Effect of Roughage Level and Calcium Magnesium Carbonate on Ruminal Metabolism and Site and Extent of Digestion in Beef Steers Fed a High-Grain Diet

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Story in Brief

Five crossbred steers fitted with ruminal and duodenal cannulas were used to evaluate the effects of roughage level and calcium magnesium carbonate ($CaMg(CO_3)_2$) on ruminal metabolism and site and extent of digestion. Treatments were: 1) 3.8% roughage and 0% $CaMg(CO_3)_2$; 2) 7.5% roughage and 0% $CaMg(CO_3)_2$; 3) 11.3% roughage and 0% $CaMg(CO_3)_2$; 4) 3.8% roughage and 1.5% $CaMg(CO_3)_2$; or 5) 7.5% roughage and 1.5% $CaMg(CO_3)_2$. For Treatments 4 and 5, $CaMg(CO_3)_2$ replaced MgO and limestone in the diet (DM basis). Roughage appeared to have a greater impact on ruminal kinetics and site and extent of digestion than $CaMg(CO_3)_2$. Results suggest that $CaMg(CO_3)_2$ can replace MgO and limestone in high-grain diets with no effect on site and extent of digestion.

Key Words: Calcium, Cattle, Magnesium, Roughage Level

Introduction

Roughages are included in high-grain finishing diets to reduce digestive and metabolic disorders. The optimal roughage level varies with grain source, grain-processing method, and roughage source. Roughage in feedlot diets is one of the most expensive ingredients on an energy basis, and is usually included in finishing diets in minimal (3 to 11%) levels (Galyean and Gleghorn, 2001). Research to decrease the dietary roughage content to near zero generally results in reduced cattle performance (Kreikemeier et al., 1990; Loerch, 1991), most likely due to an increase in the incidence of ruminal acidosis. Though the literature is inconsistent regarding the addition of dietary buffers, it has been noted that dietary buffers can help minimize ruminal acidosis, and maintain or increase ruminal, duodenal, and/or fecal pH. Dunn et al. (1979) reported that feeding buffer decreased mortality due to ruminal acidosis compared with a high-concentrate diet fed without buffer. In addition, Erdman (1988) suggested that the addition of dietary buffers tends to increase the ruminal pH when diets containing low roughage are fed. Because the end results of including roughage and buffer in the diets of feedlot cattle are similar, replacing roughage in the diet with buffer might reduce or maintain a low incidence of metabolic disorders, and reduce costs and management problems associated with handling roughage in feedlots. Therefore our objective was to evaluate the effects of level of roughage and calcium magnesium carbonate on ruminal kinetics and site and extent of digestion in steers fed a high-grain diet.

Materials and Methods

Five ruminally and duodenally cannulated crossbred steers (initial BW = 263 ± 9 kg) were used in a Latin square design experiment to evaluate the effects of roughage level and calcium magnesium carbonate ($CaMg(CO_3)_2$; MIN-AD®, MIN-AD, Inc., Amarillo, TX) on ruminal kinetics and site and extent of digestion in steers fed a high-grain diet. Five steers were

randomly assigned to one of five treatments: 1) 3.8% roughage and 0% $CaMg(CO_3)_2$; 2) 7.5% roughage and 0% $CaMg(CO_3)_2$; 3) 11.3% roughage and 0% $CaMg(CO_3)_2$; 4) 3.8% roughage and 1.5% $CaMg(CO_3)_2$; or 5) 7.5% roughage and 1.5% $CaMg(CO_3)_2$. Diets and their nutrient compositions are presented in Table 1. The research was conducted at the ContiBeef Research Center, Lamar, CO. All surgical procedures, post-surgical care, and the experimental protocol were reviewed and approved by the Oklahoma State University Institutional Animal Care and Use Committee.

Table 1. Composition of diets (DM basis)

	No MIN-AD			MIN-AD	
Item	3.8	7.6	11.4	3.8	7.6
Steam-flaked corn	81.95	76.45	70.95	81.62	76.10
Corn silage	5.60	11.19	16.79	5.60	11.19
Condensed corn distillers plus solubles	3.00	3.00	3.00	3.00	3.00
Fat	3.00	3.00	3.00	3.00	3.00
Soybean meal	2.49	2.60	2.71	2.60	2.70
Supplement	3.96	3.76	3.56	4.19	4.00

All steers were initially adapted to the 7.5% roughage and 0% $CaMg(CO_2)_3$ diet for a period of 12 d prior to the experiment. During the first 5 d, steers were offered grass hay (ad libitum) and the concentrate (0.9 kg) diet; grass hay was gradually removed and concentrate increased. The experiment consisted of five 21-d periods. Dry matter intake was recorded on a daily basis; all refusals were weighed, DM content was determined (AOAC, 1996), and DM refused was subtracted from the total intake of that steer for that respective adaptation period. Steers were fed twice daily at 0800 and 1300 h. Chromic oxide (Cr_2O_3; 15 g/d) was intraruminally dosed twice daily at feeding on d 1 through 20 via gelatin capsules (2/steer) as an indigestible marker of digesta flow.

Cattle had ad libitum access to water. Water was measured into 50 L tubs using a flow meter (Kent water meter, Hackensack, NJ). Water refused was measured via graduated cylinder and discarded; tubs were immediately replenished with fresh water.

Sampling. Feed was subsampled throughout the experiment on d 8 through 21 of each period, and dried (50°C; 48 h). Fecal grab samples were taken on d 17 through 20 of each period at 0700 and 1900 h and composited by animal within period. A portion of the composite for each animal was dried in a forced-air oven (50°C for 72 h) and ground to pass a 2-mm screen in a Wiley mill for later determination of OM, Cr, starch, NDF and macro-minerals. A second portion of the fecal composite was frozen, lyophilized, and used for N determination. On d 17 and 18 duodenal contents (250 mL) were collected every 4 h during a 48-h period; collection

times were adjusted on d 18 so that every 2 h in a 24-h period were represented. Duodenal contents were frozen (-20°C) and lyophilized, ground using a coffee grinder, and composited within animal and period on an equal weight of DM basis. On d 17, five whole ruminal contents samples (approximately 400 mL) were collected and mixed with 400 mL of 10% formalin. Ruminal contents were frozen (-20°C) and used for bacterial isolation.

On d 20 of each period at approximately 0800, Co-EDTA (200 mL) was pulsed-dosed intraruminally. Ruminal fluid was collected at 0, 3, 6, 9, 12, 18, and 24 h after dosing. Immediately after collection, ruminal fluid pH was measured using a combination electrode. A 10-mL aliquot was acidified with 0.5 mL of 6 N HCl and frozen (-20°C) for later ammonia-N analysis. A second 10-mL aliquot was acidified with 2 mL of 25% (wt/vol) metaphosphoric acid and frozen (-20°C) for later VFA analysis. A third and final 10-mL aliquot was frozen (-20°C) for Co analysis.

Laboratory analysis. Ground samples of feed, feces, ruminal bacteria, and duodenal contents were analyzed for laboratory DM and OM (AOAC, 1996). Nitrogen content of feed, feces, ruminal bacteria, and duodenal contents was determined by the combustion method (Leco NS2000, St. Joseph, MI; AOAC 1996). Neutral detergent fiber concentration of feed, feces, and duodenal contents was determined by the methods of Van Soest (1991). Feed, feces, and duodenal starch concentrations were determined using the Megazyme total starch assay procedure (Megazyme International Ireland Ltd., Wicklow, Ireland).

Feed, feces, and duodenal Ca, Mg, and P concentrations were determined following acid digestion. Briefly, 1.5 g of sample was ashed in a 500ºC ashing oven (Thermolyne Corporation, Dubuque, IA). The ashed sample was digested in 5 mL of concentrated HNO_3 and 5 mL of perchloric acid boiled on a hot plate for approximately 5 min. The sample was subsequently diluted with distilled water in a 100-mL volumetric and read on an Inductively Coupled Plasma Spectrophotometer (ICP Spectro Analytical Instruments, Fitchburg, MA). Chromium concentrations of fecal and duodenal composites were quantified using ICP.

Ruminal fluid samples were thawed and centrifuged at approximately 10,000 X g for 10 minutes. Concentrations of Co in ruminal fluid samples were determined via ICP analysis. Ruminal and duodenal ammonia N was determined using procedures outlined by Broderick and Kang (1980). Duodenal contents were reconstituted for ammonia N analysis. Volatile fatty acid analysis of ruminal fluid was conducted using gas chromatography. Ruminal bacteria and duodenal purines were determined using a modification of the procedure of Zinn and Owens (1986).

Statistical Analysis. All statistical analyses were performed using the SAS/Mixed procedure (SAS Inst. Inc., Cary, NC). Data were analyzed as a Latin square design with a 2x2+1 factorial arrangement of treatments. The model included fixed effects of roughage level, $CaMg(CO_3)_2$, roughage x $CaMg(CO_3)_2$, and period. Data repeated over time were analyzed with a model that included fixed effects of roughage level, $CaMg(CO_3)_2$, roughage x $CaMg(CO_3)_2$, time, roughage level x time, $CaMg(CO_3)_2$ x time, and roughage x $CaMg(CO_3)_2$ x time. Orthogonal contrasts were used to test for significant linear and quadratic effects of roughage level. Results are discussed as significant if $P<0.05$ and as a tendencies if $P>0.05$ and $P<0.10$.

Results and Discussion

Daily water intake decreased (quadratic roughage effect, P=0.003) as roughage level increased (Table 2). In addition, there was a tendency (P=0.06) for an interaction between roughage level and $CaMg(CO_3)_2$ for daily water intake. This resulted from the greater water intake for steers consuming 3.8% roughage and $CaMg(CO_3)_2$, and lower water intake for steers consuming 7.5% roughage with $CaMg(CO_3)_2$ compared with steers not consuming $CaMg(CO_3)_2$. Calcium magnesium carbonate supplementation and roughage level had no affect (P>0.10) on intake of DM, OM, or N. However, NDF intake increased (P=0.02) as roughage level increased. Starch intake tended (P=0.09) to respond with a roughage level x $CaMg(CO_3)_2$ interaction.

Duodenal flow and stomach digestion of nutrients was not affected (P>0.10) by roughage level or $CaMg(CO_3)_2$ (Table 2). Doudenal flow of NH_3-N numerically (P=0.10) increased as roughage increased. Percent post-stomach digestion of OM (P=0.08) and N (P =0.09) tended to decrease as roughage level increased. Similar results were observed when post-stomach digestion was expressed as a percent leaving the abomasum. Percent of starch leaving the abomasum that was digested in the post-stomach decreased (P=0.02) with increasing roughage, and there was a tendency (P=0.07) for post-stomach starch digestibility to increase with the addition of $CaMg(CO_3)_2$. In addition, there was a tendency for a roughage level x $CaMg(CO_3)_2$ supplementation interaction for post-stomach digestion (% leaving the abomasum) of OM (P=0.08) and starch (P=0.09). Post-stomach digestion of OM and starch were greater when 3.8% roughage and $CaMg(CO_3)_2$ were fed, and lower when 7.6% roughage and $CaMg(CO_3)_2$ were fed compared with the same diets with no $CaMg(CO_3)_2$. Post-stomach NDF digestion did not differ (P>0.10) among treatments. Total tract digestion of OM (P=0.05) and starch (P=0.02) decreased with increasing roughage level. In addition, there was a roughage level x $CaMg(CO_3)_2$ interaction (P=0.06) for total tract digestion of OM.

Table 2. Site and extent of nutrient digestion in steers fed increasing roughage with or without Min-Ad

	No MIN-AD			MIN-AD			P-values		
Item	3.8	7.6	11.4	3.8	7.6	SEM	Roughage (R)	Min-Ad (MA)	R X MA
Water intake, L/d	31.8	30.3	32.8	33.2	26.2	2.6	< .01	.11	.06
Nutrient intake, g/d									
DM	6,156	6,864	7,501	7,004	6,600	563	.16	.91	.19
OM	5,787	6,437	7,026	6,612	6,211	529	.18	.99	.19
NDF	1,090	1,361	1,467	1,174	1,235	122	.02	.19	.30
Starch									
N	119	131	149	137	136	11.2	.11	.63	.46
Duodenal flow, g/d									
OM	2668	2840	3103	3390	2987	411	.74	.13	.24

NDF	919	1010	901	918	656	235	.83	.24	.32
Starch									
Total N	120	123	124	135	125	9.6	.78	.20	.37
NH_3-N	2.03	2.33	2.65	2.21	2.01	.21	.10	.20	.23
Microbial N	67.1	66.1	71.7	75.0	66.2	5.64	.21	.41	.25
Feed N	51.1	52.7	49.5	56.8	53.9	6.83	.85	.48	.74
Ruminal digestion, %									
OM	54.5	56.4	56.5	50.6	54.6	4.41	.49	.27	.77
NDF	16.0	25.5	38.6	23.9	42.9	19.4	.44	.58	.76
Starch									
Feed N	58.4	60.3	66.9	59.1	62.1	5.14	.38	.78	.92
Microbial efficiency	21.8	18.6	18.5	24.2	20.2	2.80	.21	.25	.87
Postruminal digestion, %									
OM	32.8	30.4	28.6	39.6	28.9	4.69	.08	.21	.22
NDF	29.5	26.3	15.0	29.9	-3.7	21.3	.49	.45	.40
Starch									
N	76.7	69.3	60.5	79.0	62.2	7.71	.09	.77	.50
Postruminal digestion, % leaving abomasum									
OM	71.4	69.1	65.0	81.9	61.0	6.38	.05	.48	.08
NDF	22.9	33.2	11.0	39.7	2.7	19.3	.46	.93	.17
Starch									
N	76.6	75.0	71.6	83.1	69.8	5.05	.11	.56	.17
Total-tract digestion, %									
OM	87.2	86.9	85.2	90.2	83.4	1.97	.05	.78	.06
NDF	45.4	51.8	53.9	54.7	38.7	8.95	.54	.54	.16
Starch									

N	76.6	77.2	76.6	82.5	73.8	3.77	.36	.62	.15

There was a roughage level x $CaMg(CO_3)_2$ interaction (P=0.05) for Ca intake (data not shown). Calcium intake was greater when 3.8% roughage and $CaMg(CO_3)_2$ were fed, and lower when 7.6% roughage and $CaMg(CO_3)_2$ were fed compared with the same diets with no $CaMg(CO_3)_2$. A similar roughage level x $CaMg(CO_3)_2$ interaction (P=0.04) was observed for stomach digestion of Mg. Post- stomach and total tract digestibility of Ca, P, and Mg were not altered (P>0.10) by dietary treatment.

Fluid dilution rate did not differ (P>0.20) among dietary treatments; however, fluid flow rate out of the rumen was decreased (P=0.03) with the addition of $CaMg(CO_3)_2$ (Table 3). There was also a tendency (P=.06) for a roughage level x $CaMg(CO_3)_2$ interaction for fluid flow rate. Ruminal pH tended (P=0.08) to increase with increasing roughage level. In addition, time spent below ruminal pH of 6.2 tended (P=0.10) to decrease with increasing roughage level. Roughage level or $CaMg(CO_3)_2$ supplementation had no effect (P>0.10) on total VFA or molar proportions of propionate, butyrate, valerate, isobutyrate, isovalerate, or NH_3. Molar proportion of acetate tended (P=0.09) to increase with increasing roughage level.

Table 3. Ruminal pH, VFA and ammonia in steers fed increasing roughage with or without Min-Ad

	No MIN-AD			MIN-AD			P - values		
Item	3.8	7.6	11.4	3.8	7.6	SEM	Roughage (R)	Min-Ad (MA)	R X MA
Fluid dilution rate, $\%/h^{-1}$	7.62	7.85	8.49	6.95	7.15	.95	.52	.24	.99
Fluid flow rate, L/h	4.75	5.48	4.64	4.55	3.94	.41	.98	.03	.06
Ruminal pH									
Mean	5.98	6.05	6.13	5.94	6.11	.11	.08	.60	.49
Area < pH 6.2, pH*h[a]	8.12	7.03	5.65	8.82	6.51	1.52	.10	.45	.58
Area < pH 6.0, pH*h	4.22	3.48	3.07	5.16	3.25	1.07	.11	.35	.44
Area < pH 5.8, pH*h	1.66	1.43	.73	2.10	1.11	.62	.12	.42	.43
VFA									
Total, mM	79.1	82.7	80.8	79.2	74.8	6.93	.93	.34	.41
Acetate (A), %	46.5	51.5	50.3	45.8	52.1	3.13	.09	.82	.82
Propionate (P), %	39.7	33.6	35.5	36.4	36.4	2.67	.46	.92	.24

Butyrate, %	9.82	10.70	12.20	14.24	7.50	2.31	.34	.98	.10
A:P	1.23	1.58	1.47	1.39	1.51	.20	.43	.88	.56
NH_3, mM	3.13	3.90	2.65	2.82	3.11	.46	.23	.51	.59
[a]Linear roughage effect, (P=0.05).									

Implications

From the present data it appears that roughage has a greater impact on ruminal fermentation and site and extent of digestion than calcium magnesium carbonate. As site and extent of digestion were similar, calcium magnesium carbonate can replace magnesium oxide and limestone in high-concentrate diets fed to finishing cattle.

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