Forage: How Much do Dairy Cows need in a Time of Scarcity?

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▪ Take Home Message

Lack of available good quality forages may prompt some producers to reduce the proportion of forage in the diet. It is possible to maintain high levels of production and animal health with low forage diets, however a higher level of management is required to be successful.

Much more care must be taken in formulating low forage diets, particularly with barley diets. To prevent ruminal acidosis, starch content of the diet should not exceed 33%. In most cases, this corresponds to 21 to 23% forage NDF. Lower levels of forage fiber can be fed, but starch content must also be adjusted downward. Maintaining adequate forage particle size is critical in low forage diets.

▪ Introduction

Dairy cows need to consume high-energy diets in order to meet the increasing demands placed on them to produce large quantities of milk. Consequently, diets fed to high producing cows tend to be low in fiber, high in starch, and contain relatively short particles. However, it is critical to balance the need for high-energy diets with the need to supply adequate fiber, in a form that is physically effective. Physically effective fiber stimulates the cow to chew and produce the buffers that neutralize the acids produced during fermentation of feed. In order for cows to achieve their genetic potential for milk production and remain healthy, it is critical that the rumen environment be kept healthy. When the rumen becomes dysfunctional, feed digestion is impaired and cows become susceptible to a range of metabolic diseases.

The drought experienced in many parts of Western Canada this past year has lead to high cost forages, as well as a general shortage of good quality forages.

Given the need for fiber in dairy cows diets, there is a need to question “how much forage is necessary”. This paper addresses the minimum fiber requirements of dairy cows, with an emphasis on cows fed barley grain.

▪ Maintaining a “Healthy” Rumen Environment

The rumen is essentially a fermentation chamber in which the resident microbial population helps to digest the diet. The partially fermented food and the microorganisms then pass out of the rumen, into the small intestine. Digestion of food in the rumen occurs by a combination of microbial fermentation and physical breakdown during regurgitation of the food by rumination. Microbial attack is carried out by a mixed population of bacteria, ciliate protozoa and a small number of anaerobic fungi. The products of microbial fermentation, mainly volatile fatty acids (VFA) and microbial protein, are available for absorption by the cow. Volatile fatty acids can supply up to 80% of the animal's energy requirement, while microbial protein leaving the rumen can account for between 50 and 90% of the protein entering the small intestine

The rumen is buffered over a range of pH 5.7 to 7.3 by phosphate and bicarbonate from saliva and bicarbonate produced during rumen fermentation. Rumen microbes are well adapted to these conditions and their specific growth requirements reflect the availability and types of nutrients present in the feed.

Keeping the rumen healthy and in balance means that both fiber digestion and intake will be maximized. Diets that are rapidly fermented in the rumen lead to rapid production of VFA, which can exceed the buffering capacity of the cows leading to a decline in rumen pH. When this happens, cows are at high risk for subclinical ruminal acidosis. Maintaining a high rumen pH is the central issue in maintaining healthy rumen function of dairy cows.

▪ Subclinical Ruminal Acidosis

Subclinical ruminal acidosis occurs when the production of VFA in the rumen exceeds the ability of the system to remove or neutralize the acids produced (Allen 1997). During subclinical ruminal acidosis, the pH in the rumen declines below optimum for fiber digestion by the rumen bacteria, but remains higher than for clinical acidosis. A pH below 5.8, but above 5.0, is often used to indicate subclinical ruminal acidosis in ruminally cannulated dairy cows. Subclinical acidosis is not to be confused with lactic acidosis -- lactic acid concentration in the rumen does not usually exceed 1 m*M* during subclinical acidosis.

We have conducted many research studies to measure rumen pH in cows fed a range of diets. Typically, ruminal pH is high before the morning feeding because extensive rumination and limited feed intake occur at night. After feeding, the pH drops and the extent of this decline depends upon the size and fermentability of the meal. An example of mean pH profiles for two groups of cows fed barley-based diets is shown in Fig. 1.

Many research trials report mean ruminal pH for a group of cows fed a particular diet. However, it is important to realize that mean pH does not reflect the extent of variation in pH among cows, or the extent of diurnal fluctuations in rumen pH for individual cows. There is considerable variation in ruminal pH among animals fed the same diet. Some animals experience prolonged periods of low pH, while pH remains consistently high in other cows. Within most herds a portion of the cows will occasionally experience ruminal acidosis particularly when cows are fed for maximum production. The goal is to minimize the number of cows affected, and to minimize the time each day that pH drops below 5.8. In our research studies using cannulated cows, cows are considered to be experiencing ruminal acidosis if rumen pH remains below 5.8 for more than 5 consecutive hours per day.

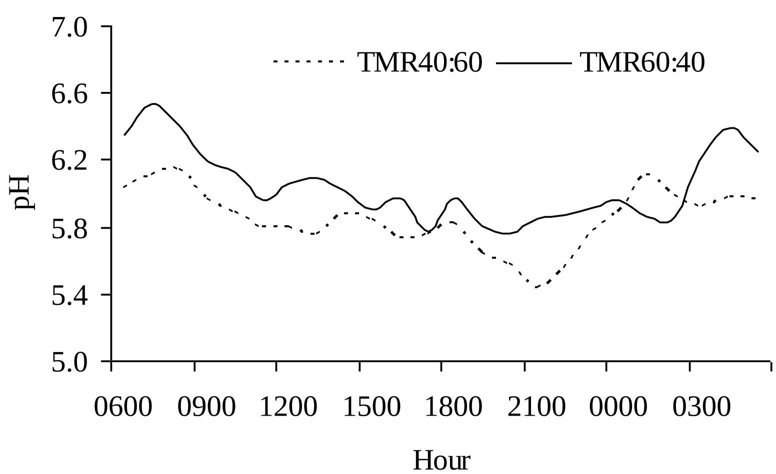

Fig.1 Mean rumen pH profiles for dairy cows fed a TMR consisting of 40% forage (16.8% forage NDF, 28.3% total NDF, 34.8% starch) or 60% forage (25.2% forage NDF, 32.2% total NDF, 27.7% starch) on a dry matter basis. Mean pH was 5.84 and 5.98, respectively. Cows were fed twice daily at 800 and 1500 h (Maekawa at al. 2002).

Signs of Subclinical Ruminal Acidosis

Subclinical ruminal acidosis is difficult to judge in the field. Signs of acidosis are subtle because, in many cases, the cow remains alert, mobile, and consumes feed. Some signs of subclinical ruminal acidosis are as follows.

- Milk fat and milk protein test inversions. Individual cows can have milk protein tests that are higher than milk fat tests. Significant inversions occur when more than 10% of the cows have milk fat tests that are 0.4 points or more lower than milk fat tests (for example, 3.2% protein and 2.7% fat). Another inversion indicator is any cow that is one full point below the herd average (for example, cows below 2.5% if the herd averages 3.5% fat).
- Loose manure. If manure excretions are watery or fluid, physically effective fiber may be lacking in the diet. Manure should stack up 4 to 5 cm in depth.
- Lack of rumination. At resting times (when cows are not eating or being milked), 40% of the cows should be ruminating at any one time (Fig. 2).
- Eating of soil, bedding, or wood. When cows are short of fiber, they may develop depraved or unusual appetites.
- Lameness. Cows with sore feet may have experienced rumen acidosis which could be related to a lack of physically effective fiber in the diet. However, other factors can also cause these symptoms. Presence of a white line or a hoof ridge can indicate rumen acidosis occurred (the hoof grows about 5 mm per month, so an acidosis insult only shows up 2 to 3 months afterwards).
- Variable dry matter intake. Cows exhibiting wide swings and variations in dry matter intake and milk production may be experiencing acidosis (Fig. 3). These variations are usually much greater for individuals than for the herd as a whole.

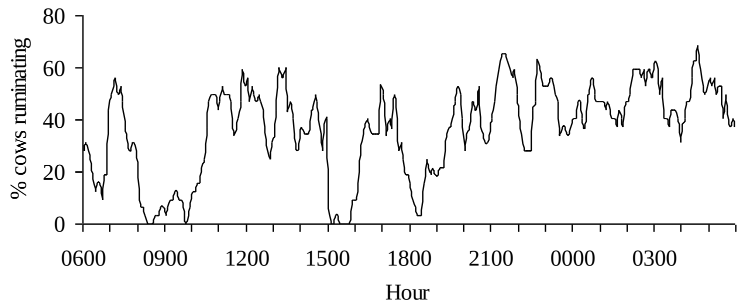

Fig. 2. Proportion of cows ruminating (Maekawa et al. 2002). On average, 40% of the cows were ruminating at any one time when observed during the daytime between feedings (1000 to 1500 h) or during the nighttime (1900 to 0700 h).

Consequences of Sub-Clinical Ruminal Acidosis

Cows that experience subclinical ruminal acidosis reduce their feed intake and become susceptible to a range of metabolic disorders. Also, acidosis has been implicated in the increased incidence of lameness (Nocek 1997), however the mechanism by which diet causes laminitis is not completely understood. In addition to the obvious financial losses attributed to health problems caused by subclinical ruminal acidosis, feed costs increase due to poor fiber digestion and lower feed efficiency. Cows suffering from acidosis have an increased amount of undigested feed in the manure due to low ruminal fiber digestion.

Studies conducted at the Lethbridge Research Centre using cannulated cows indicate a substantial decline in fiber digestion when cows experience subclinical ruminal acidosis. Ruminal NDF digestion declined from 51.8% for cows with a mean ruminal pH of 6.4 to 44.1% for cows with a mean ruminal pH of 5.8. This represents a 17% loss in potential fiber digestion and is equivalent to a loss of 2.5 kg/d of milk produced.

Sub-clinical ruminal acidosis can also reduce feed intake due to both short-term and long-term effects. The long-term effects on intake are mediated through a decrease in fiber digestion. Because sub-clinical ruminal acidosis decreases the rate of fiber digestion, the “fill effect” of the forage is increased, and intake is subsequently decreased. Furthermore, high production of fermentation endproducts increases the effects of ruminal osmolality on the satiety centers in the brain, thereby decreasing intake to protect from over-consumption of highly fermentable feed. Low ruminal pH can also have short-term effects on dry matter intake that cause erratic intake patterns. When ruminal pH is low, the cow decreases her intake in an attempt to limit the production of fermentation acids and restore pH conditions to a “comfortable” level. Once the pH is restored, the cow then resumes a high level of feed intake which leads once again to excessive production of acids, causing the cycle to repeat. An example of this cyclical effect is presented in Fig. 3. Although these data are for a feedlot steer, we have observed a similar phenomenon in dairy cows. Variation in day-to-day intake is undesirable in terms of stabilizing the rumen ecosystem.

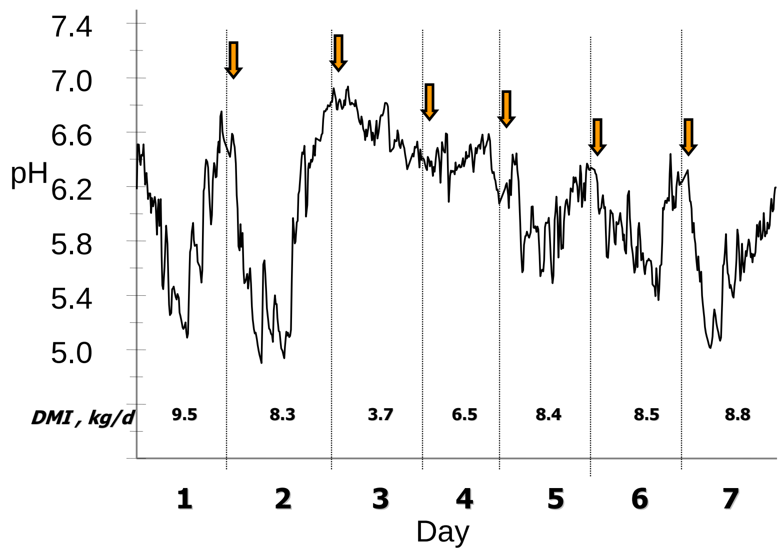

Fig.3. Rumen pH and dry matter intake of a feedlot steer fed once daily measured for 7-d. Arrows indicate the time of feeding. The graph illustrates the cyclical effect of rumen pH on feed intake.

■ Preventing Subclinical Ruminal Acidosis Through Nutrition

Diets that minimize ruminal acidosis are formulated to balance the production of fermentation acids with the neutralization and removal of these acids from the rumen. Therefore, an understanding of these factors is necessary for a discussion of minimum fiber requirements.

Chewing Activity

Saliva secretion increases when cows chew during eating and ruminating, thus diets that increase chewing time increase the buffering capacity within the rumen. Because of its effects on salivary secretion, chewing time has been measured as a indirect indication of the potential of the diet to maintain high rumen pH. The dairy cow typically spends 3 to 8 h/d eating and 6 to 9 h/d ruminating. Dietary factors that affect time spent chewing are primarily 1) the fiber content of the diet, and 2) the particle size of the diet.

Fiber content of the diet Fiber content of the diet can be manipulated to increase chewing time and, consequently, salivary secretion. Increasing the proportion of long forage particles in the diet increases the time required for chewing, as shown in Table 1. In general, chewing time increases about 2.5 to 3 h/d for every 1 kg/d increase in NDF intake or 0.5 to 1.5 h/d for every 1 kg/d increase in forage NDF.

Table 1. Chewing activity of as affected by proportion (% of DM) of forage in the diet.

Item	Yang et al. 2001			Beauchemin et al. 1991		
Forage (%)	**35**	**65**		**42**	**58**	**74**
NDF intake, kg/d	6.69[b]	7.47[a]		7.0	7.5	7.7
NDF-forage intake, kg/d	3.19[b]	4.64[a]		3.07	4.73	6.25
Eating, h/d	4.0[b]	4.6[a]		6.1	6.4	7.5
Ruminating, h/d	6.8[b]	8.0[a]		6.7	7.0	7.4
Total chewing, h/d	10.7[b]	12.6[a]		12.8	13.4	14.8
Salivary secretion (est.), L/d	218	232		233	237	247
Mean ruminal pH	6.04	6.06		5.63	5.78	6.08
pH < 5.8*, h/d	5.9	6.1		6.7	4.5	0.77

* Values for Beauchemin et al. are pH < 6.0.
[a,b] Within a study means with different letters differ ($P < 0.05$).

Particle size Increasing the particle size of forage also has a significant effect on increasing chewing time, but only if diets contain low levels of forage fiber or when the particle size of the TMR is fine. For example, Krause et al. (2002) increased the particle size of alfalfa silage and increased chewing by 4.3 h/d (Table 2). In that study, the original alfalfa silage was chopped very fine. In contrast, the forage used by Yang et al. (2001) was a medium chop length, and increasing its particle size only increased chewing time by 0.6 h/d. In another study, we used fine and coarsely chopped alfalfa silage in diets containing less than adequate or adequate NDF from forage (12 vs 22% of dietary DM) (Beauchemin et al. 1994). Feeding coarsely chopped silage increased rumination time of cows fed the low fiber diet, but had no effect on cows fed the adequate fiber diet.

Table 2. Chewing activity of dairy cows as affected by particle length of forage.

Item	Krause et al. 2002		Yang et al. 2001	
	Short	**Long**	**Medium**	**Long**
Eating, h/d	4.0	5.0	4.0[b]	4.5[a]
Ruminating, h/d	4.8	7.8	7.3	7.5
Total chewing, h/d	8.7	13.0	11.4[d]	12.0[c]
Salivary secretion (est.), L/d	204	235	223	228
Mean ruminal pH	5.90	6.07	5.99	6.09
pH < 5.8, h/d	9.3	5.5	7.0	5.0
Mean lowest pH	5.59	5.73	5.46	5.47

[a,b] Within a study means with different letters differ ($P < 0.05$).
[c,d] Within a study means with different letters differ ($P < 0.10$).

Salivary Secretion

The increase in saliva output due to increased chewing is not as great as often assumed (Table 1 and 2). This is because increasing eating and ruminating time decreases resting time, and the accompanying resting saliva secretion. Assuming a salivary secretion rate of 99 ml/min during resting and 217 ml/min during chewing (Maekawa et al. 2002), the increase in total salivary secretion due to 1 h/d more chewing is about 7 L. The buffering capacity supplied by the additional saliva would adequately buffer the digestion of about 0.5 kg of ground barley. Thus, the net effect of this incremental saliva production on mean ruminal pH is relatively small. However, an increase in saliva secretion, particularly if secreted during eating, can help reduce the extent to which pH drops below 5.8 following meals, even though mean rumen pH is not greatly affected. In addition, if the increase in chewing time is accompanied by a reduction in starch intake due to increased intake of fiber (as in Table 1), there can be a substantial effect on ruminal pH. In that case, the total amount of fermentation acids produced is lower, and more importantly, the rate of fermentation acids produced would be considerably slower and more in tune with the constant output of salivary secretion during the day.

Fermentability of Feed

The quantity of organic matter fermented in the rumen drives VFA production. Furthermore, it is the rate of digestion that causes diurnal fluctuations in pH. For example, Krause et al. (2002) compared the effects of feeding high moisture shelled corn to feeding dry, cracked shelled corn to dairy cows (Fig. 4). Even though particle size of the forage was coarse, and considered adequate, rumen pH was lower for cows fed the high moisture grain because of its higher fermentability. A similar effect was observed between coarsely rolled barley and finely rolled barley (Yang et al. 2000). It is critical to balance the rate of fermentability of carbohydrates with the ability of the diet to stimulate buffering through salivary secretion. Diets with higher fermentable carbohydrate sources require a higher minimum level of forage fiber to reduce the risk of acidosis.

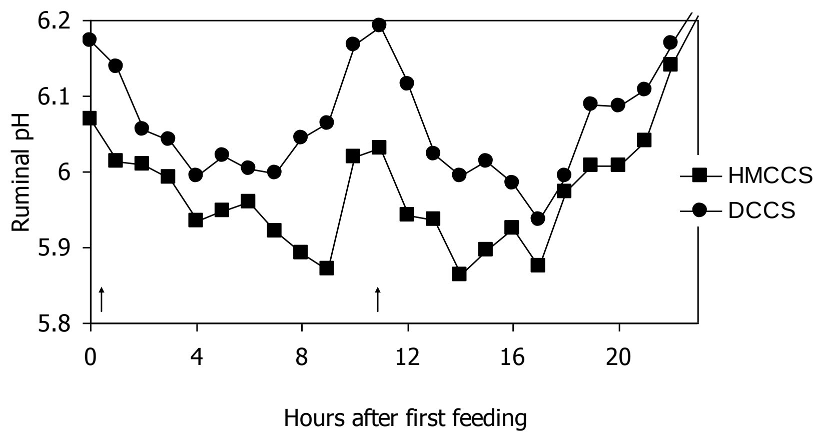

Fig. 4. Ruminal pH of dairy cows fed high moisture corn (HMC) vs cracked shelled corn (DC). The forage was coarsely chopped (CS) alfalfa silage (Krause et al. 2002).

▪ How much Fiber is Required?

The most recent NRC (2001) recommendations for minimum concentrations of total and forage fiber in dairy cow diets are in Table 3. These recommendations are based on diets that contain alfalfa or corn silage as the predominant forage and dry ground corn grain as the predominant starch source. The NRC recommended minimum level of NDF in the diet is 25%, with 75% of the NDF from forage sources (i.e., 19% NDF from forages). The amount of NDF from forage sources can be decreased to as low at 15%, but total dietary NDF should be increased and dietary nonfiber carbohydrates (NFC) should be lowered to compensate. Nonfiber carbohydrates are calculated by difference: 100 – (% NDF + % crude protein + % fat + % ash - % NDFIP) (where NDFIP is the proportion of crude protein in the NDF fraction, % of DM). The only way to decrease NDF from forages and increase total dietary NDF is to use high fiber concentrate feeds. It is important to understand that these recommendations are for cows fed total mixed diets and for forages of adequate particle size. Diets with small particle size, diets not fed as a total mixed ration, or diets based on starch sources with higher ruminal availability than corn, require higher minimal concentrations of NDF.

Table 3. Recommended minimum concentrations (% of dry matter) of total and forage NDF for corn grain based diets (NRC 2001).

Minimum Forage NDF	Minimum dietary NDF	Maximum dietary NFC[1]	Minimum dietary ADF
19	25	44	17
18	27	42	18
17	29	40	19
16	31	38	20
15	33	36	21

[1] Nonfiber carbohydrates (NFC) are calculated by differences as 100 – (% NDF + % CP + % fat + % ash - % NDFIP)

Thus, the NRC recommendations for fiber need to be adjusted for cows fed barley grain. The maximum dietary NFC values in Table 1 are too high for barley-based diets, because in barley diets, about 87 to 90% of NFC is starch Thus, this table would result in diets containing as high as 39% starch, which far exceeds the maximum desirable level for starch in barley diets. Starch from barley is more rapidly digested in the rumen than is starch from corn grain. Thus, when fed the same level of forage fiber in the diet, or the same level of dietary starch, cows fed barley-based diets are at higher risk for ruminal acidosis than cows fed corn-based diets. For diets containing 22% NDF from forages, we observed that ruminal pH was about 0.2 units lower for cows fed barley compared to corn grain (Yang et al. 1997).

Assuming that particle size of forages is not a limiting factor, then the minimum level of forage fiber required in barley diets to prevent ruminal acidosis is 21 to 23% NDF, depending upon the starch content of the diet. The important concept is that the minimum fiber requirement depends on the fermentability of the diet. For diets containing barley as the predominant grain, the maximum starch content of the diet should be 33% (38% NFC) and dietary NDF content should be greater than 32%.

Unfortunately, many feed evaluation laboratories do not measure starch. Mean starch content of some feeds measured at the Lethbridge Research Centre is given in Table 4. Starch content of feeds, especially cereal silage and corn silage, can vary from year to year, thus using tabular values can underestimate the starch content of the diet, and thus underestimate the risk of acidosis.

Table 4. NDF and starch content of some feeds used in Western Canada (% DM basis).

Feeds	NDF			Starch	
	Mean	**Range**		**Mean**	**Range**
Forages					
Alfalfa hay	35	26 – 50		2	1 – 3
Alfalfa silage	37	26 – 50		2	1 – 3
Barley silage	48	40 – 60		20	7 - 30
Corn silage	49	35 – 60		20	7 - 30
Concentrates					
Barley grain	21	17 – 26		56	52 - 60
Canola meal[1]	27	24 – 29		2	1 - 3
Corn grain	9.5	7 – 12		64	58 - 68
Soybean meal[1]	9.8	4 – 15		2	1 - 3

[1]regular and heat-treated

It is possible to reduce the amount of forage fiber in barley-based diets below the recommended minimum of 21%; we have successfully fed diets containing only 12% NDF from forage. Similarly, in many parts of the U.S. high-fiber byproducts are fed and diets often contain < 17% NDF from forage (Mary Beth Hall, personal communication). However, in low forage diets it is extremely important to ensure that the maximum starch content is not exceeded. In fact, when the amount of forage in the diet supplies less than the recommended minimum level of NDF from forages, starch content of the diet should be reduced to below the maximum threshold value of 33%. In barley-based diets formulated using cereal silages or corn silage, the maximum starch content of the diet is usually exceeded if the diet contains more than 35% barley grain (about 7.5 to 8.0 kg/d). A higher proportion of barley grain can be fed when grass or legume forages are fed, or when cereal silages are low in grain content, because these forages are lower in starch. High-fiber concentrate feeds like beet pulp, soy hulls, corn gluten feed, grain screenings, and dehydrated alfalfa meal can replace some of the barley grain in low forage diets, so that the starch level is kept under control.

The composition of example rations based on barley grain is presented in Table 5. These rations contain barley grain, protein supplements (provided to attain 18% crude protein and 40% undegraded intake protein), protected fat (total of 5% fat), and forages (1/3 barley silage, 1/3 corn silage, 1/3 alfalfa haylage). In this table**,** diets containing 17 to 21% forage-NDF would exceed the recommended maximum starch level and are expected to increase the risk of acidosis. These lower forage-NDF diets would be recommended only if the starch content was reduced.

Table 5. Expected carbohydrate concentrations in barley-based diets. Composition of ingredients is given in Table 4. Numbers in bold represent the recommended limit.

Item	Forage-NDF (% DM)							
	17	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Risk of acidosis	**very high**	**very high**	**high**	**med. to high**	**med .**	**low to med**	**low**	**low**
Forage (% of DMI)	38.3	41.0	42.6	45.1	47.1	49.3	51.9	53.9
NE_L, Mcal/kg	1.77	1.75	1.74	1.73	1.71	1.70	1.69	1.67
NDF (% of DMI)	29.1	29.7	30.1	30.7	31.2	31.7	**32.3**	32.8
NFC (% of DMI)	42.4	41.6	41.1	40.3	39.7	39.0	**38.2**	37.6
Starch (% of DMI)	38.3	37.3	36.7	35.8	35.1	34.3	**33.3**	32.6

▪ Physically Effective Fiber

Minimum fiber recommendations assume that particle size of forages is adequate. However, particle size of feeds can have a big impact on the risk of acidosis, particularly when diets are low in forage. When particle size of forages is fine, the minimum amount of fiber required in the diet to prevent acidosis must be increased.

The term effective fiber was proposed as a method of describing the potential of individual feeds to maintain rumen pH (Mertens 1992). Effective NDF (eNDF) is measured by assessing of the ability of a feed to replace forage in a ration so that milk fat of the cows fed that particular feed is maintained (Mertens 1997). In some models of feed formulation, including the Cornell Net Carbohydrate and Protein Synthesis model (Pitt et al. 1996), the Cornell Penn Minor Dairy model, and the NRC beef cattle model, the eNDF content of the diet is used to predict ruminal pH. However, our research indicates that these predictions are not very reliable.

Recently, the term physically effective (pe) NDF (peNDF) was introduced (Mertens 1997) to refine the concept of effectiveness of fiber. Physically effective fiber is an indication of the potential of a feed to stimulate chewing. However, measuring chewing time is labor intensive and not practical for many feeds. Thus, the alternative is to measure particle size. The pe factor can be measured as the sum of the proportion of material retained on the 2 sieves (19 and 8 mm) of the Penn State Particle Separator. We have observed that the mean pe factor of barley silage is 63% (ranging from 40 to 88%), or 63% of the barley silage is retained by the sieves. The peNDF is calculated by multiplying the NDF content by the pe factor.

To evaluate the relationship between peNDF intake and ruminal pH we used data from two studies (Yang et al. 2001, 2002). The pe factors for the forages ranged from 49.5% (very fine) to 90% (very coarse). An inverse relationship (r = -0.55; $P < 0.05$) was observed between peNDF intake and acidosis, measured as the depression (area) in pH below 5.8. This relationship indicates that that greater the peNDF intake of the cow, the lower the risk of acidosis.

The bottomline is that physically effective fiber plays a significant role in reducing the risk of acidosis. When rolled barley is the predominant grain in a total mixed diet, a minimum pe factor of 40% is required for the total mixed ration, because much of the grain is captured on the middle sieve of the Penn State Separator. A maximum of 8% of the total mixed ration should be retained on the top sieve to reduce the potential for sorting. It is important to determine the pe factors of individual forages as well. Silages with a pe factor greater than 75% are considered coarse. Silages with a pe factor less than 60% are considered to be fine, and are not recommended in low forage diets.

The minimum required level of physically effective fiber also depends on the other risk factors. In particular, the level of starch in the diet and feeding management practices can significantly affect the relationship between fiber and ruminal pH. Thus, increasing the physically effective fiber content of the diet can increase chewing time, but this does not guarantee an increase in ruminal pH if the diet exceeds the maximum limit for starch.

■ Conclusion

Lack of available good quality forages may prompt some producers to reduce the proportion of forage in the diet. High quality forages give producers more flexibility in the diet and help cushion against the risk of ruminal acidosis. It is possible to maintain high levels of production and animal health with low forage diets; however a higher level of management is required to be successful. Much more care must be taken in formulating low forage diets, particularly with barley diets. When barley grain is the predominant grain, starch content of the diet should not exceed 33% to prevent ruminal acidosis. In most cases this corresponds to a minimum level of forage fiber of 21 to 23% NDF. Lower levels of forage fiber can be fed, but starch content must also be adjusted. Maintaining adequate forage particle size is critical in low forage diets.

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