EFFECTS OF PHOSPHORUS AND CALCIUM ON FEED INTAKE AND YIELD AND COMPOSITION OF MILK OF HOLSTEIN COWS

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Summary

Three concentrations of P (0.33, 0.43 and 0.54%) and two concentrations of Ca (0.60 and 0.97%) in ration dry matter were evaluated for effects on dry matter intake and on milk yield and composition using 24 Holstein cows. Cows were arranged in a 3×2 factorial experiment as an incomplete randomized block design with three 28-day periods. Each cow consumed at least one ration with each concentration of Ca. Dry matter intake, yield of 3.5% Fat Corrected Milk, and milk composition were not affected by concentration of P, but milk yield was greater when lowest concentration of P was fed (22.8 vs. 22.1 kg/day; $p<0.07$). Cows fed rations containing 0.60% Ca had greater milk (22.7 vs. 21.9 kg/day; $p<0.02$) and 3.5% Fat Corrected Milk yields ($p<0.03$) and slightly greater protein content than when fed 0.97% Ca. Dietary Ca:P ratios between 1.1:1 and 2.9:1 had no effect on dry matter intake, milk yield, or composition. Concentrations of P in plasma were within the normal range for all rations. Because cows had high dry matter intake, mean daily intakes of both P and Ca were greater than required for their level of milk yield.
(Key Words: Phosphorus, Calcium, Milk Yield, Milk Composition, Feed Intake, Dairy Cows)

Introduction

For optimal milk yields, animal health, and reproductive performance, feeding programs for dairy cattle must provide sufficient nutrients. Also, they should minimize, as much as possible, excretion of nutrients that could contribute to environmental degradation. Few researchers have evaluated the effects of concentrations of dietary Ca and P on milk yields of lactating cows (Carstairs et al., 1981; Kincaid et al., 1981; Roussel et al., 1990; Steevens et al., 1971). Authors concluded that P in diet dry matter (DM) should not exceed that recommended (NRC, 1978 and 1989), based upon cow weight and level of milk yield (i.e., 0.32-0.40% of diet DM).

Requirements of Ca and P for lactating cows are calculated as grams per day based upon parity, body weight, milk yield and pregnancy status (NRC, 1989). Thus, feeding rations containing a certain concentration to meet daily needs assumes that dry matter intake (DMI) is not greatly above or below that required to provide recommended daily intakes and that neither Ca nor P are fed free choice (Coppock et al., 1972).

When Holstein cows were fed a constant amount of DM (20 kg/d) with different P concentrations (0.30, 0.41 and 0.56%), P excretion through feces increased by 0.55 g/d for each gram extra P intake (Morse et al., 1992). Although excretion of P was changed by altering concentration of P in diet DM, and thus P intake, effects of P on DMI were not evaluated because DMI was restricted to 20 kg/day. Inadequate or excess intake of P may decrease DMI and utilization of nutrients, decrease concentration of inorganic P in blood plasma, and cause loss of body weight and mineral imbalance (Call et al., 1987; Hibbs and Conrad, 1983; Horst, 1986; Witt and Owens, 1983). Feeding excess P is costly, increases excretion of P in feces (Morse et al., 1992; Van Horn, 1991), and may cause a reduction in milk yield (Call et al., 1987; Hibbs and Conrad, 1983; Kincaid et al., 1981; Morse et al., 1992). Furthermore, excretion of minerals and organic compounds by animals, especially P and compounds containing N, is important to livestock producers and regulatory agencies responsible for maintaining quality of surface and ground water

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(Lanyon, 1992; Tamminga, 1992; Van Horn, 1991). Reduction in excretion of P results from decreasing cows' intake to better match their needs or by increasing output in the milk or meat produced (Tamminga, 1992). Thus, dietary manipulation of nutrient intake is one practice to address environmental quality. Objectives of this experiment were to determine the short-term effects of feeding different concentrations and ratios of P and Ca on DMI and on yield and composition of milk.

Materials and Methods

Cows and feeding

Twenty-four lactating Holstein cows (11 primiparous) were used in a 3 × 2 partially balanced incomplete randomized block design. Cows were 101 ± 35 days in milk ($\bar{x}\pm$SD; DIM) at assignment. Three dietary concentrations of P and two concentrations of Ca were evaluated (table 1). Concentrations of P were 0.33, 0.43 and 0.54% of ration DM, which represented adequate, high, and excess of concentrations recommended for dairy cows such as those on the study that were producing 22-24 kg/day of 3.5% FCM (0.35% of ration DM; NRC, 1989). Concentrations of Ca were 0.60 and 0.97% of ration DM, high and excess of that recommended (NRC, 1989).

Cows were housed in a free-stall barn equipped with Calan gates (American Calan Electronics, Northwood, NH) and had access to outside lots for exercise. Total mixed rations (TMR) were fed twice daily at 09:00 and 14:30 hours, and fresh water was available for *ad libitum* intake. Basal ration (table 2) was formulated to contain 0.33% P and 0.60% Ca of ration DM. The two greater concentrations of P were obtained by addition of monoammonium phosphate with reductions of urea to balance the N content of the ration. Higher concentration of Ca (0.97%) was achieved by addition of feed grade $CaCO_3$.

TABLE 1. CONCENTRATIONS AND RATIOS OF Ca AND P IN DIET DRY MATTER[1]

Concentration of Ca	Concentration of P					
	0.33% DM		0.43% DM		0.54% DM	
% DM	Ratio	Ration no.	Ratio	Ration no.	Ratio	Ration no.
0.60	1.8	1	1.4	2	1.1	3
0.97	2.9	4	2.3	5	1.8	6

[1] Means of chemical analyses of composite samples of total mixed rations averaged across periods. Analyses conducted in Dairy Science Nutrition Laboratory, Gainesville, FL.

TABLE 2. COMPOSITION OF BASAL RATION

Ingredient	% of Diet DM
Ground corn	49.15
Corn silage	17.98
Cottonseed hulls	15.41
Soybean meal (48% CP)	13.48
Urea	1.73
$CaCO_3$	1.02
Trace-mineralized salt	0.84
Magnesium oxide	0.32
Monoammonium phosphate	0.07

Cows were trained to use the feeding gates during a 12-day adjustment period, during which they consumed the basal ration (0.33% P, 0.6% Ca) *ad libitum*. Thereafter, cows were assigned randomly to be fed three of the six rations: one ration during each of the three 28 day-periods. Each cow consumed at least one ration with each concentration of Ca. All 24 cows provided data during all three periods.

Sample collection and analyses

Concentrates were mixed every 3 to 4 weeks, sampled once weekly, and analyzed for concentrations of P and Ca (AOAC, 1984; Fick et al., 1979). Corn silage was sampled three times weekly and cottonseed hulls biweekly for determination of DM and concentrations of P and Ca (AOAC, 1984; Fick et al., 1979). Mean nutrient composition for each of the six rations is in table 3. Refused feed was collected daily, weighed and sampled during the last 7 days of each period for determination of DMI based on DM offered and refused.

Milk weights were recorded for a.m. (06:00-07:00 hours) and p.m. (18:00-19:00 hours) milkings, and milk yields were averaged for the last 7 days of each period. Analyses for milk components were on individual milk samples obtained during the last 3 days of each period (six milkings). Percentages of fat, protein, lactose, and the somatic cell count were determined (Dairy Herd Improvement Testing Laboratory, Blacksburg, VA). Average daily percentages of components were corrected for a.m. and p.m. milk yields for days 22 through 28.

Samples of blood were obtained from cows once weekly between 07:30 and 08:30 hours, after the a.m. milking but before a.m. feeding. Samples were collected from the coccygeal vein or artery into heparinized tubes (10 ml, vacutainer; Becton-Dickson Co., Rutherford, NJ), stored on ice, and centrifuged within 1 hour at 770 × g for 15 minutes; plasma was harvested and frozen until analyzed for P (Fick et al., 1979). Samples that were hemolyzed were discarded and replacements were obtained the next day. Only samples taken during the final 7 days of the 28-day period were used in the statistical analysis. This provided a 21-day adjustment period prior to testing for effects of treatment.

Statistical analyses

Data were analyzed by method of least squares ANOVA using the general linear models procedures (SAS, 1985). Variation of all dependent variables was attributed to age, cow in age, period, diet, and age × period. Significance was declared at $p < 0.05$ unless otherwise indicated.

Results and Discussion

Chemical analyses of composite samples of TMR across periods were used to obtain nutrient analyses in table 3. Results of the statistical analyses are in table 4. Average daily DMI adjusted for age of the cow and treatment decreased from 24.7 in period 1 to 23.0 kg/day in period 3 (SE = 0.4). Concentrations of P or Ca in the TMR did not affect DMI, but there was a small and nonsignificant trend for DMI to increase as concentration of P decreased. Consumption of P exceeded requirements for all diets because DMI was greater than expected for cows producing about 22-24 kg/day of milk. Cows consumed an average of 80, 102 and 127 g/day of P, whereas requirements of cows producing 21-32 kg/day of 3.5% FCM would be 58-80 g/day of P. Because intakes of P were 22 and 47 g/day greater than recommended for the two higher concentrations of P fed, and the excess largely would be excreted in feces by cows (Morse et al., 1992), the potential for environmental contamination would be greater. Although amount of P in urine increased over 450% when cows were fed the high P diet (0.54% of ration DM), the absolute amount excreted via urine still was much less than that excreted in the feces (Morse et al., 1992). If excreted materials were distributed on land for uptake by crops it might necessitate additional cropping practices to ensure that the excess minerals and N compounds applied to the land did not contaminate surface or ground water (Lanyon, 1992; Tamminga, 1992).

When milk yields were adjusted for age of cow, period, and concentration of Ca in the ration, effect of concentration of P was significant ($p < 0.09$). Cows consuming lowest concentration of P produced more milk (22.8 vs. 22.3 and 21.8 kg/day of milk; $p < 0.07$) than when fed rations with greater concentrations of P (0.43 and 0.54%). Actual milk and 3.5% FCM yields for cows fed 0.43 or 0.54% P did not differ.

Results of our short-term study (28-day periods) differed from those for a full lactation study (Kincaid et al., 1981). These authors found that cows fed a diet containing 0.3% P and 1% Ca consumed 3.6% less DM and produced 10.2% less milk or 8.8% less 3.5% FCM during a 10-month lactation than cows fed 0.54% P and 1% Ca. Concentrations of P and Ca in the latter rations were 1.3- and 2.8-fold greater than formerly recommended (NRC, 1978) and greater than fed during the current study. The low P diet provided about 10% less P than required for cows yielding greater than 25 kg/day of milk (Kincaid et al., 1981; NRC, 1978), whereas absolute intakes of P were adequate or in excess of needs of cows in our study. In another study (Carstairs et al., 1981), cows fed diets adequate in P (0.4% of diet DM, 98% of requirement) and Ca (0.6% of diet DM) for 12 weeks yielded 1.8 kg/day more milk ($p < 0.10$) between 5 and 12 weeks than cows fed 135% of P requirement. Feeding concentrations of Ca greatly exceeding that required may result in formation of mono- or dicalcium phosphates which can reduce P availability. When both P and Ca are fed in excess of requirements, P absorption still may be adequate, even if there is formation of calcium phosphates.

TABLE 3. NUTRIENT COMPOSITION OF TOTAL MIXED RATION COMPOSITE SAMPLES[1]

Nutrient	Ration					
	1	2	3	4	5	6
	(%) of DM					
CP	16.1	15.4	15.4	15.6	13.5	14.7
ADF	23.1	22.6	21.2	21.0	24.5	22.4
NDF	35.9	36.0	36.4	35.5	39.9	36.1
TDN	75	75	77	77	74	76
NE_L (Mcal/kg)	0.70	0.71	0.72	0.72	0.69	0.71
Ca	0.60	0.61	0.63	0.95	0.79	0.91
P	0.33	0.42	0.48	0.33	0.37	0.51
K	1.01	1.03	1.00	0.99	1.02	1.01
Mg	0.41	0.42	0.37	0.41	0.43	0.41
Na	0.49	0.49	0.52	0.56	0.55	0.54
	(parts per million)					
Fe	496	593	421	433	487	513
Zn	42	37	36	36	37	37
Cu	21	23	15	22	27	15
Mn	128	138	84	130	178	84
Mo	1.8	1.9	1.5	1.5	1.5	1.8

[1] Analyzed at New York Dairy Herd Improvement Forage Testing Laboratory, Ithaca, NY.

Percentages of fat, protein, and lactose were not affected by concentration of P in diet when results were adjusted for age of cow, period, and concentration of Ca (table 4). This agreed with reports that concentrations of P in the range 0.32 to 0.57% of diet DM did not alter protein or fat percentages of milk (Call et al., 1987; Kincaid et al., 1981). Protein percentage of milk was reduced, but not fat percentage or P concentration of milk, when cows were fed 0.24% P in diet DM (Call et al., 1987). This concentration of P was approximately 40% less than required by cows producing 27 kg/day of milk at the start of the lactation (NRC, 1989) and resulted in decreased DMI and in a further reduction in total intake of P.

Milk and 3.5% FCM yields differed for the cows fed the two concentrations of Ca (table 4). Cows fed diets containing 0.6% Ca yielded 0.8 and 1.0 kg/day more milk ($p < 0.02$) or 3.5% FCM ($p < 0.03$) than those fed 0.97% Ca. Very small, but significant, effects of Ca concentration on protein percentage were detected (table 4). No reason for this small effect was apparent. Generally, no effects of Ca concentration on milk composition have been detected when concentrations of Ca in the diet have been adequate (Kincaid et al., 1981; NRC, 1989; Wohlt et al., 1986). Kincaid et al. (1981) reported no differences in milk yield attributed to concentration of Ca in diet when concentrations were 1.0 and 1.7% Ca of ration DM. Lowest concentration of Ca they fed about equaled the highest Ca concentration fed to cows in our experiment. This intake of Ca (350 g/day) was almost two times greater than currently recommended for high yielding dairy cows not receiving fat supplement in the diet (NRC, 1989). Calcium retention by dairy cows fed 0.97% Ca in the ration DM was greater than cows fed 0.63%, although neither source nor percentage of Ca affected milk yield over an 18-week period (Wohlt et al., 1986). Milk yield was less, but milk composition was unchanged when a readily available source of Ca (albacar) was compared with other less readily available sources (aragonite or calcite flour) fed in rations containing 0.97% Ca, perhaps as a result of an imbalance or excess of diet Ca.

TABLE 4. LEAST SQUARES ANOVA FOR DEPENDENT VARIABLES, PROBABILITY VALUES, COEFFICIENTS OF VARIATION, AND LEAST SQUARES (LS) MEANS FOR MODELS ANALYZED

		Dependent variable[1]						
Source	df	DMI	MY	3.5% FCM	FAT %	PRO %	LAC %	BLD-P
Age	1	0.31	0.01	0.03	0.11	0.09	0.01	0.04
Cow (age)	22	0.01	0.01	0.01	0.01	0.01	0.01	0.02
Period	2	0.01	0.01	0.01	0.24	0.01	0.01	0.65
Treatment								
P	2	0.77	0.09	0.37	0.56	0.74	0.72	0.15
0.33 vs. 0.43 and 0.54	1	0.54	0.07	0.17	0.97	0.88	0.46	0.10
0.43 vs. 0.54	1	0.73	0.25	0.85	0.29	0.46	0.75	0.26
Ca	1	0.47	0.02	0.03	0.66	0.01	0.33	0.71
P × Ca	2	0.45	0.57	0.72	0.95	0.78	0.87	0.61
Age × Period	2	0.79	0.03	0.02	0.24	0.23	0.66	0.59
CV		8.0	5.4	7.4	7.3	2.3	1.1	14.3
R^2		0.80	0.96	0.91	0.80	0.94	0.94	0.64
LS Means	(% of DM)	(............ kg/d	....	............)	(....................	.... %	....	............)
	0.33	24.1	22.8	24.0	3.9	3.5	4.9	7.0
P	0.43	23.8	22.3	23.3	3.8	3.5	4.9	7.7
	0.54	23.6	21.8	23.2	3.9	3.5	4.9	7.3
SE		0.4	0.3	0.4	0.1	0.02	0.01	0.2
Ca	0.60	23.7	22.7	24.0	3.9	3.51	4.9	7.4
	0.97	24.0	21.9	23.0	3.9	3.45	4.9	7.3
SE		0.3	0.2	0.3	0.1	0.01	0.01	0.2

[1] Dependent variables. DMI = dry matter intake; MY = actual milk yield; FCM = 3.5% fat corrected milk; FAT % = milkfat percentage; PRO % = protein percentage; LAC % = lactose percentage; BLD-P = concentration of P in plasma (milligrams per deciliter).

Ratios of Ca : P in TMR were 1.1 to 2.9 (table 1). No significant effects on DMI, milk yield, or milk composition were detected from ratio of Ca : P. During a 40-week lactation study with 48 cows, feeding Ca : P ratios from 1.5 : 1 to 3.0 : 1 did not affect milk yield, milk composition, or persistency of lactation when concentrations of P in diet DM were 0.4 or 0.6% (Steevens et al., 1971). These results would be expected, because actual intakes of P and Ca were greater than required for level of milk yield of the cows. No difference in milk yield response of cows was detected when they were fed rations with wider Ca : P ratios (Smith et al., 1966). Ratios of Ca : P fed may be a poor indicator of ratio in the material reaching the lower digestive tract because of extensive recycling of P in the saliva, variable recycling of Ca, and differences in the rate at which these minerals become available from ingested feeds (Horst, 1986; NRC, 1989; Wohlt et al., 1986). Intakes of P much greater than required occurred when cows were fed diets with the higher concentrations of P. Ruminants apparently can tolerate wide Ca : P ratios without a noticeable reduction in P availability (Horst, 1986). As long as the concentrations of dietary Ca and P are adequate (NRC, 1989), ratios ranging from 1.2 : 1 to 5 : 1 are acceptable in most feeding situations with lactating cows (Hibbs and Conrad, 1983; NRC, 1989; Smith et al., 1966; Wohlt et al., 1986).

Concentration of P in plasma of cows fed the six rations was within the range normally expected (4 to 8 mg/day; table 4; e.g. Roussel et al., 1990; Wohlt et al., 1986), indicating that *P status was adequate during the short-term* feeding periods evaluated. Concentrations of P in plasma were not affected by rations fed. This agreed with data reported in NRC (1989); however, there was a trend for cows fed the ration with the lowest concentration of P in DM to have slightly less P in plasma than those fed rations with the greater concentrations of P (table 4; $p<0.10$; least squares means, 7.0 vs. 7.7 and 7.3 mg/dl), but all were within expected range for cows consuming either 0.4 or 0.6% P during lactation (Call et al., 1987; Carstairs et al., 1981; Roussel et al., 1990). Feeding lactating cows 0.24% P in diet DM led to persistently low concentrations of P in serum (Call et al., 1987), but not when concentration of P in ration DM fed was at least 0.32% or greater (Call et al., 1987; Kincaid et al., 1981; Steevens et al., 1971; Wohlt et al., 1986). When concentrations of P in rations were very low, deficiency of P was exacerbated by a decrease in DMI, which further reduced intake of P (Call et al., 1987).

Conclusions

Overall, results of this short-term lactation trial indicated that 0.33% P and 0.60% Ca in diet DM, provided about 80 and 142 g/day of P and Ca, which were adequate or in excess of needs of lactating Holstein cows when milk yield was less than 24 kg/d. High DMI was responsible, in part, for the high intakes and further indicates that concentration of these minerals in diet DM and actual daily DMI of lactating cows both are important (NRC, 1989). Greater concentrations of P and Ca than these in ration DM resulted in high and excess intakes of P and Ca and decreased yields of milk and 3.5% FCM, but no changes in milkfat percentage. Greater concentrations of P and Ca in ration DM and greater DMI would meet requirements of higher-yielding dairy cows, where more of these minerals would be secreted in the milk (Hibbs and Conrad, 1983; Morse et al., 1992). Concentration and actual intake of Ca and P by lactating cows is more important than absolute ratio of Ca : P fed (Hibbs and Conrad, 1983; Kincaid et al., 1981; Morse et al., 1992; Steevens et al., 1971). Feeding nutrients to meet animal needs will reduce feed costs, improve efficiency of production, and improve animal well-being (NRC, 1989; Morse et al., 1992). The additional need to establish whole farm nutrient plans and to apply nutrients to land to meet and not exceed crop needs is another reason to feed appropriate amounts of nutrients to animals.

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Literature Cited

AOAC, 1984. Official methods of analysis. 13th ed. Sec 7.099. AOAC, Washington, DC.

Call, J. W., J. E. Butcher, J. L. Shupe, R. C. Lamb, R. L. Boman and A. E. Olson. 1987. Clinical effects of low dietary phosphorus concentration in feed given to lactating dairy cows. Am. J. Vet. Res. 48:133-136.

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. 64:34-41.

Coppock, C. E., R. W. Everett and W. G. Merrill. 1972. Effect of ration on free choice consumption of calcium-phosphorus supplements by dairy cattle. J. Dairy Sci. 55:245-256.

Fick, K. R., L. R. McDowell, P. H. Miles, N. S. Wilkinson, J. D. Funk and J. H. Conrad. 1979. Methods of mineral analysis for plant and animal tissues. 2nd ed. Anim. Sci. Dep., Univ. Florida., Gainesville.

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 Agric. Exp. Stn. Res. Bull. 1150, Columbus.

Horst, R. L. 1986. Regulation of calcium and phosphorus homeostasis in the dairy cow. J. Dairy Sci. 69:604-616.

Kincaid, R. L., J. K. Hillers and J. D. Cronrath. 1981. Calcium and phophorus supplementation of rations for lactating cows. J. Dairy Sci. 64:754-758.

Lanyon, L. E. 1992. Implications of dairy herd size for farm material transport, plant nutrient management, and water quality. J. Dairy Sci., 75:334-349.

Morse, D., H. H. Head, C. J. Wilcox, H. H. Van Horn and Jr. B. Harris. 1992. Effect of concentration of dietary phosphorus on amount and route of excretion. J. Dairy Sci. 75:3039-3949.

National Research Council. 1978. Nutrient requirements of dairy cattle. 5th ed. Natl. Acad. Sci., Washington, DC.

National Research Council. 1989. Nutrient requirements of dairy cattle 6th rev. ed. Natl. Acad. Sci., Washington, DC.

Roussel, J. D., E. Fraering, M. S. Rahmanian, J. K. Thibodeaux and L. L. Goodeaux. 1990. Effects of lactation on various blood parameters in Holstein cows. II. Serum minerals and enzymes. Prof. Anim. Sci. 6:17-23.

SAS Users Guide: Statistics. Version 5th edition. 1985. SAS Inst. Inc., Cary, NC.

Smith, A. M., G. L. Holck and H. B. Apafford. 1966. Re-evaluation of nutrient allowances for high-producing cows. I. Calcium, phosphorus, and Vitamin D. J. Dairy Sci. 49:239-243.

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. 54:655-661.

Tamminga, S. 1992. Nutrient management of dairy cows as a contribution to pollution control. J. Dairy Sci. 75:345-357.

Van Horn, H. H. 1991. Achieving environmental balance of nutrient flow through animal production systems. Prof. Anim. Sci. 7:22-34.

Witt, K. G. and F. N. Owens. 1983. Phosphorus ruminal availability and effects on digestion. J. Anim. Sci. 56:930-937.

Wohlt, J. E., D. E. Ritter and J. L. Evans. 1986. Calcium sources for milk production in Holstein cows via changes in dry matter intake, mineral utilization, and mineral source buffering potential. J. Dairy Sci. 69:2815-2824.