EFFECTIVE FIBER FOR DAIRY DIETS

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INTRODUCTION

Dairy cows require high energy diets to meet the increasing demands placed on them for high levels of milk production. High energy diets are rapidly fermented in the rumen because they are low in neutral detergent fiber (NDF), high in starch, and contain forages that are finely chopped and highly digestible. These types of diets increase the risk of ruminal acidosis, which can reduce profit margins. While it is critical to supply digestible energy, the need for energy must be balanced with the need for fiber in a form that is physically effective. Physically effective fiber helps prevent ruminal acidosis, promotes high milk production, and can improve feed conversion efficiency.

THE ROLE OF FIBER IN DAIRY DIETS

Long forage particles in the diet promote chewing and salivary secretion, which helps buffer the acids resulting from feed digestion. Thus, particle length of forages and the amount of forage fiber in the diet can have a significant impact on rumen pH through the provision of salivary buffers. In addition, long forage fiber creates a floating mat in the rumen, which stimulates reticuloruminal contractions. Without these mixing motions the rumen can become a stagnant pool, and removal of volatile fatty acids (VFA) via absorption and fluid passage from the rumen declines, thereby increasing the risk of acidosis. Fiber is more slowly digested than starch and sugar, so including fiber in the diet slows the rate of carbohydrate digestion in the rumen. Decreasing the rate of carbohydrate digestion reduces the rate of VFA production, thereby preventing large drops in rumen pH. Feeding long particle fiber can also shift the site of starch digestion from the rumen to the intestine, which reduces the potential for ruminal acidosis (Yang and Beauchemin 2006b).

EFFECTIVE FIBER (eNDF)

There are several ways of characterizing physical fiber, and it is important to understand the difference between these terms. The term effective fiber, measured as effective neutral detergent fiber (eNDF), is the total ability of a feed to replace forage in a ration, so that milk fat percentage is maintained (Mertens 1997). Thus, the eNDF value of a feed depends upon its particle length, buffering capacity, fermentation rate, and other inherent characteristics. The difficulty with this term is that there is no standardized method of assessment; assignment of eNDF values to feeds is arbitrary. Furthermore, recent understandings of milk fat synthesis have shown that numerous factors other than fiber affect milk fat content (Bauman et al. 2006). The term eNDF is used in early versions of the Cornell Net Carbohydrate and Protein System (CNCPS) model and the Cornell-Penn-Minor Dairy (CPM-Dairy) model, and in the 1996 beef NRC model.

PHYSICALLY EFFECTIVE FIBER (peNDF)

The term physically effective fiber was introduced to refine the concept of effective fiber (Mertens 1997). Physically effective fiber relates solely to the physical characteristics of a feed and is an indication of the potential of a feed to stimulate chewing. Thus, physically effective fiber differs from effective fiber in that physically effective fiber is narrowly defined in terms of chewing, whereas effective fiber encompasses more factors.

Mertens (1997) developed a system to assess the physical effectiveness of feeds based on chewing activity. A physical effectiveness factor (pef) is determined for a feed or diet by assessing its ability to stimulate chewing during eating or ruminating. The pef_C (i.e., determined by chewing time) is an index ranging from 0 to 1.0, and this factor is then multiplied by the NDF content to determine $peNDF_C$ of a feed or diet. The system uses long grass hay as a reference feed with a pef_C of 1.0 and the pef_C of other feeds are relative to this standard. For example, finely chopped alfalfa silage containing 42% NDF (DM basis) has a pef_C of 0.60, so its $peNDF_C$ content would be 25.2% (42% × 0.60).

A limitation to using chewing time to indicate the physical effectiveness of feeds is the need to rely on book values to adjust the values for individual feed samples. Thus, laboratory approaches to measuring physical effectiveness of feeds based on particle length have been developed. The pef values determined by sieving are based on the concept that long particles retained on sieves represent particles that require chewing. One limitation to this system is the many ways of measuring particle length of feeds.

USE OF THE PENN STATE PARTICLE SEPARATOR TO MEASURE PHYSICALLY EFFECTIVE FIBER

The Penn State Particle Separator (PSPS) is one method of measuring particle length of feeds that is gaining in popularity (Lammers et al. 1996). The physical effectiveness factor of a feed or TMR can be determined using the PSPS, which consists of two sieves (19- and 8-mm openings), and a collection pan. The pef_{2s} (the 2s denotes two sieves were used) of a feed is the total proportion of material (DM) retained on both sieves. Using the long corn silage in Table 1 as an example, 10.2% of corn silage DM was retained on the 19-mm screen and 61.3% of the DM was retained on the 8-mm screen, so pef_{2s} is 0.72 (ie., 0.102 + 0.613 = 0.72). That corn silage contained 49.3% NDF, so its $peNDF_{2s}$ is 35.5% (49.3% × 0.72).

The pef should be determined on fresh samples, with the pef expressed as a proportion of the total sample DM content retained on each sieve. This requires performing a DM analysis for the original sample and the material retained on each sieve. The correction for DM is important because moisture content of the sample affects the pef value (Kononoff et al. 2003). For example, the pef_{2s} of alfalfa haylage at 43% DM was 0.87 versus 0.77 at 100% DM. Similarly, the pef_{2s} of corn silage was 0.88 at 42% DM versus 0.65 at 100% DM. Physical effectiveness factors will be overestimated by up to 30% if not corrected for DM.

The PSPS now includes an additional third screen with 1.18-mm openings (Kononoff et al. 2003). Using three sieves results in higher pef_{3s} (3s denotes three sieves were used) values than when two sieves are used (Table 1). The advantage of using three sieves is the values are more closely in line with the values used in the current versions of CNCPS and CPM models. The peNDF values used in those models are based on sieving using a 1.18-mm screen.

The disadvantage of using three sieves is that the pef_{3s} values for forages with differing chop lengths are not very different, as shown in Table 1 for corn silage of various chop lengths. With two sieves, the pef_{2s} ranged from 0.41 to 0.72, but with three sieves the pef_{3s} ranged from 0.93 to 0.96, with no difference between long and medium chopped silages. Furthermore, rolled grains and pelleted supplements are trapped on the 1.18-mm sieve, thereby inflating the pef_{3s} values of TMR. For the TMRs in Table 1, which contained 45.8% corn silage (DM), the pef_{3s} of the grain would have had to be 0.84 to 0.92 to account for the pef_{3s} values obtained for the TMR, given the pef_{3s} values of the corn silages by themselves. Thus, pef_{3s} values overestimate the physical effectiveness of TMRs, especially the grain component. In contrast, when 2 sieves are used, there is only a small difference between using the TMR itself or the component forages to measure $peNDF_{2s}$, except when the TMR contains very coarse grains or large pellets. Although each system of measuring peNDF has its disadvantages, the PSPS with two sieves is the most useful of the systems available for measuring peNDF because it differentiates feeds based on particle length and it is correlated with chewing and rumen pH.

Table 1. Example of physically effective NDF (peNDF) values determined for some feeds using the Penn State Particle Separator with two (2s) or three sieves (3s) (Yang and Beauchemin 2006a).

Feed	Proportion of DM retained on each sieve				Physically effectiveness factor[1]		peNDF[2] (% of DM)	
	Top (19-mm)	Middle (8-mm)	Bottom (1.18 mm)	Pan	pef_{2s}	pef_{3s}	$peND_{2s}$	$peNDF_{3s}$
Corn silage								
Coarse	10.2	61.3	24.0	4.5	.72	.96	35.5	57.3
Medium	8.3	59.8	27.6	4.3	.68	.96	31.5	44.5
Fine	2.7	38.7	51.5	7.2	.41	.93	19.6	44.5
TMR containing corn silage								
Coarse	7.6	47.9	33.8	10.7	.56	.89	17.7	28.1
Medium	4.8	43.7	38.6	12.9	.49	.87	15.0	26.6
Fine	2.3	29.9	52.8	15.0	.32	.85	10.0	26.5

[1]Determined using the Penn State Particle Separator. pef_{2s} = determined using two sieves (19-, 8-mm); pef_{3s} = determined using three sieves (19-, 8-, 1.18-mm).
[2]peNDF = % NDF × pef

PREVENTING ACIDOSIS

Subacute Ruminal Acidosis

Diets that are rapidly fermented in the rumen lead to rapid production of VFA. When the rate of production of VFA exceeds the ability of the rumen environment to buffer, absorb, or remove the VFA, rumen pH drops causing subacute ruminal acidosis. Ruminal acidosis occurs when rumen pH drops below a threshold value. A threshold value between 5.5 to 5.8 is normally used to define ruminal acidosis depending upon the researchers and method of determining pH. We use pH < 5.8 to denote acidosis because cellulolytic ruminal bacteria cannot grow below 6.0 (Russell and Wilson 1996), causing a decrease in fiber digestion and feed efficiency (Calsamiglia et al. 2002). A typical pH profile for a dairy cow is shown in Fig. 1. Rumen pH changes throughout the day in relation to feeding with fluctuations of ±1.5 pH units. Subacute acidosis is not to be confused with acute acidosis, which is more common in feedlot cattle. Lactic acid rarely accumulates in the rumen fluid of dairy cows and, when lactic acid concentration does increase, the increase is often short lived.

Ruminal acidosis is a major problem for the North American dairy industry (Krause and Oetzel 2006) costing between $500 million to $1 billion a year (Donovan 1997). Stone (2004) calculated $400 to $475 lost income per cow per year due to ruminal acidosis because of decreased milk production. In one US study, one-third of the herds tested had an incidence rate of ruminal acidosis greater than 40% (Garrett et al. 1999). Subacute ruminal acidosis is implicated in the increased incidence of lameness, erratic intake patterns, body weight loss, diarrhea, reduced milk production, and higher feed costs due to reduced feed efficiency (Nocek 1997, Stone 1999). Low rumen pH can damage the surface of the rumen wall causing ulceration of the ruminal epithelium (Krause and Oetzel 2006). Once the ruminal epithelium is damaged, bacteria may leak into portal circulation, causing liver abscesses, and an inflammatory response (Gohzo et al. 2005).

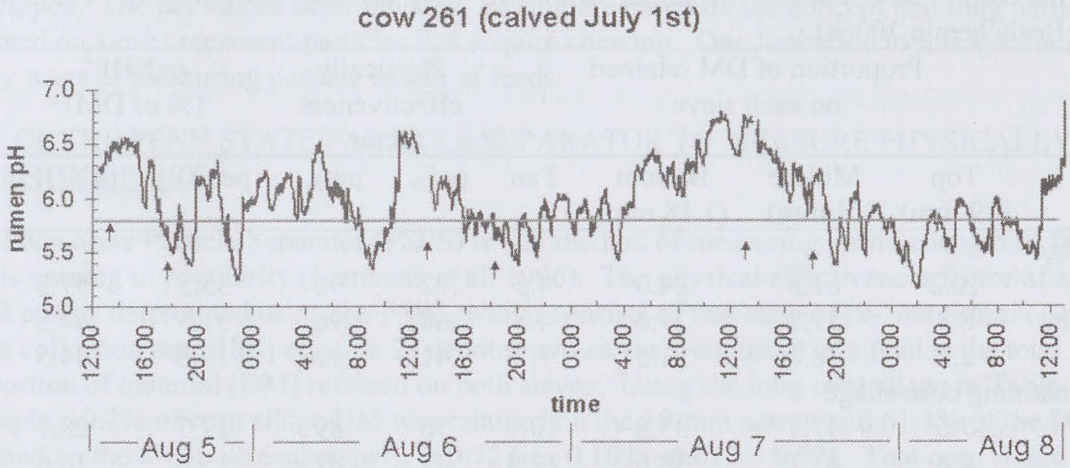

Fig. 1. Ruminal pH measured in a dairy cow over a 72 h period. Subacute ruminal acidosis (pH < 5.8) occurred for 6.4, 6.5 and 11.8 h/d and DMI was 16.0, 15.6 and 14.1 kg/d on Aug 5/6, 6/7 and 7/8, respectively. Arrows show feeding times at 1330 and 1600 h; the solid line indicates the ruminal acidosis threshold of pH 5.8.

Risk of Acidosis for Fresh Cows

Cows in early lactation are particularly vulnerable to ruminal acidosis. Garrett et al. (1999) reported that 19% of early lactation cows experienced ruminal acidosis while Krause and Oetzel (2006) reported that the occurrence of ruminal acidosis from 0 to 140 days in milk ranged between 12% and 30%. Gröhn and Bruss (1990) observed that the number of cases of ruminal acidosis was greatest during the first months after calving.

Abrupt changes in the composition of the diet and/or the amount of feed offered from day-to-day predisposes cows to ruminal acidosis. Thus, the drastic change in diet composition that occurs at parturition puts the fresh cow at risk. The "close-up" diet fed pre-partum is usually forage based, and at parturition, the cow is abruptly switched to a high grain diet. The absorption of VFA from the rumen occurs passively through papillae (finger-like projections) located on the rumen wall. These papillae increase gradually in length after cows are exposed to close-up diets which contain more grain than the far-off dry cow diets (Penner, Beauchemin, Mutsvangwa and Van Kessel, unpublished data). Increased surface area and absorptive capacity of the rumen protects the cow from VFAs accumulating in the rumen causing pH to drop. If the papillae have not attained their full potential size, fresh cows are susceptible to ruminal acidosis.

We studied the occurrence of acidosis pre- and post-calving using 14 ruminally cannulated primiparous cows fed a "close-up" diet, followed by a lactation diet containing adequate peNDF. Rumen pH was measured continuously before and after calving using a stand-alone system placed within each cow's rumen (Penner et al. 2006a). Mean ruminal pH dropped abruptly from an average of 6.32 before calving, to an average of 5.98 after calving (Table 1). The pH remained consistently low during the first 60 d after calving. Each day, pH was < 5.8 for about 6 to 9 h, with the greatest occurrence of acidosis at about 3 weeks after calving.

Table 1. The effect of day relative to parturition on mean ruminal acidosis in primiparous Holstein cows (Penner et al. 2006b).

	Day relative to parturition				
Variable	-5 to -1	1 to 5	17 to19	37 to 39	58 to 60
Minimum pH	5.74[a]	5.38[b]	5.37[b]	5.32[b]	5.37[b]
Mean pH	6.32[a]	5.96[b]	5.95[b]	5.96[b]	6.03[b]
Acidosis, h/d					
Total (pH < 5.8)	1.1[c]	7.3[ab]	9.0[a]	8.3[ab]	6.1[b]
Mild (pH < 5.8 but > 5.5)	0.9[c]	3.6[b]	5.4[a]	4.8[ab]	3.9[b]
Moderate (pH < 5.5 but > 5.2)	0.3[c]	2.4[ab]	3.2[a]	2.7[ab]	1.7[b]
Acute (pH < 5.2)	0.0[c]	1.4[a]	0.4[bc]	0.9[ab]	0.6[bc]

[abc] $P < 0.05$

<u>Risk for Acidosis Varies Among Cows</u>

The risk of acidosis is not equal for all cows, even for cows fed the same diet. Figure 2 shows the rumen pH profiles for two fresh cows fed the same diet. Ruminal pH in the cow with the "best" profile remained very high throughout the day, whereas the pH of the cow with the "worst" profile remained below pH 6.0 for the entire day. The factors that account for individual variation among cows are many, including DMI, eating rate, sorting of feed, salivation rate, rate of passage, and other aspects of cow physiology and behavior. The bottom line is that within most herds some cows will experience ruminal acidosis for some period of time if cows are fed for maximum production. The goal is to minimize the number of cows affected and the duration and intensity that individual cows experience low pH.

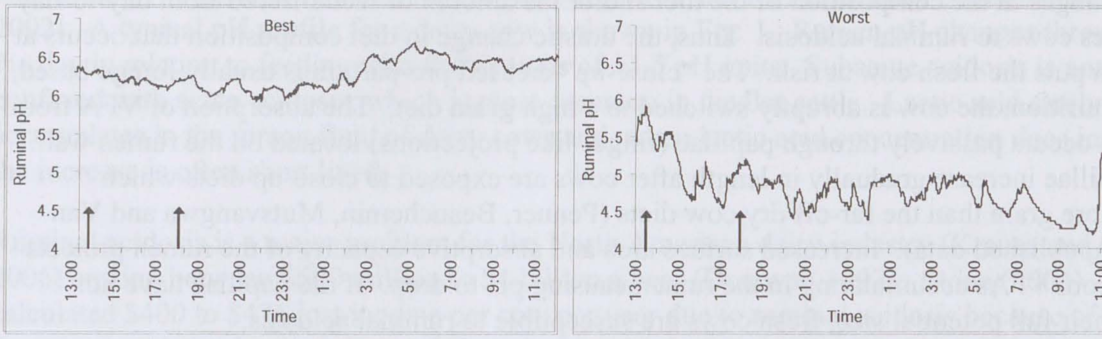

Fig. 2. Ruminal pH curves measured 5 days after calving in two cows (best and worst-case acidosis cows) fed the same lactation diet (Penner, Beauchemin and Mutsvangwa, unpublished data).

THE ROLE OF FIBER IN PREVENTING ACIDOSIS

Chewing Activity and Salivary Secretion

The dairy cow spends 2 to 6 h/d eating, 3 to 9 h/d ruminating, and a maximum of about 14 h/d chewing depending upon the diet (Fig. 3). Increasing the physically effective fiber content of the diet either by 1) increasing the NDF content (i.e., including more forage), or 2) increasing the chop length of forages increases chewing, with greatest increases in chewing for low fiber diets.

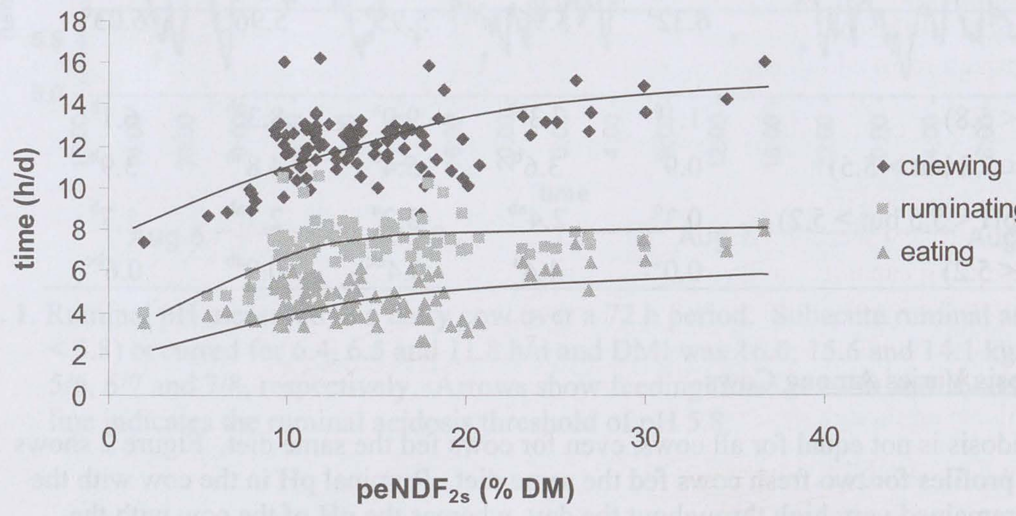

Fig 3. Relationship between physically effective fiber ($peNDF_{2s}$) content of the diet and chewing time. Each point represents a treatment mean summarized from 24 studies published in the literature.

Increasing the $peNDF_{2s}$ content of the diet increases chewing time and, consequently, salivary secretion. With diets low in peNDF, each additional kilogram of $peNDF_{2s}$ will increase chewing time by up to 7 h/d (Fig. 4). With diets containing adequate peNDF, each kilogram of $peNDF_{2s}$ promotes only 2 h/d of chewing. Thus, a small increase in the peNDF content of the diet can be very effective when diets are low in fiber.

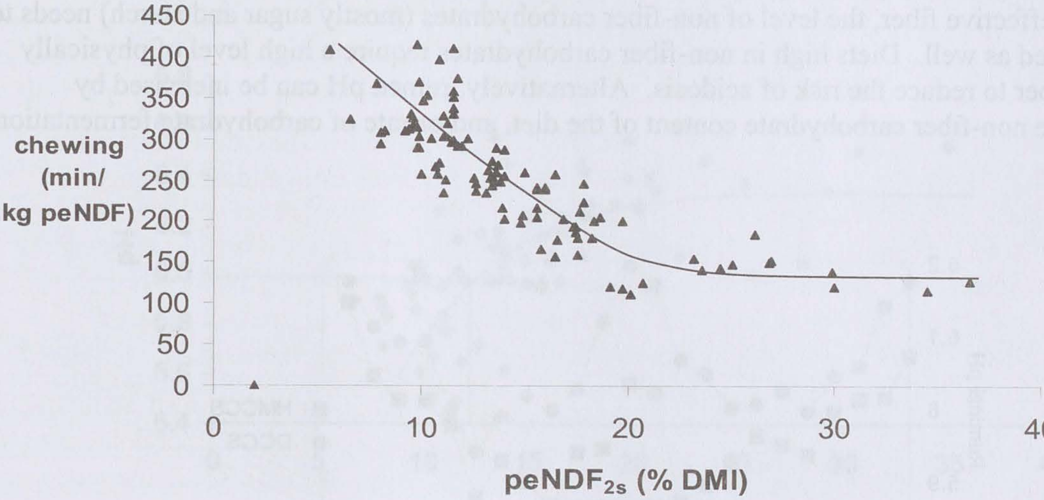

Fig. 4. Chewing time promoted by each kilogram of physically effective fiber for diets varying in physically effective fiber ($peNDF_{2s}$) content. Each point represents a treatment mean summarized from 24 studies published in the literature.

Increasing the peNDF content of the diet can increase chewing time, but the increase in saliva output due to increased chewing is not as great as often assumed. This is because the increased flow of saliva during chewing is accompanied by a decrease in resting saliva secretion. The net increase in total salivary secretion due to 1 h/d more chewing is about 7 L (Maekawa et al. 2002). 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 rumen 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.

Decreasing the Fermentability of the Diet

The quantity of feed fermented in the rumen drives VFA production, and rapidly digestible feeds such as grains and high quality forages, result in the rapid production of VFA. Increasing the physically effective fiber content of the diet slows the rate of fermentation, helping to synchronize the rate of VFA production with salivary secretion and the absorption of VFA from the rumen.

It is important to understand that the concept of physically effective fiber does not account for differences in fermentability of feeds, and does not predict differences in rumen pH due to fermentability of the diet. For example, Krause et al. (2002) compared the effects of feeding high moisture corn or dry cracked corn to dairy cows (Fig. 5). Even though particle size of the forage was coarse, rumen pH was lower for cows fed high moisture corn because of its higher fermentability. A similar effect was observed between coarsely rolled barley and finely rolled barley (Yang et al. 2000). Thus, at the same concentration of physically effective NDF, diets will be lower in rumen pH when they contain high levels of non-fiber carbohydrates, and/or carbohydrates that are rapidly digested. Thus, in addition to formulating diets on the basis of physically effective fiber, the level of non-fiber carbohydrates (mostly sugar and starch) needs to be considered as well. Diets high in non-fiber carbohydrates require a high level of physically effective fiber to reduce the risk of acidosis. Alternatively, rumen pH can be increased by reducing the non-fiber carbohydrate content of the diet, and/or rate of carbohydrate fermentation.

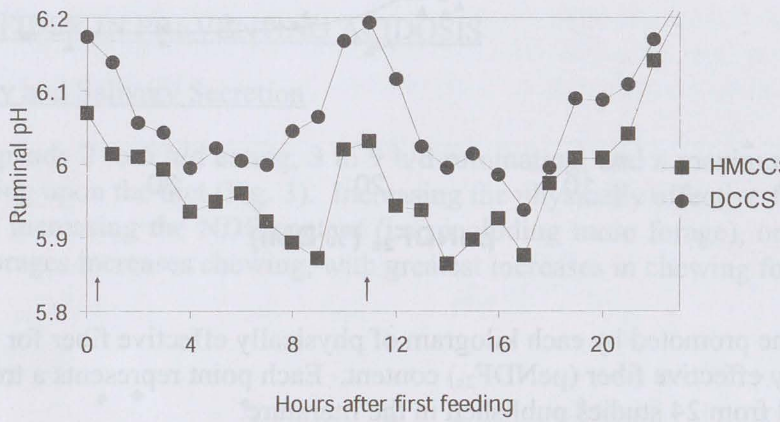

Fig. 5. Ruminal pH of dairy cows fed high moisture corn (HMC) versus cracked shelled corn (DC). The forage was coarsely chopped (CS) corn silage (Krause et al. 2002).

HOW MUCH PHYSICALLY EFFECTIVE FIBER IS NEEDED IN DAIRY RATIONS?

NRC (2001) recommends a minimum of 25% NDF in the diet, with 75% of this fiber coming from forage sources (i.e., 19% NDF from forages). The amount of NDF from forage sources can be decreased to as low at 15% if total dietary NDF is increased and the non-fiber carbohydrate levels are lowered from 44% to 36%. 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. When more highly fermentable sources of grain are used (e.g., barley, high moisture corn), we recommend a minimum of 21 to 23% NDF from forage sources and a maximum of 38% non-fiber carbohydrates.

Minimum fiber recommendations assume that the silages are coarsely chopped. When forage particle size is fine and diets are formulated to contain minimum levels of NDF, then intake of physically effective fiber will be less than required. In that case, intake of physically effective fiber can be increased by increasing the NDF content of the diet and/or by increasing the physically effectiveness (pef) of the forage.

The relationship between $peNDF_{2s}$ content of the diet and rumen pH is shown in Fig. 6. About 14% $peNDF_{2s}$ is required in the diet to maintain a mean pH of 6.0. Thus, for a diet formulated to supply the minimum NRC requirement of 25% NDF, the pef_{2s} of the TMR would need to be 0.56 (i.e., 14%/25% = 56% of the TMR captured on the two sieves of the PSPS). If 75% percent of the NDF is from forages, the pef_{2s} of the forage would need to be > 0.70. If three sieves are used with the PSPS, then a minimum of 19% $peNDF_{3s}$ is required (Zebeli et al. 2006).

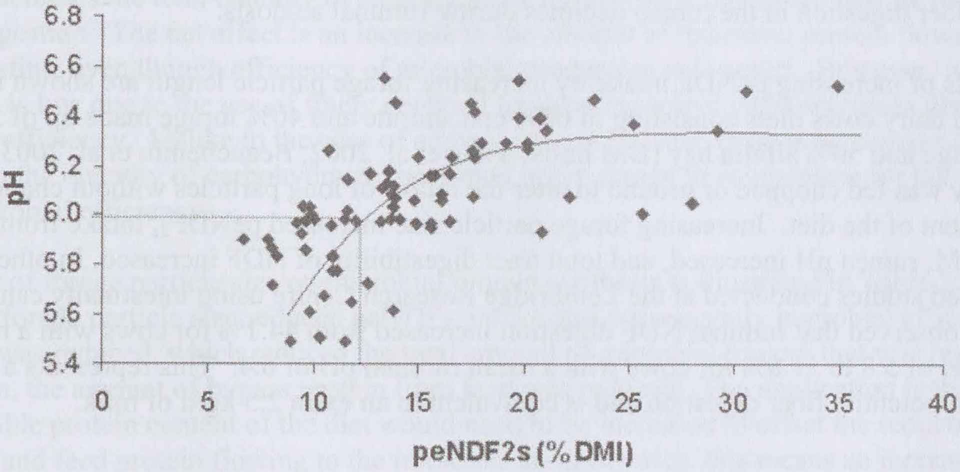

Fig. 6. Relationship between increasing the physically effective fiber ($peNDF_{2s}$) content of the diet and rumen pH. Each point represents a treatment mean summarized from 23 studies published in the literature.

In addition to providing adequate peNDF, good feedbunk management practices are critical aspects of preventing acidosis. In particular, limited bunk space, infrequent TMR push-up, high competition at the bunk, component feeding (feeding grains separately from forages), abrupt changes in diet composition, and variation in the amount of feed allocated from day-to-day, all increase the risk of acidosis. Furthermore, diets with excessive (> 15% of the DM on the 19-mm sieve) long forage particles can paradoxically increase the risk for acidosis. Cows can easily sort out and refuse to eat these long particles (Leonardi and Armentano 2003), thereby decreasing the amount of peNDF consumed.

The rumen pH values in Fig. 6 are means for groups of cows, and therefore don't reflect the variation in pH among cows, or the extent of diurnal fluctuations in rumen pH for individual cows. These recommendations are minimum values and do not include a margin of error to account for the variability among cows or the fermentability of the diet. As diets are formulated closer to the minimum level of physically effective fiber, a greater portion of the cows will experience ruminal acidosis. Formulating diets for the average cow is acceptable for cows in mid and late lactation, but diets for early lactation cows should be formulated above the minimum requirement because of their higher risk for acidosis. How far above the minimum depends on the other risk factors for acidosis, as well as the producer's tolerance for risk.

PHYSICALLY EFFECTIVE FIBER AND FEED UTILIZATION

Feed Conversion Efficiency

Increasing the peNDF content of the diet can increase the digestibility of nutrients in the digestive tract (Yang et al 2002) if rumen pH also increases above the acidosis threshold. An increase in digestibility leads to improved feed conversion efficiency and reduced feed costs. The effects of peNDF on improving feed digestibility are mainly due to effects on fiber digestibility, because fiber digestion in the rumen declines during ruminal acidosis.

The effects of increasing peNDF intake by increasing forage particle length are shown in Table 2. We fed dairy cows diets consisting of 60% concentrate and 40% forage made up of 50% alfalfa silage and 50% alfalfa hay (DM basis; Yang et al. 2002, Beauchemin et al. 2003). The alfalfa hay was fed chopped or ground to alter the intake of long particles without changing the NDF content of the diet. Increasing forage particle size increased $peNDF_{2s}$ intake from 10 to 15% of DM, rumen pH increased, and total tract digestibility of NDF increased. In other unpublished studies conducted at the Lethbridge Research Centre using intestinally cannulated cows, we observed that ruminal NDF digestion increased from 44.1% for cows with a mean ruminal pH of 5.8 to 51.8% for cows with a mean ruminal pH of 6.4. This represents a 17% increase in potential fiber digestion and is equivalent to an extra 2.5 kg/d of milk.

Table 2. Effects of forage particle size on digestion and protein metabolism (from Yang et al. 2002 and Beauchemin et al. 2003).

Item	Chopped hay	Ground hay
$peNDF_{2S}$ intake, % DMI	15.0 a	10.1 b
Total chewing time, h/d	12.1 a	10.4 b
Mean rumen pH	5.97	5.78
pH < 5.8, h/d	7.5 b	13.0 a
Ruminally fermentable organic matter (RFOM), kg/d	10.9	12.0
Ruminal NDF digestibility, % of intake	39.1	37.0
Total tract NDF digestibility, % of intake	51.1 a	41.7 b
Microbial CP, kg/d	1.71	1.41
Efficiency of microbial synthesis, g N/kg RFOM	24.9 a	18.2 b
Feed and endogenous CP (bypass protein), kg/d	2.01	1.89

a,b ($P < 0.05$)

Microbial Protein Synthesis

Low ruminal pH lowers the efficiency by which microbial protein is produced in the rumen (i.e., the amount of microbial protein produced per unit of carbohydrate digested in the rumen). A decrease in microbial efficiency will decrease the yield of microbial protein (g/d), unless more fermentable carbohydrate is supplied. Decreased microbial protein synthesis increases the need for supplemental feed protein in the diet.

Reduced peNDF intake of cattle can be due to low NDF content and/or the use of finely chopped forages. Decreased peNDF intake caused by increased feeding of grain (i.e., low NDF content of the diet) increases the total quantity of carbohydrates fermented in the rumen despite reductions in fiber digestion. The net effect is an increase in the amount of microbial protein flowing to the small intestine, even though efficiency of microbial production is lowered. However, when rumen pH is low due to the use of finely chopped forages, microbial yield decreases due to lower microbial efficiency. Unlike in the case of adding grain to the diet, there is no concomitant increase in the quantity of carbohydrates fermented in the rumen to compensate for the decrease in the microbial efficiency.

The effect of forage particle size on microbial protein synthesis is illustrated in Table 2. Reducing forage particle size reduced $peNDF_{2s}$ intake and consequently microbial efficiency synthesis was reduced, which reduced the total amount of microbial protein that was produced. In addition, the amount of bypass protein from feed was reduced. The implication is that the undegradable protein content of the diet would need to be increased to offset the reduction of microbial and feed protein flowing to the intestine. In most cases, this means an increase in feed costs.

CONCLUSION

The concept of physically effective fiber offers a means of balancing diets to promote healthy rumen function of dairy cows, which reduces the risk of acidosis and promotes improved feed conversion efficiency. Other factors that affect rumen pH, such as the fermentability of the diet and feeding management practices, need to be considered in addition to physically effective fiber to prevent ruminal acidosis. Use of high quality forages helps cushion against the risk of ruminal acidosis, because a greater proportion of forage can be included in the diet without lowering its digestible energy content.

Our recommendations for minimum levels of dietary physically effective fiber are based on the average cow, and do not include a margin of error to account for the variability among cows or the differences in the fermentability of the diet. As diets are formulated closer to the minimum level of physically effective fiber, a greater portion of the cows will experience ruminal acidosis. Formulating diets for the average cow may be acceptable for cows in mid and late lactation, but diets for cows in early lactation should be formulated above the minimum requirement because of their higher risk for acidosis.

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