OFFERING SODIUM BENTONITE AND SODIUM BICARBONATE FREE-CHOICE TO LACTATING DAIRY CATTLE

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(ABSTRACT)

The objective of this experiment was to evaluate the effects of free-choice intake of sodium bentonite and sodium bicarbonate on physiological and production parameters. Eight Jerseys and seventeen Holsteins (four fistulated) were randomly assigned to two groups to equalize stage of lactation, age and production history. Two diets were fed: diet 1 without added sodium bicarbonate and diet 2 with sodium bicarbonate added at 1.2% of dry matter. Each group followed a different diet regime: 1) diet 1 with no free-choice (D1-NFC), 2) diet 2 with no free-choice (D2-NFC), 3) diet 1 with free-choice (D1-WFC), and 4) diet 2 with free-choice (D2-WFC). Free-choice options of sodium bentonite and sodium bicarbonate were offered side by side in a covered feeder to breed groups. Diets were changed every 10 d to provide 8 periods with a repetition of each diet regime. All diets were adjusted to 17% ADF and 17% CP. There were no differences with either breed among diets for blood and fecal observations or milk protein. Urine specific gravity was lower in both breeds when sodium bicarbonate was force-fed. Holsteins force-fed sodium bicarbonate had greater intake and milk production than Holsteins not force-fed. In Jerseys, milk urea nitrogen (MUN) decreased when sodium bicarbonate was added to the TMR. During periods in which cows were allowed free-choice access to sodium bentonite and sodium bicarbonate, Jerseys had higher urine pH,

fat-corrected milk, MUN, and dry matter intake (DMI), and Holsteins had higher milk fat percentages and fecal pH.

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INTRODUCTION

Dairy producers commonly offer feed additives free-choice to dairy cattle. In order to manage acidosis in a lactating herd, it is a common practice to offer those considered rumen buffers, specifically sodium bentonite and sodium bicarbonate. There are a few common reasons behind this "management tool". The popular reason is that cows experiencing acidosis will consume the buffers because of an innate ability to alleviate discomfort. In this way rumen buffers may act as "antacids". Fluctuations in consumption levels may serve as an "acidosis barometer", with sudden increases alerting producers to possible ration problems, thus prompting a change in the TMR formula or more current laboratory analysis of the feed. Thus, if this adds to effective management of acidosis, intake and therefore production may not be impaired.

Innate abilities to correct acid-base imbalances may be a valid factor as to why cows will select for rumen buffers. There have been continual observations of cows eating dirt. Could there be a factor of palatability? Could consumption be a simple imitation of other herd mates? There are no sure answers to these questions, however they do fuel current research such as this.

This experiment assimilated what is commonly found in the field by using TMRs rich in corn silage and fermentable carbohydrates, and low in ADF as well as free-choice options of sodium bentonite and sodium bicarbonate.

Important questions

Does offering free-choice rumen buffers:

1) Improve acid-base balance by reducing occurrences of rumen and systemic acidosis?

2) Improve efficiency in terms of milk production and components?

3) Offer cost effectiveness/economical profit?

Objectives of this study

1) Examine the effects of offering free-choice sodium bentonite and sodium bicarbonate to lactating dairy cattle consuming high starch diets.

- Observe fecal and urine characteristics and acid-base balance of body fluids (urine, manure, rumen fluid).
- Monitor rumen parameters (rumen pH and volatile fatty acids).
- Observe feed intake and milk production and composition.

2) Determine cost effectiveness of offering sodium bentonite and sodium bicarbonate free-choice to lactating dairy cattle.

LITERATURE REVIEW

ACID-BASE BALANCE IN DAIRY CATTLE

Physiological regulations

Regulation of acids and bases in the body are controlled through slight changes in hydrogen ion concentration, which may depress or accelerate chemical reactions in cells. High hydrogen ion concentration leads to acidosis. To prevent acidosis, the body has defense mechanisms: acid-base buffer systems (bicarbonate buffer system), respiration regulation, and kidney excretion (42). Feeding high concentrate rations to dairy cattle not only results in higher milk production but also a higher risk of acidosis due to acid production in the rumen.

Implications of acidosis

Definition

Rumen acidosis is a condition that results when a cow consumes a diet high in fermentable carbohydrates, low in effective fiber, or both. These diets encourage increased ruminal fermentation, which changes the microbial profile of the rumen. These changes result in decreased glucose utilization and a build up of lactic acid, which, by negatively affecting rumination and natural buffering effects, is detrimental to a cow's productivity and health (62).

Clinical signs

When fluctuations in rumen pH move towards acidic, there is a predisposition to subclinical acidosis. While cows in this state are not termed "sick" they are at risk of associated consequences. At a ruminal pH of 5.5, changes begin to occur and daily episodes below 5.5 predispose cattle to acidosis, even though little accumulation of lactic acid may be detected (33, 65). The rate and extent of lactic acid production and accumulation will determine changes in physiological conditions in the gastrointestinal tract and body fluids. When a cow is in an acidotic state, early signs such as reduced feed intake and production resulting from reduced rumen turnover and less microbial synthesis occur (62). Fulton et al. (32) observed decreased intake in cattle fed between 35 and 90% of concentrate on a dry matter basis when dry-rolled corn or hard red winter wheat were fed. Cows fed wheat exhibited a more pronounced decrease in feed intake to the point they slowed eating rates and reduced rumen acid load. Wheat, as a feed, has a weak buffering effect and thus a low cation exchange capacity, which will be discussed further. Cattle fed corn did not reduce intake until the 90% concentrate level was fed. More pronounced signs of acidosis include weight loss, reduced production, suppressed milk fat, and lameness or laminitis (62).

Decreased pH in the rumen causes vasoconstrictive substances such as histamine and endotoxins to be released into the systemic circulation. These substances can cause inflammation and ultimately destroy the microvasculature of the corium in the hoof, which leads to laminitis (12, 56). Sole hemorrhaging represents a clinical sign of laminitis. Enevoldsen et al. (26) reported that 29.7% of first lactation cows and 24.7% of second and third lactation cows possessed sole hemorrhages in more than one hoof. Factors causing acidosis are species, amount of feed fed, pre-existing microbial populations in the rumen and gut, and individual animal differences such as feed consumption rate and an individual's own ability to effectively excrete potentially toxic substances (62).

Rumen pH and microbial populations

The severity of acidosis is measured by rumen pH. Less extreme subclinical cases score as low as 5.5. Acute acidosis is achieved at an even lower pH of 5.0 or less. A pH of 6.8 is believed to be the optimal for maximum fiber digestibility (63). In vitro studies have suggested that a pH range of 6.7-7.0 is optimal for the digestion of cellulose (17). In most dairy operations, subclinical acidosis cases are more common than acute. Kennelly et al. (49) found cows fed both 50 and 75% concentrate reached the lowest ruminal pH 6 h post feeding. Ghorbani et al. (34) found that fistulated cows reached a pH low point at 6 h post feeding on a 60% concentrate control diet without rumen buffers, and 4 h post feeding on diets including buffering agents. Erdman et al. (28) reported rumen pH to be lowest 4 h post feeding on a 60% concentrate diet. These studies identify a general range of 4 to 6 h post feeding for pH to reach nadir.

High concentrate diets disturb the balance between bacteria that produce versus utilize lactic acid until producers outnumber utilizers (73). Russell et al. (75) demonstrated that *Streptocoecus bovis* that produces lactic acid and *Megasphera elsdenii* that utilizes lactic acid undergo competition with optimum pH levels at 5.1-5.3 (*S. bovis* predominant) and 5.5-6.0 (*M. elsdinii* predominant) respectively. At pH 5.5, these microbes are in equilibrium with each other. Forms of lactic acid include the D and L isomers with the later constituting an important precursor for fatty acid synthesis and glucogenesis, because 16 to 38% of acetate originates from L-lactate (35). High concentrate diets support shifts towards higher concentrations of these isomers but with L-lactate at a lower concentration (43). Giesecke and Stangassinger (35) reported D-lactate constitutes about 20% of total lactic acid at pH 6 but dramatically elevates to 50% at pH 5. Harmon (43) observed net portal absorption of lactate in steers ruminally infused with sugar or fed a 70% concentrate diet. Glucose-infused steers reached a rumen pH of 4.2 in 18 h following treatment with 53 m*M* of L-lactate and 30.2 m*M* of D-lactate. Steers fed high concentrate diets reached a pH of 6.0 in 14 h following treatment with 2.1 m*M* of L-lactate and 1.2 m*M* of D-lactate. It was concluded that rapidly fermentable carbohydrates cause a rapid elevation of both isomers of lactate within 8 h, peaking at 20 h.

With a disturbance of microorganism populations from acidosis comes a change in volatile fatty acid production and ratios. Two in vitro studies by Esdale and Satter (30) showed consistently in two studies that VFA ratios changed according to pH. For instance, acetate production was inhibited between pH 5.6 and 6.2 while propionate and butyrate production increased when pH levels decreased to 5.6. Because acetate is the VFA responsible for fat production in cow's milk, this might explain why many studies have found high concentrate diets to suppress fat in milk.

Animal condition and predisposition

Body condition of an animal can predispose to acidosis because health status influences how efficiently toxins are excreted. Telle and Preston (85) found that sheep in poor, undernourished condition fed wheat succumbed to acidosis at 50 g/kg of body weight as opposed to well-conditioned sheep who succumbed at 75 to 80 g/kg of body weight. Dinius and Williams (22) saw a similar trend in cattle when changing from forage to concentrate diets. They found that while grain intake was not different, malnourished cows showed symptoms of acidosis with diarrhea as a prominent clinical sign.

Influence of forage types

Over the past few decades, dairy cattle rations have changed drastically with concentrate percents rising from 30% (20-30 years ago) to 60% (present day) of dry matter. In addition, the main forage fed has switched from haylage and/or pasture to corn silage, which is more acidic (84). Corn silage has a lower cation-exchange capacity (CEC) and is thus less able to assist with buffering. CEC is a measure of the ionized surface groups of fibers and can affect the rate of digestion by affecting microorganism attachment to the fibers as well as neutralizing rumen pH (2). The consumption of finer-sized feed particles has also increased, which reduces saliva production and buffering. Feeding of high-grain rations and/or feeding succulent/wet or finely chopped or pelleted forage can decrease salivation. Saliva is rich in bicarbonate for natural buffering. Feeds that increase fermentation produce conditions favoring an acidic rumen environment (62).

Recovery from and avoidance of acidosis

When microbial populations are disrupted, time is needed to reestablish them. Results from in vitro studies have found that 10-15 volume turnovers may be required to shift a rumen microbial population receiving glucose to a balanced state. That would translate into 6-10 d for recovery of a microbial population (83). As a result, recovery period translates into reduced milk production and thus profit. An easy solution would be to simply increase fiber content of the ration. Another approach is buffering and/or alkalinizing supplements that assist in stabilization of rumen pH.

RUMEN MINERAL SALTS

Modes of action

Buffers are defined as a combination of a weak acid and its salt, which assist in maintaining rumen pH. Alkalizing agents neutralize acid and increase pH (38). For the majority of this review, rumen buffers will be the main focus. Primarily, buffers have been fed to sustain milk fat levels and feed consumption. They inhibit dramatic drops in rumen pH and thus work to sustain the critical balance of acetic and propionic acid. Animals experiencing abrupt dietary changes such as dairy cattle following parturition and beef cattle entering the feedlot stage of meat production are especially in need of buffers. Rumen buffers were originally believed to work by neutralizing acids in feedstuffs or acids produced during nutrient digestion and metabolism (16).

According to Bigner et al. (7), bicarbonate, the corresponding anion of the Na salt, has a strong negative charge, which is believed to facilitate maintenance or increased pH of a body fluid compartment. This theory has been supported many times with a variety of buffering feed additives when both fistulated and nonfistulated cows were sampled for rumen pH (24, 30, 34, 44) and would describe buffers as working more as an antacid; however, this may not be the logical action. Some researchers have found no significant changes in rumen pH. To work as an antacid, the bicarbonate ion must dissociate into carbon dioxide and water when in solution. Rumen fluid is, however, already saturated with carbon dioxide. Dissociation would logically not be favored in regard to chemical equilibrium (74). Rogers et al. (72) observed that rumen fluid volume increases with the addition of mineral salts to the diet. These salts cause hypertonicity because there is a positive correlation between water and ion balance. Rumen fluid is also closely regulated to preserve blood isotonicity. Russell and Chow (74) proposed that buffers worked by indirectly increasing water intake which increases dilution in the rumen, increases the amount of undegraded starch flow from the rumen, decreases amount of propionate in the rumen, and thus decreases incidence of acidosis. Observations by Rogers et al. (72) of increased water consumption when cows were force-fed sodium bicarbonate in their diets support this theory.

Types of buffers and alkalizing agents:

Listed below along with their chemical formulas are buffers and alkalizing agents that can be used in dairy cattle feeds.

MINERAL SALT	**TYPE**	**CHEMICAL FORMULA**
Sodium Bentonite	Buffers	$(Na)(Al, Mg)_6(Si_4O_{10})_3(OH_6)\text{-}nH_20$
Sodium Bicarbonate		$NaHCO_3$
Sodium Sesquicarbonate		$NaCO_3\text{-}NaHCO_3\text{-}2H_2O$
Calcium Carbonate		$CaCO_3$
Potassium Bicarbonate		$KHCO_3$
Magnesium Carbonate		$MgCO_3$
Sodium Carbonate	Alkalizing Agents	$NaCO_3$
Magnesium Oxide		MgO
Potassium Carbonate		KCO_3

Of these substances, the discussion will be focused on sodium bentonite and sodium bicarbonate because they are commonly found in dairy cattle rations. An in vitro experiment conducted by Herod et al. (45) tested the buffering capacity of 35 chemicals incubated with rumen fluid. Sodium bentonite was rated “fair” and sodium bicarbonate “good” on a scale of good, fair, and poor.

Sodium bentonite

Sodium bentonite is an inert, hydrated, colloidal aluminum silicate clay of volcanic origin. While it consists primarily of mineral montmorillonite, it has a high cation exchange and an affinity for divalent ions. In addition, it has high moisture absorbing capacity making it a prime agent and binder for pelleted feeds (24, 54). Sodium bentonite is believed to absorb and release proteins and other nitrogenous substrates. The result is protection for these substances from microbial digestion and thus the amount of protein bypassing the rumen is increased (14, 55). McCullough (55) reported reduced rumen ammonia and increased rumen microbial populations in cows supplemented with sodium bentonite.

Sodium bicarbonate

Sodium bicarbonate, or baking soda, is a white alkaline-tasting powder. It is the buffer most thoroughly researched and used in dairy cattle rations. Bicarbonate is present in saliva and body fluids and is a natural buffer.

Other agents

Magnesium oxide and calcium carbonate or “limestone” are used as sources of minerals as well as alkalizing and buffering agents, respectively. Magnesium oxide is believed to aid in the mammary uptake of acetate and other fat precursors from the blood. Calcium carbonate may buffer in the small intestine. This may create a more favorable environment for enzymatic digestion, and, thus increase starch digestion. (16).

Influence of buffers on acid-base balance in the ruminant

Blood pH

Blood pH is crucial for animal survival with fatal levels outside the range of 7.0-7.8; normal pH is 7.4 (42). The efficiency of the respiratory system to supply sufficient CO_2 to steady blood pH is evident in the difficulty many researchers experience in detecting pH differences. A study by Schneider et al. (77) found cows subject to heat stress experienced blood alkalosis at a pH of 7.44 probably due to hyperventilation and a decrease of pCO2. The difference compared with the normal level of 7.40 was statistically significant; however, only 0.04 units different. Huntington and Britton (47) were successful in finding reduced blood pH in lambs fed 90% concentrate diets where pH declined from 7.44 to 7.20. When comparing sodium compounds, a study by Bigner et al. (7) reported sodium bicarbonate and sodium propionate were equally effective in raising blood bicarbonate concentration and blood pH to 7.4 in acidotic dairy cows. Diets with salt were ineffective at correcting acidosis with blood pH of 7.34.

Rumen pH

In 1980, Erdman et al. (27) did not find a change in rumen pH in postpartum cows when 1.5% sodium bicarbonate was added to a 60% concentrate ration on a dry matter basis. Also, magnesium oxide was shown to have more effect on pH stability than sodium bicarbonate. However, in a similar trial in 1982 (28) it was found that fistulated cows fed a similar diet with combined 0.8% magnesium oxide and 1.0% sodium bicarbonate exhibited increases in rumen pH from 6.03 to 6.28. Harrison et al. (44) reported steers fed 60% concentrate with either sodium sesquicarbonate or sodium bicarbonate at 1.2%

remained at a rumen pH above 5.5. In contrast, steers not receiving buffers experienced extreme drops in rumen pH to 4.0.

Fecal and urinary pH

Cattle have also been shown to exhibit changes in fecal and urinary pH when supplemented with buffers. Erdman et al. (28) reported feeding early postpartum cows 60% concentrate diets with 0.8% magnesium oxide and a combination of 0.9% magnesium oxide plus 1.0% sodium bicarbonate. The combination raised fecal pH from 5.95 to 6.44 while urinary pH did not change. Ghorbani et al. (34) reported that cows averaging 180 d postpartum and supplemented with 1.0% sodium bicarbonate exhibited an increase in urine pH from 8.05 to 8.15. This experiment also revealed that urine pH continued to fall for approximately 2 and 4 h post feeding on buffer and control diets, respectively. Nonbuffered diets resulted in lower urinary pH after feeding. Ruminants excrete alkaline urine except when fed diets high in concentrate. Most acid in urine is in the NH_4^+ ion form, which contributes to lower pH (78). Limestone was reported to be a successful buffering agent by Wheeler (92, 93) when it was observed to increase the pH of the lower gastrointestinal tract and feces. These studies demonstrate a negative correlation between fecal starch and fecal pH.

Effect on production

Milk fat

The primary reasons buffers are fed are to alleviate milk fat depression and encourage feed intake. High concentrate rations favor a rumen environment that supports propionate rather than acetate production. Logically, milk fat would be increased if acetate levels increased. Some studies do not support this theory. Rearte et al. (68) reported no significant changes in milk fat or VFA proportions when 1.9% $NaHCO_3$ was supplemented to rotationally grazed, lactating Holsteins. On the other hand, many studies have shown an increase of milk fat when cows are fed buffers (28, 34, 69, 77). Likewise, it has been shown that the acetate to propionate ratio (A:P) can be increased through buffer supplementation (13, 28). Rindsig et al. (69) observed cows supplemented with sodium bentonite at 5 and 10% of a pelleted concentrate had increased acetate and decreased propionate in the rumen. Kennelly et al. (49) found cows fed 75% concentrate diets increased A:P from 1.31 to 2.0 when supplemented with sodium bicarbonate. In accordance, Esdale and Satter (30) found cows continually infused with 9-12 moles of sodium bicarbonate increased A:P from 1.1 to 2.8. However, milk fat content has not typically correlated with a higher A:P among these studies. Reasons could stem from the many environmental, physiological, genetic, and feed-type situations dairy cattle encounter. For instance, Donker and Marx (23) found no change in milk fat percentage even though cows increased milk production, forage intake, and weight gain compared with control cows. Priorities of fat use could have shifted towards tissues rather than milk production in this case. Perhaps physical condition of the cow was favored in some instances when buffers increased acetate while milk fat levels did not change (27, 30, 49).

Milk protein

Tucker et al. (88) reported an increase in milk protein when sodium bicarbonate was fed to cows during middle and late lactation (9-44 wk). Sodium bicarbonate may have increased microbial utilization of protein. However, other studies have found no changes (24, 34, 68).

Milk production

Rindsig et al. (69) studied the effects of sodium bentonite at 5 or 10% of a pelletted concentrate to cows fed milk fat-depressing diets and found milk production significantly increased at the 5% level only. In contrast, a study by Fisher and Mackay (31) compared the feeding of sodium bicarbonate and sodium bentonite. There was a trend of decreased dry matter digestibility and milk production with the addition of sodium bentonite, however differences were not significant from the control diet. Erdman et al. (27) found an increase in production when 0.8% MgO and 1.5% sodium bicarbonate were fed in combination on a 60% concentrate diet. Schneider et al. (77) also found a production increase for cows fed 1.0% sodium bicarbonate compared with cows fed salt or potassium chloride.

Effect on feed Intake

Because buffers have the ability to stabilize rumen pH there is more efficient cellulose digestion and increased rumen turnover, resulting in greater feed intake and decreased rumen fill (57). Miller et al. (57) reported cows fed high and low fill diets with and without 1.5% sodium bicarbonate exhibited no production responses although dry matter intake increased slightly on buffered diets. Erdman et al. (28) studied digestibility parameters where an increase in ADF apparent digestion increased from 36% to 45.1% and 46.8% for 1.0% $NaHCO_3$, and 0.8% MgO, respectively. Many other studies support findings that buffers increase dry matter intake (23, 27, 50, 94). In contrast, Erlich and Davison (24) found intake to decrease with cows fed 4% sodium bentonite when fed sorghum-based diets. Fisher and Mackay (31) reported decreased apparent dry matter digestibility when sodium bentonite was added to the diet at 0.6 and 1.2%. Likewise ADF digestibility was also lower for cows consuming 1.2% sodium bentonite. Kennelly et al. (49) found no difference in cellulose or ADF digestion when like diets were compared with or without sodium bicarbonate.

FREE CHOICE CONSUMPTION

Innate abilities to reach nutritional homeostasis

The theory in feeding supplements *ad libitum* is based on allowing an animal to choose what and how much of a food to eat based on innate demands. An experiment by Scott et al. (80) proposed two mechanisms that could influence intake of needed supplements. Animals could either learn that choosing a supplement gives feelings of well being resulting in a preferred choice, also called “learned appetite,” or there could exist an instinctive desire relating to appetite for a specific supplement, which is termed a “true hunger.” The later might be the underlying factor of cattle experiencing osteophagia, a condition resulting in “chewing on bones”.

Common in South Africa, this disease is related to phosphorus deficiencies in cattle. Because bones are high in P content, the “true hunger” theory seems to have some validity. When cattle in this condition are fed bone meal, the P deficiency is alleviated (40). However, when unfamiliar sources of utilizable P such as precipitated calcium phosphate are offered to cattle, they are not craved or selected. This suggests that selection of a supplement is learned. Young cattle raised in areas carefully cleaned of bones did not show symptoms of osteophagia when bones were presented. It is possible that the behavior of chewing on bones may simply be an imitation of other herd mates. Young (95), in a review on food-seeking behavior commented that "although food selections often are in accord with nutritional needs, the correlation between need and acceptance is far from perfect. Food acceptance is regulated by the characteristics of the food object, by the environmental surroundings of the food object, by established feeding habits, as well as intraorganic chemical conditions which themselves may or may not be directly related to metabolic needs."

Experiments support the innate ability of animals to balance diets nutritionally. In an experiment with chicks fed low protein-low carbohydrate diets, it was observed that they improved their diets when free-choice supplements were offered. To compensate, they adapted a nocturnal feeding habit of eating during the night that was contrary to previous habit (15). Richter et al. (71) reported that rats offered a cafeteria of olive oil, casein, sucrose, salt, and other nutrients resulted in normal growth and more regular reproductive cycles among females compared with rats fed a balanced, basal diet. In addition, Tepperman (86) lists selection of oils and rejection of sugar in adaptation to vitamin B deficiencies as an adaptation to a nutritional deficiency.

Maller (53) suggested domestication could have produced an animal more responsive to taste than nutritive value. When lard was added to control diets fed to Norway rats, caloric intake increased, but in wild rats, intake decreased to remain at a constant caloric intake. This work suggested that the wild animal is better able to regulate intake regardless of taste and appeal.

Experiments with cattle

Many factors are involved in determining when and why dairy cattle select a feed. The basic decision of where the supplement will be offered may determine how much is consumed. Horvath (46) supplemented magnesium with molasses in blocks and found consumption decreased when cows were on pasture or when the blocks were not placed near the loafing lots. Miller et al. (59) reported free-choice studies with calves to determine the palatability of calf starters with 1% and 10 % brown grease. While 1% brown grease was predominantly selected, one calf was observed to prefer the 10%. This suggested that individual preferences occur. Blauwiekel et al. (9) conducted a study on the free-choice feeding of baker's yeast liquid effluent, a by-product high in N, Na, and K. While no differences were observed in rumen pH and VFA ratios, milk protein and fat percentages were greater in groups fed effluent free-choice. Rumen ammonia concentrations were greater for free-choice feeding, which could have contributed to a higher flow of microbial protein to the small intestine possibly encouraging higher milk protein synthesis.

Miller and Clifton (58) suggested the nature of the experimental design might influence the outcome of palatability studies. They reported that giving more than two choices could influence intake. They also suggested that only two feeds be included in a cafeteria-type experiment for meaningful results. This could explain why Muller et al.

(60) found that cows offered minerals in a cafeteria style free-choice feeder exhibited large ranges of intake from the 13 choices given. Cunha et al. (21) made a list of several factors aside from experimental protocols that could influence mineral intake by beef cattle. These included soil fertility, types of forages fed and consumed, types and amounts of supplements fed, individual requirements for minerals in regards to age, gestation and lactation, mineral content of water for drinking, palatability of minerals fed, and availability and freshness of minerals fed.

Palatability and taste acceptance

Palatability of feeds is measured in terms of consumption and selection. Arave et al. (3) found that even the physical form of a feed influences palatability. Pellets were preferred by heifers over dry meal and flavored feeds. Even so, flavored feeds have been shown to enhance feed acceptance (consumption) in dairy cows (4). Taste is characterized as a neurological response to stimuli and usually fits into 4 main categories of sweet, sour, salty and bitter. Goatcher and Church (36) found marked differences in taste sensitivities in ruminants between deer, cattle, goats, and sheep. Their two-choice method of testing was to provide two containers of fluid, one consisting of tap water and the other a solution presenting a concentration of a flavor. Cattle were the least tolerant species to sodium chloride where discrimination of salt solution became pronounced at 0.16%. A study with cattle by Nombekela et al. (65) ranked sweet taste over the control followed by sour, bitter, and salt tastes. In another study, Nombekela et al. (64) revealed that dairy cattle selected sucrose flavored feed followed by the control, bitter, salt, and sour, respectively. It was also noted by Kudryavtzev (52) that taste sensitivities changed when silage-fed cattle became more sensitive to sweet taste and less sensitive to the sour taste. These studies are in agreement that sweet is the flavor most accepted by cattle and salt one of the least. In a report by Klopfer et al. (51), two cows were used to test for palatability of 20 feeds by exposing them to all possible pairs. Selection was made by depressing a nose plate in order for feed to be presented for consumption. Salt was one of the least selected with only typha (or cattail) silage scoring lower. Molasses block was another feed of low selection comparable to salt. This agrees with the findings of Graham et al. (39) who observed low and varied intake of molasses blocks. These results are a contrast to the idea that cows possess a "sweet tooth". They do however agree that cows find salt to be one of the less palatable tastes. Variations in salt concentrations could be a factor. In 1970, Goatcher and Church (37) found that plain water was preferred to salt solutions only when the salt solution exceeded concentrations of 12.5 g/L.

Offering buffers to cattle as a free-choice option

Field studies have suggested that supplementing sodium bicarbonate and sodium bentonite free-choice is useful. Muller et al. (60) found that lactating dairy cows in mid lactation selected for buffers with cafeteria style feeding in which each supplement was offered separately side by side in feeders. Group rather than individual intake was monitored. In the first trial, cattle consumed comparable levels of sodium bentonite on both alfalfa hay and corn silage based diets at a rate of 82.3 and 78.3 g/cow/d, respectively. Sodium bicarbonate intake was less at 6.9 and 6.6 g/cow/d, respectively. In a second trial, 2 groups of cows were fed the same alfalfa and corn silage based diet.

Only one group was allowed free-choice access to minerals (and buffers) in addition to inclusion in a TMR. The other group was given free-choice access only to the cafeteria feeder. While no differences were observed for sodium bentonite consumption compared with the first trial, cows force-fed sodium bicarbonate in the second trial consumed an additional 27 g/cow/d of sodium bicarbonate compared with 8.3 g/cow/d for cattle allowed free-choice only. Ranges of sodium bicarbonate intake were large. Force-fed cattle might have found the buffer less offensive through possible desensitization. This trial did not find cattle to select vitamins and minerals to their specific need. This outcome supports the belief of Pamp et al. (69) that "ruminants do not consume sufficient amounts of minerals and vitamins free-choice to meet requirements" and that acceptability (palatability) rather than appetite or craving for minerals influences free-choice consumption.

SALT AND SODIUM INTAKE

Sodium metabolism

For centuries, the importance of salt has been well known to support homeostasis of the body. One role sodium plays is sustaining the osmotic pressure of the extra cellular fluid in the body (6). Ruminants in particular have adapted a digestive tract that depends on sodium homeostasis. Alkaline saliva rich in bicarbonate ions is needed in constant flow to help buffer the diets and provide the ruminal bacteria a substrate in which to maintain the fermentation process. The high need of sodium ions for the alimentary tract may leave the rest of the body with a deficit of sodium. This moves ruminants into a position of aggravated sodium depletion especially when diets are relatively low in sodium (6).

This raises the question whether selection of salt and compounds containing sodium are learned, pleasurable tendencies, or naturally inborn responses to a physiological need or deficiency. Bell and Sly (6) reported considerable variation in salt intake between calves and sheep as well as individual animals within species. Calves inexperienced in salt selection were found to have a preference for salt solutions but calves previously exposed to salt solutions exhibited indifference to them.

Lactating cows have one of the highest water turnover rates and because this increases ion output, ion requirement increases as well (62). According to Murphy (61), the water turnover rate for cows is the highest among mammals. Logically, secretions of Na, Cl, and K are greater and requirements higher because water and ion balances are positively correlated. When Na is in a negative metabolic balance, there is a marked reduction in loss via the feces. While there is limited cutaneous loss, reduced efficiency of thermoregulation could affect milk yields adversely (82). Silanikove et al. (82) found that water intake tripled in postpartum compared with prepartum cows and respiratory cutaneous water loss was 4 times greater. Retention of Na did not differ through 2-7 weeks postpartum. Excretion was positively correlated to DMI and milk production. Since milk is more than 80% water, water turnover is accelerated by the onset of lactation.

Shalit et al. (81) conducted a study on Na balance in cows at the onset of lactation in which diets exceeded dietary requirements. Sodium losses in milk were compensated by increases in DMI and lower levels of Na excreted through the feces. The amount of Na excreted in feces is equal to that lost in the urine. This study showed that 52% of the Na intake was excreted in the milk of cattle. This demonstrates that an increase of sodium excretion takes place in cows during lactation. Sodium balance was reduced postpartum showing that the sodium milk-free balance, or, intake minus milk secreted, was about 56% of the prepartum intake of sodium. When sodium is deficient it decreases in saliva and K increases. This trend is also observed in the feces.

Acceptability and intake of sodium

Other species

Richter and Eckert (70) reported that spontaneous intake of salt solution by rats was controlled by a hormonal factor produced by the adrenals. They observed that adrenalectomized rats exhibited increased appetites for salt, and, as a result, enhanced survivability. They also reported additional evidence for hormonal regulation of salt intake when salt intake returned to normal after administering desoxycorticosterone acetate, a synthetic hormone**.** In addition, hypothyroid rats also have been shown to exhibit increased appetites for salt. Scott et al. (80) examined rats for innate abilities to compensate sodium deficiency through diet selection. While no differences in sodium intake between normal rats and sodium-deficient rats were found, diets containing sodium in the form of sodium bicarbonate tended to be selected more often than other diets. The residing question is “can an animal self-manipulate a diet in order to neutralize an extreme physiological acid-base condition? Cook et al. (18) found that in a free-choice trial with cats in neutrality, academia, or alkalemia, neutral diets were selected over both basic and acidic diets, and basic diets were favored over acidic diets. In each situation, the diets chosen supported acid-base homeostasis.

Ruminants

The benefit of feeding sodium-containing buffers has already been discussed. Only limited studies on free-choice feeding of sodium-containing supplements have been conducted. When cattle choose to consume buffers, are the stimuli due to an innate physiological need or craving of the taste? In other words, is acceptance attributed to post-ingestive or oropharyngeal responses? Blasdell et al. (11) theorized that palatability is determined as the result of the integration of orosensory and postingestive stimuli meaning it depends ultimately on the interaction between the food and the organism. In another study by Grovum and Chapman (41), a test was performed on sheep with esophageal fistulas in order to eliminate post-ingestive and metabolic feedback responses on palatability. The focus could be directed on oropharyngeal responses. In this way, palatability can be studied by itself although it may be influenced by novelty and learning. Sheep were fed lucerne pellets with five added chemicals to represent five tastes. These included sweet, sour, salty, bitter, and monosodium glutamate, a chemical often added to human foods for taste enhancement. Salt in sodium chloride pellets were preferred at all concentrations over plain (unflavored) pellets. Because salt was available ad libitum, salt deficiency was ruled out as a possible explanation. While it is known that salt decreases intake with increasing concentrations it was theorized that salt is rejected based on post-ingestive effects even though the salty taste is readily accepted.

It was shown by Coppock et al. (19) that cows have an ability to balance ionic intake. In this experiment cows were fed either 0.5% salt or 0.75% sodium bicarbonate. Half of the cows in each group were allowed access to a salt block. It was observed that cows given sodium bicarbonate consumed more salt (337 vs. 149 g/cow/d) than cows receiving salt. This suggests cows are able to compensate for dietary cation-anion difference (DCAD) imbalances by consuming more chloride (negative ions) in the form of NaCl. The DCAD is calculated by the equation: mEq $(Na^{+}+K^{+})-(Cl^{-})$/100g (10). Researchers have related milk yield responses to these minerals with the theory that all body fluids must remain electrically neutral (76). In the intestine, if there is an overload of Cl^{-}, it will be exchanged for the bicarbonate ion in the lumen and may result in acidosis. On the other hand, if there is an overload of Na^{+} in the intestinal lumen, it will be exchanged for H^{+} resulting in alkalosis (10). Vagnoni (89) induced a mild metabolic acidosis by feeding anionic salts to non-lactating Holstein cows. However, acid-base balance was preserved by decreased bicarbonate and increased NH_4^{+} excretion through the urine. Tucker (90) found that intake, blood pH, and blood bicarbonate increased linearly with DCAD. Lactating cows fed diets containing DCAD of +10 and +20 mEq/100 g had higher blood pH compared to DCAD of –10 and 0. West et al. (94) compared diets of +2.5, +15, +27.5, and +40 DCAD but observed no differences in performance.

The olfaction sense of sodium is also very strong in cattle. Bell (5) observed sodium-depleted cattle had the ability to distinguish between salt-supplemented water versus water that was not supplemented with salt. In addition, bizarre behavior such as leaping barricades to get to salt sources was observed. Because of the sodium content of salt, sodium may have bearing on the free-choice intake of sodium-containing buffers.

The theory that cows have the ability to innately select for feed additives (rumen buffers) is the reason this experiment was performed. In addition, it was important to study a practice commonly observed and this is why the effects of free-choice consumption of sodium bentonite and sodium bicarbonate on acid-base balance, and rumen and production parameters were studied. Furthermore, this study allowed calculation of cost effectiveness of this common management practice.

MATERIALS AND METHODS

Animals

Eight Jersey and seventeen Holstein cows were selected from the Virginia Tech Dairy Center and randomly divided into two diet treatment groups according to lactation, production, and days in milk. At the beginning of the experiment, Jerseys averaged a parity of 2.5, 26.9 kg/d milk, 91 days in milk (DIM), and 434 kg bodyweight. Holsteins averaged a parity of 2, 40.4 kg/d milk, 91.7 DIM, and 621 kg bodyweight. Cows were housed in free stalls and separated by breed. Cows were fed individually 100% of their daily ration at 0900h. Diets were fed for ad libitum intake, allowing for at least 10% refusal. Cows had access to water at all times except during milking. Cows were out of the free stall barns approximately 1 h for milking at 0145 h and 1245 h.

Diets

Four experimental dietary regimes were offered to cows during eight 10-d periods allowing for each regime to be replicated once. The first two dietary regimes were total mixed rations only, one containing no buffering agent (diet 1) and the other containing 1.2% sodium bicarbonate on a dry matter basis (diet 2). The remaining two dietary regimes were addition of free-choice options to the two total mixed rations. Sodium bentonite (Volclay, Arlington Heights, IL) and sodium bicarbonate (Church & Dwight; Division of Arm & Hammer Co.) were offered side by side in a covered feeder to breed groups during specific periods (Figure 1). Total mixed rations were formulated to contain 17.0% acid detergent fiber and 17.0% crude protein. They also contained 30% soluble protein, 72% total digestible nutrients (TDN), 34% starch, and 1.61 mcal/d NE_L.

The ration was approximately 60% forage. Corn silage, alfalfa silage, high moisture corn, and 48% soybean meal were the main ingredients. Both diets contained approximately 50% dry matter. Particle size was analyzed using a Penn State Particle Size Separator with the top, middle, and bottom sieves containing 2.3, 33.0, and 64.7 % of the TMR, respectively. Percentages of dry matter and chemical analyses are in Table 1.

D1-NFC	**Diet 1, No Free-Choice**	**BASAL DIET**
D2-NFC	**Diet 2, No Free-Choice**	**BASAL DIET** + **Bicarb (1.2%)**
D1-WFC	**Diet 1, With Free-Choice**	**BASAL DIET** + **Sodium bentonite &** **Sodium bicarbonate** **offered free-choice**
D2-WFC	**Diet 2, With Free-Choice**	**BASAL DIET** + **Bicarb (1.2%)** + **Sodium bentonite &** **Sodium bicarbonate** **offered free-choice**

Figure 1. Dietary regimes with two total mixed rations without and with free-choice options.

TABLE 1. Ingredient content and chemical composition of total mixed rations

	Diet 1	Diet 2
Component	(%, DM basis)	
Corn silage	40.10	40.07
Alfalfa silage	19.10	19.07
High moisture corn	18.09	17.43
Soybean meal (48% CP)	14.79	14.57
Ground corn	5.49	5.40
Limestone	0.80	0.80
[1]Dairy vitamin/mineral premix	1.60	1.57
[2]$NaHCO_3$	0	1.20
TOTAL	100.0	100.0
[3]Chemical analysis		
Acid detergent fiber	17.20	17.00
Neutral detergent fiber	29.90	29.53
Crude protein	17.07	16.87
Ca	0.80	0.79
P	0.37	0.36
Mg	0.30	0.29
Na	0.64	0.94
K	1.51	1.50
Cl	1.23	1.21
S	0.19	0.19
[4]DCAD	+20	+33.4

[1]Supplies 184,700 IU of vitamin A, 18,598 IU of vitamin D/kg, and 1361 IU vitamin E/kg of premix
Minimum percentages: Ca=6.35, P=4.17, NaCl=38.35, Mg=3.82, K=4.05, S=4.03, F=0.05
Minimum ppm: Co=10, I=46, Fe=1150, Mn=1600, Se=46, Zn=1700

[2]Sodium Bicarbonate (Church & Dwight Co., Inc., Princeton, N.J.)

[3]Calculated using laboratory analysis for each feedstuff

[4]DCAD = mEq $(Na^+ + K^+) - (Cl^- + S^-)$/ 100 g

Experimental design

The study was conducted from September 19 through December 8, 2001. A total of eight 10-d periods were conducted with 8-d diet adjustment and 2-d sample collection. Every 2 periods (20 days) cows were switched to the alternate TMR (diet 1 or 2). During periods 2, 3, 5, and 8, free-choice options were offered to each breed group (Figure 2) and average group intake of sodium bentonite and sodium bicarbonate was recorded every 48 h during the period. Because only group intake was determined, it was not possible to establish individual cow intake of sodium bentonite or sodium bicarbonate. Diets were maintained at similar ADF and crude protein percentages throughout the trial.

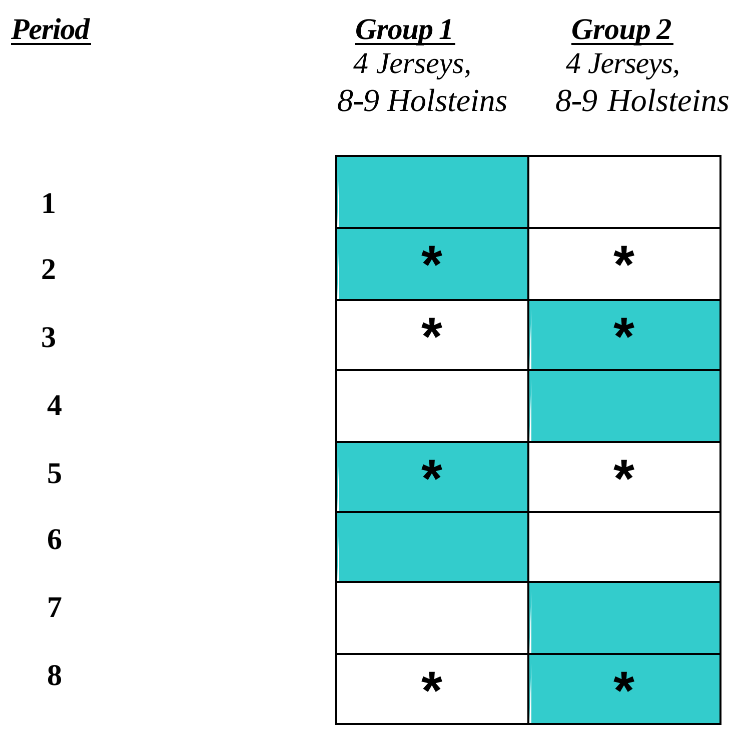


Figure 2. Diagram of experimental design showing sequence of dietary regimes.
Shaded areas = Diet 1, Unshaded areas = Diet 2.
Starred boxes = Free-choice options of sodium bicarbonate and sodium bentonite were offered.

Measurements and sampling

Samples of corn and alfalfa silages were sampled weekly and submitted to the Virginia Tech Forage Testing Laboratory for determination of dry matter, crude protein, and ADF to adjust the diets. Feed refusals were recorded daily for each cow and the amounts of ration adjusted accordingly to allow for optimum intake and to record daily intake. Daily intakes were used to calculate period averages. Milk production was measured daily throughout the 80 d trial (0130h, 1300h) to establish a period average. Milk samples were obtained from one morning and two consecutive afternoon milkings for component analysis. Milk was analyzed by the Virginia Dairy Herd Improvement Association for fat and protein percentages (MilkoScan 4000 series, Foss North America, Eden Prairie, MN) and somatic cell count (FM 5000, Foss North America, Eden Prairie, MN). MUN was analyzed (ChemSpec 150, Bently Instruments, Inc., Chaska, MN). Cows were weighed for three consecutive days: two days before the trial started, at the beginning of period 5, and at the end of the trial.

On d 10 of each period, samples of blood, urine, and manure were obtained between 1430 h and 1730 h. Blood was collected in evacuated heparinized centrifuge tubes via tail or jugular venipuncture and analyzed after collection. Hematocrit samples (subsample drawn from the original blood sample into capillary tubes) were centrifuged at 13,700 *x g* (Autocrit Ultra3, Clay Adams) for 5 min and analyzed for packed cell volume (PCV). Remaining blood was centrifuged at 3,600 *x g* for 10 min at 4^{o}C to separate plasma. Plasma was collected and analyzed for protein levels by refractometer. Remaining blood plasma was stored at -20^{o}C for later analysis. Urine was obtained by manual stimulation, refrigerated for 24 h, and warmed to room temperature prior to testing for pH by probe and specific gravity by refractometer. Fecal samples were obtained by rectal evacuation. Fecal pH (VXR digital model 2000, Orion Research, Inc.) was measured shortly after collection by inserting the pH probe directly into a sample of feces. Feces were then stored at –20^{o}C, then thawed and dried in a forced air oven at 60^{o}C for determination of dry matter percentages. The following fecal consistency scale was followed for visual scoring for consistency by a two-person panel (48).

SCORE #1:	Runny liquid consistency, splatters on impact, spreads readily.
SCORE #2	Loose consistency yet may pile slightly, may splatter and/or spread moderately upon impact and settling.
SCORE #3	Soft, yet firm consistency, not hard, piles but spreads slightly upon impact and settling.
SCORE #4	Dry and hard, dry appearance and original form is not distorted on impact and settling.

On day 9 and 10 of each period, rumen samples from four fistulated Holsteins were collected at 0900h just prior to offering fresh feed and at 1530h for measurement of volatile fatty acids (VFA). Grab samples were obtained from the rumens of the fistulated Holsteins, combined, and strained through four layers of cheesecloth. One ml of 25% phosphoric acid and one ml of 30 m*M* 4-methylvaleric internal std. were added to five ml of strained rumen fluid and stored at –20 ^{o}C for later analysis of VFA. Samples were thawed, centrifuged, filtered, and molar proportions of volatile fatty acids were estimated by gas chromatography (HP 5890 Series II gas chromatograph, Agilent Technologies, Wilmington, DE). On d 9 or 10 of each period, pH measurements (VXR digital Model 2000, Orion Research, Inc.) were obtained at 0, 2, 4, 6, and 8 h post feeding (0830h, 1130h, 1330h, 1530h, and 1780h) in the similar locations as grab samples in the rumen.

Dry matter of saliva-contaminated sodium bentonite and sodium bicarbonate was determined by drying in a forced air oven at 60 ^{o}C to a constant weight. Intake of both bentonite and bicarb could then be more accurately determined.

Chemical analysis

Acid detergent fiber (ADF) and neutral detergent fiber (NDF) of corn and alfalfa silages was determined using the method of Goering and Van Soest to remove starch interference (38). NDF analysis of corn grain and soybean meal was determined using the procedure outlined by Van Soest (93). Crude protein was determined by nitrogen analysis for corn and alfalfa silages, corn meal, and soybean meal using macro-Kjeldahl procedure (68). Mineral analyses of K and S in corn silage and high moisture corn, and K, S, and Na in alfalfa silage were analyzed using inductively coupled plasma atomic emission spectroscopy (SpectroFlame Modula Tabletop ICP with autosampler Type FTMOA85D, Spectro Analytical Instruments, Inc., Fitchburg, MA).

Statistical Analyses

All data were analyzed using Proc Mixed in SAS.
The model for all 25 cows was:

$$Y = u + G_i + B_j + F_k + (BF)_{jk} + P_{(k)l} + T_m + (BT)_{jm} + (FT)_{km} + (BFT)_{jkm} + C_{(ij)n} + (TC)_{(ij)mn} + E_{ijklmn}$$

Where:

Y= *dependent variable*: urine pH, urine specific gravity, blood protein, blood PCV, fecal pH, fecal score, fecal dry matter %, milk fat %, milk protein %, milk urea nitrogen, milk production (kg), fat-corrected milk, dry matter intake, intake/bodyweight %,

u= overall population mean,

G_i = effect of group (i=treatment sequence 1 vs. 2),

B_j = effect of breed (j=1, 2: Jersey, Holstein),

F_k= effect of free-choice option (k=1,2: no free-choice, with free-choice),

$(BF)_{jk}$= interaction of breed and free-choice option,

$P_{(k)l}$= effect of period nested within free-choice option (l= 1…4),

T_m= effect of diet (m=1,2: diet 1, diet 2),

$(BT)_{jm}$= interaction of breed with treatment diet,

$(FT)_{km}$= interaction of free-choice option with treatment diet,

$(BFT)_{jkm}$= interaction of breed with free-choice options with treatment diet,

$C_{(ij)n}$= effect of cow nested within group and breed (n=8 for Jerseys, n=17 for Holsteins),

$(TC)_{(ij)mn}$= effect of cow by treatment diet, and

E_{ijklmn} = error.

The model for the 4 fistulated Holstein cows was :

$$\mathbf{Y = u + G_i + F_j + P_{(k)l} + T_l + (FT)_{jl} + S_m + (TS)_{lm} + (FS)_{jm} + (FTS)_{jlm} + C_{(i)n} + (TC)_{(i)ln} + E_{ijklmn}}$$

Where:

Y= *dependent variable*: rumen pH, rumen VFA percentages,

u= overall population mean,

$\mathbf{G_i}$= effect of group (i=treatment sequence 1 vs. 2),

$\mathbf{F_j}$= effect of free-choice option (j=1,2: no free-choice, with free-choice),

$\mathbf{P_{(k)l}}$ = effect of period nested within free-choice option (k= 1…4),

$\mathbf{T_l}$= effect of treatment diet (l=1,2: diet 1, diet 2),

$\mathbf{(FT)_{jl}}$= interaction of free-choice options with treatment diet,

$\mathbf{S_m}$= effect of sampling time (m= 1…5 for rumen pH: 0, 2, 4, 6, and 8 hours post-feeding, m= 1-2 for VFAs: 0 and 6 hours post-feeding),

$\mathbf{(TS)_{lm}}$= interaction of treatment diet with sampling time,

$\mathbf{(FS)_{jm}}$= interaction of free-choice options with sampling time,

$\mathbf{(FTS)_{jlm}}$ = interaction of free-choice options with treatment diet with sampling time,

$\mathbf{C_{(i)n}}$ = effect of cow nested within group (n= 2),

$\mathbf{(TC)_{(i)ln}}$ = interaction of cow with treatment diet nested within group, and

$\mathbf{E_{ijklmn}}$ = error.

Due to illness, one Jersey was replaced in period 1 and a spare Jersey was used in analysis. This same Jersey had to be replaced in period 2 because of habitual feeding from calan doors which were not her own. One non-fistulated Holstein was replaced in period 2 because of illness and the spare Holstein was used in analysis.

RESULTS AND DISCUSSION

Data for both multiparous and primiparous cows were pooled for analysis due to scarce number of cows in some combinations of breed, treatment, and parity. Tables 2 and 4 contain results without and with 1.2% sodium bicarbonate in the total mixed ration. In addition, results without and with free-choice options are also listed in Table 2 and 4. Results are in Tables 3 and 5 for all 4 dietary regimes (D1-NFC, D2-NFC, D1-WFC, D2-WFC). For the four diet regimes, Tukey tests were used to determine if means were different.

Dry matter intake, milk production, and milk composition

Numerous studies have observed effects of sodium bicarbonate in the ration on intake and production parameters. Most have studied exclusively Holsteins fed diets with high concentrate ratios, typically 60% concentrate with corn silage as the base forage. Most positive results have been from studies that fed corn silage rather than grass or alfalfa silage as forage. Because the forages fed in this experiment were unusually low in fiber, a lower amount of grain was fed which may account for some differences with other experiments. The grains fed, however, were corn meal and high moisture corn, that contain rapidly fermentable starch. Holsteins and Jerseys responded differently to treatments and free-choice options, and when appropriate, will be discussed separately.

<u>Holsteins</u>

Effects of diet on dry matter intake are presented in Tables 2 & 3. Holsteins consumed more feed DM when sodium bicarbonate was added to the ration (25.4 vs. 24.2 kg/d, Table 2). In addition, DMI as a percentage of bodyweight was greater (4.14 vs. 3.98 %).

This is in agreement with other studies concluding force-fed sodium bicarbonate has a positive influence on intake (27, 88). In contrast, other studies have concluded sodium bicarbonate had no influence on intake (29, 31, 49). Free-choice options did not affect intake. Greatest differences in intakes were recorded when Holsteins consumed D1-NFC (24.1, Table 3) relative to D2-NFC (25.5) and D2-WFC (25.3). Milk production increased approximately 1 kg/d or more when sodium bicarbonate was added to the ration (Tables 2 and 3). It is possible that this production response was due to both increased intake and digestibility of the ration although digestion trials were not conducted in this experiment. This production response agrees with numerous studies (27, 49, 69, 88) although a majority of trials have reported no significant differences in milk production (24, 28, 31, 34, 49, 68, 94). Fat percentage was greater when free-choice options were available (3.87 vs. 3.76, Table 2). Although free-choice options of sodium bentonite and sodium bicarbonate have not been reported to affect fat test percentage, the increase of milk fat in other experiments that included sodium bicarbonate in the diet is well documented (25, 28, 39, 69). However, it has also been documented that sodium bicarbonate does not affect milk fat percentages (24, 50, 94). One study found an increase in milk protein percent when sodium bicarbonate was fed (88). Our results are in agreement with a majority of trials that found no changes in milk protein (24, 34, 68). There were no differences in milk production or components between the four dietary regimes (Table 3). Although free-choice options increased milk fat percentage, fat-corrected milk (FCM) did not significantly change between diet regimes and was not affected by diet or free-choice options. Fat-corrected milk (FCM) has been shown to increase with force-fed sodium bicarbonate (28, 51, 77); however, some studies show no differences (29, 34).

Jerseys

Unlike Holsteins, Jerseys did not consume more dry matter with force-fed sodium bicarbonate. Jerseys had increased DM consumption (kg/d and percentage of bodyweight) when free-choice options were offered (20.4 kg vs. 19.4 kg and 4.78 vs. 4.56%, Table 2). Jerseys displayed no differences in milk production, milk protein, or fat percentage, or FCM when sodium bicarbonate was force-fed. FCM increased approximately 2.36 kg when free-choice options were available (Table 2). This corresponds to 3.0 mcal extra energy needed for milk production. However, DMI increased only 0.96 kg/d, which allowed a 1.63 mcal/d increase in energy. This may indicate more efficient digestion when free-choice options were available, however, periods were short (10 d) and not designed to show long term production changes. There were no differences in FCM between the four dietary regimes (Table 3). Jerseys had lower MUN levels when sodium bicarbonate was force-fed (14.79 vs. 15.68, Table 2) yet had higher levels when allowed free-choice options (15.74 vs. 14.73). The highest MUN level was observed with cows consuming D1-WFC (16.04, Table 3) but was different only from D2-NFC (14.14). It is not known why MUN levels in Jerseys varied, but consumption of sodium bentonite may be a factor in increasing the amount of protein escaping microbial digestion in the rumen (14, 55).

Table 2 Least square means for production and intake when sodium bicarbonate was force-fed without or with free-choice (FC) options of sodium bentonite and sodium bicarbonate.

	[1]Control	[2]$NaHCO_3$ added	SE	P>F	[3]No FC	[4]FC offered	SE	P>F
Holsteins (n=16)								
DM Intake (kg/d)	24.17	25.37	0.62	**<.01**	24.78	24.75	0.63	0.92
Intake/bodyweight (%)	3.95	4.15	0.08	**<.01**	4.06	4.04	0.008	0.74
Milk production (kg/d)	35.41	36.39	1.65	[5] **0.04**	36.13	35.68	1.65	0.38
protein (%)	3.28	3.28	0.11	0.86	3.28	3.28	0.11	0.94
fat (%)	3.83	3.79	0.10	0.63	3.76	3.87	0.09	**0.04**
FCM (kg/d)	34.16	34.96	1.62	0.15	34.40	34.71	1.63	0.67
MUN (mg/dl)	15.71	15.35	0.46	0.20	15.51	15.55	0.46	0.87
Jerseys (n=8)								
DM Intake (kg/d)	19.85	19.98	0.90	0.70	19.44	20.40	0.91	**0.04**
Intake/bodyweight (%)	4.67	4.70	0.12	0.67	4.55	4.82	0.12	**<.01**
Milk production (kg/d)	26.14	26.65	2.40	0.43	25.79	27.01	2.40	0.11
protein (%)	3.74	3.73	0.16	0.92	3.71	3.76	0.16	0.30
fat (%)	4.79	4.83	0.14	0.70	4.78	4.84	0.14	0.46
FCM (kg/d)	29.03	29.25	2.35	0.79	27.96	30.32	2.38	[6] **0.03**
MUN (mg/dl)	15.68	14.79	0.67	**0.04**	14.73	15.74	0.67	**0.01**

[1]Diet 1 (without sodium bicarbonate)

[2]Diet 2 (with sodium bicarbonate added at 1.2% of dry matter)

[3]Refers to all periods withheld access to free-choice options (sodium bentonite and sodium bicarbonate)

[4]Refers to all periods allowed access to free-choice options

[5]Standard error of the difference = 0.44

[6]Standard error of the difference = 1.03

Table 3 Least square means for diet regimes for production and intake for individual periods without and with sodium bicarbonate force-fed and free-choice options of sodium bentonite and sodium bicarbonate

Response	D1-NFC	D2-NFC	D1-WFC	D2-WFC	SE of mean	Interaction P>F
		Holsteins (n=17)				
DM intake (kg/day)	24.10^{a}	25.48^{b}	24.25^{ab}	25.26^{b}	0.647	**<0.01**
Intake/bodyweight (%)	3.94^{a}	4.17^{b}	3.96^{ab}	4.12^{ab}	0.088	**<0.01**
Milk production (kg/d)	35.66	36.59	35.17	36.19	1.679	0.14
protein (%)	3.30	3.26	3.26	3.29	0.113	0.85
fat (%)	3.77	3.74	3.89	3.85	0.109	0.23
FCM (kg/d)	33.83	34.98	34.48	34.94	1.680	0.43
MUN (mg/dl)	15.77	15.25	15.65	15.45	0.499	0.56
		Jerseys (n=8)				
DM intake (kg/day)	19.51	19.36	20.19	20.60	0.942	0.17
Intake/bodyweight (%)	4.57^{ab}	4.53^{a}	4.77^{ab}	4.87^{b}	0.129	**0.02**
Milk production (kg/d)	25.63	25.94	26.65	27.36	2.444	0.35
protein (%)	3.73	3.69	3.75	3.78	0.164	0.67
fat (%)	4.67	4.90	4.91	4.77	0.159	0.24
FCM (kg/d)	27.80	28.12	30.26	30.38	2.440	0.17
MUN (mg/dl)	15.31^{ab}	14.14^{a}	16.04^{b}	15.44^{ab}	0.733	**0.01**

D1-NFC= Diet 1 (without sodium bicarbonate), no free-choice
D2-NFC= Diet 2 (with sodium bicarbonate added at 1.2% dry matter), no free-choice
D1-WFC= Diet 1, with free-choice options
D2-WFC= Diet 2, with free-choice options
P<0.05 indicates an interaction between treatment diet and free-choice options
^{a,b}Means with common subscripts in a row do not differ

Acid-base status

Tables 4 and 5 contain results of urinary, fecal, and rumen pH analysis.

Blood pH and implications on urine pH

Blood pH is maintained within a narrow range except under extreme conditions. Changes in blood acid-base status may be related to several factors. These may include bicarbonate secretion in saliva, abomasal acid secretion, and varied rates of acid utilization and absorption from the rumen (8, 29). If acid is not metabolized it must eventually be excreted by the kidneys. Significant changes in acid excretion can take place without significant changes in blood acid-base balance (28). Hence, blood pH, pCO_2, and HCO_3^- were not measured in this experiment. It has been shown that if acidosis occurs in early lactation it can be compensated for by urinary excretion. Small changes in acid levels can be detected easily in renal excretions (28). Because changes in acid load can be detected through urinary excretion, net acid urinary excretion is a more sensitive measure of changes in acid-base balance (78, 79).

Dietary Cation-Anion Difference (DCAD)

According to the 2001 NRC (Nutrient Requirements of Dairy Cattle) and analysis through the Virginia Tech Forage Laboratory, mineral concentrations in corn and alfalfa silages, high moisture corn, ground corn, and soybean meal, our diets contained a (DCAD) of +17.4 mEq/100g of dry matter for diet 1 and +30.8 mEq/100g DM for diet 2 (Table 1) (63). A diet with a high positive DCAD will cause a mild metabolic alkalosis resulting in a reduction of plasma bicarbonate, increased urinary acid excretion, and decreased urinary pH (91). DCAD is calculated by the equation (10):

$$DCAD = mEq\ (Na^{+}+K^{+}) - (Cl^{-}+S^{-})/100ml$$

Urine pH

Urine pH is not well-documented in experiments with rumen buffers but some do report observations. Erdman et al. found sodium bicarbonate and magnesium oxide supplementation had no influence on urine pH (27). However, Ghorbani et al. found an increase in urine pH when sodium bicarbonate or sodium sesquicarbonate were force-fed (34). Both experiments fed corn silage with 60% concentrate. Differences in the two studies may be due to average days in milk (DIM) being different where Erdman studied cows immediately postpartum and Ghorbani studied cows with an average of 180 DIM. In our study, Holsteins had higher urine pH when sodium bicarbonate was force-fed in the ration (8.28 vs. 8.22, Table 4). In Jerseys, higher urine pH was observed when allowed free-choice options (8.28 and 8.22). Jerseys receiving no buffering agent (D1-NFC) had the lowest urine pH (8.20, Table 5). Both Holsteins and Jerseys had alkaline pH values averaging above 8.0. Ruminants tend to excrete alkaline urine except when diets high in concentrates are fed. Most hydrogen ions are excreted in the NH_3 form in ruminants consuming high concentrate diets (78). This has been demonstrated in sheep and calves when urine pH is below 8.0 (78, 79). When pH is above 8.0, HCO_3^- appears to be the main ion involved in net acid excretion of lactating cows (79).

Fecal pH

Fecal pH, like urine pH, is not well documented. Kilmer et al. found no significant changes in fecal pH when sodium bicarbonate was added to the ration (50). Fecal pH was higher in Holsteins allowed free-choice options (6.58 vs. 6.47, Table 4) with the highest pH in cows consuming D1-WFC (6.61, Table 5). This fecal pH was only different from D1-NFC (6.43). In the Jersey breed, there were no differences in fecal pH with the presence of free-choice options, or between all dietary regimes. Wheeler and Noller (92, 93) proposed that dietary buffers work in different parts of the digestive tract. These studies showed a negative correlation between fecal starch content and fecal pH. For instance, limestone reduced fecal starch while increasing fecal pH (20). The reason for this response is not known, but one theory is that improved pH in the small intestine supports a better environment for enzymatic digestion of starch. Although starch levels were not calculated in this experiment, Holsteins did show signs of increased digestibility by increasing intake and production when sodium bicarbonate was included in the ration.

Rumen pH

Force-feeding sodium bicarbonate or free-choice options did not influence rumen pH (Table 4). In addition, there were no differences between dietary regimes (Table 5). It has been reported by other researchers that cows fed sodium bicarbonate and/or sodium bentonite have increased rumen pH (24, 34). It has been shown that sodium bentonite alone has the ability to maintain rumen pH when included in the diet at 4% of the DM (24). Other studies have found no differences in rumen pH when sodium bicarbonate is added to the diet (27, 68). There was a trend for a more moderate drop in pH over time of day in cows allowed free-choice options, but no differences were observed (Figure 3).

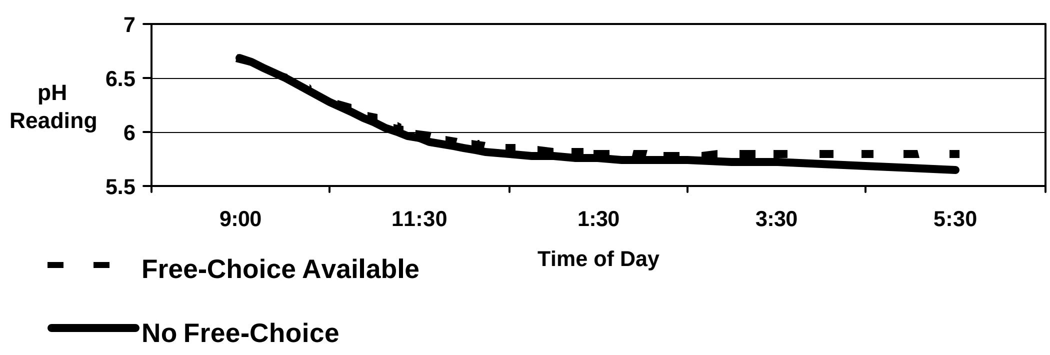


Figure 3. Rumen pH of 4 fistulated, Holstein cows.

Table 4 Least square means for urine, fecal and rumen pHs when sodium bicarbonate was force-fed without or with free-choice (FC) options of sodium bentonite and sodium bicarbonate.

Response	[1]Control	[2]$NaHCO_3$ added	SE	P>F	[3]No FC	[4]FC Offered	SE	P>F
Holsteins (n=17)								
Urine pH	8.22	8.28	0.014	**0.01**	8.25	8.25	0.014	0.68
Fecal pH	6.52	6.54	0.030	0.72	6.47	6.58	0.029	**<.01**
Rumen pH, average	5.97	5.99	0.068		5.95	6.01	0.070	
Rumen pH, [5]TOD								
0900	6.69	6.69	0.072	0.95	6.69	6.68	0.074	0.90
1130	5.97	5.95	0.080	0.80	5.93	5.98	0.083	0.64
1330	5.73	5.82	0.082	0.27	5.75	5.80	0.085	0.60
1530	5.78	5.73	0.078	0.45	5.72	5.79	0.081	0.44
1730	5.66	5.78	0.098	0.30	5.65	5.79	0.102	0.28
Jerseys (n=8)								
Urine pH	8.24	8.26	0.020	0.37	8.22	8.28	0.019	**<.01**
Fecal pH	6.47	6.52	0.040	0.38	6.49	6.51	0.040	0.72

[1]Diet 1 (without sodium bicarbonate)
[2]Diet 2 (with sodium bicarbonate added at 1.2% dry matter)
[3]Refers to all periods withheld access to free-choice options (sodium bicarbonate and sodium bentonite)
[4]Refers to all periods allowed access to free-choice options
FC = free-choice
[5]TOD= time of day

Table 5 Least square means for diets for urine, fecal and rumen pHs for individual periods without and with sodium bicarbonate force-fed and free-choice options of sodium bentonite and sodium bicarbonate.

Response	**D1-NFC**	**D2-NFC**	**D1-WFC**	**D2-WFC**	**SE of mean**	**Interaction P>F**
Holsteins (n=17)						
Urine pH	8.21	8.28	8.23	8.27	0.020	0.06
Fecal pH	6.43^{a}	6.52^{ab}	6.61^{b}	6.56^{ab}	0.040	**<0.01**
Rumen pH, [1]TOD						
0900	6.67	6.71	6.70	6.66	0.086	0.90
1130	5.92	5.95	6.02	5.94	0.098	0.64
1330	5.67	5.83	5.80	5.81	0.102	0.60
1530	5.70	5.75	5.88	5.70	0.095	0.44
1730	5.56	5.73	5.76	5.82	0.126	0.28
Jerseys (n=8)						
Urine pH	8.20^{a}	8.24^{ab}	8.28^{b}	8.29^{b}	0.028	**0.04**
Fecal pH	6.47	6.51	6.48	6.53	0.056	0.81

D1-NFC= Diet 1 (without sodium bicarbonate), no free-choice
D2-NFC= Diet 2 (with sodium bicarbonate added at 1.2% dry matter), no free-choice
D1-WFC= Diet 1, with free-choice options
D2-WFC= Diet 2, with free-choice options
P<0.05 indicates an interaction between treatment diet and free-choice options
[1]TOD= time of day
Means with common subscripts in a row do not differ

Rumen volatile fatty acids (VFA)

Table 6 lists total rumen fluid molar concentration (µmol/ml), individual VFA percentages, and the acetate to propionate ratio (A:P) of four fistulated Holsteins. Diets 1 and 2 were compared when free-choice was offered versus when it was not. In addition, comparisons of free-choice options were made within each diet. Total VFA in µmol/ml was lower with D1-WFC when compared to D2-WFC. Isovalerate was lower in cows fed D1-NFC than those fed D2-NFC. While no differences were observed in acetate percentages, propionate levels where higher with D1-NFC when compared with D2-NFC and D1-WFC and this correlated to a decreased A:P of 3.69 in D1-NFC versus 4.02 (D2-NFC) and 4.05 (D1-WFC). This change in mean propionate molar percentage contributed to the increased A:P. These findings are in agreement with other studies in which the addition of buffers widen the A:P when basal diets consist of high percentages of concentrate (13, 25). Effects are consistently more pronounced with low fiber intake and have correlated to increases of milk fat percentage in many studies when buffers are added to the diet. Rearte et al. (68) found no differences in A:P ratios when grazing cows were force-fed sodium bicarbonate in a concentrate mix. Kennelly et al. (49) found elevated VFA with inclusion of sodium bicarbonate in a diet consisting of alfalfa and barley silage, and 75% concentrate. Rindsig et al. (69) found that when cows were fed 5% sodium bentonite in the ration, acetate percentages increased while propionate and valerate percentages decreased thus increasing the A:P. In our experiment, percent propionate decreased while the A:P increased when free-choice was offered on diet 1 only. Average free-choice consumption of sodium bentonite, however, was well below the 5% level used by Rindsig.

Table 6

The effect of sodium bicarbonate force-fed and free-choice options on rumen fluid molar proportions of volatile fatty acids.

						P>F			
					LSM	NFC	WFC	D1	D2
	D1-NFC	**D2-NFC**	**D1-WFC**	**D2-WFC**	**SE**	D1 vs D2	D1 vs D2	NFC vs WFC	NFC vs WFC
Total VFA, µmol/mL	348.80	344.36	344.70	359.70	7.820	0.52	**0.04**	0.70	0.16
Acetate, molar %	68.67	69.62	69.65	69.25	0.490	0.16	0.53	0.19	0.61
Propionate, molar %	18.95	17.50	17.27	18.19	0.490	**0.02**	0.11	**0.03**	0.34
Butyrate, molar %	9.59	9.95	10.11	9.70	0.004	0.47	0.43	0.36	0.67
Isobutyrate, molar %	0.93	0.97	0.96	0.93	0.001	0.16	0.40	0.34	0.24
Valerate, molar %	1.19	1.16	1.15	1.17	0.001	0.60	0.69	0.46	0.92
Isovalerate, molar %	0.75	0.84	0.79	0.77	0.001	**0.01**	0.40	0.29	0.14
Acetate/propionate	3.69	4.02	4.05	3.86	0.110	**0.02**	0.14	**0.03**	0.33

D1-NFC= Diet 1 (without sodium bicarbonate), no free-choice
D2-NFC= Diet 2 (with sodium bicarbonate added at 1.2% dry matter), no free-choice
D1-WFC= Diet 1, with free-choice options
D2-WFC= Diet 2, with free-choice options
P>F is from the slice option in proc mixed of SAS

Blood parameters

Most trials have found no changes in blood parameters when sodium bicarbonate was force-fed in the TMR (34, 69). Blood packed cell volume (PCV) and blood protein were not affected by diet or free-choice options with either breed (Table 7). Neither were there any differences between the four diet regimes with either breed (Table 8). No changes may indicate that cows did not differ in terms of protein metabolism and uptake by the blood. In addition, comparable PCV may indicate no differences in body hydration.

Urine specific gravity

Urine specific gravity was lower in both Holsteins (1.027 vs. 1.030, Table7) and Jerseys (1.024 vs. 1.027) when sodium bicarbonate was force-fed in the ration. In Holsteins, no differences were observed when cows were allowed free-choice options but the highest urine specific gravity was seen in cows receiving D1-NFC (1.030, Table 8), and was different from cows receiving sodium bicarbonate in their rations (D2-NFC= 1.026, D2-WFC= 1.027). Jerseys had the lowest urine specific gravity measures when consuming D2-NFC (1.023) and this was different from D1-NFC (1.028). However, D1-WFC and D2-WFC were not different from each other or from the other two diet regimes. The decrease in urine specific gravity when sodium bicarbonate is force-fed may suggest an increase in water consumption. It was observed by Rogers et al. (72) that cows consume more water when force-fed buffers in their ration. Findings of lower urine specific gravity with inclusion of sodium bicarbonate to the ration may support Rogers' findings. Dehydration is not supported by blood PCV observations because values were not different between diets in either breed. Erdman et al. (27) did not find significant changes in blood hematocrit between control and treatment groups fed sodium bicarbonate.

Fecal score and dry matter

Fecal score and dry matter may reflect water consumption both in free form and in the ration. These measurements were not affected by diet, free-choice options, or diet regime with either breed (Tables 7 and 8). Forage source and crude protein content of the diet can affect fecal dry matter and fecal score (48). Ireland-Perry observed cattle consuming alfalfa and corn silage had average fecal scores of 2.31 and DM percentages of 15.25 (48). Our fecal DM percentages were between 13.06 and 13.65 on different diet regimes and fecal scores were similar to Ireland-Perry's results (Table 8) with Holsteins averaging 2.4 and Jerseys averaging 2.5.

Table 7 Least square means for blood and manure parameters and urine specific gravity when sodium bicarbonate was force-fed without or with free-choice (FC) options of sodium bentonite and sodium bicarbonate.

Response	**[1]Control**	**[2]$NaHCO_3$ added**	**SE**	**P>F**	**[3]No FC**	**[4]FC Offered**	**SE**	**P>F**
Holsteins (n=17)								
Blood Protein, g/dl	8.02	7.96	0.098	0.16	7.98	8.00	0.099	0.70
Blood PCV, cL/L	30.13	30.33	0.460	0.35	30.24	30.22	0.460	0.91
Urine specific gravity	1.030	1.027	0.001	**<.01**	1.028	1.028	0.001	0.70
Fecal Score	2.33	2.41	0.095	0.37	2.38	2.36	0.094	0.82
Fecal DM, %	13.48	13.12	0.178	0.07	13.19	13.42	0.185	0.31
Jerseys (n=8)								
Blood Protein, g/dl	7.45	7.41	0.136	0.57	7.43	7.42	0.136	0.88
Blood PCV, cL/L	29.23	29.10	0.630	0.68	29.33	28.99	0.630	0.21
Urine specific gravity	1.027	1.024	0.001	**<.01**	1.025	1.026	0.001	0.92
Fecal Score	2.55	2.50	0.130	0.71	2.57	2.49	0.130	0.50
Fecal DM, %	12.80	12.96	0.263	0.60	12.98	12.78	0.273	0.57

[1]Diet 1 (without sodium bicarbonate)
[2]Diet 2 (with sodium bicarbonate added at 1.2% dry matter)
[3]Refers to all diet periods withheld access to free-choice options (sodium bicarbonate and sodium bentonite)
[4]Refers to all periods allowed access to free-choice options
FC= free-choice

Table 8 Least square means for diets for blood and fecal parameters and urine specific gravity for individual periods during which sodium bicarbonate was force-fed and free-choice options of sodium bentonite and sodium bicarbonate were offered

Response	**D1-NFC**	**D2-NFC**	**D1-WFC**	**D2-WFC**	**SE of mean**	**Interaction P>F**
		Holsteins (n=17)				
Blood Protein, g/dl	8.04	7.90	8.0	8.0	0.136	0.37
Blood PCV, cL/L	30.19	30.29	30.07	30.37	0.482	0.77
Urine Specific Gravity	1.030^{a}	1.026^{b}	1.029^{ab}	1.027^{b}	0.001	**<0.01**
Fecal Score	2.35	2.40	2.30	2.40	0.112	0.80
Fecal DM	13.31	13.06	13.65	13.18	0.234	0.21
		Jerseys (n=8)				
Blood Protein, g/dl	7.46	7.41	7.44	7.41	0.146	0.95
Blood PCV, cL/L	29.40	29.26	29.04	28.95	0.673	0.61
Urine Specific Gravity	1.028^{a}	1.023^{b}	1.026^{ab}	1.025^{ab}	0.001	**<0.01**
Fecal Score	2.59	2.54	2.51	2.46	0.160	0.90
Fecal DM	12.79	13.16	12.81	12.76	0.351	0.79

D1-NFC= Diet 1 (without sodium bicarbonate), no free-choice
D2-NFC= Diet 2 (with sodium bicarbonate added at 1.2% dry matter), no free-choice
D1-WFC= Diet 1, with free-choice options
D2-WFC= Diet 2, with free-choice options
P<0.05 indicates an interaction between treatment diet and free-choice options
Means with common subscripts in a row do not differ

Free-choice Intake of sodium bentonite and sodium bicarbonate

Table 9 lists DM intakes of sodium bentonite and sodium bicarbonate from those periods in which they were offered free-choice to breed groups. On average, force-fed sodium bicarbonate intake was approximately 300 g/d for Holsteins and 240 g/d for Jerseys. Free-choice intake of sodium bicarbonate averaged 34 g/d for Holsteins and 59 g/d for Jerseys, and free-choice intake of sodium bentonite averaged 83 g/d for Holsteins and 60 g/d for Jerseys. In both breeds free-choice intake of both components tended to increase as the experiment progressed. Total intake of sodium bicarbonate when force-fed and offered free-choice was approximately 334 g/d for Holsteins and 300 g/d for Jerseys.

Sodium bentonite has the ability to expand 10-15 times its size when water is added. This may create more bulk in the rumen, reduce rate of passage, and thus increase feed efficiency (13). However, in our observations, when given free-choice options, Jerseys increased DMI (20.40 versus 19.44 kg/d, Table 2) as well as a percentage of bodyweight (4.78 versus 4.56). While these results do not support a slower rate of passage through the rumen, FCM in Jerseys improved when sodium bentonite and sodium bicarbonate were offered free-choice. It is theorized that because sodium bentonite has a high affinity for divalent ions, calcium may be absorbed from dicalcium phosphate and the PO_4^- ion would be able to bond with other cations. Formation of ammonium phosphate may result and thus retention of the ammonium ion within the rumen fluid for extended times (54). This may create an environment for increased microbial protein synthesis.

During the trial it was noted that certain cows lingered around the free-choice feeders more than others after morning feeding and milking. Sodium bentonite was occasionally seen caked onto the muzzles of some cows. However, determining individual intake was not possible and it is unclear as to which cows consumed which free-choice options.

Table 9 Average breed dry matter intake (g/cow/d) of free-choice options of sodium bentonite and sodium bicarbonate.

	Holsteins (n=17)		***Jerseys (n=8)***	
	Sodium bentonite	Sodium bicarbonate	Sodium bentonite	Sodium bicarbonate
Periods				
2	9.1	0.0	27.2	36.3
3	31.8	27.2	36.3	59.0
5	95.3	49.9	77.1	99.8
8	195.0	59.0	99.8	40.8
Average	82.8	34.0	60.1	59.0

Interactions

Means and tests of interactions among breed, treatment, and free-choice are listed on Tables 3, 5, and 8. They are also illustrated in Figure 4 (Holsteins) and 5 (Jerseys).

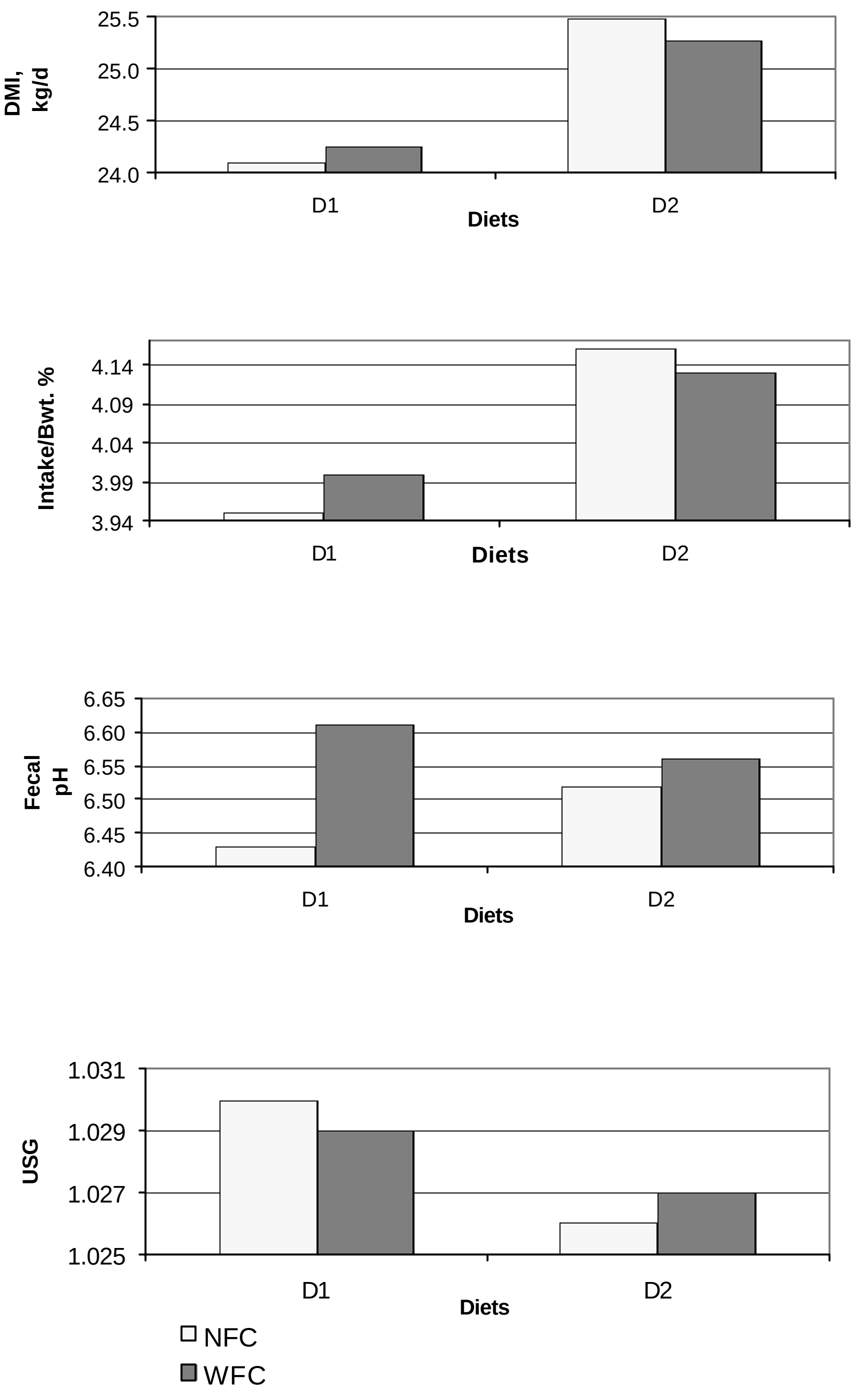
Holsteins

In Holsteins, DMI in diet 2 was enhanced when free-choice options were not available. On diet 1, fecal pH was lower when sodium bicarbonate was not added to the TMR. Fecal pH on diet 2 was similar without or with free-choice options but different on diet 1. Differences in urine specific gravity between diet 1 and diet 2 were more pronounced when free-choice was not offered. Free-choice options displayed greater urine specific gravity on diet 1 whereas it was lowest on diet 2. This indicates free-choice sodium bentonite and sodium bicarbonate moderated the response to force-fed sodium bicarbonate.

Jerseys

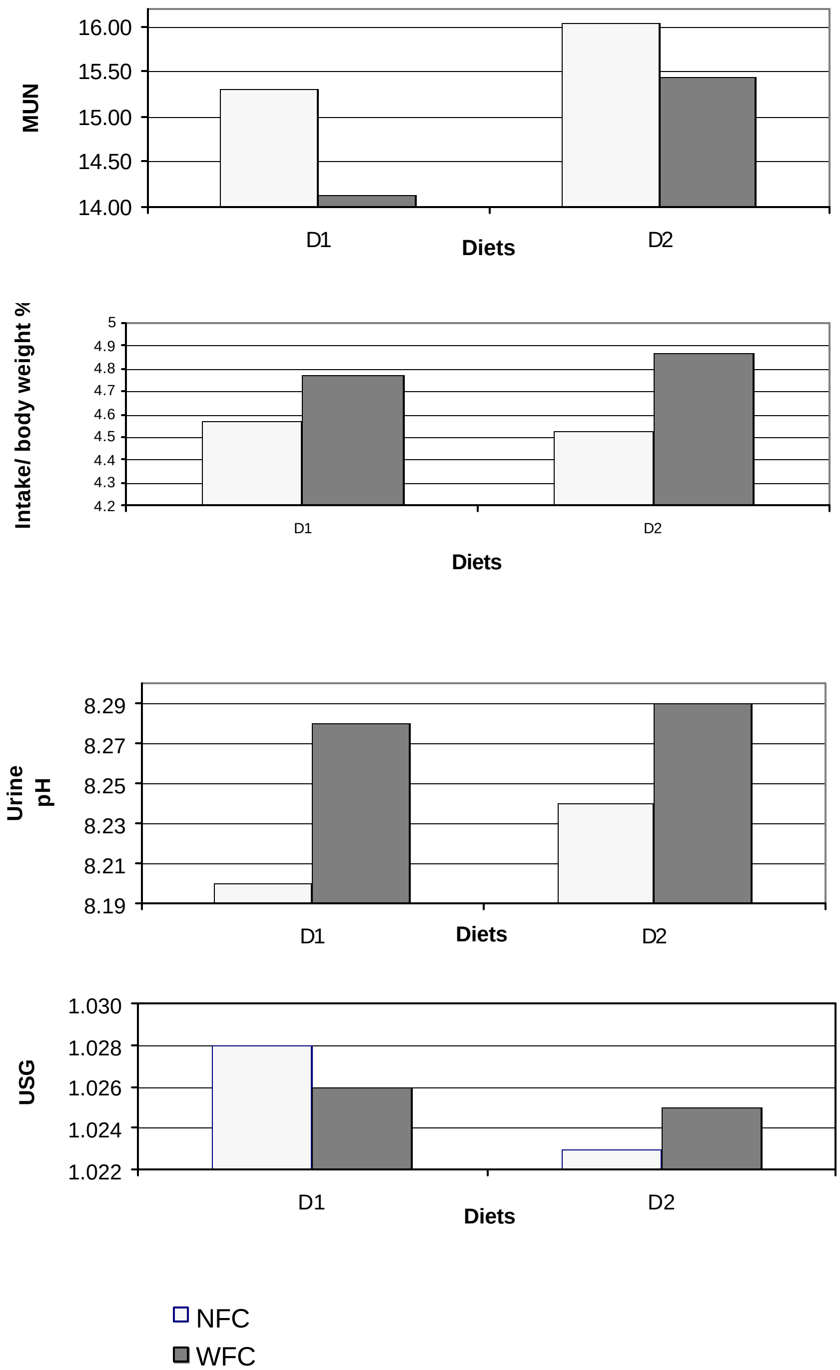
In Jerseys, MUN was always higher when free-choice was not available, but the difference between without or with free-choice was least on diet 2. Intake (intake/body weight %) was greater on diet 2 than diet 1 while free-choice was offered but was less when free-choice was not offered. Urine pH was always greater when free-choice was offered, but the difference between without or with free-choice was least on diet 2. Urine specific gravity was highest on diet 1 and lowest on diet 2 without free-choice. The difference between diet 1 and diet 2 was extreme when free-choice was restricted and this observation is consistent with Holsteins.

Figure 4 Holstein breed x treatment x free-choice interactions. Adapted from tables 3 (DMI, Intake/body weight %) and 5 (Fecal pH, Urine Specific Gravity)



Diet 1 = No sodium bicarbonate added to TMR
Diet 2 = Sodium bicarbonate added to the TMR at 1.2% dry matter

Figure 5 Jersey breed x treatment x free-choice interactions. Adapted from tables 3 (MUNs, Intake/body weight %) and 5 (Urine pH, Urine Specific Gravity)



Diet 1 = No sodium bicarbonate added to TMR
Diet 2 = Sodium bicarbonate added to the TMR at 1.2% dry matter

Cost effectiveness

Prices for sodium bentonite and sodium bicarbonate are listed as $0.35/kg and $0.484/kg, respectively (1). Force-fed sodium bicarbonate cost $0.15/cow/d for Holsteins and $0.12 for Jerseys. Free-choice intake of sodium bentonite averaged 82.8 g/cow/d for Holsteins and 60.1 g/cow/d for Jerseys, and free-choice intake of sodium bicarbonate averaged 34 g/cow/d for Holsteins and 59 g/cow/d for Jerseys. For Holsteins, this would correspond to $0.029/cow/d for sodium bentonite and $0.016/cow/d for sodium bicarbonate, totaling approximately $0.045/cow/d cost for free-choice consumption (Table 10). Jerseys consumed $0.021 of sodium bentonite and $0.029 of sodium bicarbonate daily totaling $0.05/cow/d for free-choice consumption. Milk production increased in Jerseys 2.36 kg of FCM/cow/day when allowed free-choice. According to July 2002 Commonwealth of Virginia State Milk Commission announcement of producer milk prices (at 3.5% butterfat), price/cwt was $16.31 and $2.64/kg of fat. This would correspond to approximately $0.53/cow/d increase in gross income. Feed intake in Jerseys increased 0.96 kg, which corresponds to a $0.12 increase in feed cost/cow/d with free-choice consumption. This would result in $0.41/cow/d net income with Jersey cows. Taking both free-choice and force-fed sodium bicarbonate into account, net return would be $0.29/cow/d.

Free-choice feeding of sodium bentonite and sodium bicarbonate is thus considered cost-effective in this experiment in Jerseys. In addition, its influence on rumen health and acid-base balance may be an important factor for more efficient management.

Table 10 Average cost/cow/d for free-choice intake of sodium bentonite and sodium bicarbonate.

	Holsteins (n=17)		***Jerseys (n=8)***	
	Sodium bentonite	Sodium bicarbonate	Sodium bentonite	Sodium bicarbonate
Period				
2	0.003	0.0	0.010	0.018
3	0.011	0.013	0.013	0.029
5	0.033	0.024	0.027	0.048
8	0.068	0.029	0.035	0.020
Average	$0.029	$0.016	$0.021	$0.029

SUMMARY

1. Force-feeding sodium bicarbonate reinforced conclusions found in several other experiments. In Holsteins these include higher milk production, greater DMI, greater intake as a percent of bodyweight, and higher urine pH.

2. In both Jerseys and Holsteins, urine specific gravity decreased when sodium bicarbonate was force-fed in the ration indicating less concentrated urine with supplemented cows. This may indicate greater water consumption.

3. Free-choice options of sodium bentonite and sodium bicarbonate had an effect on performance and acid-base status. In Holsteins, allowing free-choice consumption increased milk fat percent and fecal pH. However, response from the Jersey breed was more apparent with increased FCM, DMI, and greater urine pH.

4. In Jerseys, MUN decreased when sodium bicarbonate was added to the diet but increased when free-choice options were available. All MUN values were within normal range.

5. Breed x treatment x free-choice interactions were observed in both breeds. With Holsteins, significant interactions included DMI, intake as a percentage of body weight, urine specific gravity, and fecal pH. With Jerseys, significant interactions included MUN levels, intake as a percentage of body weight, urine pH, and urine specific gravity.

6. In fistulated cows, rumen pH did not change, but changes were observed with rumen VFA. Addition of sodium bicarbonate and free-choice options to diet 1 decreased total VFA (µmol/mL), decreased molar % propionate, and increased the acetate to propionate ratio. The addition of sodium bicarbonate to the diet increased molar valerate percentages.

7. No changes were observed in blood protein or blood PCV. Comparable blood PCV may indicate no differences in body hydration among all cows.

CONCLUSIONS

Results with production and acid-base balance in this experiment support free-choice options of sodium bentonite and sodium bicarbonate when it is cost-effective, especially for Jerseys. The nature of this experiment was to reproduce situations commonly found and practiced on farms. Observations in Holsteins force-fed sodium bicarbonate were similar to those found in other experiments, which suggest that cows responded normally and our results were comparable. Jerseys responded to free-choice options in terms of production; however, Holsteins responded only with an increase of milk fat. Jerseys were more aggressive consumers of free-choice options in all periods except the last (period 8). Physiological differences may account for this result. Both breeds tended to consume more free-choice as the experiment progressed. Increases in fecal pH in Holsteins and urine pH in Jerseys offer evidence that acid-base status was influenced by selection of free-choice options. Cows may have consumed sodium bentonite and sodium bicarbonate to relieve acidosis discomfort or cravings such as for sodium. It is questionable, however, if cows craved sodium or other minerals because the diet was nutritionally balanced and contained adequate salt.

Decreases in urine specific gravity when both breeds were force-fed sodium bicarbonate in the diet could have resulted from increased water intake. Although water intake was not measured, diluted urine may have resulted. Buffers are believed to work through an upset in water-ion balance, thus cause more water deposition into the rumen by tissue secretion and/or drinking, and thus increased rumen turnover. More starch would bypass rumen degradation and decrease likelihood of acidosis. Evidence of improved DMI and milk production in Holstein cows force-fed sodium bicarbonate supports this theory.

In fistulated Holsteins, total VFA in μmol/ml increased on diet 2 as compared to diet 1 when free-choice was offered. Propionate decreased while acetate did not change when sodium bicarbonate was force fed and when free-choice options were allowed for cows on diet 1. This increased the acetate to propionate ratio for cows force-fed sodium bicarbonate and given free-choice on diet 1. This may explain why Holsteins produced greater milk fat when allowed free-choice. This has been observed before as well as an increase in rumen pH when sodium bicarbonate is force-fed. Fistulated cows showed no differences in rumen pH in this experiment, however. It is possible that carry-over effects took place, and that 10 d was not a sufficient amount of time to measure significant changes in rumen pH for free-choice options. It may be that these period sizes and experimental design are inappropriate for studying the effects of offering separate free-choice options of sodium bentonite and sodium bicarbonate to lactating dairy cattle.

More studies may be needed to further evaluate free-choice consumption of rumen buffers and/or feed additives to investigate if cows have the ability to select the correct amounts to establish a more favorable acid-base balance within the body. Investigation of water consumption, urine specific gravity, and plasma osmolarity, and how they may relate in terms of mineral salts may clarify how buffers work in a ruminant's digestive tract when given free-choice options.

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