Effect of Three Calcium:Phosphorus Ratios on Performance of Growing Holstein Steers

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Abstract
Dietary Ca/P ratios of 1:1, 4:1, and 8:1 were studied in 30 Holstein steers in a 168-day split plot in time and space experiment. A factorial arrangement among feed intakes and Ca/P ratios existed at each time period.

Animals receiving the 8:1 Ca/P ratio diets gained less daily than the 1:1 and 4:1 groups. Animals fed the 1:1 Ca/P ratio diets had higher serum inorganic phosphorus, lower serum calcium, and a narrower serum Ca/P ratio than those fed the 4:1 and 8:1 diets. There were no adverse effects on average daily gain and feed efficiency from feeding the 4:1 Ca/P ratio diet.

Introduction
That a dietary lack of either calcium or phosphorus will result in improper bone formation and defective teeth in many mammals is well known. Bohstedt (2) found a decrease in average daily gain of swine when the dietary Ca/P ratios were widened from 1.1:1 to 2.9:1. Similar findings were reported by Bethke et al. (1) and Lloyd et al. (11) in their studies with swine. Hogan (7) found that when sows were fed diets containing excess calcium, adverse effects on reproduction occurred and most of their piglets died at birth.

Dowe et al. (4) reported a decrease in ADG of calves when the Ca/P ratio was widened from 4.3:1 to 9.1:1. Smith et al. (14) found no decrease in growth rates of 4-month-old calves receiving Ca/P ratios as high as 8:1.

Haag et al. (5) noted that alfalfa hay may contain from 3 to 25 times as much calcium as phosphorus. However, the average Ca/P ratio of alfalfa frequently approximates 8:1. Many cattle feeders use alfalfa hay as the sole forage and in some cases as the only feedstuff. When alfalfa hay constitutes the major portion of the diet, it is not unusual for the Ca/P ratio to be 3 to 4 times greater than the generally accepted optimal ratio. Stott (16) demonstrated that post-parturient paresis of cows could be prevented by adding sufficient phosphorus to the diet to give a 1:1 Ca/P ratio. Krook et al. (8) reported a high incidence of osteopetrosis, vertebral ankylosis, and degenerative osteoarthritis in dairy bulls fed diets having calcium concentrations 3.5 to 5.8 times that recommended by NRC (12).

The objective of this experiment was to study the effects of three Ca/P ratios on growth, feed efficiency, and blood calcium and phosphorus in growing Holstein steers.

Materials and Methods
Calves were purchased locally. They were fed 1.0 kg whole milk per 10 kg body weight (BW) with a maximum of 3.45 kg daily. They received a grass-legume hay mixture ad libitum after 1 month of age. A pre-experimental calf starter diet (Table 1) was fed ad libitum until calves were weaned and castrated at 2 months.

TABLE 1. Composition of pre-experimental calf starter diet.

<table>
<thead>
<tr>
<th>Ingredienta</th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number 2 yellow corn, crimped</td>
<td>35.0</td>
</tr>
<tr>
<td>Oats, crimped</td>
<td>34.0</td>
</tr>
<tr>
<td>Soybean meal, 44% (solvent process)</td>
<td>15.0</td>
</tr>
<tr>
<td>Dried skimmed milk (animal feeding grade)</td>
<td>10.0</td>
</tr>
<tr>
<td>Molasses, blackstrap (liquid)</td>
<td>4.0</td>
</tr>
<tr>
<td>Diocalcium phosphate</td>
<td>1.0</td>
</tr>
<tr>
<td>Salt, iodized, trace-mineralized</td>
<td>1.0</td>
</tr>
</tbody>
</table>

a The diet contained a minimum of 13,228 IU of Vitamin A and 1,323 IU of Vitamin D/kg.
Thereafter, the starter diet was limited to 2.72 kg/calf/day. After weaning, calves were offered NRC levels of the 1:1 Ca/P ratio ration. The experiment was initiated when these intakes were attained and stabilized (10 days).

The 30 Holstein steers were divided into 5 weight groups and assigned to the experiment in a split plot in time and space design (15) as shown in Table 2. Each weight group was randomly divided into groups of equal numbers of animals to receive either feed intake ad libitum or intake recommended by the National Research Council (12). Steers at each intake were then randomly assigned to dietary treatments with a Ca/P ratio of 1:1, 4:1, or 8:1.

Steers fed ad libitum were placed in individual stalls equipped with feed buckets and automatic waterers. Steers receiving the NRC intake were housed in 3 pens (5 animals/pen). These pens were also equipped with individual feed buckets and automatic waterers.

Diets were formulated according to the recommendations of the NRC for Dairy Cattle Feeding (12). Individual daily feed intakes were recorded for all animals. Feed intake for the NRC group was adjusted each fortnight according to body weight as recommended by NRC. Since the initial average weight and age of the calves was 102.5 kg (range 60.0 to 150.0) and 13.5 weeks (range 9 to 20), respectively, the recommendations for growth of dairy heifers were used until the mean body weight of all calves reached 150 kg. The recommendations for growing dairy bulls were then used for the rest of the experiment. Diets were reformulated according to NRC recommendations each time the mean body weight of the 30 calves increased 50 kg.

All feed ingredients (number 2 yellow corn, cottonseed hulls, soybean meal (44%), calcium carbonate, dicalcium phosphate, and liquid feed molasses) were purchased before initiation of the study. The NRC recommendation for phosphorus was met by adding dicalcium phosphate, and Ca/P ratios were widened by adding calcium carbonate. Aliquot samples of these ingredients were analyzed periodically for proximate analysis. Digestible energy values quoted by NRC

Table 3. Chemical analyses of dietary ingredients.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Corn</th>
<th>Cottonseed hulls</th>
<th>Soybean meal (44%)</th>
<th>Calcium carbonate</th>
<th>Dicalcium phosphate</th>
<th>Molasses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (%)</td>
<td>10.8</td>
<td>11.5</td>
<td>9.5</td>
<td>1.3</td>
<td>16.85</td>
<td></td>
</tr>
<tr>
<td>Fat (%)</td>
<td>4.2</td>
<td>35.3</td>
<td>2.0</td>
<td>1.1</td>
<td>0.220</td>
<td></td>
</tr>
<tr>
<td>Fiber (%)</td>
<td>1.1</td>
<td>6.0</td>
<td>1.39</td>
<td>6.0</td>
<td>325.0</td>
<td></td>
</tr>
<tr>
<td>Ash (%)</td>
<td>1.39</td>
<td>0.66</td>
<td>0.02</td>
<td>0.024</td>
<td>0.038</td>
<td></td>
</tr>
<tr>
<td>Nitrogen (%)</td>
<td>1.39</td>
<td>0.06</td>
<td>0.024</td>
<td>0.06</td>
<td>0.566</td>
<td></td>
</tr>
<tr>
<td>DE (Kcal/kg)</td>
<td>3,578</td>
<td>1,634</td>
<td>3,225</td>
<td>E</td>
<td>2,900</td>
<td></td>
</tr>
</tbody>
</table>

*National Research Council (12) values were used for calculations of energy.
were used to calculate isocaloric diets and chemical analyses (Table 3) were used to calculate isonitrogenous diets. Vitamins A and D were added to the diets at the rates of 1,600 and 25 IU/kg of feed. Chemical analyses of feed ingredients and trace minerals are listed in Table 3.

Biweekly 2-day weights were averaged for computation of average daily gain. Each steer was weighed between 8 and 9 AM to minimize variations in body weights from eating and drinking habits. Two-day measurements were averaged for average daily change in wither height, length from tip of nose to tip of pinbones, height from ground to the animal's chest floor, and heart girth.

Blood samples were obtained by venous puncture at 4-week intervals. Serum inorganic phosphorus and calcium were analyzed by Tumbleson's technique (17) with a modified survey model Sequential Multiple Analyzer (SMA 12/30). Serum Ca/P ratios and serum calcium by phosphorus products were calculated.

Results and Discussion

Feed intake. The 3 diets had no effect on average daily feed intake. However, there was a significant (P < 0.01) interaction among diets, intakes, and time periods (Table 4). During the first 14 weeks of the experiment, the ad libitum-fed steers receiving the 8:1 Ca/P ratio diets consumed significantly (P < 0.01) less than did the ad libitum-fed steers receiving the 1:1 or 4:1 Ca/P ratio diets. After 14 weeks, the average daily feed intake of steers fed the 8:1 Ca/P ratio diets did not differ from those receiving the 1:1 or 4:1 Ca/P ratio diets. Analysis of variance for feed intake per BW$^{0.75}$ was the same as for average daily feed intake except that weight groups were not different. This indicated that animals in different weight groups consumed the same amount of feed per unit of metabolic body weight. The significant (P < 0.01) interactions among diets by feed intake and by periods showed that although steers fed the 8:1 Ca/P ratio diets ad libitum consumed less per BW$^{0.75}$ (P < 0.01) during the first 14 weeks of the experiment, they consumed more feed (P < 0.05) during the balance of the study. Smith et al. (14) reported that they were able to maintain steers fed isocaloric diets at the NRC recommended level when the Ca/P ratio was 8:1. Otto (13) reported that cattle fed a diet with a Ca/P ratio of 4:1 consumed the entire portion fed except when dietary phosphorus was deficient. These workers (13, 14) did not feed animals at the ad libitum levels at which the steers in our experiment initially consumed less feed while receiving the 8:1 Ca/P diets.

Average daily gain. Steers in the heaviest weight group gained 1.18 kg/day, which was significantly (P < 0.01) greater than the 0.87 kg/day gain of the lightest weight group. Average daily gains of other weight groups were between the 1.18 and 0.87 kg, with the daily gains of all steers during the entire experiment being 1.05 kg. Steers receiving the 8:1 Ca/P diet at both levels of intake during all time periods gained significantly (P < 0.01) less than steers receiving either the 1:1 or the 4:1 Ca/P diet. There were no differences in average daily gains between steers receiving the 1:1 and 4:1 Ca/P diets.

Steers fed the 4:1 Ca/P ratio diets gained 1.35 kg/day and steers fed the 1:1 Ca/P ratio diets gained 1.27 kg/day. Steers fed the 8:1 Ca/P ratio diets gained 1.15 kg/day (Table 5).
TABLE 5. Average daily gain.

<table>
<thead>
<tr>
<th>Ca/P Ratio</th>
<th>2 (kg)</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>16</th>
<th>18</th>
<th>20</th>
<th>22</th>
<th>24</th>
<th>Over-all mean (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:1</td>
<td>1.59</td>
<td>1.34</td>
<td>1.47</td>
<td>1.49</td>
<td>0.56</td>
<td>1.79</td>
<td>1.37</td>
<td>0.96</td>
<td>1.40</td>
<td>1.00</td>
<td>0.91</td>
<td>1.41</td>
<td>1.27</td>
</tr>
<tr>
<td>4:1</td>
<td>1.51</td>
<td>1.27</td>
<td>1.41</td>
<td>1.30</td>
<td>1.43</td>
<td>0.71</td>
<td>1.69</td>
<td>1.26</td>
<td>1.57</td>
<td>1.09</td>
<td>1.84</td>
<td>1.16</td>
<td>1.35</td>
</tr>
<tr>
<td>8:1</td>
<td>0.80</td>
<td>1.04</td>
<td>1.13</td>
<td>1.09</td>
<td>1.04</td>
<td>1.16</td>
<td>1.21</td>
<td>1.49</td>
<td>1.04</td>
<td>1.27</td>
<td>1.14</td>
<td>1.33</td>
<td>1.15</td>
</tr>
</tbody>
</table>

Average daily gain of those steers fed the NRC (12) recommended intake for the 1:1, 4:1, and 8:1 Ca/P ratio diets were 0.87, 0.83, and 0.79 kg, respectively. During the first 2 weeks, calves fed the 8:1 Ca/P ratio diets gained less (P < 0.01) than calves fed either the 4:1 or 1:1 Ca/P diets. Part of the reduced average daily gain of the 8:1 Ca/P ratio fed animals was attributed to a lower feed intake in the first 14 weeks of the trial by steers fed ad libitum. However, during Weeks 15 through 18, calves receiving the 8:1 Ca/P ratio diets consumed more feed per BW$^{0.75}$ (P < 0.05) than calves receiving the other Ca/P ratio diets. During Weeks 19 through 22, calves fed the 8:1 Ca/P ratio diets consumed more (P < 0.01) than steers fed either the 1:1 or 4:1 Ca/P ratio diets. However, this was not reflected as an increase in daily gain. Similar results were reported by Dowe et al. (4), who observed that when Ca/P ratios fed to calves were widened from 4.3:1 to 9.1:1 there was a corresponding decrease in average daily gain. Smith et al. (14) reported no changes in daily gains among Holstein steers fed diets with Ca/P ratios as wide as 8:1. In this study, feeding the 4:1 Ca/P ratio diet was no more detrimental than feeding the generally accepted 1:1 Ca/P ratio diets. Although not significantly different, calves fed the 4:1 Ca/P ratio diets had greater average daily gains than those fed the 1:1 and 8:1.

Feed efficiency. Steers in the lightest weight group were more efficient (P < 0.01) in converting feed to body weight. Feed efficiencies (kg gain/kg feed × 100) of animals in the lightest and heaviest weight groups were 22 and 17%. The percentage of feed converted to body weight for all calves decreased from 34 during the first 2 weeks to 12 for the last 2 weeks of the experiment. Animals receiving the 8:1 ratio diets had a mean efficiency of 18.4%, which was not significantly lower than the 19.6 and 18.8% of calves fed the 1:1 and 4:1 ratio diets. The feed efficiencies of steers receiving ad libitum and NRC levels of intake which were 18.4 and 19.5, were not significantly different (Table 6). Many workers (3, 4, 6) have found that wider Ca/P ratios decrease feed efficiency.

Growth measurements. Feeding the different Ca/P ratio diets had no effect on average daily change in wither height, distance from floor to barrel, heart girth, or length. During the 168-day experiment, steers had average daily changes in wither height, distance from floor to barrel, heart girth, and length of 0.186, 0.482, 0.249, and 0.189 cm, respectively. These measurements are consistent with those reported by Smith et al. (14), who observed that feeding different Ca/P ratio diets caused no difference in skeletal measurements of young Holstein steers.

Serum inorganic phosphorus and calcium. Steers fed the 1:1 Ca/P ratio diets had higher
Fig. 1. Mean serum calcium values for steers fed 1:1, 4:1, or 8:1 Ca/P ratio diets ad libitum or at the level recommended by National Research Council for 24 weeks.

There was a Ca/P ratio by period interaction in serum calcium between levels of diet by Ca/P ratios and by periods. Steers receiving the 4:1 and 8:1 ratio diets, regardless of level of intake, had serum calcium values higher (P < 0.05) than those receiving the 1:1 Ca/P ratio diets. The average serum calcium values per period for steers receiving ad libitum and NRC recommended intakes fed different Ca/P ratios at different periods are presented in Figure 1. Animals receiving the 1:1 Ca/P diets had serum calcium values lower (P < 0.05) than those fed 4:1 Ca/P ratio diets. There was no difference between serum calcium of steers fed the 8:1 Ca/P ratio diets and those fed the 4:1 Ca/P diets. There was a period effect (P < 0.05) which indicated a decrease in serum calcium concentration with increased age. Further support for the suggestion of a decrease in blood serum calcium with increased age was found in the weight group data which showed that the heavier and older animals had a lower blood calcium concentration (P < 0.05) than the lighter-weight groups. Dowe et al. (4) reported that when calves were fed excessive calcium while phosphorus was held constant, no changes were reflected in their serum calcium concentration. Similar results were reported by Lewis et al. (10) and Smith et al. (14).

There was a Ca/P ratio by period interaction in blood serum Ca/P ratios (P < 0.05). Calves fed the 1:1 Ca/P ratio diets had a narrower blood serum Ca/P ratio than those fed the 4:1 or 8:1 Ca/P ratio diets. Blood serum Ca/P ratios of steers fed the 1:1, 4:1, and 8:1 Ca/P ratio diets were 1.26:1, 1.38:1, and 1.42:1, respectively. The average blood Ca/P ratio for all calves was 1.35:1, somewhat wider than the ratios reported by Lane et al. (9), who found the range of Ca/P ratios of 236 Guernsey cows to be from 1.14:1 to 1.28:1. However, these differences may be due to breed, age, or sex, or all.

The ratios of Ca/P in the diet had no effect on serum calcium and phosphorus products (serum phosphorus × serum calcium concentrations). The blood serum calcium and phosphorus products were affected by levels of diet (P < 0.01). The ad libitum-fed steers had mean serum calcium and inorganic phosphorus products of 99.8 which was higher (P < 0.01) than the 95.1 mean of the NRC-fed group.

Acknowledgment

We are grateful to Dr. G. F. Krause for advice and assistance with the experimental design and statistical analyses.

References

(4) Dowe, T. W., J. Matsushima, and V. H. Arthaud. 1957. The effects of adequate and excessive calcium when fed with ade-


