meal	5-20-638	10	0.79	1.13	0.69	0.84	0.08
Soybeans	5-04-597	2	0.84	1.31	0.72	0.95	…

[1]Provided by Dairy One Co. Inc. Ithaca, NY.
[2]International Feed Number.
[3]Average content divided by the values listed in NRC (2001).

CONCLUSIONS

Dairy producers are facing environmental challenges that call for reductions in manure N and P excretion. We can meet the challenges in P by reducing P feeding to the amounts recommended by the 2001 NRC. This reduction will not affect milk production, reproductive performance, or bone strength, but will result in less manure P and lower feed cost. Nitrogen, on the other hand, presents a bigger challenge. Dietary protein level can only be manipulated moderately without affecting milk production. Contributions from other means including balancing rations for maximal microbial protein production and using synthetic limiting amino acids are all needed for a significant reduction in N excretion.

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