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Understanding Effective Fiber in Rations for Dairy Cattle

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Fiber type, quality and length are key to herd health and production.

Fiber is a key component in dairy rations. When nutritionists are faced with herd challenges such as low milkfat tests, foot problems or low feed conversions, ration fiber often is evaluated. Effective fiber depends on the type and amount of forages and nonforage fiber sources being fed, the particle size of those forages and the amount of available nonfiberous carbohydrate included in the diet.

Effective Fiber

The need for physically effective fiber

Dairy nutritionists consider neutral detergent fiber (**NDF**) the most common method to estimate fiber. The cow's need for long, coarse fiber in the form of forage has long been recognized. For example; in 1948, Cole and Mead noted that without it, a "physical deficiency ... results in the following syndrome: failure of, or diminished rumination; difficulty in eructation, often causing tympany or bloat, ... reduction in food consumption in cattle; and depraved appetite." The coarse fiber portion of the ration is believed to be **effective** in stimulating chewing activity and salivary buffer production resulting in increased rumen pH. The concept of physically effective NDF (**peNDF**) has been proposed to estimate the NDF portion of the diet that stimulates chewing activity and possibly the formation of the rumen mat.

Measuring TMR (Total Mixed Ration) particle size

The Penn State Particle Separator (**PSPS**) was originally introduced in 1996. This simple, low-cost procedure is now routinely used to evaluate feed particle size. The original device was constructed out of two sieves measuring 19.0 and 8.0-mm, and was based on the S424 standard of the American Society of Agricultural Engineers (ASAE). Even though the original apparatus was widely accepted by nutritionists, TMRs typically contain 40 percent to 60 percent concentrate, most of which pass through the 8.0-mm sieve. As a result, an additional sieve with a pore size of 1.18-mm was developed and now is used to more accurately describe the smaller particle fraction of TMRs. Some suggest that 1.18-mm is a critical length governing retention in the reticulo-rumen.

Measuring effective fiber

The peNDF content of an individual feed is calculated as the product of the NDF concentration and the physically effectiveness factor. This system is based on the assumption that a hypothetical standard feed would be most effective if it contained 100 percent NDF and possessed a physically effectiveness factor of 100 percent, yielding a peNDF of 100 percent. Thus, the estimation of peNDF is a function of the concentration of NDF and the physical form of the feed itself. As a result, high fiber and coarse feeds possess higher peNDF values. For example, assume physically effective factors of 0.82 and 0.67 are assigned to a coarsely chopped and finely chopped alfalfa haylage. Assume also that both samples contained 50 percent NDF. The resulting peNDF values would be 41 (50 percent NDF x 0.82 physically effectiveness factor) and 33.5 (50 percent NDF x 0.67 physically effectiveness factor) for the coarsely and finely chopped haylages, respectively. Mertens (1997) has suggested that a TMR should contain a minimum of 22 percent peNDF to adequately stimulate the amount of chewing activity required to maintain an average rumen pH of greater than 6.0. This system has been adopted by a number of ration balancing programs, including the Cornell Net Carbohydrate and Protein System and the CPM Dairy Version 3.

To calculate the peNDF value of individual feeds, determine the physically effective factor. Mertens (1997) proposed that this value may be calculated by measuring the proportion of dry matter retained on a 1.18-mm sieve after the sieve is vertically shaken. Because particles greater than 1.18-mm are believed to be highly resistant to passage out of the rumen, it is speculated this friction stimulates chewing activity. An additional method to estimate the physically effective value is to sum the amount of dry matter retained on the 19.0 and 8.0-mm sieves of the PSPS. Another approach is to avoid an index system and to evaluate effective fiber

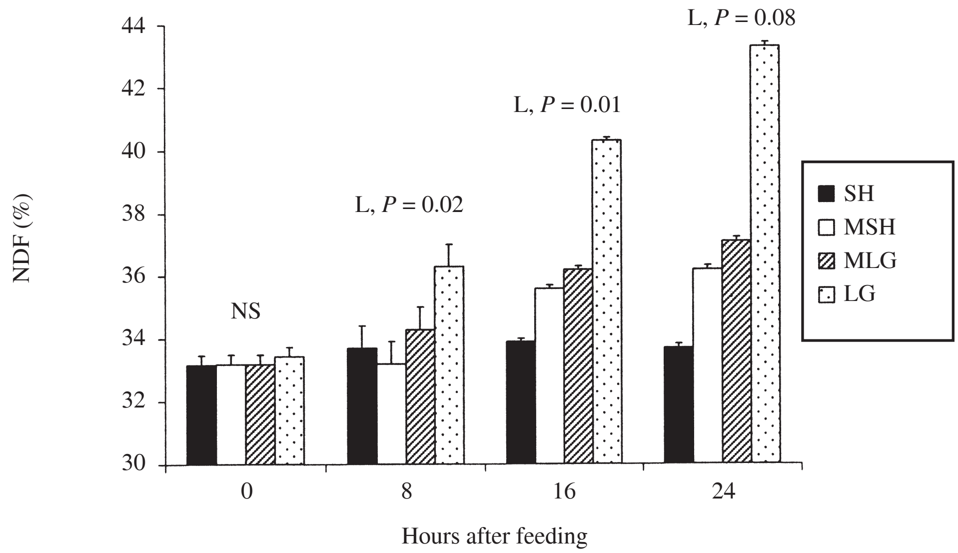

Figure 1. The effect of reducing corn silage particle size on NDF content of feed (0 h) or orts 8, 16 and 24 hours after feeding. Dietary treatments were as follows SH = SHORT, MSH = mostly short, MLG = mostly long LG = long. Treatments contained increasing amounts of TMR ≥ 19.0-mm: SH =2.8%, MSH= 6.7%, MLG=11.1%, LG= 15.5%.

levels by considering the fiber content and particle size of the TMR separately.

TMR Particle Size, Effective Fiber, Chewing Activity

Increasing forage particle size generally results in increased amount of time eating and ruminating. It also may affect the nature of feeding behavior. In normal feeding patterns a consistent supply of nutrients to the rumen leads to a constant environment for bacterial growth. Alternatively, rapid or selective ingestion may result in large diurnal variations in acid production and ruminal pH.

Increasing evidence shows that the amount of material retained on the 19.0-mm sieve of the PSPS is best correlated to feeding behavior and chewing activities. Again, as ration particle size or effective fiber content increases, the amount of time feeding and chewing also increases. This response is due to an increase in the chewing rate or the time spent chewing per unit of dry matter consumed.

The relationship between particle size and chewing activity is not completely linear. Coarse, longer and high-fiber particles are easier for animals to select against, and greatly affect rumen fermentation. Studies seek to improve practical understanding of the effects of forage particle size on the salient features of daily feeding activity and behavior. *Figure 1* illustrates the effects of corn silage particle size on the concentration of NDF remaining in the feedbunk over a 24-hour period. In this study diets were similar in NDF content but contained increasing amounts of material greater than or equal to 19.0-mm. Animals consuming the diet of longest particle size refused more fiber particles, as demonstrated by the highest NDF content in the refusals. The practical consequence of this is less chewing activity per unit of feed consumed.

Although reducing chop length or particle size may reduce sorting, mechanical processing of corn silage also can be effective. Even if TMRs contain unprocessed corn silage, extensive sorting usually is not observed if the particle size is close to recommended ranges listed in *Table I*. Thus, although finely chopping or processing corn silage increases the power requirements and harvesting costs, studies demonstrate that these practices reduce sorting behavior of dairy cattle. The moisture content of the TMR also is believed to affect sorting activity. This effect was recently observed by Wisconsin investigators who tested the effects of increasing the moisture content of a hay-based TMR from 20 percent to 35 percent. Added moisture in this experiment resulted in increased NDF intake, which also was followed by an increase in milkfat concentration from 3.31 percent to 3.41 percent.

Table I. Forage and TMR particle size recommendations as estimated by the Penn State Particle Size Separator

	Type		
	Corn Silage	*Haylage*	*TMR*
Sieve Size	*% DM retained*		
> 19.0 mm	5 ± 3	15 ± 5	5 ± 3
19.0 - 8.0 mm	55 ± 10	60 ± 15	40 ± 10
8.0 - 1.18 mm	40 ± 10	30 ± 10	40 ± 10
< 1.18 mm	< 5	< 5	≤ 20
MPL (mm)[a,b]	8 ± 2	10 ± 2	5 ± 2

[a]As estimated by the Penn State Particle Separator (Kononoff et al., 2003a).

[b]MPL = geometric mean length as calculated by the ASAE (2001)

TMR Particle Size, Effective Fiber, Rumen pH

Rumen pH is important because when levels fall below 6.0, fiber digestion may be impeded and milkfat levels may become depressed. Rumen pH is a function of lactic acid and VFA production and is buffered by saliva. Because of this diets commonly include longer particle size and greater amounts of effective fiber to stimulate salvia production. Nutritionists have noted that the intake of particles greater than 19.0-mm was negatively correlated with the amount of time rumen pH was below 5.8. However, forage should not be harvested at excessively long lengths. In one experiment that evaluated the effect of reducing alfalfa haylage particle size, mean rumen pH levels were only moderately affected (6.04 versus 6.15) when the proportion of particles greater than or equal to 19.0-mm was increased from 3 percent to 12 percent. Furthermore diets of shortest particle size were consumed in greatest amounts and had the highest digestibility; both factors resulted in greater rumen VFA concentrations. The effects of haylage particle size on rumen pH, ammonia concentration and eating activity is illustrated in *Figure 2*. In this experiment, a quadratic effect was observed on rumen pH, with highest values observed on the intermediate diets. Although rumen pH measurements for the intermediate diets appeared to have similar patterns, greatest fluctuation was observed in the shortest and longest diets. This observation may be due to the higher DMI, lower chewing activity and presumably salivary buffer flow when animals consumed the shortest diet. In comparison, *Figure 2* illustrates higher feeding patterns early in the day, which may have resulted in the marked decrease in rumen pH in animals consuming the longest diet. Note that severe depressions in rumen pH were not observed with any treatment and was likely a function of the fact that rations contained on average 31.5 percent NDF and 42.5 percent NFC, which are similar to NRC (2001) recommendations. In formulating diets, nutritionists should be mindful of these recommendations and understand that rapidly fermentable carbohydrates may have even greater

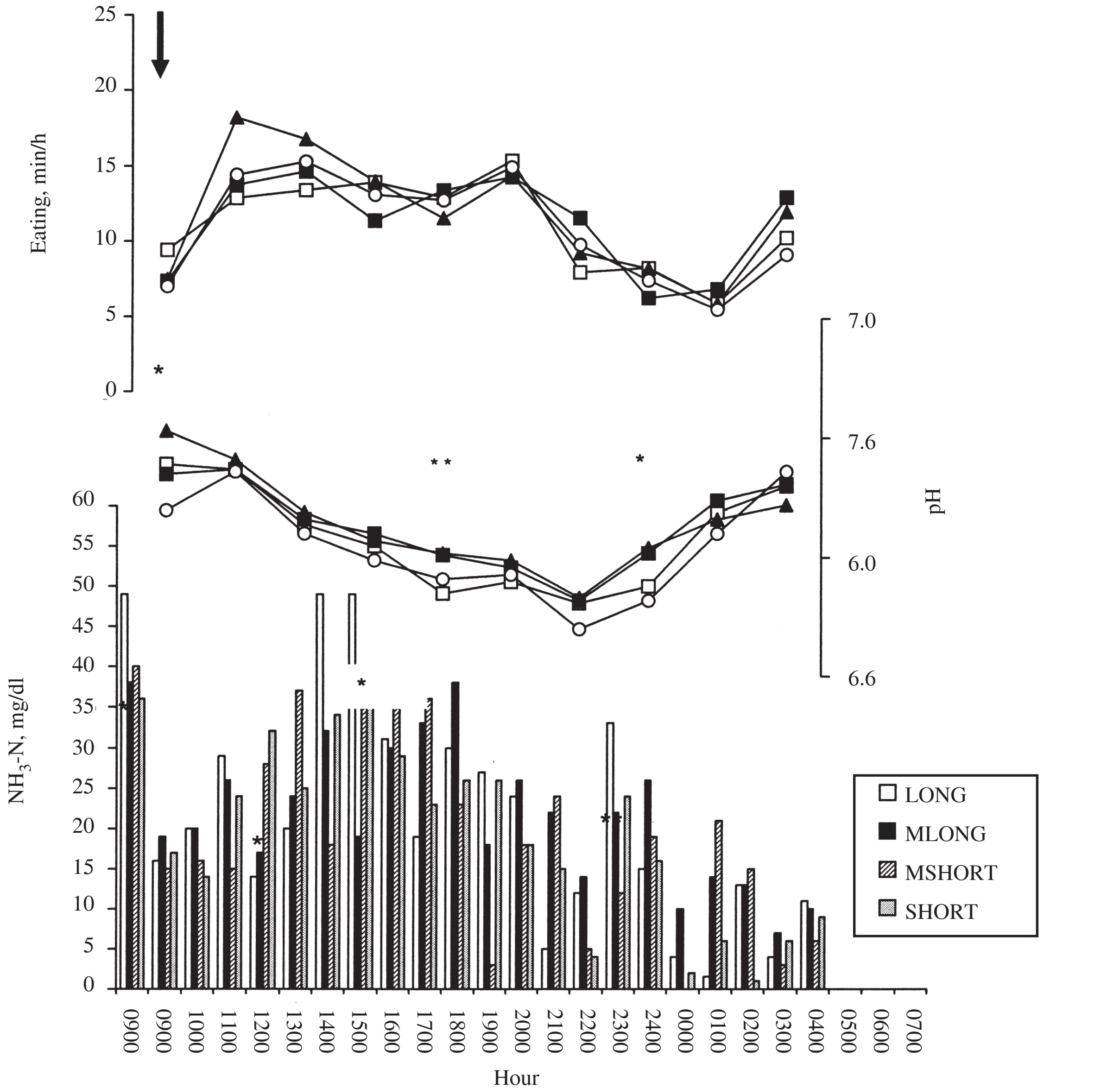

Figure 2. Effects of reducing alfalfa haylage particle size on daily rumen pH and NH_3-N concentration and eating pattern in min/hour for a 24-hour period for dairy cows LONG (□), MLONG (■),MSHORT (▲) or SHORT (○). Treatments contained increasing amounts of TMR ≥ 19.0-mm: SHORT =3.0%, MSHORT= 12.3%, MLONG=21.9%, LONG= 31.4%. Arrow indicates feeding time (* $P \leq 0.05$; ** $P \leq 0.10$).

effects on variation in rumen pH than just ration particle size.

Along with particle size, the nature of effective fiber also depends upon other physical properties such as type of forage. Substituting silage for dry hay increases the effectiveness of the total diet. Adding straw to increase ration effective fiber also is a common field practice. Typically wheat straw is chopped and mixed into the TMR to slow down rate of passage, improve rumination activity and increase rumen DM digestibility. This practice was evaluated by Ohio State investigators, who added alfalfa hay (11.7 percent DM), grass hay (7.0 percent DM) or wheat straw (5.2 percent DM) to diets containing corn silage as the primary forage source (35.7 percent DM). In this experiment total ration NDF was similar across treatments (39 percent DM), and intake was observed to be unaffected by NDF source. Although chewing activity was not reported, milkfat concentration and rumen pH were similar across treatments, indicating that total diet peNDF levels were not different. Total tract DM and NDF digestibility was observed to be highest in diets containing straw, possibly due to slower passage out of the rumen. Presently, a lack of data supports recommendations to add straw.

Although fiber levels may have an effect on rumen pH, dairy nutritionists should be mindful of the amount and fermentability of nonstructural carbohydrates in the diet. In an experiment in which dry cracked corn replaced ground high moisture corn, rumen pH was reduced from 5.99 to 5.85. The diurnal variation of rumen pH also is often considered when evaluating dietary effects on rumen pH. On average, pH was below 5.8 for over three hours when cows consumed high-moisture corn. The practical effects of these factors was a negative correlation between rumen pH and milkfat concentration. While it is apparent that effective fiber and particle size can affect rumen pH, differences in particle size do not always result in differences in mean rumen pH. When evaluating a diet to determine a possible risk of subclinical acidosis, it is important to consider levels of fiber and nonstructural carbohydrates, along with their associated fermentability.

Particle Size and Effective Fiber Recommendations

The Nutrient Recommendations of Dairy Cattle (NRC, 2001) does not outline effective fiber limits during lactation. This is because more information is needed on the proposed methods used to estimate peNDF and the relationship to rumen fermentation and milk production. The most current reliable method to assess effective fiber may be to evaluate fiber levels and particle size distributions individually.

For lactating cows, the recommended minimum concentration of NDF is 25 percent of the diet DM with 19 percent of forage origin. When the amount of fiber from forage is reduced to 15 percent the amount of NDF in the diet should be at least 33 percent DM. *Table I* outlines forage and TMR particle size recommendations. When evaluating a TMR, the proportion of material retained on the top screen, or greater than or equal to 19.0-mm is often considered. This is because the intake of DM from this portion of the diet is known to be positively correlated with ruminating activity and has been demonstrated to be negatively correlated when time rumen pH is below 5.8. The current recommendations indicate that the amount of TMR retained on the top screen of the PSPS is 2 percent to 8 percent. This recommendation is based on the collective observations of a series of experiments that evaluated diets within a wide range of particle lengths.

Summary and Conclusions

Effective fiber is that portion of a dairy diet that stimulates chewing activity, salivary buffer production and increased rumen pH. Physically effective NDF has been proposed to *estimate* effective fiber and is the portion of NDF in the diet that stimulates chewing activity and possibly forming the rumen mat. Several methods to measure peNDF have been proposed with each at differing stages of development and validation. The NRC (2001) nutrient requirements of dairy cattle have proven useful in outlining the fiber requirements of dairy cattle; and the PSPS has become a widely used tool to quantitatively estimate forage and TMR particle size. Until more research is available on the proposed peNDF systems, the most practical method to evaluate the effective fiber level in dairy diets may be to ensure that ration NDF, forage NDF and TMR particle size are within recommended ranges. Reducing forage particle size may reduce the effective fiber levels in dairy diets but increase DMI, digestibility and concentrations of rumen total VFAs. Reducing feed particle size within recommended ranges also may reduce the feed bunk sorting behavior of dairy cattle and increase fiber intake. Although chewing activity is closely related to particle size, it may have moderate effects on rumen pH (a function of increased salivary flow). Other factors such as the amount of fermentable carbohydrates may be more critical when ration NDF levels are near recommended levels.

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