DIETARY PHOSPHORUS, EXCRETORY PHOSPHORUS AND ENVIRONMENTAL CONCERNS

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Introduction

Recently the amount of phosphorus in the feeds of cattle has become a significant value in budgeting total farm phosphorus (Van Horn, 1998). The new development of total farm nutrient budgeting has arisen from the mandates born of legislation to control source points of minerals entering streams and aquifers. This paper brings into focus the biological responses in cattle that contribute to the concentration of phosphorus in manure. In developing the present scientific perspective on phosphorus metabolism selected trials from 30 trials at the Ohio Agricultural Experiment Station (Forbes et al., 1922), 181 trials at the Pennsylvania Agricultural Experiment Station (Forbes et al., 1935), 179 trials from the Ohio Agricultural Research and Development Center (Hibbs and Conrad, 1983) and 26 trials from the National Dairy Forage Laboratory (Wu et al., 1998) were used. Using these data phosphorus requirements in the feed are related to phosphorus in milk produced (MP), feed intake, the amount of phosphorus in bacterial debris of undigested dry matter (BP), the total undigested fecal phosphorus (FeP), the calcium to phosphorus ratio (Ca/P), and the availability of added dietary phosphorus (AP).

Digestibility of Phosphorus

The apparent digestibility of phosphorus (DP) increases .47 g per gram of phosphorus consumed (PI), Figure 1. The regression equation was:

$$DP = -3.90 + .47\ PI\ (g/d) \quad (1)$$

The 3.9 grams, the negative intercept, represents inorganic phosphate passing from the blood to the intestine but independent of the dry matter intake. Studies with radioactive phosphorus (P_{32}) showed that much larger amounts of endogenous phosphorus are present (Conrad et al., 1956). There were 14 grams per day in mature steers. It is presumed to be structurally part of the cells and cell walls of bacteria.

In cattle and sheep a large amount of phosphate is recycled to the rumen in saliva (Preston and Pfander, 1964). These salts of phosphoric acid are the most important ruminally buffering systems (Annison and Lewis, 1959). At any one time they also provide about one-half of the phosphate available in the rumen. This is a mechanism of conservation in the ruminants and symbiosis with microbes. Conserving phosphorus is important since significant amounts are lost in bacterial debris and endogenous protein in the feces (Van Soest, 1994).

The computation of the components of fecal phosphorus attributable to microbial matter is complex. Van Soest (1994) implied that it is part of the total microbial protein fraction in the crude protein of feces (6.25 × fecal nitrogen). Microbial protein was estimated as 89.5% of the crude protein in fecal crude protein. In the Ohio trials associated with these reports, the mean fecal nitrogen content was 2.3% of the dry matter (Conrad et al., 1960). The undigested plant nitrogen and nitrogenous volatiles averages about 11%, hence a multiplier of .89 was used to help quantitate the fecal proteins. The mean phosphorus content of rumen bacteria with eight different diets was 1.438% (Durwand and Kawashimo, 1971). Assuming the bacterial matter is 50% protein and crude protein is 6.25 × N, the accumulated multipliers equal .00334, the prediction equation becomes:

$$PB\ (g/d) = .00334\ FDM \quad (2)$$

where PB equals phosphorus in fecal microbial debris and FDM is fecal dry matter. The results are in Table 2. The fecal bacterial phosphorus minus the fixed endogenous phosphorus ranged between 8 and 20 grams per day. These amounts are about one-half of the total fecal phosphorus. As Van Soest (1994) points out this is a major depository for phosphorus and an obligatory requirement. The persistence of this non-conserving pathway is observed best in the drawings of Forbes et al. (1935). Similar results were found in lambs. At 0.29% P in the diet 33% was metabolic fecal P (Preston and Pfander, 1964).

The second major factor having a significant effect on fecal phosphorus is the combination of the calcium and phosphorus intake and the calcium (Ca) to phosphorus (P) ratio (Ca/P). Holemans and Meyer (1963) working with human subjects discovered a quantitative association between Ca and P absorption and their dependence on Ca and P intake. They showed a highly significant correlation (r = .88) between fecal P and fecal Ca divided by the Ca:P ratio in the diet. A simplification of their equation is:

$$\text{Fecal P} = 0.5\,\frac{\text{fecal Ca}}{\text{Ca:P ratio}} \quad (3)$$

or

$$\text{Fecal P} = 0.5\,\frac{\text{fecal Ca}}{\text{Ca intake}} \times \text{P intake} \quad (4)$$

Using 179 Ca and P metabolism trials, Hibbs and Conrad (1983) computed similar regressions for lactating dairy cows. Again the correlation was good (r = .81). The cow equations were:

$$\text{Fecal P} = 0.88\,\frac{\text{fecal Ca}}{\text{Ca:P ratio in the diet}} \qquad (5)$$

or

$$\text{Fecal P} = 0.88\,\frac{\text{fecal Ca}}{\text{Ca intake}} \times \text{P intake} \qquad (6)$$

The difference between the coefficient for humans (0.5) and cows (0.88) is thought to be the difference between pathways of humans; who excrete larger proportions of phosphorus in the urine and the primary intestinal excretory pathway in cows that results in much of the phosphorus excreted as obligatory bacterial P.

Solubilized Ca (digested Ca) in the alimentary tract is another depleting factor reducing P digestibility (Hibbs and Conrad, 1983).

Using the coefficients in equation 1 and combining them proportionately with coefficients of equation 6, we were able to quantitate the approximate amount of fecal P related to the calcium digested (fecal Ca/Ca intake). Results are in Table 2 where 7.6 to 14.9 g of fecal phosphorus was calculated to be associated with the amount of calcium digested. It is not known whether this is a direct effect of more available Ca reacting with P in the gut and passing into the feces or phosphorus following complex pathways into the animals' tissue and being secreted later into the alimentary tract as saliva or from blood.

The unavailable plant phosphorus (8%) was calculated and its partitioning in fecal phosphorus is shown (Table 2).

Dietary Phosphorus

The amount of dietary phosphorus required to maintain phosphorus balance at near 0 in high producing cows and retention of 2 to 6 grams in later lactation is presented in Table 1. More than 0.4% is needed in high producing Holstein cows. The concentration may drop. If the lactating cows are fed in three groupings by milk production the mean concentration in the total herd diets would be about 0.36%. It would be considerable less if the non lactating cattle are factored in. It should be pointed out that the dietary concentration may change with the amount of dry matter eaten, as well as milk phosphorus and fecal phosphorus yields. There are two choices available for overcoming the phosphorus deficit of cows producing large amounts of milk such as 132 pounds shown for line one (Table 1). A very large cow might eat 60 pounds of dry matter daily or the percent phosphorus in the diet may be increased from 0.40 to 0.45%. Either of these will cover the negative balance of ten grams. Negative balances may be tolerated the first 30 to 40 days of lactation, but long-term deficits predispose cows to parturient paresis, hypocalcemia and/or hypophosphatemia.

Julien et al. (1977) studied dry cow diets in 17 herds and related dietary phosphorus and calcium to milk fever incidence. Careful control of daily dietary Ca and P during the dry period to 0.5% Ca (57 g) and .25% P (29 g) limited milk fever incidence to about 6%. In contrast, when Ca was > 0.53% (81 g) and P > 0.25% (42 g), milk fever incidence was 34%. When Ca was low < 0.47% (41 g) and P was high > 0.25% (40 g) milk fever incidence was 24%.

Availability of Phosphorus

Most (60-80%) of the phosphorus in seeds accumulates as a form of phytin. The phosphorus linked as phytin in forages is split off enzymatically in the presence of phytase in the rumen. Thus, phytates become free phosphates in the rumen where they are readily used by rumen microorganisms (Lofgreen and Kleiber, 1954; Morse et al., 1992). Morse et al. (1992) found that 94% of the phytate P was hydrolyzed in the digestive tract. What is important is that most of plant phosphorus is available but must be shared with rumen bacteria and other intestinal microorganisms.

Similarly added phosphate minerals are highly available. Preston and Pfander (1964) found the true digestibility of P in additional dicalcium phosphate to be 91.5% in lambs. When we calculated the partial digestibility of phosphorus added in corn meal and bone meal 92% of the added P was absorbed and used for milk and tissue P (Hibbs and Conrad, 1983). This means that supplemental additions of phosphorus at high levels of milk production will be 92% efficient provided cows are fed for a small positive balance. These marginal additions are independent of metabolic fecal phosphorus which is determined by the total fecal dry matter (Conrad et al., 1956 and Preston and Pfander, 1964).

Environmental Concerns

Phosphorus is a key mineral presently targeted in legislation nationally and in various states. It is important, therefore, to compare the national yield from cattle with some other benchmark population. The total population of people is useful for this comparison. Nationally there are 9.5 million milk cows producing 35 g of P in manure or 333 metric tons per day and 90 million other cattle producing 14 g of manure P or 1260 metric tons daily. Human population excretes on the average 2 g of P per day per person (Potter and Kramer, 1930). With a population of 270,000,000 the excretion of phosphorus equals 540 metric tons. In Florida, 165,000 cows produce 5.8 metric tons of P in manure and 14.3 million people produce 28.6 metric tons (World Almanac, 1998).

Summary and Conclusions

The amount of phosphorus in the diet may be varied between 0.42% P at very high production (55 kg milk) to 0.24% in the dry cow. In this scheme the average across the herd is 0.36% P for the total herd including the dry cows. The decline is 0.003% feed phosphorus per kilogram of milk.

The average availability of phosphorus from all sources up to approximately 40 kilograms of milk (Holstein cows) is 47% for milk and tissue retention. In the region of 40 to 60 kg, P efficiencies of 92% may be expected and transferred to milk from digestible plant and dicalcium phosphate supplements.

Competition by bacteria depleting metabolic phosphorus and which is excreted in manure may equal the amount in average milk production. This becomes an obligatory requirement for phosphorus in the feed.

Finally, it should be pointed out that legislation setting allowances of phosphorus from source points is determined by adversarial procedures whereas the biological requirement for cows is determined as a mean with a normal distribution of variances that represent error terms not easily predicted.

References

Annison, E. F. and D. Lewis. 1959. Metabolism in the rumen. p 135. John Wiley and Sons, New York.

Chase, L. E. 1998. Phosphorus nutrition of dairy cows. Mid-South Ruminant Nutrition Conference. Texas Animal Nutrition Council, Texas Agricultural Ext. Service. Fort Worth, TX.

Conrad, H. R., J. W. Hibbs and A D. Pratt. 1960. Nitrogen metabolism in dairy cattle. Ohio Agricultural Expt. Sta. Res. Bulletin 861. OAES, Wooster, OH.

Conrad, H. R., S. L. Hansard and J. W. Hibbs. 1956. Studies on milk fever V. Excretion and retention of calcium and phosphorus. J. Dairy Sci. 39:1697.

Durand, M. and R. Kawashimo. 1971. The influence of mineral in rumen microbial digestion. In: Digestive Physiology and Metabolism in Ruminants, Ruckenbush and Thivends, eds. Butterworths, London.

Forbes, E. B., A. Black, W. W. Braman, D.E.H. Frear, O. J. Kahlenberg, F. J. McClure, R. W. Swift and L. LeVoris. 1935. The mineral requirements of milk production. Technical Bulletin 319. Pennsylvania A.E.S. State College, PA.

Forbes, E. B., C. H. Hunt, J. A. Schulz, A. R. Winter, and R. F. Remler. 1922. The mineral metabolism of milk cows. 4. Ohio Agr. Expt. Sta. Bull. 363. Wooster, OH.

Hibbs, J. W. and H. R. Conrad. 1983. The relation of calcium and phosphorus intake and digestion and the effects of vitamin D feeding on the utilization of calcium and phosphorus by lactating dairy cows. Ohio Agricultural Research and Development Center Res. Bull. 1150. Wooster, OH.

Holemans, K. C. and B. J. Meyer. 1963. A quantitative relationship between the absorption of calcium and phosphorus. Amer. J. Clin. Nutr. 12:30.

Julien, W. E., H. R. Conrad, J. W. Hibbs and W. H. Crist. 1977. Milk fever in dairy cows VIII. Effect of injected vitamin D_3 and calcium and phosphorus intake on incidence. J. Dairy Sci. 60:431.

Lofgreen, G. P. and M. Kleiber. 1954. Further studies on the availability of phosphorus in alfalfa hay. J. Anim. Sci. 13:258.

Morse, D., H. H. Head and C. J. Wilcox. 1992. Disappearance of phosphorus in phytate from concentrates in vitro and from rations fed lactating cows. J. Dairy Sci. 75:1979.

Potter, M. F. and M. M. Kramer. 1930. Utilization of milk and inorganic calcium and phosphorus. Home Economics 22:923.

Preston, R. L. and W. H. Pfander. 1964. Phosphorus metabolism in lambs fed varying phosphorus intakes. J. Nutr. 83:369.

VanHorn, H. H. 1998. Factors affecting manure quantity, quality, and use. Proceedings of Mid-South Ruminant Nutrition Conference. Texas Animal Nutrition Council, 17360 Coit Road, Dallas, TX.

Van Soest, P. J. 1994. Nutritional Ecology of the Ruminant. pp 128. Comstock Cornell University Press, Ithaca.

Wu, Z., L. D. Satter, R. Sojo and A. Blowhiak. 1998. Phosphorus balance of dairy cows in early lactation at three levels of phosphorus. J. Dairy Sci. 81(Suppl. 1):358.

Table 1. Feed phosphorus computed from amounts used and excreted using fixed inputs for milk produced and dry matter intake per day.

Milk		Feed Intake		Milk P	Excreta P	Balance	In feed	
kg	lb	kg	lb	g	g	g	g	%
60	132	24	52.8	52.8	54.9	-10.0	97.7	.407
55	121	23	50.6	48.4	50.6	-6.5	92.5	.402
50	110	22	48.4	44.0	45.8	-2.7	87.1	.396
45	99	21	46.2	39.6	42.2	-2.0	81.8	.390
40	88	20	44.0	35.2	43.3	2.8	81.3	.407
35	77	19.8	43.6	30.8	43.8	3.0	77.6	.392
30	66	19.5	42.9	26.4	42.8	3.2	72.4	.389
25	55	19.2	42.2	22.0	42.3	3.4	68.5	.357
20	44	18.9	41.6	17.6	43.1	4.5	65.2	.345
15	33	18.6	40.9	13.2	43.7	4.5	61.4	.330
10	22	17.2	37.8	8.8	42.2	4.5	55.6	.323
5	11	16.6	36.5	4.4	37.6	4.5	46.5	.280
0	0	12.7	27.9	0	36.4	6.0	42.4	.333
0	0	10.0	22.0	0	21.8	2.0	23.8	.238

Table 2. Estimates of excreted phosphorus at fixed amounts of milk phosphorus (P) (.088% of milk) and fecal dry matter intake.

Retained	Milk	Excreta, g/d						
g/d	g/d	FDM	Endogenous[2]	Urine	Bacteria[3]	Fecal Ca (%)	P Unavailable	Total
-10.0	52.8	7272 (30.3)	3.9	.10	20.1	12.5	8.42	54.9
-6.5	48.4	6969 (30.3)	3.9	.10	19.7	12.8	7.78	50.6
-2.7	44.0	6666 (30.3)	3.9	.16	18.6	12.1	7.49	45.8
0	39.6	6363 (30.3)	3.9	.16	17.6	11.8	6.87	40.2
2.8	35.2	6840 (34.2)	3.9	.16	19.2	13.1	6.79	43.3
3.0	30.8	6900 (34.2)	3.9	.16	19.3	13.3	6.73	43.8
3.2	26.4	6772 (34.2)	3.9	.16	18.9	13.6	6.28	42.8
3.4	22.0	6669 (34.2)	3.9	.16	18.6	13.7	5.87	42.3
4.5	17.6	6787 (34.2)	3.9	.25	19.0	14.3	5.64	43.1
4.5	13.2	6854 (35.7)	3.9	.25	19.3	14.9	5.31	43.7
4.5	8.8	6640 (35.7)	3.9	.25	18.5	14.7	4.80	42.2
4.5	4.4	5951 (35.7)	3.9	.25	16.2	13.5	4.04	37.6
6.0	0	5712 (45.0)	3.9	.26	15.4	13.2	3.64	36.4
6.0	0	3420 (46.0)	3.9	.26	7.6	7.6	2.39	21.8

1) % indigestibility used.
2) See figure 1 in text.
3) Bacterial debris and cells in feces. Holstein cows may yield as much as 1600 grams daily containing 1.436 % phosphorus.
4) Effect of the % digestible calcium in the diet (Hibbs and Conrad, 1983).
5) Eight percent of plant and supplement phosphorus unavailable. See text.

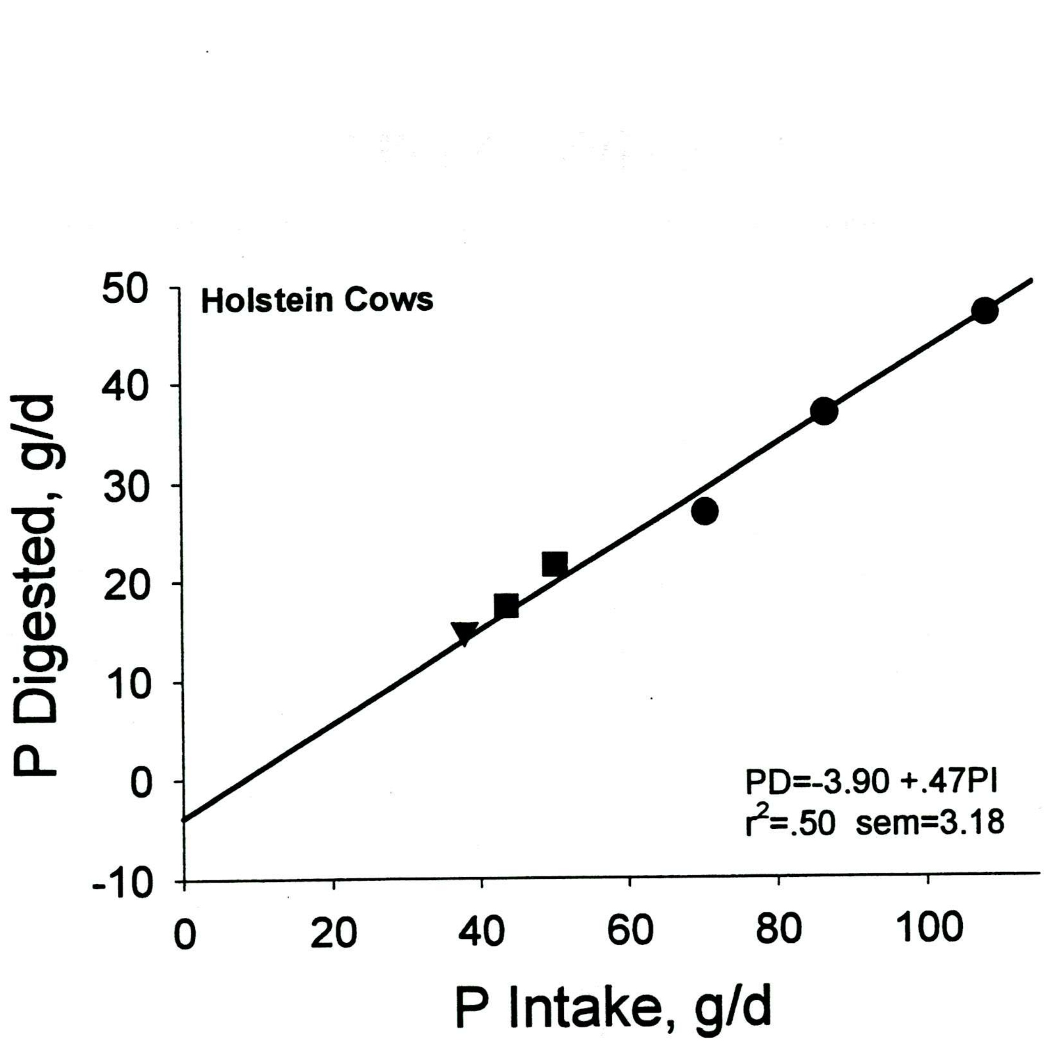

Figure 1. The close association between phosphorus intake and phosphorus digested in balance trials with dairy cows at experiment stations over a 76 year period. (● 1988, National Dairy Forage Laboratory), (—— 1983, Ohio Agricultural Research and Development Center),∇ 1922, Ohio Agricultural Experiment Station) and (■ 1935, Pennsylvania Agricultural Experiment Station).