Influence of Variations in Dietary Calcium: Phosphorus Ratio on Performance and Blood Constituents of Calves[1]

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An interrelationship in the metabolism of calcium and phosphorus has long been recognized and the proper ratios of the two have been established for many species of simple-stomach animals. For these species it is generally agreed that the optimal ratio of Ca:P lies between 1:1 and 2:1.

Although levels of the two elements involved influence the optimal ratio, research with rats has indicated that ratios ranging from 1:1 to 2:1 are desirable (Bethke et al., '32; Cox and Imboden, '36; Boutwell et al., '46). In growing chicks it appears that Ca:P ratios from 1:1 up to 2.5:1 may be used with satisfactory results (Bethke et al., '29; Wilgus, '31). Growing swine exhibit optimal performance when fed diets containing ratios from 1:1 to 2:1 (Bethke, '33) with the optimum being about 1.4:1 for the 100-pound pig (Chapman et al., '55).

Strangely enough, optimal ratios of Ca:P for ruminants have received little attention in the past. Huffman et al. ('33) observed satisfactory growth among dairy calves fed a ration based on alfalfa hay and containing calcium and phosphorus at a ratio between 4:1 and 5:1. Theiler et al. ('37) stated that a Ca:P ratio of 4:1 did not significantly affect performance of growing beef heifers and steers when an adequate amount of phosphorus was supplied in the ration. The National Research Council ('49) summed up the situation with respect to ruminants by the statement, "It is recognized that not all are agreed on the question of the requirements for calcium and phosphorus nor on the optimum calcium-phosphorus ratio."

The research reported herein was designed to determine the optimal Ca:P ratio or the range over which the ratio may vary without harmful effects on growing cattle, and to study the influence of variations in dietary calcium and phosphorus on the metabolism of certain micronutrients.

EXPERIMENTAL PROCEDURES

Forty-five Hereford calves averaging 114 kg were used in a factorial experiment (Snedecor, '56) with three levels of calcium and three levels of phosphorus resulting in 9 Ca:P ratios ranging from 0.4:1 to 14.3:1. The study consisted of 5 replications (four of steers and one of heifers) assigned to blocks on the basis of body weight within sexes. Two replications of the design were completed during one period and three other replications were conducted during a second period. The 5 replications were sufficiently similar to allow pooling of the data and consideration of the combined results.

A period of 4 weeks was used to accustom the young calves to a dry diet after separating them from their dams at 3 to 4 months of age. During the terminal week of this transition period the diet was changed gradually to a low-calcium, low-phosphorus semi-purified basal one, the composition of which is shown in table 1.

The basal diet analyzed 0.17% phosphorus (Koenig and Johnson, '42) and 0.27% calcium (McCrudden, '10, with modifications). Levels and ratios of cal-

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cium and phosphorus were obtained by addition of varying amounts of calcium carbonate, defluorinated rock phosphate and dibasic sodium phosphate to the basal diet. These additions resulted in the design represented in table 2.

The animals were housed in individual tie stalls with concrete floors. Wood shavings were used for bedding. The calves were individually fed, ad libitum, throughout a test period of 98 days for the first two replications and 112 days for the last three replications.

Daily feed intakes were recorded and body weights were measured at two-week intervals. Blood was sampled by jugular puncture, initially and at 14-day intervals thereafter. Serum calcium was determined by the method of Weybrew et al. ('48) and serum inorganic phosphorus was assayed by the Simonsen et al. ('46) method. The analytical procedure of Simonsen et al. ('47) was employed for serum magnesium determinations, and serum alkaline phosphatase activity was assayed by the method of Bessey et al. ('46).

TABLE 1

Composition of basal diet[1]

	%
Degerminated corn meal	40.0
Beet pulp and dried molasses	15.0
Glucose·H_2O[2]	15.0
Corn oil	5.0
Corn starch	14.5
Blood meal	9.0
Urea	0.5
NaCl	1.0
Trace minerals[3]	—

[1] Vitamin A and D concentrates were added to supply 1,531 IU of vitamin A activity and 295 IU of vitamin D/kg of feed.
[2] Cerelose, Corn Products Company, Argo, Illinois.
[3] A trace mineral mixture supplied 9.07 mg of iron, 4.54 mg of copper, 4.54 mg of manganese and 0.45 mg of cobalt/kg of feed.

TABLE 2

Experimental design including calcium levels, phosphorus levels and Ca:P ratios

	Phosphorus, %		
	0.17	0.34	0.68
Calcium, 0.27%	1.6[1]	0.8	0.4
Calcium, 0.81%	4.8	2.4	1.2
Calcium, 2.43%	14.3	7.2	3.6

[1] The tabular values represent the units of calcium per unit of phosphorus. Five calves received each treatment combination (Ca:P ratio).

Data for the criteria used in the growth and blood studies were statistically analyzed using the analysis of variance technique. Linear and quadratic components were isolated to evaluate treatment effects. A covariance analysis was applied when its use appeared logical.

RESULTS

Based on the data reported herein, the semi-purified basal rations used in these studies apparently supplied the nutrients required for normal responses in calves. Average responses of the calves fed the 9 different Ca:P ratios are presented in table 3. A summary of the mean squares from the analyses of variance is shown in table 4.

Growth study. Body weight gains were markedly influenced by the treatments. Growth was more rapid with the intermediate level of dietary calcium (0.81%). This resulted in a curvilinear growth response due to calcium levels. Response to phosphorus levels was similar at the two lower levels, but growth was reduced at the 0.68% phosphorus level. This reduction in growth due to elevated dietary phosphorus was more dramatic at the lowest level of calcium (0.27%) than at higher levels.

Depression of growth attributable to Ca:P ratio aberrations was apparent at ratios below 1:1 (0.4:1 and 0.8:1) and also at the highest ratio (14.3:1). The depression was much more severe at the low than at the high ratio. These statements are illustrated in figure 1 which also shows that ratios varying from 1:1 to 7:1 did not cause significant differences in calf growth. This plot of performance by Ca:P ratios (fig. 1) revealed a growth rate curve that was remarkably smooth with optimal growth performance at a ratio of 4.8:1. The only point which did not fall directly on the curve represented the diet that contained both elements at the highest level. The depression below the expected value in this case may be due, at least in part, to the high mineral content (over 7% of added minerals) of this particular diet.

The daily feed intake ranged from 2.72 to 3.63 kg/animal with the various rations and did not prove to be different in the analysis of variance. When body weight

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TABLE 3

Average responses of calves receiving various dietary calcium:phosphorus ratios[1,2]

Ca level, %	0.27	0.27	0.27	0.81	0.81	0.81	2.43	2.43	2.43
P level, %	0.17	0.34	0.68	0.17	0.34	0.68	0.17	0.34	0.68
Ca:P ratio	1.6	0.8	0.4	4.8	2.4	1.2	14.3	7.2	3.6
Initial weight, kg	117.5	115.7	110.7	108.9	118.8	109.3	114.3	113.9	116.1
Final weight, kg	188.7	169.2	140.6	184.6	192.8	176.4	166.9	184.6	169.6
Avg total gain, kg	71.2	53.5	29.9	75.7	74.0	67.1	52.6	70.7	53.5
Avg daily gain, gm	669	503	281	712	694	631	494	664	503
Avg daily feed, kg	3.63	3.36	2.72	3.40	3.49	3.54	3.18	3.63	3.36
Feed/gain[3]	5.6	6.7	14.6	4.8	5.1	5.9	6.5	5.5	6.9
Serum Ca, mg/100 ml									
Change[4]	+0.8	+0.3	−0.9	+1.9	+0.9	+0.2	+1.2	+0.7	+0.7
Terminal[5]	15.3	15.0	13.3	16.6	14.8	14.0	16.1	14.9	14.6
Serum P, mg/100 ml									
Change[4]	+1.5	+1.2	+1.9	−0.9	+2.0	+1.4	−1.3	+1.5	+3.3
Terminal[5]	9.4	9.7	10.2	7.7	10.2	10.3	7.2	9.8	11.3
Serum Mg, mg/100 ml									
Change[4]	+0.16	+0.31	−0.55	−0.11	+0.06	−0.29	+0.23	+0.06	+0.25
Terminal[5]	2.04	2.00	1.43	1.76	2.02	1.66	2.06	1.90	2.05
Serum phosphatase, μM units									
Change[4]	+3.1	+2.7	+0.2	+5.8	+3.0	+1.3	+3.8	+3.8	+3.2
Terminal[5]	5.6	5.4	2.6	8.4	4.9	3.5	5.4	6.1	5.5

[1] Each tabular value represents an average of 5 individuals.
[2] Average number of days on experiment was 106.4. First two replications, 98 days; last three replications, 112 days.
[3] Calculated as an average of individual feed/gain ratios.
[4] Represents difference in first and average of last three determinations on each individual.
[5] Average of last three determinations for each individual.

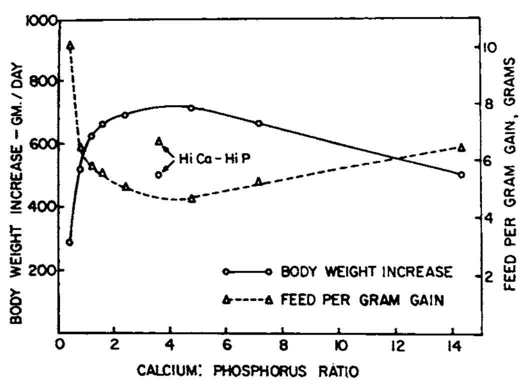

Fig. 1 Growth and feed conversion of calves fed Ca:P ratios varying from 0.4:1 to 14.3:1.

gains were adjusted for feed intake by covariance analysis, the differences in gain were still significant ($P < 0.01$). Feed intake differences attributable to treatment remained insignificant ($P > 0.05$) after covariance adjustment for average body weight during the experiment.

Efficiency of conversion of the diet to body weight gains (table 3) was most favorable with the 4.8:1 Ca:P ratio and poorest with the 0.4:1 ratio. Individual variation for this criterion (tables 4 and 5) was greater than is normally experienced in similar experiments due primarily to variation in response of calves fed the 0.4:1 ratio. A significant linear trend ($P < 0.05$) was noted in the statistical analysis indicating a decrease in feed efficiency as dietary phosphorus level increased. This, also, was attributable primarily to a low feed intake among calves fed the lowest calcium with the highest phosphorus level. Feed conversion ratios are graphically presented in figure 1 along with values for growth. Notable in this presentation is that the feed/gain ratio curve forms an almost exact inversion of the growth rate curve.

Blood studies. Serum calcium was lowest with the lowest Ca:P ratio and elevated at the higher ratios in the presence of low

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TABLE 4

Summary of mean squares from the analysis of variance of growth, feed and blood data

Source of variation	df	Avg daily gain	Feed intake	Feed/gain	Serum Ca[1]	Serum P[1]	Serum Mg[1]	Serum phosphatase[1]
Replication	4	0.02	3.51*	20.06	4.90**	3.55	0.02	28.97**
Treatments	8	0.45**	2.02	45.24*	5.09**	8.28**	0.24**	12.76*
Ca levels[2]	2	0.66**	1.22	54.49	1.97	0.61	0.18	5.72
Ca linear	1	0.16	1.01	52.99	3.31	0.77	0.25*	8.69
Ca quadratic	1	1.16**	1.44	56.00	0.64	0.44	0.11	2.74
P levels	2	0.56**	1.57	59.85*	16.19**	24.15**	0.30**	24.86**
P linear	1	0.84**	1.47	93.32*	32.30**	45.51**	0.42**	48.82**
P quadratic	1	0.29	1.68	26.38	0.08	2.78	0.19	0.90
Ca × P	4	0.29	2.64	33.31	1.10	4.18*	0.24**	10.23
Ca × P linear × linear	1	0.87**	7.32*	92.49*	0.22	14.18**	0.45**	11.49
Ca × P linear × quadratic	1	0.13	0.25	8.64	2.35	0.47	0.29*	0.76
Ca × P quadratic × linear	1	0.08	2.27	22.31	1.02	0.03	0.07	19.47*
Ca × P quadratic × quadratic	1	0.07	0.71	9.78	0.80	2.04	0.15	9.20
Experimental error	32	0.095	1.318	17.78	0.85	1.48	0.054	4.61

[1] Analysis of average of last three determinations on each animal.
[2] Isolation of individual degrees of freedom.
* $P < 0.05$.
** $P < 0.01$.

TABLE 5

Coefficients of variation of response criteria used in these studies[1]

Criteria	%
Average daily gain	24
Feed intake	15
Feed/gain	62
Serum calcium	6
Serum phosphorus	13
Serum magnesium	12
Serum phosphatase	41

[1] Computed from values on 45 calves.

dietary phosphorus; however, in no case were serum calcium levels markedly changed. Dietary calcium level did not influence serum levels of this element. On the other hand, elevation of dietary phosphorus effected a distinct linear decrease in serum calcium at all dietary calcium levels.

Inorganic phosphorus levels in the serum (table 3) were not significantly influenced by dietary calcium but were markedly increased by higher levels of dietary phosphorus. The response of blood phosphorus to increases of this element is rapid and directly related to the amount in the feed (Wise et al., '58, '61).

Mean values for serum magnesium (table 3) were lowest among calves fed the 0.4:1 Ca:P ratio (1.43 mg/100 ml) and highest with the 14.3:1 ratio (2.06 mg/100 ml). Increasing dietary phosphorus levels caused a concurrent decrease in serum magnesium as indicated by the significant linear component in the statistical analysis (table 4). The influence of the high level of dietary phosphorus on serum magnesium was not in evidence in the presence of high dietary calcium. This observation is supported by the comparatively large Ca × P interaction term (table 4). Covariance adjustments of magnesium values for variations in serum inorganic

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phosphorus accentuated treatment differences in serum magnesium.

Activity of the enzyme serum alkaline phosphatase was inversely related to serum inorganic phosphorus with values of 2.64 μM units at the 0.4:1 Ca:P ratio ranging up to value of 8.37 μM units at the 4.8:1 Ca:P ratio. Increasing levels of dietary phosphorus resulted in a linear decrease in serum alkaline phosphatase at the two lower dietary calcium levels but in no difference at the highest (2.43%) dietary calcium level.

DISCUSSION

The results presented herein strongly indicate that wide Ca:P ratios are tolerated by the ruminant animal. This is in agreement with previous observations by Huffman et al. ('33) and Theiler et al. ('37). The data suggest that Ca:P ratios as high as 7 or 8:1 may be fed to the ruminant without serious effects. This is in sharp contrast with the growing chicken, pig and rat which do not thrive on ratios wider than approximately 3:1 (Wilgus, '31; Bethke et al., '32, '33; Boutwell et al., '46; Chapman et al., '55).

In this research, Ca:P ratios lower than unity (0.4:1 and 0.8:1) resulted in reduced growth and poor nutrient conversion. The 0.4:1 ratio markedly reduced serum magnesium. These observations also contrast with results involving the simple-stomach animal in that Combs et al. ('62) reported an optimal Ca:P ratio of 0.9:1 for the young growing pig.

Hence, the optimal Ca:P ratio for the ruminant is higher than that for the nonruminant animal and that the ruminant will tolerate wide ratios of Ca:P (7:1) but ratios lower than unity are deleterious. This is in contrast with the nonruminant which tolerates a Ca:P ratio of less than 1:1 with ratios wider than 3:1 resulting in undesirable effects. Teleological reasoning, though admittedly hazardous, would suggest that the ruminant has subsisted and developed on forages which normally have a high Ca:P ratio, and has more highly developed physiological mechanism(s) than the nonruminant for handling higher levels of calcium. This does not, however, give insight into the mechanism(s) involved. Research is needed to elucidate this question.

Depression of serum magnesium by high levels of dietary phosphorus as observed in this study has been reported previously by O'Dell et al. ('60) working with guinea pigs and rats, and by Bunce et al. ('62) working with dogs. This depression of serum magnesium in the presence of high dietary phosphorus and low calcium perhaps reflects an excretory pattern in which magnesium furnished the cation which combined with the phosphate anion for elimination through the urinary pathway. The fact that serum calcium was also lowest at this dietary calcium-phosphorus combination supports this hypothesis. It is probable that other monovalent and divalent cations would have followed this pattern had they been measured. Hawkins et al. ('55) reported that high levels of calcium and phosphorus caused a depression of serum manganese; however, in their experiment, it was not possible to determine whether the depression resulted from high calcium or phosphorus or both.

SUMMARY

Forty-five Hereford calves were used in a factorial experiment with three levels each of calcium (0.27, 0.81 and 2.43% of the diet) and of phosphorus (0.17, 0.34 and 0.68% of the diet). The 9 resulting calcium: phosphorus ratios ranged from 0.4:1 to 14.3:1. Levels and ratios of Ca and P were obtained by addition of varying amounts of calcium carbonate, defluorinated rock phosphate and dibasic sodium phosphate to a semi-purified diet based on degerminated corn meal, starch, glucose, urea, blood meal, beet pulp, corn oil, minerals and vitamins. The calves were individually fed, ad libitum, over a period of 98 days for the first two replications and 112 days for the last three replications.

Performance and nutrient conversion were markedly decreased with Ca:P ratios lower than 1:1. Ratios between 1:1 and 7:1 gave similar and satisfactory results. Ca:P ratios above 7:1 resulted in decreased performance and nutrient conversion values, but adverse effects were not as marked as with the ratios below 1:1. Several significant trends were evi-

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denced in serum inorganic phosphorus, magnesium and phosphatase activity attributable to levels and ratios of dietary calcium and phosphorus. Notable among these observations was that serum magnesium levels were decreased with high levels of dietary phosphorus when dietary calcium levels were low. Diets with high calcium levels resulted in a "normal" serum magnesium level even at the highest phosphorus level.

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