Effects of Sodium Bicarbonate and Sodium Sesquicarbonate on Animal Performance, Ruminal Metabolism, and Systemic Acid-Base Status[1]

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ABSTRACT

Six rumen-fistulated lactating Holstein cows were arranged in a replicated 3 × 3 latin square design with 3-wk periods and offered diets containing concentrate and corn silage in a 60:40 ratio (DM basis). Treatments were: 1) basal diet, 2) basal diet with 1% $NaHCO_3$, and 3) basal diet with 1% sodium sesquicarbonate. There were no differences among treatments in milk production, milk protein, or 3.5% FCM, but sodium sesquicarbonate increased milk fat percentage (3.89, 3.94, 4.06%) compared with that of the control. Rumen pH was higher for cows fed buffered diets than for control cows. Urine pH was higher for cows fed the $NaHCO_3$ diet than for those fed sodium sesquicarbonate and control diets. No differences were detected among treatment means for molar percentage of isobutyrate, isovalerate, or total VFA. Dietary sesquicarbonate addition increased molar percentage of acetate, decreased propionate, and resulted in a higher acetate:propionate ratio compared with the cows fed $NaHCO_3$. However, molar percentage of butyrate and valerate decreased in cows fed sodium sesquicarbonate when compared with those fed the control diet. No differences among treatment means were detected for blood pH, pCO_2, or HCO_3.

INTRODUCTION

The most consistent benefit of dietary buffer supplementation for lactating dairy cattle has been the prevention of milk fat depression. This is especially true when diets contain a high proportion of concentrate in relationship to forage. High concentrate diets often reduce rumen pH and decrease fiber digestibility (21, 22). Dietary buffer addition has been used to prevent abrupt declines in rumen pH, which has been observed to be higher in cows fed buffers than in cows fed the same diet without buffers. Erdman et al. (8) found no change in rumen pH when 1.5% $NaHCO_3$ was added to a ration of 40% corn silage and 60% concentrate. However, in later work by Erdman et al. (9), 1% $NaHCO_3$ increased rumen pH from 6.13 to 6.43 in early postpartum cows receiving similar diets. These findings are in agreement with those reported by Kilmer et al. (15), who reported an increase of rumen pH from 6.07 to 6.36 when .8% $NaHCO_3$ was added to the diet of lactating cows.

Jimenez (12) reported that sodium sesquicarbonate (NaSC) has a higher acid-neutralizing capability than sodium bicarbonate ($NaHCO_3$) and thus may be an effective ruminal buffer. No difference in rumen pH, dry matter intake (DMI) (kg/d), milk production, or milk fat percentage was noted when NaSC was compared with $NaHCO_3$ (3, 13, 24). Experimental data on the effect of NaSC on rumen pH and fermentation are limited, therefore, the objective of this experiment was to determine and compare the difference between dietary addition of $NaHCO_3$ and NaSC.

MATERIALS AND METHODS

Six rumen-fistulated Holstein cows, averaging 180 d (range 170 to 195 d) postpartum and milking 30 kg/d (range 25 to 35 kg), were

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TABLE 1. Ingredients and chemical composition of control, sodium bicarbonate, and sodium sesquicarbonate (NaSC)-supplemented total mix diets fed to dairy cows.

	Diet		
	Control	$NaHCO_3$	NaSC
Ingredient	(% of DM)		
Corn silage	40.00	40.00	40.00
Corn grain	40.50	39.81	39.81
Soybean meal (44%)	16.95	16.65	16.65
Limestone	1.35	1.35	1.35
Trace-mineralized salt	.60	.60	.60
Dicalcium phosphate	.30	.30	.30
Selenium premix	.12	.12	.12
Dynamate	.09	.09	.09
Vitamin A, D, E premix	.09	.09	.09
Sodium bicarbonate	. . .	1.00	. . .
Sodium sesquicarbonate	. . .	. . .	1.00
Total	100.0	100.0	100.0
Chemical composition, %			
Crude protein	16.0	15.5	16.4
ADF	15.6	15.5	14.9
NDF	38.0	39.9	36.9
Mg	.18	.18	.19
Ca	.77	.79	.75
Na	.18	.51	.52
K	.88	.89	.93
P	.45	.43	.47

arranged in a replicated 3 × 3 Latin square with 3-wk periods to compare treatment: 1) no buffer addition (control), 2) 1% $NaHCO_3$, or 3) 1% NaSC (DM basis). All cows received a diet containing 40% corn silage and 60% concentrate (DM basis) during a 2-wk preliminary period before assignment to treatment. Treatment periods were 3 wk in length with the first 2 wk used for adaptation and wk 3 serving as the collection period. Diets were formulated to meet established nutrient requirements of dairy cattle (20) with the exception of fiber content. Ingredients and chemical composition of diets are presented in Table 1.

Cows were individually fed their respective diets at 95% ad libitum intake of what was consumed during the 2-wk preliminary period to reduce among and within treatment variability and to provide a more uniform pattern of rumen function. Because cows were restricted in feed intake, total feed consumption was usually completed in 20 to 30 min after feeding. The proportion of corn silage in the diet (as fed basis) was adjusted each week according to silage DM fluctuations. Cows were housed in individual tie stalls and fed twice daily at 0700 and 1700 h. All cows were allowed access to an exercise lot daily for 2 h before the evening milking (1500 h). Daily measurements included milk production and feed intake. Milk samples were collected once weekly during consecutive a.m. and p.m. milkings and analyzed for milk fat and milk protein. Means reported for these parameters represents the 3-wk trial period.

Concentrate mixes were sampled upon mixing and stored at (–20°C) for subsequent analysis. The corn silage was sampled weekly for DM determination by toluene distillation, and concentrate DM was determined by placing samples in a drying oven for 48 h at 60°C. Concentrate and corn silage samples were stored for subsequent nutrient analysis. Chemical analysis of the diets (Table 1) was determined according to the methods of AOAC (1) by Chemical Service Laboratory, Inc., Jeffersonville, IN.

Blood, ruminal fluid, and urine samples were collected at 0, 2, 4, 6, and 8 h postfeeding, with 0-h samples beginning just prior to the morning feeding. Thirty-milliliter blood sam-

TABLE 2. Feed intake and milk production composition in dairy cows fed control, sodium bicarbonate, or sodium sesquicarbonate (NaSC)-supplemented diets.

Item	Diet			
	Control	$NaHCO_3$	NaSC	SEM
Dry matter intake, kg/d	19.5	19.2	19.2	.22
Milk production, kg/d	23.2	23.9	23.2	.54
FCM, kg/d[1]	24.7	25.7	25.3	.87
Milk fat, %	3.89[a]	3.94[ab]	4.06[b]	.13
Milk protein, %	3.44	3.39	3.44	.05

[a,b]Treatment effect ($P<.10$).

[1]3.5% FCM = .432 kg milk + 16.23 kg fat.

ples were collected via jugular venipuncture and transferred into evacuated heparinized tubes (Beckton-Dickson, Rutherford, NJ). The blood was placed on crushed ice and analyzed within 1 h for blood pH and pCO_2 (Instrumentation Laboratories Model 213-05). Blood bicarbonate was calculated from pCO_2 and blood pH by fitting the data into the Henderson-Hasselbalch equation.

Ruminal fluid samples were collected via esophageal tube equipped with an attached strainer (1-mm^2 pores). Suction was applied with a 60-cc catheter tip syringe, and ruminal fluid was collected into plastic vials. Ruminal fluid was first analyzed for pH (Corning pH meter), and then centrifuged at 7000 × *g* for 10 min. Exactly 8 ml supernatant were transferred into a glass tube with 1.6 ml of metaphosphoric acid (25% wt/vol). The tubes were stored at −20°C for later VFA analysis. Volatile fatty acids were determined by GLC on a 5880A series gas chromatograph (Hewlett Packard, Avondale, PA), using GP 10% SP-1000/1% H_3PO_4 on 100/120 Chromosorb W AW (Supelco, Inc., Bellfonte, PA) packing in a 2-m glass column at 125°C, with cyclohexanone used as an internal standard. Urine was collected via manual stimulation of the vulva and immediately analyzed for pH.

The data were analyzed by least squares analysis. The model employed was $Y_{ijk} = u + T_i + C_j + P_k + e_{ijk}$, where u = overall mean; T_i = treatment effect; C_j = cow effect; P_k = period effect; and e_{ijk} = residual. The least squares difference test was used to compare treatment means with significant F values.

RESULTS AND DISCUSSION

Feed Intake

Mean daily DM intake (Table 2) was unaffected by treatment, a result of 95% ad libitum intake limitation. Mean DM intakes were 19.5, 19.2, and 19.2 kg/d for cows fed control, $NaHCO_3$, and NaSC, respectively. Buffer addition increased food consumption in some studies (10, 14) but not in others (9, 21).

Milk Yield and Composition

Mean daily milk yield for the 3-wk trial period was not affected by buffer addition (Table 2); however, there was a tendency for cows receiving $NaHCO_3$ to produce more milk than control cows. Cows fed $NaHCO_3$ produced .7 kg more milk/d than the control and NaSC cows. Supplementation with $NaHCO_3$ increased milk production in midlactation cows (28); however, most midlactation fat depression studies have reported no effect on milk production by NaSC or $NaHCO_3$ (3, 13) addition.

Milk fat percentage was higher for cows fed the NaSC diet ($P<.10$) than for control cows. These results are in agreement with those observed by Cassida et al. (4). However, other studies utilizing $NaHCO_3$ and NaSC to maintain fat test have reported no increase in milk fat percentage (3, 13).

Yield of 3.5% FCM was not different among treatments; however, cows fed buffered diets tended to have higher FCM production than those fed the control diet. Cows fed $NaHCO_3$

TABLE 3. Ruminal pH and VFA profile in dairy cows fed control, sodium bicarbonate, or sodium sesquicarbonate (NaSC)-supplemented diets.

Item	Diet			
	Control	$NaHCO_3$	NaSC	SEM
Rumen pH	6.06[a]	6.24[b]	6.25[b]	.08
Total VFA	102.1	102.2	96.2	4.7
	(mol/100 mol)			
VFA				
Acetate (A)	59.2[a]	59.7[abc]	62.4[bd]	1.0
Propionate (P)	20.6[ab]	21.5[a]	18.3[b]	1.0
Isobutyrate	2.4	2.3	2.6	.24
Butyrate	13.4[bd]	12.4[ac]	12.5[abc]	.34
Isovalerate	2.3	2.2	2.3	.12
Valerate	2.0[c]	1.8[cd]	1.8[d]	.09
A:P	3.0[cd]	2.9[d]	3.4[c]	.19

[a,b]Treatment effect ($P<.05$).

[c,d]Treatment effect ($P<.10$).

and NaSC produced 1.0 and .6 kg/d more 3.5% FCM/d, respectively, than the control cows. Muller and Kilmer (19) reviewed data that established dietary $NaHCO_3$ addition in dairy cattle rations generally had beneficial effects on 4% FCM production. Dietary NaSC addition tended to have the same beneficial effect on 4% FCM production (4). Milk protein percentages were unaffected by treatment.

Metabolic and Physiological Measures

Results of buffer treatments on postprandial rumen pH are shown in Figure 1. Dietary buffer additions increased ($P<.05$) rumen pH when compared with that of the control. Rumen pH was depressed for all treatments from 2 to 8 h postfeeding and was lowest at 4 h, which is in agreement with Rogers et al. (21) and West et al. (29). Time by treatment interaction was not significant, which suggests that buffer in the rumen functioned equally at a constant rate in acid neuralization. Mertens (18) reported that fiber digestion is maximum at a pH of approximately 6.8 and declines rapidly as pH is reduced. Rumen pH in this study declined to a minimum of 5.72, well below the range at which fiber digestibility is depressed. However, rumen pH with added NaSC and $NaHCO_3$ was higher than 6.0 throughout the study, which is in agreement with the general theory that dietary buffer may improve milk fat percentage by raising rumen pH and producing conditions that favor a higher rumen acetate:propionate ration (A:P) (7). Previous research has shown increased rumen pH with $NaHCO_3$ supplementation (21, 26, whereas others have not reported any increase with $NaHCO_3$ (3, 24 or NaSC (3, 5, 13).

Mean ruminal VFA values are reported in Table 3. No differences in molar percentage of isobutyrate and isovalerate were detected among treatments. Molar percentage of acetate increased in cows fed NaSC when compared with those fed the control diet ($P<.05$) and with

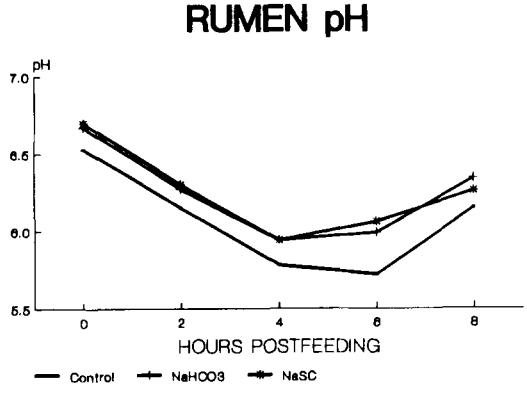

Figure 1. Effect of time postfeeding on rumen pH for control and treatment groups.

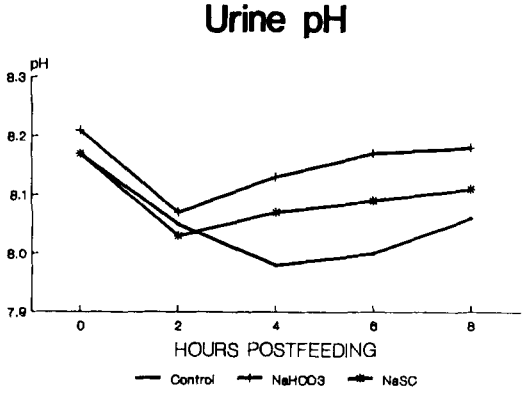

Figure 2. Effect of time postfeeding on urine pH for control and treatment groups.

those fed the $NaHCO_3$ diet ($P<.10$). Cows fed the $NaHCO_3$ diet had increased ($P<.05$) molar percentage of propionate when compared with cows fed NaSC. A similar increase in molar percentage of propionate was also observed by Boerne et al. (2) when 1% $NaHCO_3$ or trona was added to a 50% concentrate diet. Esdale and Satter (11) observed a significant decrease in propionate by increasing rumen pH from 5.5 to 7.0. A similar response was also observed in our study with added NaSC to the diet.

The increased molar percentage of propionate and a decreased molar percentage of acetate by addition of $NaHCO_3$ resulted in lower ($P<.10$) A:P compared with NaSC. The supplementation of $NaHCO_3$ diets of lactating cows has been observed to increase rumen A:P by some (9, 21, 23), but other studies with supplemented $NaHCO_3$ and NaSC reported no effects (3, 13, 24) on A:P. Thomas and Emergy (27) observed a positive linear relationship between the A:P and milk fat percentage. Erdman et al. (9) and Snyder et al. (23) reported increased milk fat percentage with increased A:P. Results were similar in this study, with milk fat percentage being higher in cows fed NaSC than in those cows fed the control.

Buffer addition to high concentrate diets often results in a higher molar percentage of acetic acid, a lower molar percentage of propionic acid, and a wider acetate to propionate ratio (6). Our results in cows supplemented with NaSC support this generalization (Table 3).

Molar percentage of butyrate was reduced in cows fed added NaSC ($P<.05$) and $NaHCO_3$ ($P<.10$) compared with that of the control group. Boerne et al. (2) observed the same response for butyrate when 1% trona was added to a 90% concentrate diet. Molar percentage of valerate was also lower in cows fed NaSC ($P<.05$) compared with that of the control.

Total VFA concentration was not affected by buffer addition. Dietary buffer addition has little effect on total VFA concentration. Snyder et al. (23) reported an increase in total VFA with $NaHCO_3$ addition, while Erdman et al. (9) indicated that $NaHCO_3$ decreased total VFA.

Figure 2 shows the changes in urine pH with time postfeeding. Urine pH was increased in $NaHCO_3$-fed cows compared with urine pH of cows in the control ($P<.002$) and NaSC groups ($P<.03$). Urine pH was higher throughout the sampling time in cows fed the buffered diets than in the control group. Urine pH dropped sharply at 2 h postfeeding and tended to increase with time in the buffered diets. However, urine pH tended to decrease with time in control cows until 4 h, probably reflecting differences in acidogenicity of the diets. Urine pH increased with added NaSC (4) and $NaHCO_3$ (14, 21, 22), or remained unchanged (25) when $NaHCO_3$ was fed. Differences in urine pH among treatments was not evident at 2 h postfeeding, which is probably indicative of the time frame in which a renal response to an acid or base challenge may be expected. Under alkali conditions, the kidney increases alkali excretion and simultaneously suppress H+ excretion in order to maintain normal blood pH, and as a result, increases urine pH (5). The near normal pH of urine in the control diet indicates that diets did not cause an acidotic stress, which may explain the small responses to buffer addition observed in this study. Increased urine pH indicates that buffers may be useful to alleviate systemic acidosis.

Blood Acid-Base Status

There were no differences (Table 4) in blood pH, pCO_2, or bicarbonate among treatments. Dietary $NaHCO_3$ addition has been reported to increase blood pH in lactating cows (16); however, others have not observed this increase (9, 14). Because the measurements were taken at

TABLE 4. Urine pH and blood acid-base status in dairy cows fed control, sodium bicarbonate, or sodium sesquicarbonate (NaSC)-supplemented diets.

Item	Diet			
	Control	$NaHCO_3$	NaSC	SEM
Urine pH	8.05[a]	8.15[b]	8.09[a]	.02
Blood pH	7.44	7.44	7.43	.009
pCO_2, mm Hg	44.04	44.24	45.11	1.31
HCO_3, meq/L	28.93	28.99	28.88	.94

[a,b]Treatment effect ($P<.05$).

the end of the 3rd wk, inherent homeostatic mechanisms could possibly have adjusted free proton, HCO_3, and CO_2 excretion or retention sufficiently to attenuate treatment effects.

Kronfeld (17) stated that ingestion of excessive buffer would be expected to induce primary metabolic alkalosis. However, our results indicate no effect due to treatment on any blood variable. Snyder et al. (23) and Teh et al. (26) observed no effect of dietary $NaHCO_3$ addition on blood pH, pCO_2, pO_2, or HCO_3.

In general, the response to dietary buffer addition in lactating dairy cows is limited to the first few weeks postpartum. This response is indicated by increased DM intake and FCM production and by reduced incidences and severity of cows being off feed. The buffers usually exert their most significant effects in early lactation following the transition to a high concentrate diet (15).

In summary, as evidenced by similar milk yield, and fat and protein percentages, cows fed diets containing NaSC performed comparably with those receiving $NaHCO_3$; however, cows with added NaSC dietary addition had higher molar percentage of acetate, A:P, and lower molar percentage of propionate than did cows fed the $NaHCO_3$ diets. In contrast, cows fed the diet with added $NaHCO_3$ had higher urine pH than those fed the NaSC added diets.

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