RUMINAL ACIDOSIS: ROOTS, REPERCUSSIONS, AND RESOLUTION

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INTRODUCTION

With increasing production has come an increase in the reports of ruminal acidosis in dairy cattle herds. As we attempt to meet cow requirements by increasing energy levels in rations, increased grain feeding, and decreased levels of forage have become more commonplace. Rather than enhancing performance, these rations can lead to problems attendant with ruminal acidosis: reduced milk production, digestive upset, laminitis, and associated ills that can lead to involuntary culling. With some of these health problems, such as laminitis, animals can be treated, but there is no complete cure. Ruminal acidosis is something to be prevented, not repaired.

Subclinical, or chronic, ruminal acidosis is best described as a syndrome related to a fermentative disorder of the rumen. Although it involves a lowering of ruminal pH below pH 5.5 or 5.6 (Nocek, 1997; Owens, et al., 1998), it is not adequate to define ruminal acidosis as being caused by low pH. The ruminal problems can typically be traced to feeding management in need of improvement, misfeeding of highly digestible carbohydrates, underfeeding of effective fiber, or all of the above. Symptoms associated with subclinical ruminal acidosis include:

- Reduction in ruminal pH
- Rumen hypermotility or stasis
- Reduced rumination (cud chewing)
- Great daily variation in feed intake
- Feces in the same feeding group varies from firm to diarrhea
- Feces foamy, contains gas bubbles
- Appearance of mucin/fibrin casts in feces
- Increase in fiber particle size (> 0.5 inch) in feces
- Appearance of undigested fiber/feed in feces
- Appearance of undigested, ground (≤ 1/4 inch) grain in feces
- Reduced feed efficiency
- Reduced production compared to what the ration is calculated to support.

The chain of ruminal events that is associated with these symptoms is shown in Figure 1. What do the symptoms listed above represent?

Increased Particle Size/Undigested Material in Feces

Large fiber particles or noticeable ground grain in the feces suggest that feed is not being retained in the rumen for a sufficient period to be fermented by the microbes, or to be reduced in size through rumination or microbial digestion. The depression in ruminal digestion may be related to low pH (Strobel and Russell, 1986). An inadequate ruminal fiber mat may not

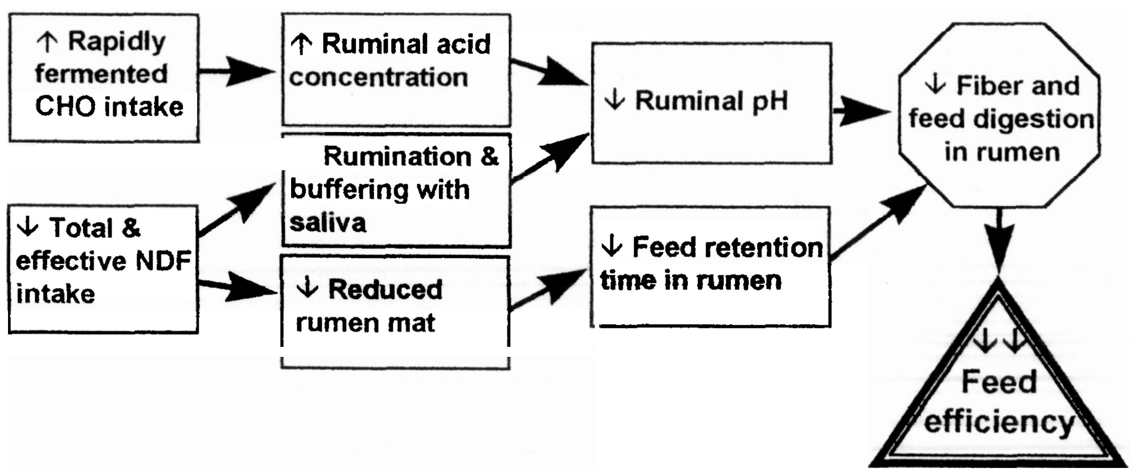


Figure 1. Chain of events in ruminal acidosis.

effectively retain larger particles in the rumen. Both of these situations can be related to inadequate effective fiber (eNDF) intake. The eNDF is fiber in the ration that enhances rumination and rumen motility. Generally, when there is adequate eNDF in the ration, fecal particle size is smaller and ground grain is less apparent, than when fiber requirements are not met.

Undigested feed in feces is indicative of an overall reduction in digestibility of the ration. Both fiber and starch can escape digestion. Long pieces of fiber from forage, or even cottonseed with the lint still intact will pass undigested through the gastrointestinal tract if they are not retained in the rumen for digestion. The particles of ground grain in feces may contain 6 to 18% starch (M. B. Hall, unpublished). Reduced digestion of feed represents a loss of ration nutrients. Consequently, the predicted protein and energy supplies for the ration overestimate what the cow actually receives.

Mucin/Fibrin Casts or Gas Bubbles in Feces

When feed is fermented in the rumen, the organic acids are absorbed across the rumen wall, the gas (carbon dioxide and methane) is eructated (belched) out by the cow, and the microbial protein passes to the small intestine for digestion and absorption. When fermentable substrates pass to the hindgut (cecum and large intestine) they are fermented there by bacteria. The microbial protein produced is not absorbed, but passes out with the manure. Gas produced from hindgut fermentation can appear as bubbles in the manure. The organic acids can be absorbed by the gut. However, a major difference between the hindgut and the rumen is the potential for the fermentation to be buffered. Where rumination and mixing with saliva provide buffers to reduce the extent of pH decline in the rumen, no system of that magnitude exists for the hindgut. When a great deal of fermentable carbohydrate reaches the hindgut, its fermentation to organic acids may result in injury to the gut. The increased acidity may result in a sloughing of the surface cells (epithelium) in the large intestine. When the damage is sufficiently severe, the intestine secretes mucous or fibrin to protect the injury (Argenzio, et al., 1988; Argenzio and Meuten, 1991). Depending upon the severity of the damage, the gut can repair itself in a few hours to a day (R. A. Argenzio, personal communication). The mucin/fibrin casts found in the feces often have the tubular form of the gut; they are evidence that intestinal damage has occurred. Damage to the large intestine and increased concentrations of organic acids in the gut lumen may play a role in causing the diarrhea often seen with ruminal acidosis.

Reduced Feed Efficiency

If the site of digestion is shifted from the rumen to the hindgut, or if it is reduced, it is no wonder that feed efficiency suffers during ruminal acidosis. The amounts of nutrients available to the cow are diminished. The argument has been raised that increased grain and decreased forage are necessary to meet the energy requirements of the cow. However, if concentrate levels are increased to the point that fiber needs are not met, the analyzed or tabular TDN or net energy levels used to formulate the ration are meaningless. In the pursuit of providing the cow with more energy, violation of the rules for formulating a balanced ration actually reduces the amount of energy that the ration provides. This quote by Dr. Paul W. Moe, a USDA researcher who did much work in the area of net energy, explains the situation (Moe, 1976):

> "...The net energy value of a single feedstuff, however, is not a constant but is influenced by such factors as the composition of the remaining portion of the diet, the level of the feed intake, the physiological state of the animal that consumes the feed, etc. This means that while a net energy value may represent the best estimate of the real energy value of a feed in a given situation, it should not be considered as a constant. ....The net energy value listed in a table usually represents an optimum value, that is the value of that feed when incorporated into a "normal" or "balanced" diet. The value may be considerably less than that if fed in excessive amount or in a diet which has a nutrient deficiency."

In this light, including excessive amounts of concentrates in an effort to increase ration energy levels is self-defeating.

Costs of Ruminal Acidosis

Although there is agreement that ruminal acidosis results in increased costs or revenue losses, it can be difficult to determine actual dollar amounts. A study with a commercial dairy examined the increased costs or revenue losses associated with each diagnosed case of digestive upset (Averhoff and Hall, 2000). In the case herd, a ration low in eNDF and high in concentrate appeared to be the cause of digestive upset in the herd. Information was collected on 164 affected cows during a one month period. Only cows with more than 30 days in milk were included in the study because of difficulties with predicting production for calculating milk loss early in lactation.

To calculate the number of pounds of milk "lost", or more accurately, milk that was never produced, daily milk production for each cow was graphed (Figure 2). Milk weights from each milking were reviewed to verify that decreases in daily production were not due to missing milk weights. Milk loss often began approximately 3 days prior to diagnosis of digestive upset. The onset of milk loss and of the digestive upset episode was determined to be the point at which milk production was 10% less than the previous 5-day average. The milk production was termed "recovered" and the episode ended when a cow's daily production returned to within 10% of the

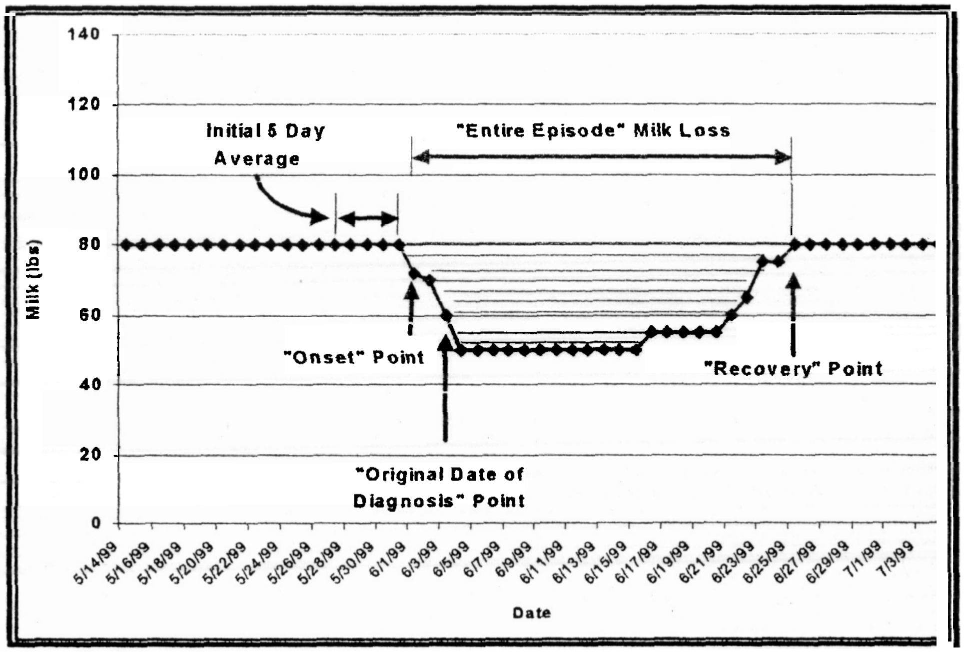
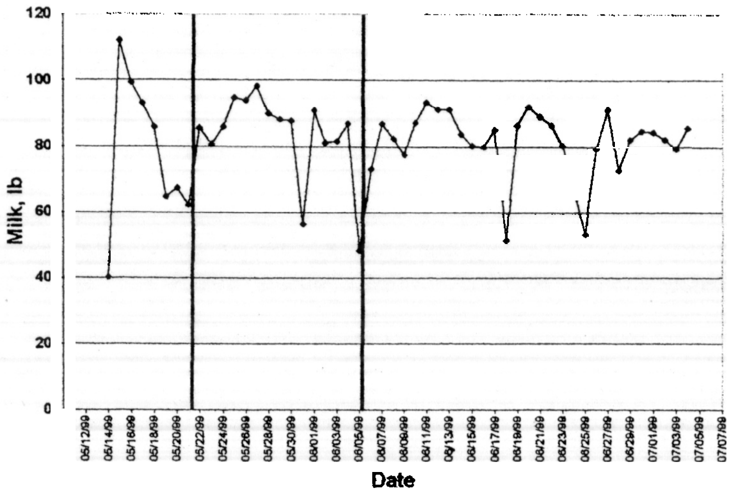


Figure 2. Example of milk production information used for calculation of milk loss, and total days in digestive upset episode.

initial 5-day average. The length of a milk loss episode encompassed the period when milk production was at least 10% less than the initial 5 day average. Total milk loss was the sum of the initial 5 day average minus the daily milk weight for each day in the entire episode. Milk was given a value of $15.50 / cwt. Production curves for some of the cows on the trial are shown (Figures 3 - 5).

Cows that exit the milking herd due to early dry-off, culling, or death present additional losses. In this study, 21 animals diagnosed with digestive upset exited the milking herd, but there were no deaths. For animals that were culled, a value of $1,100 per head was assigned. For a cull animal, the loss in value was the $1,100 minus the revenue received from her sale. The loss in value for an animal that died would be the entire $1,100. For animals that were dried off before 305 days in milk, a projection was made of the amount of milk that they would have produced between the actual date of dry off and 305 days. It was predicted that production would decrease 10% in the first 30 days, and an additional 5% (e.g., 85%, 80%, 75% etc.) from the initial milk production in each subsequent 30 day period through 305 days (D. Webb, personal communication). This milk not produced was accounted as a revenue loss.

As estimated for this study, the total cost of digestive upset was calculated as: treatment costs + lost milk revenue + cull value loss + cull/early dry-off milk revenue loss. Because this was a group feeding situation, no correction was made for reduced feed intake by the sick animals. Other losses associated with digestive upset that we were unable to evaluate included increased labor costs for additional handling of sick animals, hospital barn costs, future costs of associated disorders (e.g., laminitis), and even "opportunity costs" as efforts were devoted to tending sick animals, rather than accomplishing other tasks on the farm.



Figures 3 and 4.
Vertical lines indicate date of digestive upset diagnosis. These milk production curves are typical of the performance of animals diagnosed with digestive upset.

Figure 3.

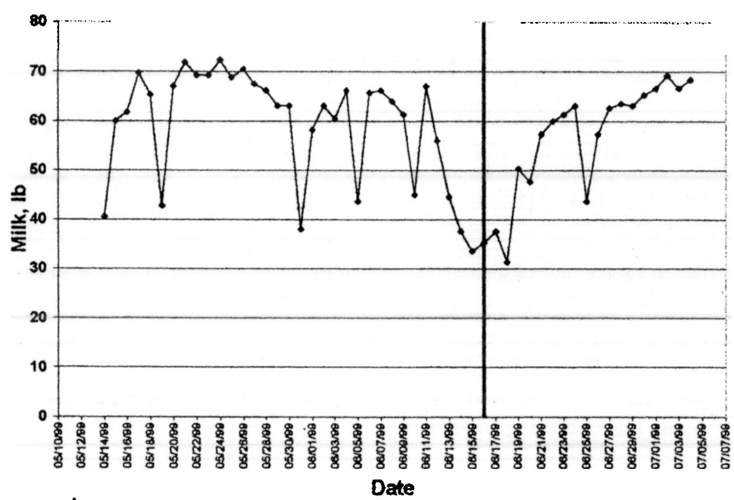


Figure 4.

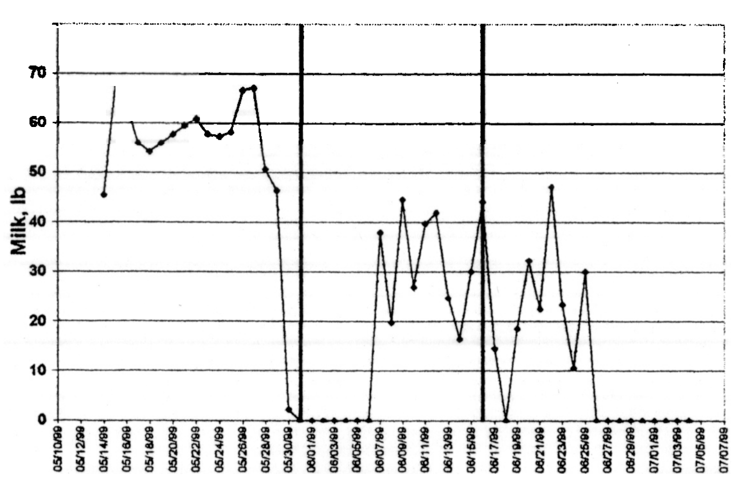


Figure 5. Example production curve of a cow that was dried off before 305 days.

	Average	Range	Cost/Revenue Loss	Average	Range
Cow #	164		Lost milk, $*	116.19	6.23 - 499.93
Lactation #	2.4	1 - 8	Treatment, $	5.60	0 - 74.22
Days in milk	228	31 - 731	Cull loss, $	23.29	0 - 672.39
Initial milk, lb	75.2	42.8 - 114.9	Early cull / Dry off, $	63.28	0 - 1904.95
Days in episode	26.9	2 - 48			
Milk "loss", lb	749.6	40.2 - 3225.3	Total per case, $	208.36	6.23 - 2872.14

There were sizeable costs for each case of digestive upset, with reduced milk revenues by far the largest loss. The cost of treating the animal was usually among the lower costs incurred. Even with milk valued at $9.00 / cwt, the loss per case is still substantial at $159.64. Milk production should typically vary no more than 1 to 5 pounds from day to day in healthy dairy cows (D. Webb, personal communication). This benchmark raises more concerns about the performance of the cows in this study. There were many 10 to 20 pound single-day decreases in milk production that were not directly associated with the diagnosis of digestive upset. One interpretation is that the feeding of a ration low in physically effective fiber to the entire herd likely resulted in subclinical acidosis affecting large portions of the herd, aside from the official diagnoses of digestive upset. The reduced rumination in the herd during the study (~30% or less of the animals chewing their cuds) and the variable manure and increased incidence of diarrhea would tend to support this idea. It is possible that the single day decreases in milk production reflect the effect of subclinical ruminal acidosis on milk production. This reinforces the idea that "pushing" grain into rations to support high milk production may instead result in cows that produce less milk, whether or not they are diagnosed as sick.

Caution should be used when trying to extend this data beyond the farm in the study. In this particular herd, limitations to forage feeding relative to concentrate feeding appeared to be the driving force behind the upsets. In cases where the problem is largely with fresh cows/dry cow management, problems with excessive non-structural carbohydrate fermentation in the rumen, other feeding management issues, or mycotoxins, the profile and severity of the problem for another herd will likely differ. Nonetheless, the results suggest that increased costs/revenue losses from digestive upset/ruminal acidosis can be staggering, and may come largely in the form of production never realized.

Preventing Ruminal Acidosis

Prevention of subclinical ruminal acidosis requires both nutritional and management approaches.

Fiber

Feeding adequate proportions and types of fiber are important, however, "adequacy" can be difficult to formulate. Perhaps to an even greater extent than for other nutrients, adequacy of dietary fiber is determined by the interaction of the cow and the ration. The NRC (1989) recommendations for lactating cow diets are for 28% of ration dry matter as NDF, and that 75% of the NDF be supplied from forage. Mertens (1985) has suggested that NDF intakes of 1.2 ± 0.1 percent of live weight with 70 to 80% of the NDF supplied from forage is optimum. These guidelines are subject to change depending upon fiber form and source. The specification that a percentage of the NDF be supplied by forage is an effort to assure that there is adequate eNDF in the ration. The difficulty is that there is no common agreement on a system to assess the effectiveness of NDF, in part, because so many factors can affect "effectiveness". Fiber's effectiveness relates to its particle size, digestibility, density, and hydration among other factors. Effectiveness of a fiber source can even vary depending upon the characteristics of the other feeds in the ration (Mooney and Allen, 1997). Particle separation systems are available to objectively evaluate particle size in rations as a way of estimating the amount of effective fiber (Lammers, et al., 1996).

The usefulness of any eNDF system depends upon how well it describes the fiber that is actually consumed. If cows can select the feeds they consume, any estimation of eNDF intake will be poor. Evaluating eNDF intake on different feeding systems requires different approaches.

- Total Mixed Rations - The feed fed, and the feed remaining should be examined to determine the extent to which sorting took place. If the ration is not sorted, the feed remaining should look similar to that which was fed. Observation of the cows as they eat also makes clear whether they can sort, and which feeds they select for or against. This may vary by animal (Coppock, et al., 1974).

- Feeding to an Empty Bunk - Since no feed remains to be evaluated, the only way to discern whether sorting is taking place is to observe the cows as they eat. Particularly if bunk space is limited, the first cows may sort the ration for preferred feeds, with the remainder providing an entirely different ration to the cows that access the bunk later.

- Offering Individual Feeds - When forages and concentrates are offered separately, particularly to groups of cows, there is no accurate way to assess what ration individual cows consumed. The ration consumed by the herd may represent an average of very high and low concentrate diets eaten by individual animals.

Cows are quite adept at sorting out longer pieces of forage. Sorting of total mixed rations can be minimized by chopping the forage to 1 to 2 inch lengths and raising the moisture level of the ration so that feeds do not sift apart.

The cow is the final arbiter of whether her fiber requirement is met. A good general rule is that the ration contains adequate amounts of effective fiber if 50% of the cows not eating or sleeping are chewing their cuds. Reformulation of the ration and feeding management need to be explored to achieve this goal.

Neutral Detergent-Soluble Carbohydrates (NDSC)

Controlling the level and type of NDSC in the ration is essential to preventing ruminal acidosis. The NDSC (a.k.a., NSC or NFC) include organic acids, sugars, starch and soluble fiber such as pectic substances. Restricting NSC to 35 to 40% of ration dry matter when the NDSC is largely sugar or starch, or 40 to 45% when other carbohydrates predominate has been suggested (Hoover and Miller, 1995). It does appear that different NDSC differ in their effects on ruminal pH. Sugars and starch may ferment to lactic acid, which is a 10-fold stronger acid than acetic, propionic, or butyric. Soluble fiber, such as pectic substances, ferment rapidly, but their fermentation is depressed at lower pH (Ben-Ghedalia, et al., 1989; Strobel and Russell, 1986), so their acid contribution may be reduced at lower ruminal pHs. Because different types of NDSC differ in their effects on ruminal pH, it is reasonable to formulate rations considering NDSC type, rather than just the total.

The effects of the quantities of NDSC fed varies with their rates of fermentation. Rapidly fermenting carbohydrates, such as sugars, soluble fiber, and some starches, have the potential to decrease ruminal pH rapidly by virtue of the sheer mass of organic acids presented to the rumen in a relatively short period of time. In feedlot cattle, a greater risk of ruminal acidosis is reported when more rapidly fermented carbohydrate sources such as wheat (Elam, 1976) or steam-flaked sorghum (Reinhart, et al., 1997) are fed. Increased gelatinization, physical availability, and digestibility of grains accomplished through heat and pressure processing, reduction in particle size, or high moisture ensiling can increase the rate of starch digestion.

The effects of NDSC on ruminal pH was explored in a recent study with lactating dairy cows (Leiva Lopez et al., Accepted). Three ruminally cannulated cows in a reversal trial were fed one of two corn silage/alfalfa hay-based diets containing approximately 40% calculated NDSC, 36% NDF, and 17.8% CP. The diets differed in that their NDSC came largely from hominy (starch) or from dried citrus pulp (sugars and soluble fiber). The citrus and hominy diets contained 4.7 and 2.5% soluble sugars, 15.0 and 26.4% starch, and 13.8 and 8.2% soluble fiber as a percentage of ration dry matter, respectively. The mean pH values of rumen samples did not differ for the two diets (citrus: 6.18, hominy: 6.24; $P = 0.52$). However, the shapes of the pH curves differed with time ($P < 0.05$) (Figure 6). The pH on the citrus diet declined more rapidly, and reached its lowest point more quickly than did the hominy diet. However, at 10 hours after feeding the pH of the hominy diet had not reached its lowest point. Further trials to compare the ruminal effects of different NDSC will provide information to allow more refined manipulation of ruminal pH through ration formulation.

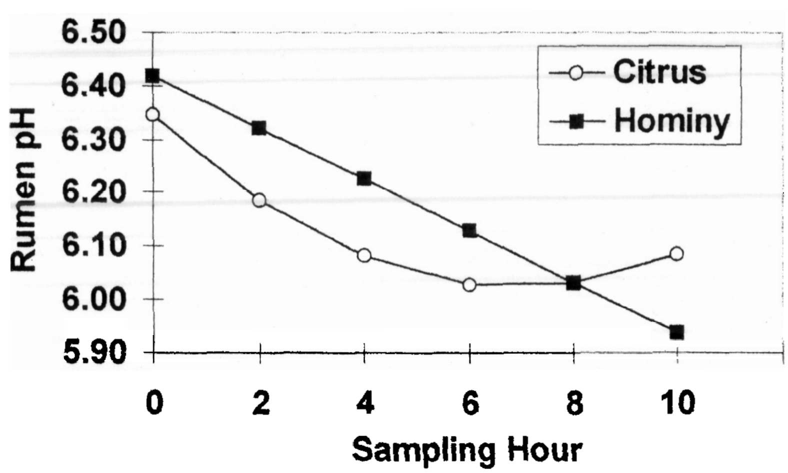


Figure 6. Regression curves of ruminal pH results for citrus and hominy rations. Hour 0 sample was taken immediately before feeding (Leiva Lopez et al., Accepted).

Table 3. Neutral detergent-soluble carbohydrate composition of feeds (% of dry matter). Values are given as average and (range).(M. B. Hall, 2000).*

Feed	Organic Acids	Sugars	Starch	Soluble Fiber
Alfalfa hay	6	10 (8 - 12)	3 (1 - 4)	16 (14 - 17)
Alfalfa silage	12 (10 - 14)	4 (1 - 7)	2 (0.7 – 4)	13 (12 - 13)
Almond hulls	8	33	1	17
Citrus pulp	9	26 (12 -40)	1	33 (25 - 44)
Corn grain	Less than 1	Less than 1	64 - 70	8 (6 - 11)
Corn silage	8	2 (0.3 - 5)	23 (14 - 30)	5 (3 - 7)
Whole cottonseed	----	6	1	9
Cottonseed hulls	----	----	Less than 1	4
Soybean meal (48%)	4	11 (11-12)	2 (1-2)	16 (14 - 19)
Soybean hulls	Less than 1	Less than 1	1	17
Sugar beet pulp	Less than 1	12	Less than 1	30
Timothy hay	4	9	Less than 1	6
Ground wheat	Less than 1	2	65	9
Wheat middlings	5	5	21	3

* Note: With the exception of citrus pulp (n=82), these values represent 1 to 6 analyses per feedstuff. They do not give a complete picture of the variation within and among feeds.

To minimize the risk of ruminal acidosis and optimize/maximize the provision of rapidly fermented carbohydrate in the ration of dairy cows a balance of NDSC types is recommended. Current recommendations for limits on quantities of specific concentrate feeds that could be included in rations indirectly dealt with this issue. On relatively low forage rations (40% of dry matter) work with field nutritionists suggest that target levels of NDSC of ~5% sugars, ~10% soluble fiber, and 19 - 20% starch, all as a percentage of dry matter appear to support good milk production and animal health. Feed and ration characteristics such as % forage, % eNDF, forage type, fermentation rate and extent of NDSC, etc. may all interact to determine appropriate levels for feeding the different types of NDSC. No clear-cut recommendations are available, however, observation of the animals as they interact with their ration will offer indication of appropriate feeding levels. Tabular values for some of the NDSC fractions in feeds are in Table 3.

Buffers

Dietary buffers do not eliminate the root causes of ruminal acidosis, but they can help in its management. Sodium bicarbonate and sodium sesquicarbonate are two common buffers used in dairy cattle rations. Both have been shown to improve milk fat percentage and/or milk yield. A review of forty-one studies of sodium bicarbonate use in dairy cattle rations averaging 57% concentrate showed varying responses depending upon the base forage fed (Staples and Lough, 1989). When corn silage was the main forage, cows produced an average of 1.8 lb more milk and 0.22% higher milk fat with sodium bicarbonate supplementation. With grass/legume silage or hay, results were inconsistent. Cows fed cottonseed hull-based diets showed little production response to sodium bicarbonate feeding. Feeding sodium bicarbonate at a rate of 0.75% of ration dry matter is recommended for cattle suffering from heat stress (West, 1994).

Dietary buffers have been purported to work by increasing ruminal pH. Another theory for their action is that when buffers are fed, cattle increase their water intake (Russell and Chow, 1993). This increases the ruminal dilution rate which in turn increases the flow of liquid and undegraded starch from the rumen.

Feeding Regimen

An additional risk factor for ruminal acidosis is "slug feeding" of high concentrate rations. This relates to the quantity of readily fermented NDSC present in the rumen at any point in time. Rapid consumption of rations containing adequate fiber is not as likely to cause ruminal problems because the fiber slows intake, decreases meal size, dilutes the NDSC, and increases rumination and saliva production (Owens, et al., 1998). Various situations which can result in cattle consuming large quantities of concentrate at one time include: dose feeding of grain in bunk, parlor, or individual cow settings; inadequate bunk space/feed provision in which cows crowd the bunk and consume as much as they can as fast as they can; changes in intake patterns due to passing weather fronts; and irregularities in feed provision in which cows are left without feed for an extended period of time. Consider that withholding feed for 12 to 24 hours and then allowing animals access to 150% of the normal day's feed allotment is an experimental method for inducing ruminal acidosis (Owens, et al., 1998). Feeding multiple times per day is recommended. Yearling dairy heifers fed high grain diets twice per day went for a longer period without going off feed than did heifers fed once per day (Tremere, et al., 1968). In general, reducing meal size while providing sufficient amounts of feed are positive steps towards reducing the incidence of ruminal acidosis.

Heat Stress

Changes in a cow's behavior and acid-base balance during heat stress predispose her to ruminal acidosis. Heat stress alters a cow's acid-base balance. As a cow pants and exhales carbon dioxide, it appears that the total amount of buffering capacity within her system is decreased (Dale and Brody, 1954). In addition, changes in feeding behavior such as consuming feed in fewer meals (slug feeding) and decreased rumination may lead to decreases in ruminal pH even on rations containing adequate fiber. In a study that tested the effect of ambient temperature on rumen environment (Mishra, et al., 1970), lactating Holstein cows were fed high roughage or high concentrate diets at ambient temperatures of 65°F (cool) or 85°F (hot) with relative humidities of 50% and 85%, respectively. Ruminal pH was lower at the higher temperature and on the higher concentrate ration ($P < 0.01$) (Figure 7). There was an interaction of diet and temperature ($P < 0.01$). Ruminal ammonia and lactic acid concentrations were higher for the hot treatment ($P < 0.01$). Other studies have reported decreased ruminal pH at hotter vs. cooler ambient temperatures (Niles, et al., 1998; Bandaranayaka and Holmes, 1976). Ruminal changes appear to be responses to ambient, not ruminal temperatures (Gengler, et al., 1970).

The most effective management for reducing the impact of heat stress on ruminal pH is to cool the cows. Fans, sprinklers, misters, cooling ponds, or shade can be used in cooling systems. A recent University of Florida study suggests that shade alone may be insufficient to decrease heat stress in lactating Holstein cows. Cows housed in a freestall barn were provided with shade, but no other cooling. The animals exhibited signs of heat stress including panting, elevated body temperatures, and increased respiration rates (A. Akinyode, J. P. Jennings, and M. B. Hall, unpublished).

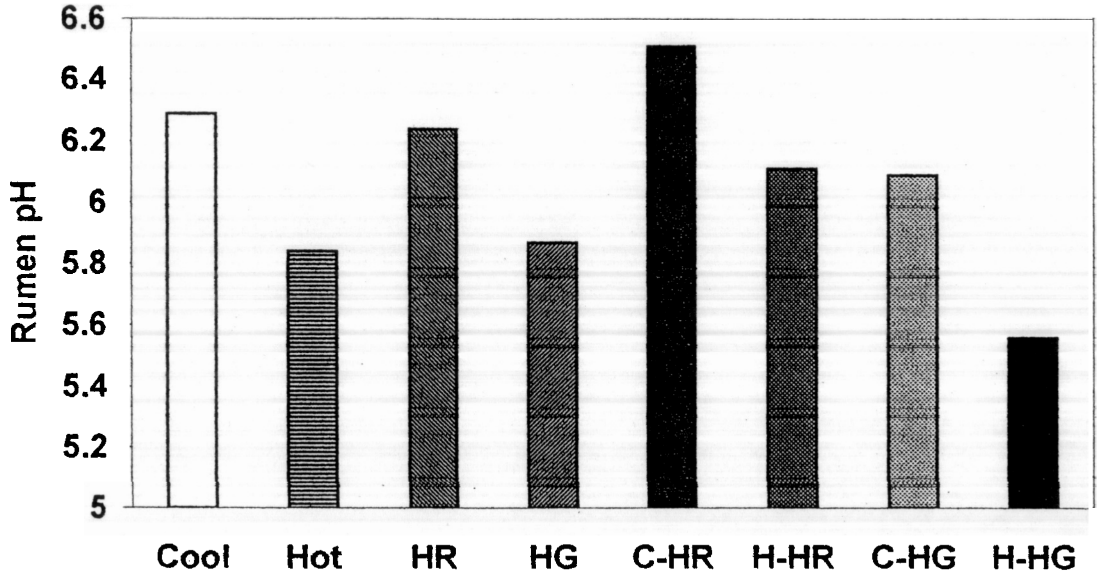


Figure 7. Ruminal pH changes with ambient temperature and diet (Mishra, et al., 1970). Cool (C) = 65°F ambient temperature, Hot (H) = 85°F ambient temperature, HR = high roughage diet, HG = high grain diet.

The common practice of adding more concentrate to rations in summer is not well advised. The rationale for decreasing forage and increasing grain during heat stress is to meet animal energy demands in the face of decreasing dry matter intake. If, as in the Missouri study, feeding more concentrate further depresses ruminal pH, little may be gained, and more may be lost by compromising the cow's health. Fiber should be provided at levels to meet animal requirements under all conditions. If the ration is palatable and contains appropriate levels of fiber and NDSC, further altering the diet for heat stress may be counterproductive.

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