FIBER REQUIREMENTS FOR DAIRY CATTLE: HOW LOW CAN YOU GO?

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INTRODUCTION

Diets for high producing dairy cattle should be balanced to maximize energy intake and microbial protein production. This requires highly fermentable feeds as energy sources for ruminal microbes. As fiber is generally less fermentable than non-fibrous feed constituents such as starch and sugars, fermentable energy generally increases as fiber content decreases. However, fiber is required in the diet to stimulate chewing and rumen movements. Chewing stimulates saliva secretion, increasing the flow of salivary buffers into the rumen, which neutralizes acids produced from fermentation. Rumen movements enhance absorption of fermentation acids from the rumen. Both are necessary to maintain ruminal pH at a level that allows microbes to grow efficiently and the animal to maximize energy intake. NRC (1989) gives minimum fiber requirements for two different measures of fiber, neutral detergent fiber (**NDF**) and acid detergent fiber (**ADF**). Chemical measures of fiber alone, whether NDF or ADF, are not adequate for ration balancing; fiber varies in its *effectiveness* at stimulating chewing. This is readily apparent when substituting high fiber byproduct feeds in place of forages. Because of this, NRC (1989) recommends balancing rations for a minimum of 25% NDF with 75% of the diet NDF from forage. However, this recommendation can be improved upon as fiber varies greatly in its *effectiveness* at stimulating chewing within byproduct feeds and forages, due to differences in the size and size distribution of fiber particles and the retention time of fiber in the rumen.

Another feed measurement that is sometimes considered when balancing rations is the non-structural carbohydrate (**NSC**) content of the diet. While rations are generally balanced for a minimum level of fiber, a maximum level of NSC is usually set. This is because NSC is generally more fermentable than fiber and as the level of NSC in a ration increases, production of fermentation acids in the rumen increases. As the NSC content of rations increases primarily at the expense of fiber, not only is there a greater rate of production of fermentation acids in the rumen, there is less fiber to stimulate chewing and the secretion of buffers in saliva. Fiber dilutes the more fermentable feed components in a ration. However, NSC are not completely fermented and ruminal fermentation of NSC ranges from less than 50 to over 90%, limiting its usefulness.

Factors that affect ***both*** the production of fermentation acids ***and*** the buffering capacity of the rumen must be considered when balancing rations for fiber. Understanding the interactions of factors that affect fiber requirements allows rations that maximize ruminal microbial protein production and energy intake leading to lower ration costs and higher milk production. This paper discusses a system for selecting the optimal fiber level for dairy cattle.

MEETING THE FIBER REQUIREMENT

NDF vs. ADF. Both NDF and ADF are used routinely for balancing rations for minimum fiber requirements. NDF is a measure of the total insoluble fiber of a feed including hemicellulose, cellulose and lignin. ADF is a measure of cellulose and lignin and does not include hemicellulose. ADF also contains some pectin, which is solubilized and rapidly fermented in the rumen. It is important to realize that the relationship between NDF content and ADF content varies by forage type. While ADF is approximately 50-60% of NDF for grasses, it is 75-85% of the NDF values for legumes. Because

NDF more closely measures total insoluble fiber, it is used more often to measure fiber requirements. Although ADF may be used, it requires adjustment depending upon forage type; grasses (including corn silage) may have a lower optimal ADF than legumes because the ADF value for grasses represents a greater amount of insoluble fiber than the ADF value of legumes. Legumes grown under wet conditions, especially in older stands, contain a variable portion of grass, making the optimal ADF level difficult to predict.

Physically Effective NDF. The term *effectiveness* of fiber is confusing because it has been used in different ways. Rations are routinely balanced for *effective* NDF using coefficients that may have been calculated differently for different feeds in the ration. Effective NDF values have been calculated for byproduct feeds based on changes in milk fat percentage when forage NDF was replaced by byproduct NDF (Swain et al., 1991; Vaughan et al., 1991; Clark and Armentano, 1993a; Clark and Armentano, 1993b). These values were calculated for use when replacing forages with other sources of roughage to maintain milk fat content. However, when measured in this way, the physical effects of NDF on chewing, salivation and ruminal buffering are confounded with metabolic effects due to different chemical composition which alters the amount and type of fermentation products produced. In addition, cows in mid- and late-lactation have typically been used in these studies as their milk composition is more sensitive to changes in ration composition. However, the physiological state of these cows is much different than cows in early lactation. Energy intake of cows in early lactation is below energy requirements and it is impossible to balance rations to meet requirements for both fiber and energy. As rations with inadequate fiber content upset rumen function, decrease energy intake and may result in health problems such as acidosis, displaced abomasums, and lameness, it is necessary to balance rations considering the effects on ruminal pH more directly. Meeting energy requirements without compromising ruminal function and animal health is much less difficult for cows in mid- and late-lactation; hepatic lipidosis, ketosis and displaced abomasums due to post-calving difficulties are reduced or eliminated and energy intake generally exceeds energy expenditure for maintenance and milk production.

Values for effective NDF based on differences in chewing response allow separation of the physical and chemical effects of fiber. These two effects need to be considered in a system for determining fiber requirements, but should not be confounded in the same measurement as when effectiveness coefficients are calculated based on milkfat response. Effectiveness values for NDF determined by differences in total chewing time will be called physically effective NDF (**peNDF**) to distinguish from values determined using milk fat percent as a response. The coefficient pe is determined based on differences in treatment response due to time spent chewing per kg NDF consumed. This coefficient is then multiplied by the NDF content to determine its ability to stimulate chewing (peNDF).

It is clear that physical effectiveness varies dramatically for different feeds. These differences are primarily due to differences in particle size distributions of forages and feeds. Total (eating + ruminating) chewing time per kg of NDF consumed by dairy cows in early lactation decreased over 16% when mean particle size of ground alfalfa hay decreased from 2.1 to 1.0 mm (Grant et al., 1990a) and over 21% when particle size of chopped alfalfa silage decreased from 3.1 to 2.0 mm (Grant et al., 1990b). Shaver et al. (1986) reported 66% less total chewing time per kg of NDF for pelleted alfalfa (1 mm) compared to chopped (7.8 mm) but no difference between long and chopped alfalfa hay. This indicates that there is no additional advantage to increasing particle size above a certain point. More research is needed to define the effect of particle size distribution of forages on chewing activity.

Few values have been calculated for byproducts based on chewing response alone. Sudweeks et al. (1981) measured chewing response for various forages, byproducts and grains but reported the values on a DM basis rather than an NDF basis. Mooney and Allen (1993) reported that whole linted cottonseed was about 50% as effective at stimulating chewing as 3/8" theoretical cut alfalfa silage but about 75% as effective as 3/16" theoretical cut alfalfa silage. This shows that the pe calculated for a feed is relative only to the feed which it replaced and that pe values may vary dramatically from one study to another. Future studies should measure the physical effectiveness of feeds relative to a common standard such as mature grass hay so that the values are comparable from one study to another and more useful for ration balancing.

Total chewing time per kg NDF consumed may not be the best measure of fiber effectiveness. Cassida and Stokes (1986) measured a small increase in saliva production when dairy cattle were eating (188 ml / min) compared to resting (152 ml / min). Others have measured saliva output during ruminating at 2.5 times the resting rate for sheep, cattle and buffalo (Beauchemin, 1991). As saliva composition is relatively constant (Erdman, 1988) and eating and ruminating activities are somewhat independent, weighting the time spent resting, eating and ruminating by saliva secretion rates for each activity may provide a more accurate measure of effectiveness of fiber for buffering the rumen. As research results become available this measure of effectiveness may be implemented.

Rations with fiber which ferments and passes from the rumen quickly require higher ration NDF levels as less fiber is retained in the rumen to stimulate rumination, chewing and saliva flow. Little information is available relating total chewing time per kg NDF to ruminal turnover time of NDF.

Fermentation Acids. Diets with high levels of ruminally fermented carbohydrate may decrease dry matter intake and subsequent performance in early lactation cows. Dry matter intake has been improved by replacing sources of rapidly available NSC with more slowly available NSC sources in the diet (Aldrich et al., 1993; Casper et al., 1990; Dhiman and Satter, 1993; McCarthy et al., 1989; Oliveira et al., 1993; Seymour et al., 1993; Varela et al., 1993). Excessive ruminal fermentation decreases ruminal pH as the production of fermentation acids exceeds the buffering capacity of the rumen (which is primarily determined by saliva flow). Of the fermentation acids produced, volatile fatty acids (primarily acetic, propionic and butyric) have roughly the same ability to decrease pH. However, lactic acid has the ability to decrease pH to a greater extent. Although lactic acid production is generally low, production may increase substantially when large amounts of ruminally degraded starch are consumed.

Starch is the primary component of NSC and accounts for 30-35% of the total dry matter of most dairy cattle rations. Ruminal fermentation of starch varies dramatically with grain type and processing. Herrera-Saldana et al. (1990) compared rates of starch digestion of five cereal grains and found that oats, wheat, barley, corn, and sorghum ranked from fastest to slowest. Although ruminal digestibility is a function of both rate of digestion and rate of passage from the rumen, it has been reported to follow the same trend (Spicer et al., 1986). Processing grains by cracking, grinding, and steam flaking, generally increases rate of fermentation. However, ruminal starch digestibility may not always be increased by grinding. Nocek and Tamminga (1991) reported that ruminal digestibility of starch varied from 51-93% for 11 different studies with ground corn and from 42-91% for 9 different studies with ground sorghum. Although rate of fermentation increases with grinding, rate of passage through the rumen also probably increases as fine particles may flow from the rumen with the liquid fraction (which passes from the rumen at 3-4 times the rate of particulate matter). Although up to 50% of the corn starch of finely ground dry corn may bypass ruminal fermentation in high producing cows, it is expected that ruminal fermentation of the same corn consumed by non-lactating cows or cows with lower intakes is much higher as ruminal liquid flow is much lower for these animals. Cracking, ensiling or steam flaking probably do not substantially reduce ruminal retention time as particles are not reduced enough in size to flow with the liquid fraction. Many large seed particles can be observed in the ventral rumen when evacuating rumens of lactating cows in research studies. The retention time of these particles in the rumen probably increases with their size. Cracked corn also may be used to reduce ruminal digestibility, but whole tract digestibility will be reduced as well. Knowlton et al. (1993) found that although ruminal digestibility of finely ground and coarsely cracked dry corn appeared to be similar when fed to high producing cows in early lactation, whole tract digestibility was about 10% higher for the ground corn.

Other feed components such as fiber and protein are fermented in the rumen in addition to NSC and they influence the total amount of fermentation acids produced. However, lactic acid is not a major fermentation end product of these feed components and as fiber is more slowly fermented, highly fermentable fiber in the ration will not cause dramatic declines in ruminal pH. Although ruminal fermentation of protein has a relatively narrow range of 60 - 70% in most dairy rations, ruminal NDF digestibility is extremely variable for both forages and byproduct feeds. Nocek and Tamminga (1991) reported that literature values of ruminal NDF digestibility ranged from 33 - 63% for alfalfa hay and from 32 - 68% for corn silage. Ruminal NDF digestibility reported for byproduct feeds tended to be higher, and the range within a feed tended to be narrower than for forages.

The Optimal NDF Level. Although research related to fiber requirements of dairy cattle is still needed, much of what was discussed above can be used in a simple system to select the appropriate level of NDF in a ration. The optimum NDF which will maximize energy intake of cows in early lactation, ranges from about 25-35% of DM. The level of NDF within this range is dependent on the cow or group of cows, the feeds available, and the feeding system used. Beginning at the midpoint of this range (30% NDF), several factors allow ruminal pH to be maintained at lower NDF contents, while other factors raise the optimal NDF content. As intake may be limited by physical fill as NDF content of the ration increases, and NDF is generally less digestible than other feed components, the goal to increase energy intake should be to balance rations with lower NDF levels while providing sufficient buffering of fermentation products. Figure 1 illustrates how several of the primary factors affect the optimal NDF content of the ration. Each of these factors is described below.

Few pe values for feeds have been published. However, longer forage particles will have a greater pe than shorter forage particles. Long hay or coarsely chopped silage allows lower NDF levels to be fed as the NDF in the ration is more effective at stimulating chewing, increasing saliva flow to buffer fermentation end products. Conversely, finely chopped silage requires higher ration NDF levels as it is less effective at stimulating chewing. If silage is chopped finely, addition of long or coarsely chopped hay may be required. Some particles greater than 1.5" in length are desirable in a ration. High fiber byproduct feeds such as soyhulls and distiller's grains are generally much less effective at stimulating chewing than forage due to fine particle size. A notable exception is whole linted cottonseed which is about 50% as physically effective as long chopped silage (Mooney and Allen, 1993). Addition of high fiber by-product feeds increases the optimal NDF content of the ration. When assessing particle length it is important to examine the feed as it is offered to the cows, not what goes into or comes out of the silos, as significant particle reduction may occur in the mixing process for TMRs.

Use of feeds with high ruminal digestibility, particularly for starch, requires greater NDF concentrations than feeds with lower ruminal digestibility. Shifting site of digestion from the rumen by substituting a source of bypass starch with high whole tract digestibility allows lower levels of NDF in the ration and higher energy intakes. Replacing high moisture corn (high ruminally degraded starch) with finely ground dry shelled corn in rations of high producing cows has been successfully used on several farms in Michigan to increase energy intake, presumably through this mechanism.

Offering grain frequently in lower amounts allows lower ration NDF levels than offering grain just twice per day. Large grain meals result in large fluctuations in ruminal pH, which can cause cows to go off feed if insufficient fiber is fed. Feeding a TMR is an ideal way to increase energy intake as ruminal pH fluctuations are reduced allowing lower ration NDF levels.

Buffers can be used to partially replace peNDF to neutralize fermentation acids and are beneficial when effective fiber and natural buffering are limited (Erdman, 1988). Additional fat in the form of cottonseeds, soybeans, tallow, etc., allows lower ration NDF levels as fat is not fermented in the rumen, so there are no fermentation products produced that require buffering from saliva. However, fat cannot be utilized by ruminal microbes and therefore does not contribute to the production of microbial protein. As fat costs 2-3 times more than grain, additional fat should be included as needed to increase energy intake after grain intake is maximized.

Highly fermentable fiber has a lower pe than less fermentable fiber because it digests and passes from the rumen faster, decreasing the pool size of fiber needed to stimulate rumination. However,

Figure 1. Factors affecting optimal level of neutral-detergent fiber for high producing cows in early lactation to maximize energy intake.

Ration Neutral Detergent Fiber Level

25% | 35%

<-- long forage particles
no long forage particles -->
high fiber byproducts -->
<-- total mixed ration
grain fed infrequently -->
high ruminal starch digestibility -->
<-- moderate ruminal starch digestibility
<-- buffers
rate of fiber digestion and passage -->
<-- additional fat
variation in forage dry matter and quality -->

feeds with highly fermentable fiber are desirable, particularly when intake is limited by physical fill because the filling effect of the fiber is lower, leading to higher energy intake. Optimal NDF content of rations containing feeds with highly digestible fiber such as immature forages are higher than that using average or less fermentable fiber sources.

Low ration NDF levels (25 - 27% NDF) should not be fed in TMRs if forage dry matter and quality is variable. Variation in dry matter and (or) NDF of forages causes great variation in ration NDF and starch levels. Cows consuming low NDF rations are not able to deal with this variation as they are *on the edge* at maximal energy intake. If ration NDF content decreases, a precipitous decline in intake and production may result due to ruminal acidosis. However, if forage NDF or dry matter content increases and is undetected and uncorrected, energy intake will be somewhat reduced and this is not a great problem. Therefore, when variation is expected, higher ration NDF levels must be fed to avoid the risk of acidosis. Variation in forage dry matter and quality is often a problem for silage; although it cannot be eliminated, it can be reduced by good silo management. Variation in forage quality at feedout decreases energy intake and reduces production. Efforts to reduce this variation when forages are harvested (or purchased) and stored will be rewarded with higher energy intakes.

RECOMMENDATIONS

The degree to which ration NDF content should be adjusted from the midpoint NDF level of 30% requires a few educated guesses that will be refined by experience. The following approach is suggested to get started. Beginning at 30% NDF:

Forage particle size:: No adjustment for silage with 5-10% of particles > 1.5". Decrease NDF content 2 units when feeding silage with many particles (>15%) over 1.5" or when feeding long hay. Increase NDF content 2 units when feeding forage with few long (>1.5") particles. Increase NDF content up to 4 units for very finely chopped silage with no long particles.

By-product feeds: No adjustment when rations do not contain high fiber byproducts. Increase NDF content up to 2 units when feeding high fiber byproducts with fine particle size at up to 10% ration dry matter (less adjustment is necessary for whole cottonseeds). Limit the combination of pelleted forages and high fiber byproducts to less than 30% of the total fiber required.

Frequency of grain feeding: No adjustment for grain fed separately three times per day. Decrease NDF content 1.5 units if grain is fed 4 or more times per day or a TMR is fed. Increase

NDF content 1.5 units if grain is fed twice a day or less.

Ruminal starch digestibility: No adjustment if 75-80% ruminally digested. Decrease NDF content up to 2 units if 65 - 75% ruminally digested. Increase NDF content up to 2 units if over 80% ruminally digested. Ruminal starch digestibility lower than 65% decreases microbial protein production and may lead to lower whole tract starch digestibility and should be avoided.

Buffers: No adjustment if buffers are not fed. Decrease NDF content 1 unit if buffers are fed at .5 to 1% of ration dry matter.

Fiber digestibility: No adjustment for average forages. Increase NDF content up to 2 units for very high NDF digestibility (immature forages).

Added fat: No adjustment without added fat. Decrease the NDF content 1 unit if additional fat is added at 2 - 3% of ration dry matter.

TMR's: For TMRs, increase the NDF content up to 3 units or more if silage dry matter and NDF content of forages are variable.

As the different factors may not be additive, additional adjustments may be required. Total net subtraction or addition should not exceed 5 units of NDF (the range for optimal NDF content is 25 - 35%). The lowest ration NDF level recommended is 25%. Rations with optimal NDF of 25% have many long particles, moderate ruminal starch digestibility, contain buffers, are fed as a TMR or grain is fed frequently, and have little variation in dry matter and NDF content of forages fed. These recommendations can be used to select the optimal NDF for rations for a given set of feeds and feeding system and can be refined with experience. Remember that the goal is to maximize energy intake and ruminal microbial protein production. This is done by adjusting feeds and feeding systems so that optimal NDF content is at the low end of the range.

CONCLUSIONS

Selecting the optimal fiber level for dairy cattle rations requires consideration of several factors which interact to significantly affect energy intake and animal performance. Adequate effective fiber should be provided to allow the animal to maximize ruminal fermentation of carbohydrates while maintaining an adequate ruminal pH. This strategy should increase fermentation efficiency, microbial protein production, and energy intake resulting in increased milk production and decreased ration costs. For a given animal or group of animals, ration ingredients, and feeding system, there is an optimal fiber concentration in the ration that maximizes animal performance. Changes in one or more of a number of different factors may affect this optimal fiber level. Animal, feed and management factors that affect fiber requirements of dairy cattle are discussed.

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