THE USE OF BUFFERS IN RATIONS FOR DAIRY CATTLE

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The dairy cow evolved as a forage eating animal; therefore it is not surprising that her digestive system developed to digest fiber. The rumen is the cow's forage processing factory. The feed is the raw material, the microbes are the workers and the microbial protein and volatile fatty acids are the products produced by the factory for use by the cow. The rumen factory normally accounts for 60 to 90% of the digestion that occurs in the cow. The volatile fatty acids are the major source of energy for the dairy cow and are also important raw materials for use in manufacturing milk and fat in the mammary gland. Thus, optimum operation of the rumen factory and its workers, the microbes, is important for the best performance of the cow. However, the relationship is not one-sided because the microbes benefit from the cow's management of the factory. The cow provides the feed and water, maintains the temperature, and controls the acidity by secreting salivary buffers and absorbing acid end-products. Because we have demanded ever greater milk production from the cow, we have changed her diet to provide the high energy materials needed to produce more milk. As we add grain to the diet, the environment in the rumen factory is altered and some of these changes are harmful to the microbial workers and the cow.

Although many factors change when grain is added to dairy cow diets, we are beginning to realize that the change in rumen pH, or acidity, may be the factor responsible for most of the harmful effects. Since buffers play a central role in the control of pH in the rumen, this discussion will focus on the use of buffers to aid rumen pH regulation. Although some buffers, such as limestone and magnesium oxide, can affect the pH of the contents of the small intestine, these effects are small compared to changes that can occur when rumen pH is buffered. Several compounds have been used to buffer the rumen, including sodium bicarbonate, magnesium oxide and bentonite. There is some research to suggest that magnesium oxide may cause its effects by means other than buffering. Bentonite also appears to affect more than the pH of the rumen. Thus, the primary compound considered to be a ruminal buffer in this discussion is sodium bicarbonate. To help predict when supplemental buffer feeding is feasible and recommended, it is pertinent to discuss changes that occur in lactating cows when grain is added to the ration.

As the amount of roughage in the diet decreases, both fiber content and ruminal pH decrease (table 1). Typical fiber contents of rations are given in table 1 to emphasize that it is the fiber and not the roughage *per se* that results in ruminal changes. In general, less roughage of a higher fiber content will result in the same rumen conditions as a larger amount of a roughage with less fiber content. Crude fiber values are given because they are most commonly available; however, recent research suggests that neutral detergent fiber is a more accurate measure of the total fibrousness of a feed and is more closely related to ruminal changes. As the fiber content of the ration decreases, the average pH in the rumen decreases. This is due primarily to two factors: (1) decreased chewing time and salivation by the cow and (2) increased volatile fatty acid production by the microbes.

Although reduced chewing time with decreased ration fiber content would imply that less energy is wasted by the cow in moving her jaw, the loss of saliva during chewing is much more detrimental than the benefits of saving energy. Ruminants, such as the cow, are unique in that they secrete saliva continuously to supply buffers to the rumen and keep pH near 6.5 to 6.8. However, the cow secretes saliva 2.5 to 3.5 times faster when eating or ruminating than when resting. Thus, the cow secretes less saliva when she chews less because the ration contains less fiber. Most dairy rations contain between 20 to 60% roughage, and decreased chewing by cows receiving these rations can result in .3 to .5 pounds less salivary sodium bicarbonate secreted each day. Since bicarbonate is the major buffer in saliva, this loss of salivary bicarbonate could explain partially the drop in rumen pH.

The relationship of chewing and salivary buffer secretion also indicates how physical form and particle size of the roughage affects pH. We have recently determined that chopping hay to pass a 3/4 inch screen reduces eating time by 10% but does not affect ruminating time. However, grinding feeds to pass a 1/4 inch screen reduces eating time by 20% and ruminating time by 50%. Thus, at the same fiber content, a ground roughage, or one consisting of small particles, will result in 30 to 40% less total chewing time. This in turn results in less saliva secretion, less buffer in the rumen, and higher rumen pH. This effect can be dramatic; for example, a ration containing 50% fiber of small particle size will result in the same chewing as a ration containing 20% long roughage. Silages may result in less salivary buffer secretion because they are not only chopped, but also they are moist. Generally, cows chew wet feeds less than dry ones when they eat. Since the relationship between ration fiber content and saliva production can be changed by altering the moisture content and physical form of the fiber, several researchers have suggested that chewing time be used directly to measure the roughage or effective fiber value of various feeds.

While decreased roughage content of rations results in less saliva bicarbonate production, increased grain content results in greater acid production. The easily digested nutrients of grains are rapidly fermented by ruminal microorganisms, causing an increase in volatile fatty acids in the rumen. The combination of less chewing of grains and greater acid production results in lower ruminal pH. Even some readily fermentable fibrous feeds, such as soybean hulls and citrus pulp, result in rapid acid accumulation in the rumen. Thus, these feeds have effective fiber values lower than their fiber contents would suggest.

As the pH of rumen contents decreases, the pattern of volatile fatty acids changes. Acetate concentration decreases and propionate concentration increases. These changes in volatile fatty acid pattern affect the metabolic function of mammary gland and body fat tissues. Acetate is used by the mammary gland to synthesize some of the fat in milk. However, a deficiency of acetate cannot explain completely the depression in milk fat that occurs when the acetate propionate ratio falls below 2.0. Infusing acetate into the bloodstream of cows secreting low fat milk will not correct the problem completely. Therefore, it appears that increased ruminal propionate may be involved. High ruminal propionate is associated with fattening in feedlot steers and it appears that it may cause metabolic changes in lactating cows that switch the conversion of absorbed energy from milk production to body fat synthesis. This results in depressed fat percentages in milk and fattening of the cow.

The relationship between ruminal pH, changes in volatile fatty acid patterns and milk fat depression suggests that this mechanism may be related to the low milk fat percentages observed during hot weather stress. Cows have limited ability to sweat and typically pant to cool themselves by evaporation in the lungs. However, panting, or hyperventilation, may affect blood bicarbonate concentration. Humans that hyperventilate have lower blood bicarbonate levels because it is broken down to carbon dioxide and exhaled. If this also occurred in cattle, then saliva bicarbonate, which comes from the blood, may be decreased. Decreased salivary buffer could result in lower rumen pH and milk fat depression. This theory is supported by some Japanese research that indicates the rumen pH of cows exposed to hot temperatures is lower than when they are exposed to temperatures that do not cause panting. Futhermore, it has been observed that giving bicarbonate to humans can elevate blood bicarbonate levels when they hyperventilate. Similarly, supplemental buffer feeding often alleviates the milk fat depression during hot weather, indicating that the animals may be suffering from a bicarbonate deficiency.

While the effects of pH on milk fat depression is dramatic, it may also affect fiber digestion, adaptation to high energy diets and fluctuations in rumen environment associated with meal feeding patterns. It has been known for many years that adding readily fermentable, high energy feeds to forage diets results in reduced fiber digestion. Recent evidence suggests that this may be due to decreases in pH because of acid accumulation during rapid fermentation. The optimum pH for many fiber-digesting enzymes is near 6.8 and their activity is greatly reduced as pH falls from 6.8 to 6.0. Thus, maintaining pH near 6.8 may be important in maximizing fiber digestion.

In addition to improving fiber digestion, maintaining rumen pH may reduce the stress associated with the adaptation of cows to high energy diets after freshening. When changed from a high roughage feed to a high energy one, the types and proportions of ruminal microbes change to accomodate the diet and the cow's physiological status. Unfortunately the microbes rapidly ferment the new diet, causing widely fluctuating pH cycles in the rumen, which not only adversely affect themselves but also affect the cow detrimentally. Adaptation to diets may be accelerated by buffer feeding because buffers moderate the pH fluctuations that occur. Although there is little direct evidence to support this theory, it is interesting that the maximum response of animals to supplemental bicarbonate feeding is often observed during the first 4 to 8 weeks after diet changes.

Supplemental buffer feeding also may reduce fluctuations in pH throughout the day that are associated with meal feeding patterns. In general, rumen pH falls after a meal because microbial workers produce acid. The extent of pH drop is related to the amount of feed eaten at the meal. More feed eaten results in larger pH decreases. Approximately 2 to 6 hours after the meal the pH begins to rise as the cow ruminates and secretes saliva. The fluctuation in rumen pH is much greater and the minimum pH reached is much lower when only one meal is eaten per day as compared to the normal 10 to 14 meals a cow will consume under the best conditions. Generally cows consume fewer meals and eat a majority of their daily feed intake during the nighttime hours during hot weather. Thus, feeding buffers may moderate the fluctuations in pH that occur with irregular feeding patterns during hot weather.

In addition to the fermentation characteristics of a feed, its natural buffering capacity and acidity may influence rumen pH and alter the efficacy of supplemental buffer feeding. Although little research is available, there are indications that legume forages have greater natural buffering capacities than grasses. While the buffering capacities of feeds are low, the large amounts of feeds eaten could have a significant effect on rumen pH. Differences in feed buffering capacities may explain some of the variable results obtained with supplemental buffers. Conversely, the acid content of feeds such as silages may result in lower rumen pH. Although the acid consumed in silages is low compared to the amount of acid produced by ruminal microbes, it may result in some changes in rumen environment. Differences in feed buffering capacities and acid contents may explain why buffers are less effective in alfalfa hay rations than other rations and why added buffers typically increase the intake of silage rations.

While supplemental buffer feeding may help correct abnormal pH conditions in the rumen, it may also affect the microbes and cow in other ways. Sodium bicarbonate may increase water turnover in the rumen by increasing water outflow from the rumen. Increasing water outflow may change the rumen microbial population because slow-growers will be washed out. In addition, increasing water outflow has been associated with decreased propionate concentration in the rumen. Since decreased propionate concentration is related to increased milk fat synthesis, this effect may explain partially the positive effect of sodium bicarbonate in correcting milk fat depression.

Supplemental buffers often result in increased intake of the total ration. Although some research suggests that sodium bicarbonate and magnesium oxide are unpalatable when included in the concentrate mixture, most research indicates that these buffers increase intake when mixed in the total ration. Increased intake is usually greater for problem diets that are low in fiber or rations containing corn silage, but also occurs in normal and hay rations. In general, sodium bicarbonate is more palatable and increases intake more than magnesium oxide.

In conclusion, supplemental buffers may be recommended in certain situations to help the dairy cow maintain optimum pH and buffering capacity in the rumen. Rations that are low in effective fiber, whether due to fiber deficiency or to small particle size, usually are benefited by additions of buffers. Problems with milk fat depression and borderline rumen dysfunction usually occur when (1) roughage is less than 40% of the total ration dry matter, (2) cows consume less than 1.5% of hay equivalent per day, (3) fibrous feeds that are highly digestable or of small particle size (soybean hulls, citrus pulp, etc.) furnish more than 30% of the roughage dry matter, or (4) cows are consuming more than 2.0% of their body weight of concentrates per day. Buffers also may improve rations containing low buffering or acid containing feeds such as when chopped and fermented silages supply more than 80% of roughage dry matter in the ration.

In addition, buffers may benefit cows suffering off-feed disorders or irregular feeding patterns that result in widely fluctuating conditions of rumen pH. They also appear to help dairy cows adapt to high energy lactating cow rations after freshening. Research indicates that buffered rations result in increased intake, more rapid attainment of peak feed intake and improved milk production during these high stress, adaptation periods. Milk fat depression during heat stress may also be reduced by buffer addition to the ration. This disorder may be due to bicarbonate deficiency caused by hyperventilation during hot weather and to unstable rumen pH associated with irregular feeding patterns during high temperature periods.

Usually sodium bicarbonate and magnesium oxide are fed in combination when buffer supplementation is indicated. It appears that their modes of action are different and their effects are additive. In general, sodium bicarbonate is more effective in improving rumen conditions by raising and stabilizing pH than is magnesium oxide, while magnesium oxide may affect volatile fatty acid patterns in the rumen and alter the metabolism of the mammary gland directly. The optimum amount of each buffer to feed has not been clearly established by research. Some work suggests that both sodium bicarbonate and magnesium oxide are unpalatable when added to the concentrate mixture. Although magnesium oxide generally is less palatable than sodium bicarbonate, intakes of complete feeds containing more than 5.0% sodium bicarbonate have been increased. Thus, it appears that supplementing buffers at normally recommended levels should not cause problems. Normal recommendations for buffer supplementation of rations are .75% sodium bicarbonate and .3% magnesium oxide in the ration dry matter. However, a recent review suggests that no additional benefits to fat depressing rations are observed with intakes greater than 280g sodium bicarbonate and 140g magnesium oxide per day. This would correspond to approximately 1.4% of sodium bicarbonate and .7% of magnesium oxide in the ration dry matter and would suggest that these levels are the maximum recommended levels for severe milk fat depression. Although no research is available, field experience suggests that the level of buffers that can be fed without detrimentally affecting palatability is related to the type of ration. In general, higher levels of buffers have been fed successfully in silage-based, completely blended rations than in low acid containing complete rations or rations where concentrates are fed separetely.

In addition to buffer supplementation, it is recommended that all other deficencies in fiber content and form be corrected to the extent that is possible. Although buffers can help, they cannot be expected to correct all the problems inherent in the diet or due to stress in the environment. Futhermore, it should be recognized that changes due to buffer feeding will be gradual. Generally some response will be observed within one week, but often 3 to 4 weeks must pass before the maximum effect of buffer feeding is acheived.

TABLE 1: Typical changes in the ration and the dairy cow associated with roughage content of the total ration.

VARIABLE	LONG ROUGHAGE CONTENT OF THE RATION					
	100%	80%	60%	40%	20%	0%
Neutral detergent fiber content(%)	70	59	48	36	25	14
Crude fiber content(%)	34	28	22	16	10	4
Rumen pH	6.8	6.7	6.5	6.2	5.8	5.3
Daily chewing time (minutes)	960	940	900	820	660	340
Daily saliva secretion (liters)	189	186	181	173	157	125
Daily salivary bicarbonate (lbs)	5.2	5.1	5.0	4.7	4.3	3.4
Rumen volatile fatty acid conc.(mM)	85	95	105	115	125	135
Rumen acetate (molar %)	70	66	61	55	48	40
Rumen propionate (molar %)	15	18	22	27	33	40
Acetate: Propionate ratio	4.7	3.7	2.8	2.0	1.4	1.0
Milk fat content (%)	3.5	3.5	3.5	3.4	2.4	1.0