ABSTRACT

At low amounts of supplementation, dietary choline as choline chloride is rapidly degraded in the rumen. Two experiments were conducted to investigate whether the bacterial choline degradation in the rumen of dairy cows could be overwhelmed. Holstein cows were fed total mixed rations containing 40% corn silage and 60% concentrate on a DM basis with treatments of 0, 10, and 20 g added choline/kg ration DM fed in a Latin square design. In Experiment 1, using three ruminally and duodenally cannulated, late lactation cows, increasing dietary choline intake from 23 to 326 g/d increased duodenal choline flow from 1.2 to 2.5 g/d, indicating a very low recovery of added dietary choline. In Experiment 2, with 18 midlactation cows, increasing choline from 18 to 282 g/d reduced feed intake from 18.4 to 16.7 kg/d. Milk composition was unaffected, and milk production tended to decrease with increasing dietary choline. High amounts of added choline reduced feed intake and did not improve milk production of cows.

INTRODUCTION

The effect of dietary supplemented choline on milk production and composition of dairy cows has not been studied extensively. Early work of Erdman et al. (9) indicated a beneficial effect of added choline on 4% FCM yield and milk fat percentage of lactating dairy cows. However, subsequent studies (1, 7, 8) failed to show any beneficial effect of dietary supplemented choline in dairy cows.

Dietary choline is rapidly and extensively degraded in the rumen of both sheep (18, 19) and steers (1). Results of experiments investigating the effect of dietary choline supplementation on ruminal microbial population have been contradictory. Earlier work using sheep (22) showed that feeding choline resulted in an increased rumen bacterial population and a decrease in rumen protozoal population. However, later studies (12), also using sheep, showed decreased rumen bacterial and increased protozoal populations due to ruminally administered choline chloride. Others (2, 16) have reported that ruminal protozoal species *Entodenium caudatum* requires choline for growth and that rumen microbial population is responsible for degradation of the dietary choline in the rumen. Choline kinase, a membrane-bound enzyme of *Entodenium caudatum*, synthesizes phosphatidylcholine from free choline in the rumen (3), and phosphatidylcholine is retained in the protozoal cell. Choline available postruminally is in the form of a phospholipid mainly of protozoal origin (2, 5, 15), rather than either dietary free choline or phosphatidylcholine.

Atkins et al. (1) showed from a short-term experiment that ruminal dosing of 27 g/d choline in steers increased duodenal choline flow by only 3 g/d. Long-term studies investigating whether the rumen bacterial degradation of dietary choline is saturable by increasing the availability of substrate have not been reported. The objective of these experiments was to determine if supplementing high amounts of dietary choline as choline chloride could overwhelm choline degradation by rumen bacteria.

MATERIALS AND METHODS

Animals and Housing

Experiment 1 utilized three mature Holstein cows fitted with rumen and duodenal canulae. Cows were in the last third of lactation and
averaged 641 kg body weight at the start of the experiment. Experiment 2 utilized 18 midlactation Holstein cows averaging 579 kg in body weight and 27.2 kg milk at the start of the experiment. In both experiments, cows were housed in comfort stalls with rubber mats and wood shavings as bedding. Cows were allowed 2 h of exercise daily. Cows were milked twice daily at 0700 and 1900 h.

Diets, Treatments, and Design

In both experiments, cows were fed total mixed rations consisting of 40% corn silage and 60% concentrate on a DM basis. Ingredient composition of the concentrate portion of the diet is in Table 1. In Experiment 1, chromic oxide, to be used as a digesta marker, was incorporated in the concentrate mixtures at the rate of 3.6 g/kg concentrate. The amount of corn silage and concentrate offered as fed to cows was adjusted weekly based on the DM content of these ingredients. Feed was offered to cows twice daily in equal portions at 0800 and 2000 h.

Treatments in both experiments consisted of 0, 10, and 20 g dietary supplemented choline/kg of total ration DM. The amounts of choline chloride (50% product) necessary to obtain required amounts in the diet were incorporated into the concentrate mixture by decreasing other ingredients proportionately (Table 1). Choline supplied to cows was increased gradually over 2 to 3 d. Treatment applications were made to cows in 3 x 3 Latin square design in Experiment 1 and a replicated 3 x 3 Latin square in Experiment 2. Experimental periods were 2 wk for Experiment 1 and 4 wk for Experiment 2.

Sampling and Recording

Feed refusals were recorded once daily. Samples of corn silage and concentrate mixture were taken weekly for DM analysis and later composited by experimental periods for each treatment. Milk production of cows in Experiment 2 was recorded at individual milkings. Milk was sampled twice weekly from a.m. and p.m. milkings and daily composites were used for determination of milk fat and milk protein content. Body weight measurements were made at weekly intervals.

In Experiment 1, duodenal contents (500 ml) were taken at 0, 2, 4, 6, 8, 10, 12, 14, 20, and 22 h post-a.m. feeding on d 13 and 14 of each experimental period and pooled to obtain a composite sample for each cow within each period. Frozen composite samples were lyophilized and stored for later analysis after grinding through a Wiley mill with a 2-mm screen. Rumen fluid (40 ml) was sampled by a suction strainer from several rumen locations at 0, 1, 2, 4, 6, and 8 h post-a.m. feeding.

TABLE 1. Ingredient composition (% as fed) of concentrate mixtures fed to cows in Experiments 1 and 2.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>0</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn, ground</td>
<td>74.00</td>
<td>71.54</td>
<td>69.07</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>11.50</td>
<td>11.12</td>
<td>10.73</td>
</tr>
<tr>
<td>Corn gluten meal</td>
<td>9.40</td>
<td>9.09</td>
<td>8.77</td>
</tr>
<tr>
<td>Trace-mineralized salt</td>
<td>1.00</td>
<td>.97</td>
<td>.93</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>.60</td>
<td>.58</td>
<td>.56</td>
</tr>
<tr>
<td>Limestone</td>
<td>2.00</td>
<td>1.90</td>
<td>1.87</td>
</tr>
<tr>
<td>Vitamin A, D, and E</td>
<td>.09</td>
<td>.09</td>
<td>.09</td>
</tr>
<tr>
<td>Dynamate</td>
<td>1.00</td>
<td>.96</td>
<td>.94</td>
</tr>
<tr>
<td>Potassium chloride</td>
<td>.40</td>
<td>.38</td>
<td>.37</td>
</tr>
<tr>
<td>Choline chloride</td>
<td>...</td>
<td>3.33</td>
<td>6.66</td>
</tr>
</tbody>
</table>

1 Chromic oxide at the rate of 3.6 g/kg was mixed to concentrates fed to cows in Experiment 1.

2 Contains Fe, .23%; Mn, .23%; Zn, .20%; Mg, .10%; S, .04%; Cu, .023%; Ca, .007%; and I .007%.

3 Contains vitamin A, 2,063,636 USP/kg; vitamin D, 454,545 USP/kg; and vitamin E, 227 IU/kg.

4 Contains S, 22%; K, 18%; and Mg, 11%.
and analyzed immediately for pH. Samples were then acidified to pH 2 to 3 using 2 ml 50% sulfuric acid and frozen. Rumen fluid (1 L) for isolation of bacteria was collected at 1.5, 3.5, and 5.5 h post-a.m. feeding by squeezing the rumen contents between two layers of cheese cloth. These samples were preserved with 83.3 ml of 0.9% NaCl (wt/vol) in formaldehyde solution (37% wt/wt)/L of sample and stored at 4°C. Bacteria were isolated by differential centrifugation as described by Santos et al. (21). The resultant bacterial samples were lyophilized and ground using 1-mm screen size prior to analysis.

Chemical and Data Analysis

Dry matter content of composites of concentrate and corn silage was determined, respectively, by oven drying at 100°C overnight and by toluene distillation (6). Corn silage used in chemical analysis was dried in a forced air oven at 65°C for 24 h and ground using 2-mm screen size. Corn silage, concentrate, rumen bacterial preparations, and duodenal digesta were analyzed for total N by micro-Kjeldahl procedures and organic matter by ashing overnight at 600°C. These samples, except for rumen bacteria, were analyzed for NDF, ADF, and acid detergent lignin content by the procedures of Goering and Van Soest (11). Corn silage and concentrate mixtures were submitted for mineral analysis to the New York Dairy Herd Improvement Laboratory. Chromic oxide content of concentrate mixtures and duodenal samples was determined by the procedure of Czarnocki et al. (4) as modified by Van Horn et al. (24). Samples of corn silage, concentrates, and duodenal digesta were analyzed for choline content by initial hydrolysis by 15% nitric acid followed by enzymatic choline oxidase procedure of Takayama et al. (23). Milk samples were tested for fat and protein content by infrared spectrophotometry (Mid-East Milk Lab Services, Inc., Hagerstown, MD). Rumen bacterial preparations and duodenal samples were also analyzed for RNA content (26) using yeast RNA (Sigma Chemical Co., St. Louis, MO) as the standard. The ratios of RNA values to total N in the rumen bacterial preparation and duodenal digesta were used for calculating passage of microbial protein (Kjeldahl N × 6.25) to the duodenum.

Rumen fluid collected at various times post-a.m. feeding was tested for rumen ammonia concentrations by automated procedures (Technicon Industrial Method No. 334-74 W/B, Technicon Industrial Systems, Tarrytown, NY). Rumen VFA content of these samples was determined as by Erdman et al. (9).

Data from both experiments were analyzed statistically using the General Linear Model procedure of SAS (10). The model included treatment, experimental period, and cow effects. Rumen VFA, pH, and rumen NH3 data for various times post-a.m. feeding in Experiment 1 also included time and time x treatment interaction terms as a subplot to the model. Orthogonal polynomials were used to test the linear and quadratic trends in response parameters for increasing choline in diets.

RESULTS

Experiment 1

Total mixed diets fed to cows were similar in chemical composition except for their choline content (Table 2). Crude protein content was more than adequate for cows in mid to late lactation (17). The control diet contained 1.1 mg choline/g and the choline supplementation increased choline to 8.9 and 16.8 mg choline/g ration DM, respectively, which were slightly lower than initially calculated.

Although not statistically different (P>.1), DM intake of cows decreased due to choline supplementation when compared with DM intake of controls (Table 3). Amount of total DM as well as dietary DM passing to the duodenum reflected the changes in the DM intake for cows fed increasing amounts of supplemented choline. Duodenal flow of bacterial DM was not changed (P>.1) due to supplemented choline. Also, duodenal flow of CP, both dietary and bacterial, was not different (P>.1) for cows fed choline supplemented diets than for cows fed control diets.

As expected, choline intake of cows increased linearly (P<.01) from 23.5 g for control to 325.9 g for 20 g choline/kg ration DM supplementation (Table 3). Although duodenal flow of choline increased 1.3 g/d (P<.1) with increasing dietary choline, duodenal choline as a percentage of choline intake was less than 1% for both choline-supplemented diets.
TABLE 2. Nutrient composition (DM basis)\(^1\) of total mixed diets fed to cows in Experiments 1 and 2.

<table>
<thead>
<tr>
<th>Item</th>
<th>Added choline, g/kg ration DM</th>
<th>Experiment 1</th>
<th>Experiment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>CP, %</td>
<td>15.3</td>
<td>15.6</td>
<td>15.7</td>
</tr>
<tr>
<td>Ash, %</td>
<td>6.2</td>
<td>6.6</td>
<td>6.4</td>
</tr>
<tr>
<td>NDF, %</td>
<td>35.6</td>
<td>35.7</td>
<td>35.9</td>
</tr>
<tr>
<td>ADF, %</td>
<td>14.8</td>
<td>15.3</td>
<td>15.9</td>
</tr>
<tr>
<td>Acid detergent lignin, %</td>
<td>2.6</td>
<td>2.7</td>
<td>2.7</td>
</tr>
<tr>
<td>Ca, %</td>
<td>.75</td>
<td>.76</td>
<td>.75</td>
</tr>
<tr>
<td>P, %</td>
<td>.45</td>
<td>.42</td>
<td>.40</td>
</tr>
<tr>
<td>Mg, %</td>
<td>.21</td>
<td>.21</td>
<td>.21</td>
</tr>
<tr>
<td>K, %</td>
<td>1.09</td>
<td>1.09</td>
<td>1.11</td>
</tr>
<tr>
<td>Na, %</td>
<td>.41</td>
<td>.42</td>
<td>.38</td>
</tr>
<tr>
<td>Choline, mg/g</td>
<td>1.1</td>
<td>8.9</td>
<td>16.8</td>
</tr>
</tbody>
</table>

\(^1\) Calculated based on chemical analyses of concentrate mixtures (n = 3) and corn silage (n = 3).

Rumen apparent digestibility of DM, CP, NDF, and ADF was similar for all treatments (P > .1) (Table 4). Numerically lower CP digestibility in the rumen was associated with choline supplementation at 10 g/kg ration DM, although differences were not significant (P > .1). Apparent digestibility of dietary choline in the rumen was more than 95% for controls and increased (P < .01) to 99.2% in choline-supplemented diets.

Analysis of rumen data for various times post-a.m. feeding showed no (P > .1) time x treatment interaction. Hence, treatment means are presented in Table 5. Rumen pH changed quadratically (P < .01) with increasing added choline. The highest rumen pH was associated with cows fed 10 g added choline/kg ration DM. Total rumen VFA concentrations of cows were similar (P > .1) for all choline concentrations, although VFA concentrations tended to be lower for cows fed 10 g choline/kg ration DM. Molar percent propionate was also lower (P < .1) for cows in the 10 g/kg treatment. Molar percent butyrate and rumen NH\(_3\) concentrations changed in a quadratic fashion (P < .01). Numerically higher values of these metabolites

TABLE 3. Effect of high amounts of choline supplementation on intake and duodenal flow of dry matter, crude protein, and choline in dairy cows in Experiment 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>Choline, g/kg ration DM</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM Intake, kg/d</td>
<td>18.3</td>
<td>16.9</td>
<td>16.8</td>
<td></td>
<td>.43</td>
</tr>
<tr>
<td>Duodenal DM flow, kg/d</td>
<td>10.50</td>
<td>9.92</td>
<td>9.65</td>
<td></td>
<td>.48</td>
</tr>
<tr>
<td>Dietary</td>
<td>8.68</td>
<td>8.08</td>
<td>7.86</td>
<td></td>
<td>.46</td>
</tr>
<tr>
<td>Bacterial</td>
<td>1.82</td>
<td>1.85</td>
<td>1.78</td>
<td></td>
<td>.05</td>
</tr>
<tr>
<td>Duodenal CP flow, kg/d</td>
<td>2.44</td>
<td>2.52</td>
<td>2.36</td>
<td></td>
<td>.14</td>
</tr>
<tr>
<td>Nonbacterial (dietary plus NH(_3) N)</td>
<td>1.59</td>
<td>1.68</td>
<td>1.53</td>
<td></td>
<td>.09</td>
</tr>
<tr>
<td>Bacterial</td>
<td>.84</td>
<td>.86</td>
<td>.83</td>
<td></td>
<td>.05</td>
</tr>
<tr>
<td>Choline intake, g/d</td>
<td>23.5</td>
<td>176.7</td>
<td>325.9</td>
<td></td>
<td>.67(^a)</td>
</tr>
<tr>
<td>Duodenal choline flow, g/d</td>
<td>1.17</td>
<td>1.34</td>
<td>2.48</td>
<td></td>
<td>.30(^b)</td>
</tr>
</tbody>
</table>

\(^a\) Linear treatment effect (P < .01).
\(^b\) Linear treatment effect (P < .1).
TABLE 4. Effect of high amounts of dietary choline supplementation on apparent rumen digestibility of nutrients (Experiment 1).

<table>
<thead>
<tr>
<th>Apparent digestibility (%) of:</th>
<th>Choline, g/kg ration DM</th>
<th></th>
<th></th>
<th></th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td>42.9</td>
<td>41.2</td>
<td>42.9</td>
<td>1.61</td>
<td></td>
</tr>
<tr>
<td>CP</td>
<td>13.2</td>
<td>8.5</td>
<td>10.8</td>
<td>1.04</td>
<td></td>
</tr>
<tr>
<td>NDF</td>
<td>68.6</td>
<td>70.7</td>
<td>70.5</td>
<td>1.31</td>
<td></td>
</tr>
<tr>
<td>ADF</td>
<td>64.2</td>
<td>63.4</td>
<td>61.0</td>
<td>1.41</td>
<td></td>
</tr>
<tr>
<td>Choline</td>
<td>95.0</td>
<td>99.2</td>
<td>99.2</td>
<td>.15</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Significant linear and quadratic treatment effect (P<.01).

were seen in cows fed diets supplemented with choline than seen in control cows (Table 5). Rumen acetate to propionate ratio for cows fed both choline supplemented diets were higher (P<.1) than for controls, possibly because of lower feed intakes. Increased rumen ammonia concentration associated with choline supplementation was probably due to the rapid degradation of choline nitrogen.

Experiment 2

Chemical composition of diets fed to cows in Experiment 2 were also similar except for choline content (Table 2). Diets containing the same amount of added choline in two experiments were similar. Acid detergent fiber content of diets in both experiments was very low partly because of the relatively high grain fed and primarily because of the abnormally low ADF content of corn silage used in Experiment 2.

Choline intake of cows in Experiment 2 also increased linearly (P<.01) from 18.4 g for control to 282 g for the highest supplementation (Table 6). Body weight of cows decreased linearly (P<.01) with increasing dietary choline. Dry matter intake of cows was depressed 1.7 kg/d by 20 g/kg choline supplementation (P<.01). Dry matter intake as a percent of body weight followed the same trend (P<.05) as DM intake where 20 g/kg added choline had a negative effect on intake of DM. Dietary choline supplementation had no effect (P>.1) on milk production or composition. However, there was a trend for lower milk yield and milk fat percent with increasing dietary choline.

TABLE 5. Effect of high amounts of dietary supplemented choline on rumen pH, volatile fatty acids, and NH₃ (Experiment 1).

<table>
<thead>
<tr>
<th>Item</th>
<th>Choline, g/kg ration DM</th>
<th></th>
<th></th>
<th></th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.90</td>
<td>6.19</td>
<td>5.90</td>
<td>.08</td>
<td></td>
</tr>
<tr>
<td>Total VFA, mmol/L</td>
<td>85.4</td>
<td>78.7</td>
<td>87.0</td>
<td>4.17</td>
<td></td>
</tr>
<tr>
<td>Acetate, molar %</td>
<td>59.9</td>
<td>61.8</td>
<td>62.4</td>
<td>1.50</td>
<td></td>
</tr>
<tr>
<td>Propionate, molar %</td>
<td>26.5</td>
<td>21.7</td>
<td>23.4</td>
<td>1.44</td>
<td></td>
</tr>
<tr>
<td>Isobutyrate, molar %</td>
<td>1.5</td>
<td>.9</td>
<td>.9</td>
<td>.25</td>
<td></td>
</tr>
<tr>
<td>Butyrate, molar %</td>
<td>8.8</td>
<td>12.2</td>
<td>10.0</td>
<td>.49</td>
<td></td>
</tr>
<tr>
<td>Acetate:propionate</td>
<td>2.4</td>
<td>3.0</td>
<td>3.0</td>
<td>.21</td>
<td></td>
</tr>
<tr>
<td>Rumen NH₃, mg/dl</td>
<td>5.3</td>
<td>8.1</td>
<td>7.6</td>
<td>.74</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Significant quadratic treatment effect (P<.01).
\(^b\)Quadratic treatment effect (P<.1).

TABLE 6. Effect of high amounts of dietary supplemented choline on body weight, dry matter intake, and milk production of lactating dairy cows (Experiment 2).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Choline intake, g/d</td>
<td>18.4</td>
<td>158.6</td>
<td>281.9</td>
<td>7.32a</td>
</tr>
<tr>
<td>Body weight, kg</td>
<td>598</td>
<td>595</td>
<td>588</td>
<td>2.84a</td>
</tr>
<tr>
<td>DM intake, kg/d</td>
<td>18.4</td>
<td>18.2</td>
<td>16.7</td>
<td>.28a</td>
</tr>
<tr>
<td>% of body weight</td>
<td>3.09</td>
<td>3.08</td>
<td>2.85</td>
<td>.04b</td>
</tr>
<tr>
<td>Milk, kg/d</td>
<td>25.0</td>
<td>24.6</td>
<td>24.4</td>
<td>.58</td>
</tr>
<tr>
<td>Milk fat, %</td>
<td>3.15</td>
<td>3.05</td>
<td>3.01</td>
<td>.07</td>
</tr>
<tr>
<td>Milk protein, %</td>
<td>3.26</td>
<td>3.28</td>
<td>3.24</td>
<td>.02</td>
</tr>
<tr>
<td>Fat yield, kg/d</td>
<td>.78</td>
<td>.74</td>
<td>.73</td>
<td>.03</td>
</tr>
<tr>
<td>Protein yield, kg/d</td>
<td>.82</td>
<td>.80</td>
<td>.79</td>
<td>.02</td>
</tr>
<tr>
<td>4% Fat-corrected milk, kg/d</td>
<td>21.8</td>
<td>21.0</td>
<td>20.7</td>
<td>.57</td>
</tr>
</tbody>
</table>

aSignificant linear treatment effect (P<.01).
bSignificant linear and quadratic treatment effect (P<.05).

DISCUSSION

Although it had been suggested (20) that high amounts of choline could have detrimental effects on animal performance, actual effects of supplementing such amounts on health and milk production of dairy cows were not known previously. In present experiments, amounts of choline supplied to cows were increased gradually over 2 to 3 d. No visible problems, such as a sudden drop in feed intake or milk yield, were noted. Over the length of the experimental periods, high amounts of supplemented choline decreased both body weight and DM intakes of cows in both experiments.

Others have noted either increased bacterial number and decreased protozoal number (22) or vice versa (12) in ruminants fed choline added diets. Although bacterial and protozoal counts were not made in the present experiments, duodenal flow data (Table 3) do not support the concept that rumen bacterial growth was affected. No differences (P>.10) were seen in the amount of bacterial DM and bacterial CP flow to the duodenum due to added choline and rumen digestibility of nutrients were not affected due to choline supplementation (Table 4). However, caution should be practiced when comparing these results with those of others, because choline amounts used in the present experiments were at least 10 times higher than those used in sheep (12, 22).

At lower amounts of choline supplementation, some workers (9, 20) have reported no change in rumen fermentation due to dietary added choline, but others (22) noted an increase in both total and individual VFA concentrations. In the present study, total rumen VFA concentration was not different (P>.05) for cows fed increasing amounts of added choline. Rumen pH of cows increased with 10 g/kg choline supplementation but decreased again with 20 g/kg. Since choline is alkaline in nature, an increase in pH after feeding might be expected. However, no plausible explanation can be made for lower pH associated with highest choline supplementation.

Although duodenal flow data from Experiment 1 showed a linear increase (P<.1) in choline flow to the duodenum with increasing amounts of dietary choline, the actual increase (1.3 g/d) would probably be of little importance to the animal. Duodenal flow of choline increased less than 2 g by increasing dietary choline intake from 23.5 g for control to more than 325 g for 20 g/kg. This finding suggests that choline added to the diet as choline chloride is extensively degraded in the rumen, which agrees with reports of others (1, 19).

Dietary choline at the high amounts of supplementation tested in our experiments did not result in any improvements in milk yield or composition of midlactation cows in Experiment 2 and actually may have depressed milk production. Others (1, 9) using much lower
amounts of choline supplementation have shown no effect on milk yield whereas milk fat may have been increased in one study.

Results of work presented suggest that dietary choline supplementation as choline chloride is not effective as it is degraded in the rumen even at intakes up to 300 g/d. Alternatively, the bacterial degradation of choline in the rumen cannot be overwhelmed by supplementation of rations with high amounts of choline. In the case of methionine, methods that attempt to circumvent its ruminal degradation with variable success have been the use of methionine hydroxy analog, DL-methionine (13), ruminally protected DL-methionine (14), and encapsulated methionine (25). Similarly, if choline supplementation is desired, choline must also be protected from rumen degradation to be available for absorption in the duodenum.

REFERENCES


