PHOSPHORUS NUTRITION OF DAIRY CATTLE

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INTRODUCTION

Increased environmental concerns and regulations have stimulated renewed interest in phosphorus (P) in dairy cattle rations. The challenge is to design rations with adequate P to meet the needs of the cow while minimizing P excretion to the environment. Environmental regulations, which limit the quantity of P applied to land, are either in place or being considered (Tamminga, 1992; Van Horn et al., 1994). A number of papers have examined the relationships which exist between P intake and excretion in dairy cattle (Brintrup et al., 1993; Chase, 1994; Dhiman et al., 1996; Harris et al., 1992; Morse et al , 1992b; Satter and Dhiman, 1996). Chandler (1996) indicated that P accounts for more than 50% of the cost of typical vitamin-mineral mixes used on dairy farms. Thus, there is rationale from both economic and environmental considerations to minimize feeding P in excess of requirements.

METABOLISM

Phosphorous has a multitude of functions in animals. A primary role is the integrity and development of the skeletal system. Approximately, 80-85% of the total P in cattle is in the bones and teeth (Horst, 1986; NRC 1989). Phosphorus is also involved with cellular energy transfer via the ADP, ATP system. Lipid metabolism is dependent on P, which is a component of phospholipids. Phosphorus is involved in a number of enzyme systems and is a constituent of saliva.

The absorption of P in the dairy cow is affected by a number of factors (Horst, 1986; Miller, 1979 and NRC, 1989). The primary site of P absorption is the small intestine (Care, 1994). This absorption appears to be an active process which is influenced by vitamin D (NRC, 1989). The total quantity of P absorbed is related to the quantity of P consumed, calcium to phosphorus ratio, feed source, age and levels of other minerals such as calcium, magnesium and potassium.

Saliva contains P and can be a significant contributor to the endogenous P pool (Horst, 1986). Any factors that depress saliva flow can shift some of the endogenous P excretion to the urine. One report indicated that P uptake was reduced in cows under heat stress conditions (Sanchez et al., 1994). The authors suggested that decreased endogenous P recycling via saliva could at least be a partial explanation.

The primary route of P excretion is fecal (Hibbs and Conrad, 1983; Morse et al., 1992b). In one study, 68.6% of the total P excreted was in the feces compared with 1% in the urine and 30.3% in milk. The total yearly P excretion of a dairy cow producing 19,800 lbs of milk consuming a ration with 0.4% P was estimated to be 40 lbs (Van Horn et al., 1994). This increased to 70 lbs/cow if ration P was increased to 0.6%. Fecal P excretion was estimated at 30 lbs/year for cows producing 13,750 lbs of milk in a review paper (Tamminga, 1992).

REQUIREMENTS

The NRC (1989) requirements provide the base for most formulation programs in the U.S. However, there is some disparity in the P requirements used for dairy cows in different countries (Tamminga, 1992). Table 1 contains the P requirements for cows at 2 levels of milk production calculated using current systems in 5 countries. There are some large differences in both the maintenance and milk requirements. The variation in total P requirement between countries is smaller. It is apparent that the P requirement for high producing cows needs better definition. The 1989 NRC requirements are 10 to 22% higher than the previous NRC (1978) due to a lowering of the assumed absorption efficiency. It is important to remember that daily requirements are for grams of P

Table 1: Variation in P requirements of dairy cattle[a]

Milk, [b]	Country	P Requirement			Assumed
		Maintenance	Milk	Total	Availability
(lbs)		----------------(grams)------------------			(%)
50	U.S.	17.5	44.9	62.4	50
	Netherlands	25.7	34.0	59.7	60
	UK	12.7	35.4	48.1	58
	France	37.9	28.4	65.9	70
	Germany	24.5	37.6	62.1	60
100	U.S.	17.5	89.8	107.3	50
	Netherlands	25.7	68.0	93.7	60
	UK	12.7	70.8	83.5	58
	France	37.9	56.7	94.6	70
	Germany	24.5	75.3	99.8	60

[a]Adapted from Tamminga, 1992
[b]4% FCM, 1350 lb cow

not P as % of the ration dry matter (**DM**). Rations should be formulated based on the grams of mineral required rather than as a % of DM.

The P requirements for replacement heifers are calculated using 3 equations based on body weight (NRC, 1989). These equations reflect the decreasing availability of ration P as calves get older. In addition, the average daily gain influences the P requirement. Phosphorus requirements of growing heifers range from 0.23 to 0.31% of the total ration DM. Two recent papers indicate that the P requirement of replacement heifers gaining 2.2 lbs/day may range from 0.15 to 0.34% of total ration DM (Bortolussi et al., 1996; Ternouth et al., 1996).

FEED COMPOSITION

The level of P found in feeds used in dairy cattle rations is quite variable. Adams (1975) reported a 10.6 fold range in the P content of legume-grass forage samples. Table 2 contains the mean, standard deviation and normal range for P in a number of feeds. Note the wide normal range for these feeds, which represents about 67% of the total samples analyzed within feed type. The range in P content of forages from the Southern U.S. was previously presented at this conference (Greene, 1997). The mean P content in these forages ranged from 0.1 to 0.66%. The P content in bermudagrass ranged from .02 to .51%. A range from 0.1 to 0.3% P encompassed 91% of the bermudagrass samples. It is important to realize that the samples in all of these summaries are from a large number of sources with diverse crop management and environmental conditions. The variation of P content of forage types grown on the same farm would be considerably less. These variations in P content indicate the importance of forage testing as a base for ration formulation. This will be even more essential as we balance rations to minimize P overfeeding. The median P level in total mixed rations fed to dairy cattle was 1.32 times the requirement at 0.49% (Spears, 1996). The range in P content of these TMR's was 0.36 to 0.66%.

AVAILABILITY

The availability of P in mineral sources has been examined in a number of trials (Jackson et al., 1988; Macrominerals, 1995; Peeler, 1972; Witt and Owens, 1983). Monoammonium phosphate and dicalcium phosphate had similar biological availabilities when used in rations for growing bull calves (Jackson et al., 1988). A recent summary indicated that the biological availability of monosodium phosphate, monoammonium phosphate, sodium tripolyphosphate and diammonium phosphate were all 95-100% (Macrominerals, 1995). Similar values for monocalcium phosphate, dicalcium phosphate, defluorinated phosphate, steamed bone meal, fish meal, and soft rock phosphate were 95-98, 93-95, 88-91, 80-82, 90-95 and 25-35%.

Table 2: Phosphorus content of feeds[a]

Feed	Phosphorus Mean	Phosphorus S.D.[b]	Normal Range[c]
	(%)		
Legume hay	.25	.05	.20 - .30
" silage	.29	.05	.24 - .34
Grass hay	.21	.06	.15 - .27
" silage	.28	.07	.21 - .35
Sudangrass hay	.19	.06	.13 - .25
" silage	.26	.07	.19 - .33
Sorghum silage	.21	.08	.13 - .29
Sorghum-sudan silage	.25	.08	.17 - .33
Corn silage	.21	.03	.18 - .24
Bakery goods	.32	.20	.12 - .52
Beet pulp	.09	.02	.07 - .11
Blood meal	.35	.24	.10 - .59
Brewers grain, dry	.59	.24	.35 - .83
Canola meal	1.13	.18	.94 - 1.31
Citrus pulp	.11	.01	.10 - .12
Corn, shelled	.30	.03	.27 - .33
Corn gluten feed	.96	.29	.67 - 1.25
Cottonseed, whole	.59	.12	.47 - .71
Cottonseed, hulls	.17	.10	.07 - .27
Cottonseed meal	1.12	.14	.98 - 1.22
Distillers grains	.79	.15	.64 - .94
Hominy	.46	.17	.29 - .63
Peanut meal	.52	.15	.37 - .67
Sorghum grain	.29	.07	.22 - .36
Soy hulls	.18	.08	.10 - .26
Soybean meal	.67	.09	.58 - .76
Sunflower meal	.84	--	--
Wheat grain	.41	.15	.26 - .56
Wheat midds	.89	.23	.66 - 1.12

[a]Source: Dairy One Forage Testing Lab, Ithaca, NY
[b]Standard deviation
[c]Mean + or - 1 standard deviation

Table 3: Daily phosphorus intake as a % of the NRC requirement.[a]

Milk	Ration P, % of DM 0.35	0.45	0.55
(lbs/day)		(% of NRC)	
40	110.7	142.5	174.2
60	97.3	125.2	153.0
80	89.3	114.8	140.4
100	83.6	107.5	131.4
120	79.6	102.3	125.0

[a]1350 lb cow, 2nd lactation, 3.5% milk fat

The relative bioavailability of P in canola meal and soybean meal was compared in Holstein bull calves (Ingalls and Okemo, 1994). The total tract disappearance of P was similar for both protein sources at 94-96%. A second component of the trial compared canola meal with a mixture of monocalcium phosphate and dicalcium phosphate. The authors concluded that the bioavailability of P in canola meal was similar to the inorganic P source.

A ruminal P release of 73% was reported for grass silages at a rumen outflow rate of 5%/hour (Rooke et al., 1983). The release of P in the rumen was investigated for 6 forage species (Emanuele and Staples, 1990). The average P release for all forages was 66% with an initial washing in water and 80% after a 72 hour incubation. The release of P was significantly higher for alfalfa than bermudagrass forage at both measurement times. This study did not evaluate total tract P absorption.

Lactating dairy cows were used in a study to examine mineral absorption (Khorasani et al., 1997). The forages used were barley, oats, triticale or alfalfa silages. The absorption of P increased as P intake increased. However, there were no differences in apparent P digestibility between these forages. The average total tract P digestibility was 30.9%.

A publication from Ohio State contains the results of a large number of trials examining calcium and P utilization in dairy cows (Hibbs and Conrad, 1983). These studies used a variety of forage sources with or without grain and vitamin D supplementation. In these studies, P digestion increased when grain was added to forage based rations.

PHYTATE PHOSPHORUS

Phytate phosphorus may account for 50 to 70% of the total P in many concentrates. In monogastrics, the ability to utilize P in the phytate form is limited by low intestinal phytase levels. Rations are commonly formulated using available P rather than total P content of feedstuffs to account for this. There is also considerable interest in the addition of phytase to monogastric diets to enhance P utilization.

The rumen microorganisms have the ability to hydrolyze the phytate P. The apparent total tract hydrolysis of phytate P in young calves and steers was > 99% (Nelson et al., 1976). A study using early lactation dairy cows reported that 98% of the phytate P was hydrolyzed (Clark et al., 1986). Eight concentrates were used to evaluate phytate P hydrolysis both in vitro and in vivo with dairy cows (Morse et al., 1992a). These concentrate mixes contained 32 to 81% of the total P in the phytate form. The in vitro results indicated that > 90% of the P in the phytate form was hydrolyzed. Total tract hydrolysis of the phytate P in this study was > 94%. The results of these studies indicate that adjustments for phytate P levels in feeds do not need to be made when formulating rations for ruminants.

REPRODUCTION

A primary reason indicated for feeding P in excess of requirements in many herds is to enhance reproductive performance. Research data to support this is weak. Many of the early studies reported depressed reproduction when ration P levels were <0.2% (McClure, 1994).

Two trials were conducted with growing dairy heifers to evaluate the role of added P on reproduction (Noller et al., 1977). These workers reported no benefit to adding 0.1% P to basal rations with 0.22% P. A similar result was reported with beef heifers fed basal rations with 0.14% P compared with supplemented rations containing 0.36% P (Call et al., 1978). The intensity of estrus was examined in another trial with dairy heifers (Hurley et al., 1982). Rations containing 73, 138 or 246% of NRC phosphorus requirements were fed to 12-16 month old heifers. Ovarian function, estrous behavior, serum progesterone or serum luteinizing hormone (LH) concentrations were not different between these treatments.

Holstein cows were fed rations containing 0.24, 0.32 and 0.42% P beginning in the 7th month of gestation for a 12 month period (Call et al., 1987). Cows fed the low level (0.24%) of P produced significantly less milk than the other 2 groups. There were no significant differences in reproductive performance in this study. Milk production of these cows was about 15,000 lbs per lactation.

A trial was conducted at Michigan State using 2 levels of energy and P (> 100 and 75% of requirements) in first-lactation heifers (Carstairs et al., 1980). This was a 2 x 2 factorial design conducted for the first 84 days of lactation. There were no differences in this study on reproduction related to either energy or P status of the rations. Actual P intakes for the 2 groups were 98 and 138% of the NRC requirement. Milk production was 1795 lbs lower for cows on the high P ration (Carstairs et al., 1981).

MILK PRODUCTION

There have been very few research trials with lactating dairy cows to define the P requirement. A trial conducted at Oklahoma State used rations containing 0.37, 0.55 or 0.56% P (Steevens et al., 1971). There were no significant differences in milk production during the first 24 weeks of lactation. Average daily milk production in this trial was 39 lbs for first-calf heifers and 45 lbs for second lactation cows. In this trial, there were no differences in milk production with Ca:P ratios of 1.5:1 or 3:1.

A trial at Washington State used rations containing either 1 or 1.7% calcium (Kincaid et al., 1981). Ration P levels of 0.3 an 0.54% were used within each level of calcium. Rations were fed for the first 10 months of lactation. Milk production was about 7% lower (4.4 lbs/day) in cows fed the low P level in the ration. The calcium level fed did not affect milk production. There was an increase in milk production when the high level of calcium was fed to cows receiving the low P ration. The Ca:P ratio in this situation was 6:1.

Rations containing either 100, 150 or 200% of NRC requirements for P, Ca, Zn and Mn were fed to dairy cows for 14 weeks prepartum through 22 weeks of lactation (deBoer et al., 1981). Rations were based on alfalfa silage. Ration Ca content was 0.69%. There were no significant differences in milk production. Actual ration P levels were 0.34, 0.51 and 0.69%. Average daily milk production was about 61 lbs. Another trial fed rations containing 0.24, 0.32 or 0.42% P for a full lactation (Call et al., 1987). Milk production was significantly reduced on the low P ration. There was no difference in milk production for the rations with 0.32 and 0.42% P. Average daily milk production on these rations was 48 lbs.

Two rations providing either 68 or 60 grams of P/day were fed to dairy cows over a 2 year period (Brintrup et al., 1993). The ration P levels were 0.39 and 0.33% on a DM basis. There were no significant differences in milk production for cows averaging 16,500 lbs of milk/year. The effect of dietary P level in rations for mid to late lactation cows was recently reported (Dhiman et al., 1996 and Satter and Dhiman, 1996). Rations contained either 0.39 or 0.65% P. There were no effects on feed intake or milk production in cows producing 53 lbs of milk per day.

ENVIRONMENTAL CONCERNS

Phosphorus is the key mineral being targeted in legislation currently pending in Congress. One proposal will limit the quantity of P applied to land to the amount removed by crops. In a survey of 3 commercial dairy herds in New York, the mass nutrient balance for P ranged between 59 and 75% (Cornell University, 1996, and Tylutki and Fox, 1997). The quantity of P entering the farm via purchased feed ranged from 59 to 85%. Milk production in these herds was between 24,000 and 28,000 lbs of milk/cow.

One question is how much could this P mass balance potentially be lowered. We have used the Cornell Net Carbohydrate and Protein System model on one of these herds for a number of years. Ration formulation has decreased nitrogen excretion by about 30% with a similar calculated reduction in P excretion of about 20%. During this same time, milk production has increased from about 23,500 to 26,000 lbs of milk per cow. Controlled research with high producing dairy cows is needed to verify and better quantify these results.

ADDITIONAL CONSIDERATIONS

Phosphorus should be force fed to dairy cattle via TMRs or concentrate mixes rather than through free choice supplements. Dairy cattle do not have the ability to balance P intake from free choice supplements (Coppock et al., 1972 and 1976). One paper with pregnant heifers indicated that feeding high ration P levels (0.64%) depressed the absorption of magnesium (Schoneville et al., 1994).

The studies available also indicate that a wide range of Ca:P ratios can be used as long as dietary P is adequate (Call et al., 1987; Deitert and Pfeffer, 1993; Kincaid et al., 1981; Rodehutscord et al. 1994 and Steevens et al., 1971). The Ca:P ratios used in these studies ranged from 1.5:1 to 8:1. It is important to remember that salivary P contributes a significant quantity of P to the animal. Thus, the ration Ca:P ratio can be altered by P contributed from saliva.

SUMMARY

1. The phosphorus requirements of the high producing dairy cow are not well defined.

2. Rations should be formulated based on the grams of P required not the % P in the ration. The NRC requirements for Holstein cows producing 60, 80 or 100 lbs of milk are 68, 85 and 100 g of P per day. At normal levels of DM intake, this is equivalent to ration levels of 0.36, 0.39 and 0.42% P. If DM intake were 95% of expected, then ration P levels would be 0.38, 0.41 and 0.44% P.

3. There is little research data to support feeding P in excess of requirements to enhance reproductive performance.

4. The cow, primarily via feces, excretes phosphorus consumed in excess of requirements.

5. Dietary P levels will decrease as we fine tune protein nutrition and decrease the crude protein levels in rations. This is a reflection of the high P levels in most protein supplements (Table 2).

6. Testing of forages for P is essential as an input for ration formulation.

7. Environmental concerns will increase the need to minimize the overfeeding of P.

8. Lowering ration P levels can reduce purchased feed costs.

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