Sodium Bicarbonate or Multielement Buffer via Diet or Rumen: Effects on Performance and Acid-Base Status of Lactating Cows[1]

W. B. TUCKER,[2,3] M. ASLAM, M. LEMA, I. S. SHIN, P. LE RUYET,[4] J. F. HOGUE, D. S. BUCHANAN, T. P. MILLER, and G. D. ADAMS
Animal Science Department
Oklahoma State University
Stillwater 74078

ABSTRACT

Our objective was to compare the influence of dietary $NaHCO_3$ and a multielement buffer on ruminal acid-base status and lactation performance of dairy cows. Five ruminally fistulated, primiparous and multiparous lactating Holstein cows averaging 123 ± 21 d postpartum were assigned randomly to treatments in a 5 × 5 Latin square with 3-wk experimental periods. Treatments were a basal diet without supplemental buffers, with 1.5% $NaHCO_3$ or 1.5% multielement buffer, or with $NaHCO_3$ or multielement buffer solutions poured into the rumen via cannula at 2 h postfeeding. Addition of either buffer to the diet reduced ruminal fluid hydrogen ion concentration from 0 to 6 h postfeeding; only $NaHCO_3$ reduced ruminal fluid acidity when dosed via the cannula. Addition of buffers via ruminal cannula appeared to retard the reduction in ruminal fluid acidity that normally occurs from 6 to 12 h postfeeding; this may have been related to a feedback mechanism inhibiting salivary buffer secretion. Buffering capacity of ruminal fluid tended to increase with buffer addition; the increase was greatest during infusion of $NaHCO_3$. The ruminal fluid buffer value index increased by 4 units for control cows from early (0 to 6 h) to late (6 to 12) postfeeding; smaller increases were noted for addition of multielement buffer. This index was not different for $NaHCO_3$ during these two intervals. Milk yield and DMI were not affected by buffer addition. Although milk fat content tended to be higher with the multielement buffer than with $NaHCO_3$, it was not accompanied by the expected alterations in ruminal acid-base status. Therefore, this increase may be related to systemic effects of specific minerals in the multielement buffer rather than to a more stable ruminal environment. Based on the ruminal fluid buffer value index, $NaHCO_3$ tended to maintain the most stable ruminal acid-base status.

(**Key words**: sodium bicarbonate, multielement buffer, acid-base status, dairy cow)

Abbreviation key: **A:P** = acetate to propionate, **BC** = buffering capacity, **BIC-CN** = basal diet with $NaHCO_3$ dosed via ruminal cannula at 2 h postfeeding, **BIC-DT** = basal diet plus 1.5% $NaHCO_3$ (DM basis), **BVI** = buffer value index, H^+ = hydrogen ion concentration, **MEB** = multielement buffer, **MEB-CN** = basal diet with multielement buffer dosed via ruminal cannula at 2 h postfeeding, **MEB-DT** = diet containing 1.5% multielement buffer (DM basis).

INTRODUCTION

Dietary buffers are useful in preventing postprandial increases in ruminal fluid hydrogen ion concentration (H^+) and are most beneficial when diets contain corn silage (4). Because the influence of exogenous buffers on the rumen typically are short-lived after the buffer dissolves (2, 5, 13), and because rumi-

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[1]Journal Article 6136 of the Oklahoma Agricultural Experiment Station, Stillwater.
[2]To whom requests for reprints should be addressed.
[3]Present address: Mississippi State University, Department of Animal and Dairy Sciences, PO Drawer 5228, Mississippi State, MS 39762.
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nal acid production is most severe several hours postfeeding, interest has focused on controlling the release of buffers in the rumen (2, 5, 11, 12, 13).

Researchers compared the influence of $NaHCO_3$ with that of a multielement buffer (**MEB**; Rumen-Mate®, Pitman-Moore, Mundelein, IL) on ruminal acid-base status, ruminal liquid kinetics, and lactation performance (11, 12). The major reactive products in MEB are KCl and $MgCO_3 \cdot Na_2CO_3 \cdot NaCl$; MEB was designed to dissolve slowly in the rumen, potentially providing acid-neutralizing capacity and buffering capacity (**BC**) throughout the postprandial interval. Staples et al. (12) reported that 1% $NaHCO_3$, 1% MEB, and 3% MEB (DM basis) each reduced ruminal acidity; however, the reduction with 1% MEB appeared to be less than that for 1% $NaHCO_3$ and 3% MEB. Ruminal fluid BC was not evaluated. Solorzano et al. (11) and Staples et al. (12) reported that neither DMI nor milk yield was affected by buffer supplementation, although MEB increased milk fat percentage and fat yield.

Both a low ruminal fluid H^+ and a high BC (resistance to change in H^+) appear to be important during periods of rapid fermentation in the rumen (2, 5, 6, 14). A buffer value index (**BVI**) has been developed (14) that increases when either ruminal fluid H^+ is reduced or BC is increased. The objective of this study was to evaluate the influence of $NaHCO_3$ and MEB on lactation performance and ruminal acid-base status of dairy cattle as characterized by alterations in the ruminal fluid BVI.

MATERIALS AND METHODS

Experimental Design and Treatments

Five ruminally fistulated, primiparous and multiparous lactating Holstein cows averaging 123 ± 21 d postpartum were assigned randomly to treatments in a 5 × 5 Latin square with 3-wk experimental periods. Treatments were a basal diet (Table 1): without supplemental buffers (control), with 1.5% $NaHCO_3$ (**BIC-DT**), with 1.5% MEB (**MEB-DT**), with $NaHCO_3$ solution poured into the rumen via cannula twice daily at 2 h postfeeding (**BIC-CN**), or with MEB solution poured into the rumen via cannula twice daily at 2 h postfeeding (**MEB-CN**). Although other researchers (11, 12) included three to four times more MEB than $NaHCO_3$ in the diet when comparing these buffers, we think that the theoretical acid-neutralizing capacity of MEB justifies comparison with $NaHCO_3$ at similar dietary concentrations. All diets were formulated to meet or exceed nutrient requirements of lactating dairy cows (8). Cows were given access to feed twice daily at 0350 and 1550 h for 2 h. The buffer solutions for BIC-CN and MEB-CN were prepared by mixing the respective buffers in 3.8 L of water. The amount of buffer used in each dose was equivalent to .75% of expected total daily DMI as predicted from the average daily DMI from the previous week; because cows were dosed after each feeding, BIC-CN and MEB-CN cows received their buffer in an amount equivalent to 1.5% of total dietary DMI. Control cows and those receiving dietary buffers were dosed intraruminally with 3.8 L of water twice daily at 2 h postfeeding.

Sample Collection and Analysis

Samples of the TMR were collected weekly, composited at the end of the study, and analyzed for nutrient content by a commercial laboratory (Northeast DHIA, Ithaca, NY). Sorghum silage was sampled weekly; DM content was determined via toluene distillation to adjust dietary ingredients to maintain a constant ratio of ingredients in the dietary DM. Orts were recorded daily.

Milk yield was measured daily throughout the study; milk samples were collected weekly during consecutive p.m. and a.m. milkings for analysis of fat, protein, lactose, and SNF content via infrared spectrophotometry (Multispec 2, Multispec Limited, Wheldrake, York, England). Milk component concentrations were calculated as weighted averages according to the average a.m. and p.m. milk yield for the week. The first 2 wk of each experimental period were utilized for adaptation; feed intake, milk yield, and milk composition were calculated from the last week of each period.

At 0350 h on the last day of each experimental period, cows were dosed intraruminally with 202 mg of Cr as Cr-EDTA in 170 ml of total volume; to allow frequent sampling of ruminal fluid without disturbing the ruminal milieu, tubes were threaded through the can-

TABLE 1. Ingredient and nutrient composition of diets (DM basis).

	Diet		
	Basal	$NaHCO_3$	MEB
Ingredient, %			
Sorghum silage	32.04	31.98	31.98
Corn grain, ground	43.96	42.56	42.56
Soybean meal, 44% CP	20.64	20.60	20.60
Sodium bicarbonate	. . .	1.50	. . .
MEB[1]	. . .	. . .	1.50
Limestone	1.07	1.07	1.07
Dicalcium phosphate	.87	.86	.86
Dynamate®[2]	.35	.35	.35
Trace-mineralized salt	.54	.53	.53
Megalac®[3]	.52	.52	.52
Vitamin A and E premix[4]	.02	.02	.02
Nutrient analyses, %			
DM	45.1	46.5	44.8
CP	15.8	16.7	16.3
NE_L,[5] Mcal/kg	1.74	1.71	1.71
ADF	21.0	19.4	19.8
NDF	31.1	29.7	34.0
Ca	.81	.76	.72
P	.44	.47	.45
Mg	.35	.34	.54
Na	.26	.73	.43
K	1.22	1.18	1.43
S	.31	.27	.36

[1]MEB = Multielement buffer, Rumen-Mate® (Pitman-Moore, Inc., Mundelein, IL).

[2]Double sulfate of K and Mg (Pitman-Moore, Inc.).

[3]Calcium salts of fatty acids (Church & Dwight Co., Inc., Princeton, NJ).

[4]Contains 30 million IU of vitamin A and 500,000 IU of vitamin E/kg.

[5]Calculated from National Research Council values (8) for individual feedstuffs.

nula stoppers and anchored in the ventral sac of the rumen with a weight. An electric vacuum pump was utilized to pump ruminal fluid from the ventral sac into a stoppered Erlenmeyer flask at 30-min intervals from 0 to 12 h postfeeding. Ruminal fluid was strained through four layers of cheesecloth; filtered fluid was decanted into a 100-ml polyethylene snap-cap vial and into a 12-ml centrifuge tube. Ruminal fluid was centrifuged for 10 min at 10,000 × *g*; then, an aliquot (5 ml) of the supernatant fluid was pipetted into a 12-ml polyethylene snap-cap tube containing 50 mg of metaphosphoric acid and frozen for later VFA analysis. Approximately 3 ml of the supernatant fluid were decanted into a 5-ml polypropylene snap-cap tube and frozen for Cr analysis. Upon thawing, acidified ruminal fluid was analyzed for VFA via gas chromatography (Autosystem GC, Perkin-Elmer, Norwalk, CT) and for Cr via atomic absorption spectrophotometry (model 4000, Perkin-Elmer). A linear regression was fitted to the natural logarithm of ruminal fluid Cr concentrations over time postfeeding and was utilized to calculate ruminal liquid kinetics.

Ruminal fluid pH was analyzed using fluid in the 100-ml vial (model 950 pH-ion analyzer, Fisher Scientific, Pittsburgh, PA); then, ruminal fluid BC was determined by titrating a 30-ml aliquot of the sample from its original pH to pH 5 with 1*N* HCl and another 30-ml aliquot from its original pH to pH 7 with 1*N* NaOH. When the original pH was higher than 7, we recorded the amount of acid required to reduce sample pH from 7 to 5. Buffering capacity was defined as the sum of milliequivalents of H^+ required to titrate 1 L of ruminal fluid from pH 7 to 5. Because BC was measured only between pH 7 and 5, it did not

account for total acid-neutralizing capacity of buffers that raised initial pH above 7; the milliequivalents of H^+ required to reduce initial pH to 7 were not included in the BC calculation. However, in practice, these buffers very rarely increase ruminal fluid above pH 7. Furthermore, the volume of acid required to reduce the fluid to pH 7 during titration typically is very small because of the low H^+ at high pH. Hence, BC should reliably indicate physiological effects of buffers.

To calculate the BVI (14) of ruminal fluid, a standard pH (StpH) of 6 and standard BC (StBC) of 50 meq/L were assumed as a base point (BVI = 100); BVI was calculated from ruminal fluid sample pH (SapH) and BC (SaBC; meq/L) by the following formula:

$$\begin{aligned}\text{BVI} = 100 + 10 \times ((((&\text{antilog}_{10}\ (-\text{StpH})) \\ &- (\text{antilog}_{10}\ (-\text{SapH})))/\text{antilog}_{10} \\ &(-\text{StpH})) + ((\text{SaBC} - \text{StBC})/\text{StBC})).\end{aligned}$$

Although pH values are inserted in the formula, these values are converted to H^+ during calculation of BVI; hence, the resulting index value should be more accurate as an assessment of changes in acidity of the ruminal fluid than if pH values, i.e., logarithmic values, had been used in calculation (7). The BVI increases as ruminal fluid H^+ decreases or as ruminal fluid BC increases; each of these responses typically would be beneficial to high yielding dairy cows. Conversely, an increase in H^+ or a reduction in BC would lower BVI. Consolidating the effects of dietary buffers on ruminal fluid H^+ and BC into a single, numeric value allows more complete evaluation of the effect of a dietary buffer on the ruminal milieu.

Statistical Analysis

Statistical analysis was via least squares ANOVA (10); cow, period, diet, and residual variation were included in the model. Ruminal fluid acid-base status and VFA were analyzed by sample time. Single degree of freedom contrasts were employed to compare the control diet with individual buffer treatments. Ruminal fluid pH was converted to H^+ before ANOVA. Statistical significance was established at $P < .05$ unless noted otherwise.

RESULTS AND DISCUSSION

Ruminal Fluid Acid-Base Status

Ruminal Fluid H^+. Postprandial alterations in ruminal fluid acid-base status are presented in Table 2 and Figure 1. Ruminal fluid H^+ increased for the control diet until 4 to 6 h postfeeding, probably the result of higher concentrations of fermentation acids; after 6 h, H^+ dropped rapidly. This pattern is typical of unbuffered high concentrate diets fed twice daily (1). Addition of either $NaHCO_3$ or MEB to the diet tended to attenuate the increase in ruminal fluid acidity from 0 to 6 h (Table 2); H^+ tended to be lower for $NaHCO_3$. Although dosing $NaHCO_3$ via ruminal cannula had an immediate effect on ruminal fluid acidity (Table 2, Figure 1), no effect was evident for MEB-CN. Compared with the control diet, MEB-DT slightly reduced ruminal fluid acidity from 6 to 12 h postfeeding, which was perhaps as a result of the slow release of its acid-neutralizing capacity.

The reduction in H^+ accompanying intraruminal infusion of $NaHCO_3$ disappeared within several hours after infusion (Figure 1). Compared with the unbuffered control diet, infusion of either the $NaHCO_3$ or MEB solution appeared to interfere with the decrease in acid content of the rumen from 6 to 8.5 h postfeeding. Wever et al. (16) reported that infusing a NaCl solution into the rumen increased plasma osmotic pressure and reduced rumination time; they suggested that plasma hypertonicity inhibits rumination. If so, this might explain the maintenance of acid in the rumen of our buffer-infused cows at the latter stages of the postfeeding interval. This retarded recovery from the traditional 4 to 6 h postfeeding nadir in ruminal fluid pH was observed previously with intraruminal $NaHCO_3$ infusion (2, 5). In the present study, addition of buffer to the diet did not slow the recovery of ruminal fluid acid-base status from fermentation acid production. Because identical quantities of the buffers were fed and infused, the lack of dietary buffer effect on recovery must be due to the different times or routes of entry of dietary versus infused buffers or due to preingestion interaction of buffers with dietary components.

Ruminal Fluid BC. Buffering capacity of ruminal fluid from cows consuming the control

TABLE 2. Least squares mean alterations in ruminal fluid acid-base status postfeeding.

	Treatment							
	1 Control	2 Dietary $NaHCO_3$	3 Dietary MEB[1]	4 Cannula $NaHCO_3$	5 Cannula MEB	SE	Effect	*P*
Ruminal fluid H^+, neq/L								
(h)								
0–2	623	412	564	532	600	85		NS[2]
2–4	1051	564	771	465	1153	216	1 vs. 4	.079
4–6	1047	638	610	997	1156	250		NS
0–6	895	512	625	670	959	156		NS
6–12	451	454	387	619	718	164		NS
Ruminal fluid buffering capacity, meq/L								
(h)								
0–2	71.2	74.0	75.6	74.7	72.6	1.6	1 vs. 3	.070
2–4	71.0	68.2	67.8	74.3	69.3	1.1	1 vs. 2	.094
							1 vs. 3	.059
							1 vs. 4	.054
4–6	68.5	64.0	62.0	69.4	65.7	1.6	1 vs. 2	.078
							1 vs. 3	.016
0–6	69.9	68.8	68.2	73.2	69.3	.6	1 vs. 3	.083
							1 vs. 4	.003
6–12	67.9	67.7	71.6	67.4	67.9	2.4		NS
Ruminal fluid buffer value index								
(h)								
0–2	108.0	110.7	109.5	109.6	108.5	1.0	1 vs. 2	.086
2–4	103.7	108.0	105.8	110.2	102.3	2.2	1 vs. 4	.055
4–6	103.2	106.4	106.3	103.9	101.6	2.4		NS
0–6	105.0	108.6	107.4	107.9	104.3	1.6		NS
6–12	109.1	109.0	110.5	107.3	106.4	1.9		NS

[1]MEB = Multielement buffer.

[2]$P > .10$.

diet increased immediately postfeeding, but BC changed by only about 5 meq/L from 0 to 6 h postfeeding (Figure 1). Cows receiving buffers in their diets had higher ruminal fluid BC than controls at 0 h, but BC fell by approximately 15 meq/L for both buffers by 6 h postfeeding and was lower than for the control diet at that time. With the exception of BIC-CN, which had the highest BC of any treatment at 0 h and increased sharply and temporarily during infusion, dosing buffers via ruminal cannula yielded temporal patterns similar to those of the dietary buffer treatments. The marked increase in BC during $NaHCO_3$ infusion and the rapid reduction in BC immediately postinfusion was observed previously (2, 5).

Ruminal fluid BC averaged 2 meq/L lower for control cows from 6 to 12 h than for 0 to 6 h postfeeding (Table 2). This response is similar to that for BIC-DT and MEB-CN, but BC for MEB-DT increased with time postfeeding, which potentially resulted from the slow release of its buffering chemicals. Ruminal fluid BC decreased by over 6 meq/L from 0 to 6 h to 6 to 12 h postfeeding for BIC-CN; this large reduction may have resulted from a combination of the sharp increase in BC during infusion for this treatment and from a feedback response to increased ruminal fluid or plasma osmolarity, inhibiting endogenous buffer secretion. Of the four buffer treatments, the $NaHCO_3$ dosed intraruminally at 2 h postfeeding (Table 2) was the most effective in main-

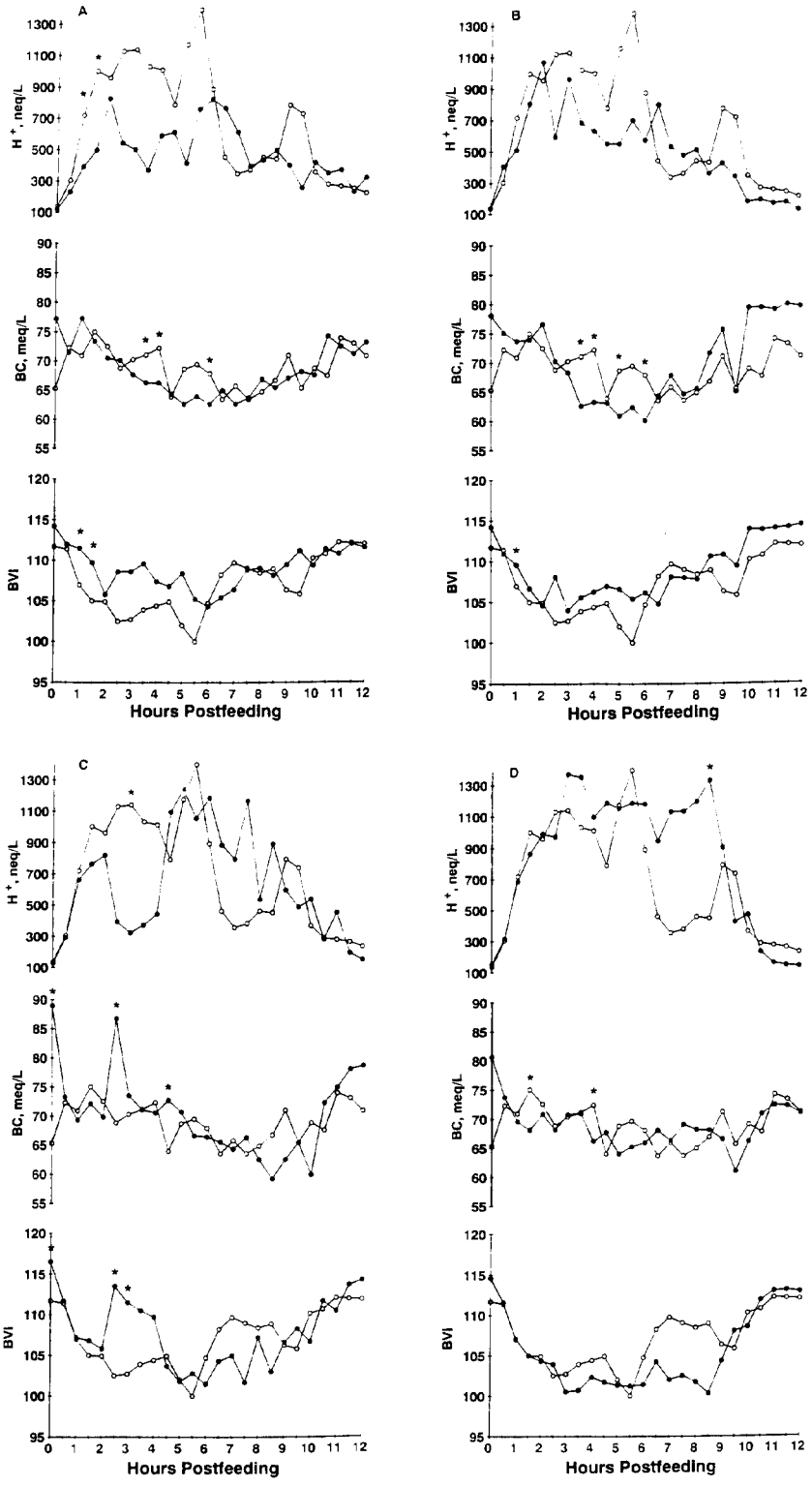
A
B
C
D
H+, neq/L
BC, meq/L
BVI
Hours Postfeeding

TABLE 3. Least squares mean ruminal liquid kinetics.

	Treatment							
	1 Control	2 Dietary $NaHCO_3$	3 Dietary MEB[1]	4 Cannula $NaHCO_3$	5 Cannula MEB	SE	Effect	*P*
Ruminal liquid								
Volume, L	41.4	35.1	38.6	37.7	38.8	2.3	1 vs. 2	.074
Dilution rate, %/h	11.65	12.23	12.71	12.55	10.92	1.01	NS[2]	
Flow rate, L/h	4.85	4.10	4.64	4.69	4.30	.19	1 vs. 2	.018
							1 vs. 5	.068
Turnover time, h	8.67	9.58	8.44	8.26	9.95	.85	NS	

[1]MEB = Multielement buffer.

[2]$P > .10$.

taining ruminal fluid BC during the 4 to 6 h postfeeding interval during which ruminal fluid acid content typically is highest (5).

Ruminal Fluid BVI. Ruminal fluid BVI for cows consuming the control diet fell approximately 10 units from 0 to 6 h postfeeding (Table 2); reductions were similar for the buffer treatments, although their initial BVI tended to be higher than for the control. The period from 0 to 2 h postfeeding represents the interval during which ruminal fluid acid-base status is affected most dramatically by dietary acidity. During this interval, each of the buffer treatments tended to increase BVI relative to the control, although the response was most evident for BIC-DT.

From 2 to 6 h postfeeding, alterations in ruminal acid-base status likely reflect the production of acid by ruminal fermentation; BVI for the control diet was 5 units lower during this interval than during 0 to 2 h postfeeding (Table 2). The BIC-CN was most effective in maintaining BVI from 2 to 4 h postfeeding, but, compared with the control, BIC-DT and MEB-DT also tended to increase BVI; MEB-CN was not effective in maintaining BVI from 2 to 6 h postfeeding.

The interval from 6 to 12 h postfeeding typically involves a slowing of ruminal fermentation, rapid absorption of ruminal VFA, and recovery of ruminal fluid acid-base status to a more alkaline condition. In our study, buffer additions via the diet or ruminal cannula had no effect on ruminal fluid BVI from 6 to 12 h postfeeding, although BVI tended to be highest for MEB-DT and lowest for MEB-CN (Table 2). The mean ruminal fluid BVI for control cows increased by 4 units from 0 to 6 h to 6 to 12 h postfeeding; change was slightly less for MEB-DT and MEB-CN during this interval. The BVI was very consistent during these two intervals for both $NaHCO_3$ treatments; the change for BIC-DT was only .4 units. We think that maintaining a stable ruminal acid-base status throughout the postfeeding interval provides a favorable environment for microbial growth, resulting in increased DMI and milk yield by the cow.

Ruminal Liquid Kinetics

The natural logarithm of ruminal fluid Cr was regressed against time postfeeding to calculate ruminal liquid kinetics (Table 3); for linearity of the regression, mean r^2 was .92, n = 25. Addition of $NaHCO_3$ to the diet reduced ruminal liquid volume, but volume was not affected significantly by the other buffer treatments. In contrast, Rogers and Davis (9) re-

Figure 1. Least squares mean temporal alterations in ruminal fluid hydrogen ion concentration (H^+), buffering capacity (BC), and buffer value index (BVI) for A) control versus $NaHCO_3$ diets, B) control versus multielement buffer diets, C) control versus $NaHCO_3$ dosed by ruminal cannula at 2 h postfeeding, and D) control versus multielement buffer dosed by ruminal cannula at 2 h postfeeding. o = Control diet, ● = buffer treatment; * = treatment means at that sampling time differ ($P < .05$).

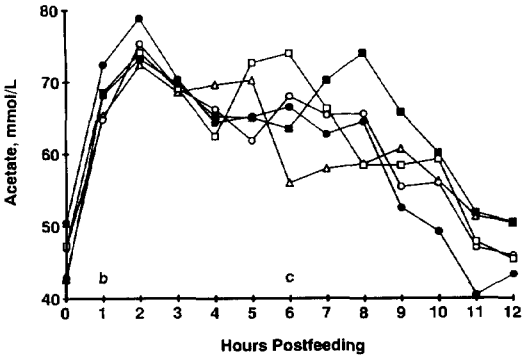

Figure 2. Least squares mean ruminal fluid acetate concentration versus time postfeeding. △ = Control diet; ○ = $NaHCO_3$ diet; ● = multielement buffer diet; □ = $NaHCO_3$ dosed via ruminal cannula at 2 h postfeeding; and ■ = multielement buffer dosed via ruminal cannula at 2 h postfeeding. Lower case letters listed above hours postfeeding represent treatment differences ($P < .05$); a = control diet versus $NaHCO_3$ diet; b = control diet versus multielement buffer diet; c = control diet versus $NaHCO_3$ dosed via ruminal cannula; and d = control diet versus multielement buffer dosed via ruminal cannula.

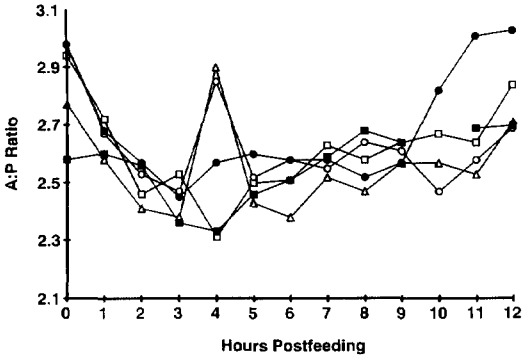

Figure 4. Least squares mean ruminal fluid acetate to propionate (A:P) ratio versus time postfeeding. △ = Control diet; ○ = $NaHCO_3$; ● = multielement buffer diet; □ = $NaHCO_3$ dosed via ruminal cannula at 2 h postfeeding; and ■ = multielement buffer dosed via ruminal cannula at 2 h postfeeding. Lower case letters listed above hours postfeeding represent treatment differences ($P < .05$); a = control diet versus $NaHCO_3$ diet; b = control diet versus multielement buffer diet; c = control diet versus $NaHCO_3$ dosed via ruminal cannula; and d = control diet versus multielement buffer dosed via ruminal cannula.

ported that supplemental dietary $NaHCO_3$ increased water intake and tended to increase ruminal liquid volume. Aslam et al. (2) and Hogue et al. (5) also reported that intraruminal $NaHCO_3$ infusion tended to increase ruminal liquid volume. In the present study, ruminal liquid dilution rate and turnover time were not affected by any of the treatments, whereas liquid flow rate was reduced by BIC-DT and tended to be reduced ($P = .068$) by MEB-CN.

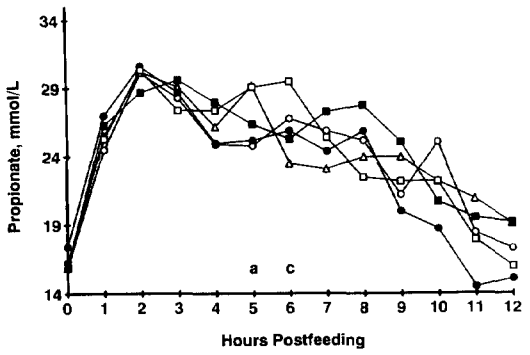

Figure 3. Least squares mean ruminal fluid propionate concentration versus time postfeeding. △ = Control diet; ○ = $NaHCO_3$ diet; ● = multielement buffer diet; □ = $NaHCO_3$ dosed via ruminal cannula at 2 h postfeeding; and ■ = multielement buffer dosed via ruminal cannula at 2 h postfeeding. Lower case letters listed above hours postfeeding represent treatment differences ($P < .05$); a = control diet versus $NaHCO_3$ diet; b = control diet versus multielement buffer diet; c = control diet versus $NaHCO_3$ dosed via ruminal cannula; and d = control diet versus multielement buffer dosed via ruminal cannula.

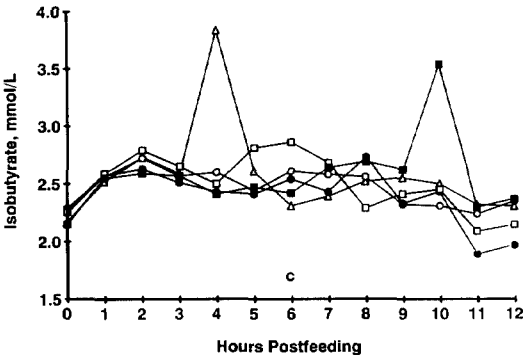

Figure 5. Least squares mean ruminal fluid isobutyrate concentration versus time postfeeding. △ = Control diet; ○ = $NaHCO_3$ diet; ● = multielement buffer diet; □ = $NaHCO_3$ dosed via ruminal cannula at 2 h postfeeding; and ■ = multielement buffer dosed via ruminal cannula at 2 h postfeeding. Lower case letters listed above hours postfeeding represent treatment differences ($P < .05$); a = control diet versus $NaHCO_3$ diet; b = control diet versus multielement buffer diet; c = control diet versus $NaHCO_3$ dosed via ruminal cannula; and d = control diet versus multielement buffer dosed via ruminal cannula.

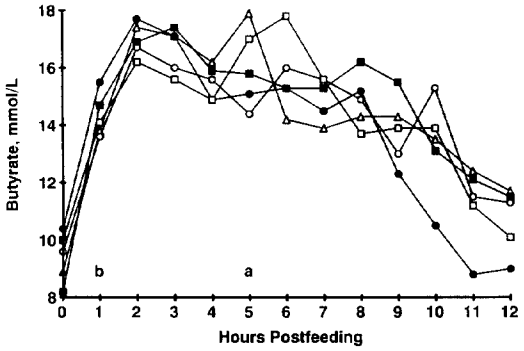

Figure 6. Least squares mean ruminal fluid butyrate concentration versus time postfeeding. △ = Control diet; ○ = $NaHCO_3$ diet; ● = multielement buffer diet; □ = $NaHCO_3$ dosed via ruminal cannula at 2 h postfeeding; and ■ = multielement buffer dosed via ruminal cannula at 2 h postfeeding. Lower case letters listed above hours postfeeding represent treatment differences ($P < .05$); a = control diet versus $NaHCO_3$ diet; b = control diet versus multielement buffer diet; c = control diet versus $NaHCO_3$ dosed via ruminal cannula; and d = control diet versus multielement buffer dosed via ruminal cannula.

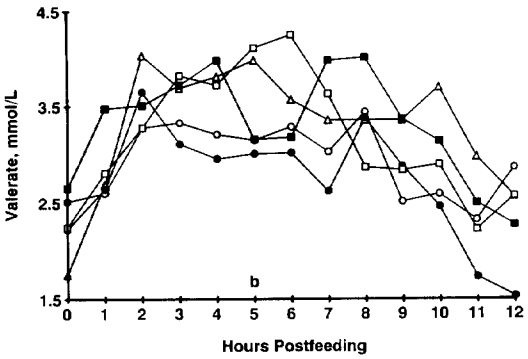

Figure 8. Least squares mean ruminal fluid valerate concentration versus time postfeeding. △ = Control diet; ○ = $NaHCO_3$ diet; ● = multielement buffer diet; □ = $NaHCO_3$ dosed via ruminal cannula at 2 h postfeeding; and ■ = multielement buffer dosed via ruminal cannula at 2 h postfeeding. Lower case letters listed above hours postfeeding represent treatment differences ($P < .05$); a = control diet versus $NaHCO_3$ diet; b = control diet versus multielement buffer diet; c = control diet versus $NaHCO_3$ dosed via ruminal cannula; and d = control diet versus multielement buffer dosed via ruminal cannula.

This response is in disagreement with Rogers and Davis (9), who observed that liquid dilution rate increased with dietary $NaHCO_3$ supplementation; however, they fed 5% $NaHCO_3$ versus only 1.5% $NaHCO_3$ in our study. Increases in the rate of passage of liquid from the rumen enhance removal of digestion end products that are inhibitory to microbial

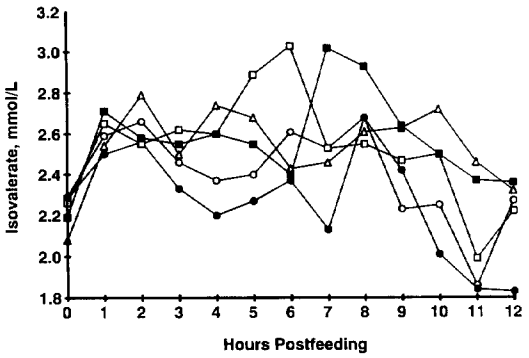

Figure 7. Least squares mean ruminal fluid isovalerate concentration versus time postfeeding. △ = Control diet; ○ = $NaHCO_3$ diet; ● = multielement buffer diet; □ = $NaHCO_3$ dosed via ruminal cannula at 2 h postfeeding; and ■ = multielement buffer dosed via ruminal cannula at 2 h postfeeding. Lower case letters listed above hours postfeeding represent treatment differences ($P < .05$); a = control diet versus $NaHCO_3$ diet; b = control diet versus multielement buffer diet; c = control diet versus $NaHCO_3$ dosed via ruminal cannula; and d = control diet versus multielement buffer dosed via ruminal cannula.

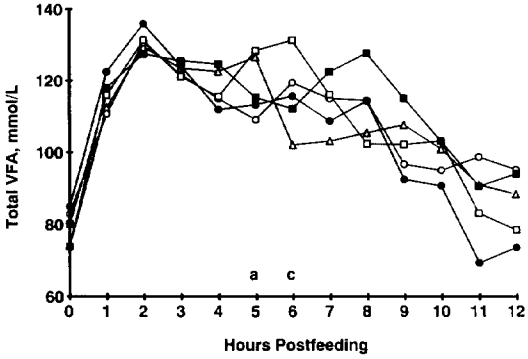

Figure 9. Least squares mean ruminal fluid total VFA concentration versus time postfeeding. △ = Control diet; ○ = $NaHCO_3$ diet; ● = multielement buffer diet; □ = $NaHCO_3$ dosed via ruminal cannula at 2 h postfeeding; and ■ = multielement buffer dosed via ruminal cannula at 2 h postfeeding. Lower case letters listed above hours postfeeding represent treatment differences ($P < .05$); a = control diet versus $NaHCO_3$ diet; b = control diet versus multielement buffer diet; c = control diet versus $NaHCO_3$ dosed via ruminal cannula; and d = control diet versus multielement buffer dosed via ruminal cannula.

TABLE 4. Least squares mean DMI, milk yield, and milk composition.

	Treatment							
	1 Control	2 Dietary $NaHCO_3$	3 Dietary MEB[1]	4 Cannula $NaHCO_3$	5 Cannula MEB	SE	Effect	*P*
DMI, kg	19.4	19.4	19.4	19.0	19.5	.4	NS[2]	
Milk yield, kg	25.6	24.0	25.7	26.0	24.1	.7	NS	
4% FCM, kg	22.9	21.3	23.6	22.9	21.8	.6	1 vs. 2	.094
Fat, %	3.26	3.19	3.41	3.18	3.35	.08	NS	
Fat, kg	.85	.78	.89	.84	.81	.03	NS	
Protein, %	3.18	3.17	3.17	3.14	3.06	.04	1 vs. 5	.054
Protein, kg	.81	.76	.82	.82	.74	.03	1 vs. 5	.074
Lactose, %	4.72	4.66	4.71	4.75	4.66	.05	NS	
Lactose, kg	1.22	1.13	1.22	1.24	1.15	.04	NS	
SNF, %	8.60	8.53	8.58	8.60	8.42	.06	1 vs. 5	.072
SNF, kg	2.21	2.07	2.22	2.24	2.06	.07	NS	

[1]MEB = Multielement buffer.

[2]$P > .10$.

growth; hence, buffers may improve microbial efficiency. The treatments in our study did not cause any alterations in ruminal liquid kinetics that would be expected to improve ruminal microbial efficiency.

Ruminal Fluid VFA

Ruminal fluid acetate concentration (Figure 2) was higher for MEB-DT than for the control at 1 h postfeeding; at 6 h postfeeding, acetate was higher for BIC-CN than for the control diet. Acetate also tended to be higher for MEB-CN than for the control diet at 7 and 8 h postfeeding. Ruminal fluid propionate concentration (Figure 3) was similar among treatments for 4 h postfeeding; the control diet was higher than BIC-DT at 5 h but lower than BIC-CN at 6 h postfeeding. Ruminal fluid acetate to propionate (**A:P**) ratio (Figure 4) ranged from 2.3 to 3.0 and was similar among diets throughout the postfeeding interval. Ruminal fluid isobutyrate concentration (Figure 5) ranged from 1.9 to 3.9 mmol/L and was higher for BIC-CN than for the control diet at 6 h postfeeding. Ruminal fluid butyrate concentration (Figure 6) increased for 2 h postfeeding, stabilized for several hours, and then declined gradually during the remainder of the postfeeding interval. Butyrate was higher for MEB-DT than for the control diet at 1 h postfeeding and was lower for BIC-DT than for the control diet at 5 h. Ruminal fluid isovalerate concentration (Figure 7) ranged from 1.8 to 3.0 mmol/L and was not affected by dietary treatment. Ruminal fluid valerate concentration (Figure 8) was lower for MEB-DT than for the control diet at 5 h postfeeding but was otherwise unaffected by buffer supplementation. Ruminal fluid total VFA concentration (Figure 9) was lower for BIC-DT than for the control diet at 5 h postfeeding and was higher for BIC-CN than for the control diet at 6 h postfeeding.

In a summary of 38 experiments in which forage constituted 30% or more of total dietary DM, Erdman (4) reported that dietary $NaHCO_3$ supplementation increased ($P < .01$) A:P ratio but did not affect total VFA concentration. Trends were similar for dietary $NaHCO_3$ supplementation of high concentrate diets, although differences between buffered and unbuffered diets were not significant. Staples et al. (12) reported that dietary MEB supplementation increased milk fat content and ruminal fluid acetate concentration; MEB reduced ruminal fluid valerate concentration. In the present study, ruminal fluid VFA concentrations did not appear to be affected markedly by buffer supplementation. Although the concentration of milk fat precursors in the rumen were not affected by dietary buffer supplementation, milk fat content and milk fat yield tended to be elevated by MEB-DT (Table 4).

Cow Performance

Dry matter intake was similar for all treatments (Table 4). Milk yield was not affected

significantly by treatment, although it was somewhat lower for BIC-DT and MEB-CN. Yield of 4% FCM tended to be highest for MEB-DT and lowest for BIC-DT; for BIC-DT, yield tended to be lower ($P = .094$) than for the control diet. Milk fat percentage tended to be higher for MEB than for $NaHCO_3$ supplementation and was highest for MEB-DT; fat yield tended to be highest for MEB-DT and lowest for BIC-DT. Milk protein content ($P = .054$) and yield ($P = .074$) were somewhat lower for MEB-CN than for the control diet; the reason for this is not apparent, but addition of MEB to the diet of lactating dairy cows reduced milk protein content previously (11). Lactose was not affected by treatment, but milk SNF content (Table 4) was slightly lower with MEB-CN than with the control diet, probably because of the lower milk protein content of MEB-CN.

Compared with previous studies, daily DMI in our study was approximately 2 kg higher than for MEB supplementation of corn silage-based diets fed to cows averaging 123 DIM (12), but DMI was 2.5 kg lower than for MEB supplementation of corn silage-based diets fed to cows averaging 55 DIM (11). Buffer supplementation, whether $NaHCO_3$ or MEB, did not affect DMI in our study or in theirs (11, 12).

Addition of 2.6 to 3% MEB (DM basis) appeared to increase milk yield in one trial, but not in the other two (11); in each trial, milk yield for MEB supplementation was similar to that for cows receiving supplemental $NaHCO_3$. Staples et al. (12) also reported that MEB did not affect milk yield. Although FCM yield was not affected significantly by treatment in our study, increases in response to dietary $NaHCO_3$ and MEB supplementation were reported previously (11, 12).

In our study, milk fat percentage tended to be highest for MEB-DT (Table 4); other researchers (11, 12) observed that milk fat percentage and milk fat yield were higher with MEB than with $NaHCO_3$ supplementation. Because ruminal fluid A:P ratio was similar for cows consuming $NaHCO_3$ and MEB (12), the increased fat yield for MEB supplementation probably was not related to the ruminal production of fatty acids for synthesis of milk fat. Instead, this may be a result of the mineral elements, Mg and S, that are provided by MEB. Emery et al. (3) suggested that Mg enhanced the uptake of fatty acids by the mammary gland, thus increasing milk fat synthesis. Tucker et al. (15) reported that increasing dietary S from .30 to .54% or from .43 to .66% of dietary DM increased both milk fat percentage and milk fat yield; those authors (15) suggested that responses may have been due to an increase in nutrient digestibility, although digestibility was not measured.

CONCLUSIONS

Addition of either buffer to the diet reduced ruminal fluid H^+ from 0 to 6 h postfeeding. Only $NaHCO_3$ was effective in reducing ruminal fluid acidity when dosed via cannula. Addition of buffers via ruminal cannula retards the drop in ruminal fluid acidity that normally occurs from 6 to 12 h postfeeding; this may be related to a feedback mechanism inhibiting salivary buffer secretion. The ruminal fluid BVI increased for cows receiving the control diet, MEB-DT, and MEB-CN from early (0 to 6 h) to later (6 to 12 h) intervals postfeeding; values for $NaHCO_3$ during these two intervals were not changed. Milk fat content was somewhat higher, and milk protein and SNF contents were somewhat lower, for MEB-CN. Although milk fat content was higher for the MEB than for $NaHCO_3$, this response was not accompanied by the expected alterations in ruminal acid-base status. Therefore, this increase may be related to systemic effects of elements contained in MEB rather than to a more stable ruminal environment. Based on the ruminal fluid BVI, $NaHCO_3$ appeared to provide the most stable ruminal acid-base status throughout the postfeeding interval.

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