

Impact of Phosphorus on Reproduction and the Environment

Donna M. Amaral-Phillips

As nutritionists, our goal is to provide cattle with the amount of phosphorus needed to optimize performance, health, and efficiency at an economic cost while minimizing the amount excreted via the feces. First, feeding excessive amounts of phosphorus increases the costs of rations. Chandler estimated that approximately 50% of the cost for mineral/vitamin premixes is associated with phosphorus. Secondly, feeding more phosphorus than needed increases the amount of phosphorus that must be dealt with in environmental-nutrient management programs. Thus, adequate, but not excessive amounts, of phosphorus should be provided to cattle.

Role of Phosphorus

Phosphorus is the second most abundant mineral element in the body with 80 to 85% of phosphorus in the body being found in the teeth and bones. Phosphorus is present in bone along with calcium as apatite salts or calcium phosphate. Phosphorus also is an important part of energy, carbohydrate, amino acid, fat, muscle, and nervous tissue metabolism, normal blood chemistry, nucleic acids, and many coenzymes in the body. Essentially, phosphorus is involved in every metabolic reaction and energy transfer within the body. It is required for normal milk secretion, growth, and efficient use of feed and by the rumen microorganisms in the digestion of cellulose and synthesis of microbial protein. Saliva contains phosphorus which serves to recycle phosphorus back into the rumen. Calculations indicate that recycled phosphorus through saliva may supply twice as much phosphorus as the diet itself.

Phosphorus is absorbed in the beginning part of the small intestine through a mechanism regulated through 1, 25 dihydroxyvitamin D but by a different transport mechanism than calcium. Very little phosphorus is absorbed from the rumen, omasum, or abomasum. The greater the need for phosphorus, the more efficient absorption becomes. Absorption of phosphorus is influenced by the source of phosphorus, intestinal pH, age of cattle, and amount of calcium, iron, aluminum, manganese, potassium, and magnesium in the diet. Within normal ratios, this ratio of calcium to phosphorus is not important as long as adequate dietary phosphorus is provided.

In ruminants, the majority of phosphorus is excreted through the feces (69% of the total) with approximately 30% being excreted through the milk and only about 1% being excreted through the urine. This is in contrast to carnivores where the majority of phosphorus is excreted through the urine instead of the feces. Scientists have calculated that 2 to 3 acres of cropland per cow and her replacement heifer are required for manure disposal in order to maintain a zero phosphorus balance on a farm.

When calculating the true requirement for phosphorus, the amount needed for maintenance, milk production, growth and pregnancy are summed. The maintenance requirement for phosphorus is defined as the amount of phosphorus excreted through the feces and urine when phosphorus is supplied at less than the true requirement. Daily maintenance requirements for phosphorus established in the United Kingdom and work by German scientists suggest that excretion of phosphorus is related to total fecal dry matter

excretion and thus is directly related to dry matter intake. This is in contrast to the calculations found in the 1989 version of the “Dairy NRC”. The requirement for growth relates to the amount of phosphorus required for bone growth. With the majority of the growth of the fetus occurring in the last two months of pregnancy, the phosphorus requirement for pregnancy corresponds to this rapid growth of the fetus.

Phosphorus Provided by the Diet

The concentration of phosphorus found in forages varies depending on the plant species, soil fertility, and stage of maturity the forage is harvested (Table 1). Forages need to have their mineral content determined via wet chemistry methods in order to balance rations for phosphorus content. In addition, the phosphorus content of grains varies considerably. Analyzing not only forages but also supplemental energy and protein sources are needed when formulating rations in order to minimize the amount of phosphorus excreted.

Phytate

Two thirds or more of the phosphorus found in cereal grains, oilseed meals, and grain byproducts is organically bound to phytate. Phosphorus bound to phytate is slightly or totally unavailable to monogastrics. However, in ruminants the phytase activity of rumen microbes makes the phosphorus bound to phytate available for absorption. Forages contain very little phytate phosphorus. Thus, in ruminants the total amount of phosphorus can be used to calculate the amount of phosphorus supplied in the diet.

Table 1. Phosphorus content of various forages, grains, and oilseeds. (Berger 1997)

	Number samples	Phosphorus		
		Average %	Ratio Observed/ Book Value ¹	Standard Deviation
Corn silage	8,197	0.23	1.05	0.06
Alfalfa	4,096	0.30	1.38	0.06
Corn grain	912	0.32	0.86	0.07
Ear corn	905	0.29	1.07	0.08
Soybean meal	148	0.72	1.03	0.28
Dried distillers grains	114	0.83	1.17	0.17
Whole cottonseed	110	0.54	0.72	0.09

¹ Average concentration measured divided by value given in US-Canadian Tables of Feed Composition

Phosphorus Deficiencies

Phosphorus deficiencies are seen especially in ruminants that graze forages grown on soils low in phosphorus or those consuming overly mature forages or crop residues with low phosphorus content. In

cattle fed diets deficient in phosphorus, plasma concentrations of phosphorus decrease but the concentration of phosphorus in milk remains constant. In deficient cattle, growth rates, feed efficiency, voluntary feed intake, and reproductive efficiency are decreased. In severely deficient cattle, bone mineral content is decreased and the bones can easily break. The key to preventing phosphorus deficiencies is to consistently supplement cattle on pasture with a free-choice complete mineral (where salt content regulates intake) that provides the proper amount of phosphorus. This means the complete mineral needs to contain the appropriate concentration of phosphorus and cattle need to consume adequate amounts of the mineral.

Free-Choice Phosphorus Supplements

Cattle do not consume the correct proportions and amounts of minerals other than salt to meet their nutritional needs. In the classical studies done by Coppock and others (1972) with growing heifers and milking dairy cows, no evidence was found to support the claim that the appetite of cattle for phosphorus from dicalcium phosphate or deflourinated phosphate coincided with their nutritional needs to correct the deficiency. Thus, phosphorus needs to be force-fed to insure cattle consume adequate amounts either through free-choice mineral supplements where salt regulates intake or through grain mixes.

Milk Production Responses to Phosphorus Supplementation

Table 2 outlines the production and dry matter intake responses of nine research studies published within the last thirty years. Except for one trial, these trials do not show an improvement in dry matter intake or milk production when phosphorus is supplemented above the needs of the cows. In the one trial which showed a positive response (Kincaid et al., 1981) from additional phosphorus supplementation, Beede (1999) suggested the data had not been analyzed properly (incorrect error term used in the statistical analysis). Thus, no improvements in milk production or dry matter intake have been seen in research trials where phosphorus has been supplemented above estimated requirements. In addition, milk composition has not consistently been altered in these studies.

In a recent paper by Satter and Wu (October 1999), they suggested that diets contains should contain 0.38 to 0.41% phosphorus (dry matter basis). They based this recommendation on the results from research studies (see table 2), current feeding recommendations, and feeding practices in Denmark and Israeli. They indicated that typical diets in the US contain 0.36 to 0.38% phosphorus before supplementation so little additional supplementation is needed.

Table 2A. Milk production and dry matter intake responses observed in research trials that compared various dietary concentrations of phosphorus.

	Stevens et al. (1971)				Carstairs et al. (1981)		Kincaid et al. (1981)			
Length of study	first 3 to 16 wks				0 to 12 wks 1 st Lact. Heifers		full lactation			
	Initial year		Second year				% Ca			
							1.0	1.8	1.0	1.8
% Dietary Phosphorus	0.41	0.62	0.40	0.55	0.40	0.50	0.31	0.31	0.54	0.54
DMI (lbs/day)	29.7	28.4	33.7	33.0	33.9	34.0	47.5 ^a	48.8 ^{ab}	49.3 ^b	49.3 ^b
Significance	NS		NS		NS		??inappropriate stats- P< 0.05			
Milk Production (lbs/day)	34.1	32.7	46.6	44.0	51.5	47.7	59.4 ^a	61.4 ^{ab}	65.1 ^b	62.7 ^b
	SCM- NS		SCM- NS		MP- NS		3.5% FCM- ??inappropriate stats- P< 0.05			

SCM= Solids-corrected milk, MP= milk production, FCM= Fat-corrected milk. NS not significantly different.

Table 2B. Milk production and dry matter intake responses observed in research trials that compared various dietary concentrations of phosphorus.

	Call et al. (1987)			Brodison et al. (1989)					
Length of study	First 5.5 mo. - first third			3 year - Northern Ireland					
				Year 1		Year 2		Year 3	
% Dietary Phosphorus	0.24	0.32	0.42	0.35	0.44	0.35	0.44	0.35	0.44
DMI (lbs/day)	50.3 ^a	65.3 ^b	66.1 ^b	Not measured		Not measured		Not measured	
	Dig. Energy Intake P<0.05								
Milk Production (lbs/day)	38.1 ^a	48.8 ^b	46.6 ^b	11,400	10,688	11,442	11,262	10,971	11,037
	FCM- P<0.05			Lactation MP - P<0.05		Lactation MP - NS		Lactation MP - NS	

SCM= Solids-corrected milk, MP= milk production, FCM= Fat-corrected milk. NS not significantly different.

Table 2C. Milk production and dry matter intake responses observed in research trials that compared various dietary concentrations of phosphorus.

	Brintrup et al. (1993)		Dhiman et al. (1996)	
Length of study	2 lactations		mid to late lactation 84 days	
% Dietary Phosphorus	0.33	0.39	0.39	0.65
DMI (lbs/day)	fed as a group		fed as a group	
Milk Production (lbs/day)	55.9	53.9	52.6	53.7
	MP-NS		MP- NS	

SCM= Solids-corrected milk, MP= milk production, FCM= Fat-corrected milk. NS not significantly different.

Table 2D. Milk production and dry matter intake responses observed in research trials that compared various dietary concentrations of phosphorus.

	Wu et al. (2000)			Wu and Satter (2000)			
Length of study	308- d lactation			2 year			
				Year 1		Year 2	
% Dietary Phosphorus	0.31	0.40	0.49	0.31-0.38	0.44-0.48	0.31-0.38	0.44-0.48
DMI (lbs/day)	50.6	49.3	51.5	45.5	44.9	51.0	51.5
	Linear- NS, Quad P<0.01			No stats		No stats	
Milk Production (lbs/day)	77.0	80.3	79.6	65.1	64.5	75.0	74.6
	MP-NS			3.5% FCM- NS		3.5% FCM- NS	

SCM= Solids-corrected milk, MP= milk production, FCM= Fat-corrected milk. NS not significantly different.

Early Lactation - Bone Provides Phosphorus

During early lactation, the 1989 Dairy NRC increased the dietary concentration of phosphorus to compensate for the decrease in dry matter intake observed during early lactation. A recent study by Knowlton and others at Virginia Tech confirms earlier work that increasing the concentration of phosphorus in early lactation may not be appropriate (Table 3). In this study, increasing the concentration of dietary phosphorus increased total phosphorus excretion but did not improve phosphorus balance, dry matter intake, or milk production. These authors concluded that mobilization of bone in response to the needs for

calcium provided a readily available source of phosphorus. Bone stores of phosphorus can be replaced later in lactation when cows are in positive phosphorus balance. This conclusion is supported by data of Wu and others (abstract - 2000) where they fed 0.31, 0.39, or 0.47% P for 2 or 3 years and did not observe a decrease in milk production, bone strength or bone phosphorus content of lactating dairy cows.

Table 3. Effects of concentrations of dietary phosphorus on the amount of phosphorus excreted, phosphorus balance, and apparent phosphorus digestibility in early lactation dairy cows.

	% dietary P			Statistics
	0.34	0.52	0.67	
P intake (g/d)	87.4	133.7	171.7	Linear increase
Fecal P (g/d)	42.5	86.3	113.0	
Urinary P (g/d)	0.32	1.28	3.89	
Total P Excretion (g/d)	42.8	87.6	117.0	
Apparent P digestibility (%)	51.1	33.2	34.4	Quadratic
P Balance (g/d)	-53.1	-50.1	-35.2	NS

Knowlton et al. 2000. J. Dairy Sci. 83(Suppl 1):303.

Effects on Reproduction

Increasing the dietary concentration of phosphorus above requirement does not improve reproductive performance. In the literature, five studies reported no differences in reproductive performance in cows supplemented with different concentrations of phosphorus. Only one report (Steevens et al 1971) observed higher services per conception when dietary phosphorus was 0.40% compared to 0.53 or 0.56% (48 cows of 3 breeds) in the second year. In the second year, services per conception averaged 4.4 for the group receiving 0.41% P compared to 1.9 and 2.8 services per conception for the cows receiving 0.60 and 0.63% P because 6 out of 16 cows received hormonal treatments for ovarian dysfunctions. They observed no differences in services per conception the first year nor in days from calving to first estrus in both the first and second year of the experiment.

In order to evaluate reproductive performance parameters, large numbers of cows per treatment are needed. Wu and Satter estimated with the variation they found in their experiments that a minimum of 250 cows per treatment were needed to detect a 10% difference at a 95% confidence level. They combined their results with six other papers published in the last 30 years which resulted in a total of 785 lactating dairy cows (Table 4). They found that reproductive performance was not different on the lower concentration of phosphorus when compared to cows fed a higher concentration of dietary phosphorus.

Table 4. Summary of the reproductive performance of lactating dairy cows fed lower and higher concentrations of phosphorus (Summary of 7 published reports and 785 cows)

	Phosphorus Concentration (% diet DM)		SE
	Lower (0.32 to 0.40%)	Higher (0.39 to 0.55%)	
Days to first estrus	46	48	4.2
Days to first AI	73	76	3.3
Days open	96	100	4.9
Services per conception	1.8	1.9	0.2
Pregnancy rate	0.87	0.86	0.02

Wu et al. 2000 J. Dairy Sci. 83:1028

Effects of Feeding Excess Phosphorus on the Environment

As nutritionists, we need to provide cattle with adequate amounts of phosphorus to meet their nutritional needs but at the same time minimize the amount of phosphorus excreted to the environment. As the amount of phosphorus supplied in the diet increases above requirements, the excess is excreted via the feces. By minimizing the amount of phosphorus excreted, rations are cheaper at the same time they can protect the environment.

Implications of Excess Phosphorus in Diets for Dairy Cows

Beede (1999) compared six models as to how well they predicted the amount of phosphorus excreted. The model proposed by Van Horn and others (1994) provided the best estimate of phosphorus excretion. This model predicts phosphorus excretion from the following relationship:

$$\begin{aligned} \text{Estimate of phosphorus excretion} = \\ \text{Intake of phosphorus (g/day) minus milk phosphorus (g/d)} \\ \text{(Milk averages 0.09 g P/kg milk)} \end{aligned}$$

The question then becomes what effect does feeding a higher concentration of phosphorus have on the amount of phosphorus that has to be applied to cropland. If we compare a total mixed ration containing 0.6% phosphorus versus one formulated at 0.4%, an additional 1600 kg phosphorus per year would be excreted for a 100-cow milking herd which averages 70 lbs milk and consumes 48 lbs dry matter daily. If we calculate the number of acres of corn silage needed to utilize this phosphorus, an additional 160 acres of corn silage are needed to remove this additional 0.2% phosphorus supplied through the diet. (Assumes 5 tons dry matter per acre with an annual plant removal rate of 0.23% P). These calculations are not intended to imply the amount of cropland needed for environmental stewardship. They are intended to illustrate the need to wisely supplement cows with the amount of phosphorus needed to maintain milk production, growth, and reproductive performance and to prevent over feeding phosphorus.

Take Home Messages

- 1) The majority of phosphorus within the body is found within the bones and teeth. Phosphorus plays a vital role in almost all metabolic reactions and energy transfers within the body.
- 2) Unlike monogastric animals, ruminants can utilize phosphorus bound to phytate because rumen microbes can break down this bond.
- 3) Phosphorus must be provided in adequate amounts for optimal growth rates, feed efficiency, milk production, and reproductive efficiency. However, over-supplementing phosphorus does not improve milk production or reproductive performance. Early lactation cows do not need additional phosphorus because they can mobilize phosphorus from bone to provide the additional phosphorus needed.
- 4) Supplementing diets with more phosphorus than necessary increases the amount of phosphorus excreted in the feces. Thus, to maintain phosphorus balance on a farm more acres of cropland may be needed in the future to dispose of the additional phosphorus supplied through the diet.

References

- Beede, D.K. and J.A. Davidson. 1999. Phosphorus: Nutritional Management for Y2K and beyond. Proc. Tri-State Dairy Nutrition Conference.
- Berger, L.L. 1997. NRC feedstuffs mineral composition data in need of updating. Feedstuffs. January 21, 1997 p. 12.
- Brintrup, R., T. Mooren, U. Meyer, H. Spiekens, and E. Pfeffer. 1993. Effects of two levels of phosphorus intake on performance and faecal phosphorus excretion of dairy cows. J. Anim. Physiol. A. Anim. Nutr. 69:29.
- Brodison, J.A., E.A. Goodall, J.D. Armstrong, D.I. Givens, F.J. Gordon, W.J. McCaughey, and J.R. Todd. 1989. Influence of dietary phosphorus on the performance of lactating dairy cattle. J. Agric. Sci. Camb. 112:303.
- Call, J.W., J.E. Butcher, J.L. Shape, R.C. Lamb, R.L. Woman, and A.E. Olson. 1987. Clinical effects of low dietary phosphorus concentrations in feed given to lactating cows. Am J. Vet. Res. 48:133.
- Carstairs, J.A., R.R. Neitzel, and R.S. Emery. 1981. Energy and phosphorus status as factors affecting postpartum performance and health of dairy cows. J. Dairy Sci. 64:34.
- Chase, L.E. 1999. Animal management strategies- How will they change with environmental regulations? Proc. Cornell Nutr. Conf. p. 65.
- Chase, L.E. 1998. Phosphorus in dairy cattle nutrition. Proc. Cornell Nutr. Conf. p. 212.
- Dairy NRC. 1989. Nutrient requirements for Dairy Cattle. National Academy Press.
- Dhiman, T.R., L.D. Satter, and R.D. Shaver. 1996. Milk production and blood phosphorus concentrations of cows fed low and high dietary phosphorus. US Dairy Forage Res Center 1995 Res. Summaries, Madison, WI. p. 105.
- Kincaid, R. L., J.K. Hillers, and J.D. Cronrath. 1981. Calcium and phosphorus supplementation of rations for lactating cows. J. Dairy Sci. 64: 754.
- Knowlton, K.F., W.A. Wark, and J.H. Herbein. 2000. Phosphorus balance throughout early lactation in dairy cows fed diets varying in phosphorus content. J. Dairy Sci. 83 (Suppl. 1): 303.
- McDowell, L.R. 1992. Minerals in Animal Nutrition. Academic Press.
- Satter, L.D. and Z. Wu. 1999. Phosphorus nutrition of dairy cattle- What's new? Proc Cornell Nutr. Conf. P. 72.
- Steevens, B.J., L.J. Bush, J.D. Stout, and E.I. Williams. 1971. Effects of varying amounts of calcium and phosphorus in rations for dairy cows. J. Dairy Sci. 54:655.
- Valk, H. and L.B.J. Sebek. 1999. Influence of long-term feeding of limited amounts of phosphorus on dry matter intake, milk production, and body weight of dairy cows. J. Dairy Sci. 82:2157.
- Wu, Z. and Satter, L.D. 2000. Milk production and reproductive performance of dairy cows fed two concentrations of phosphorus for two years. J. Dairy Sci. 83:1052.
- Wu, Z., Satter, L.D., and R. Sojo. 2000. Milk production, reproductive performance, and fecal excretion of phosphorus by dairy cows fed three amounts of P. J. Dairy Sci. 83:1028.
- Wu, Z. L. D. Satter, A.J. Blohowiak, R.H. Staffacher, and J.H. Wilson. 2000. Milk production and bone characteristics of dairy cows fed different amounts of phosphorus for two or three lactations. J. Dairy Sci. 83 (Suppl. 1): 303.