CHAPTER 39

The Conundrum of Forage Fiber in Dairy Rations

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In the past, fiber was generally considered to be a negative component of forages and other feeds, being associated with reduced energy content of the forage, reduced intake potential and reduced milk output. However it is now widely recognized that the nutritional quality of forage fiber varies within and among forages and that it is possible to select fibers which maintain rumen function by stimulating chewing, and those with faster rates of digestion in the rumen, thus combining a higher intake potential with a high energy value.

Definitions of forage fiber

Ruminant nutritionists generally define ‘fiber’ as the ‘structural fiber’ in a plant, and assay it as neutral detergent fiber (NDF). NDF is the residue left after boiling a dried and ground sample of forage for 1 h in a detergent solution at a neutral pH. This procedure captures hemicellulose (primarily 5 carbon sugars), cellulose (primarily 6 carbon sugars), lignin (carbon based ring structures), cutin (the waxy cuticular covering of plants) and ND (neutral detergent) insoluble ash which, combined, are referred to as ‘structural fiber’ and are mostly composed of plant cell walls. The main non-structural fiber is pectin, which is also a portion of plant cell walls, but contrasts to structural fiber in having a much more rapid rate of ruminal fermentation. Indeed, NDF represents the slowest fermenting (generally by far) portion of a forage.

NDF is the simplest measure of forage structural fiber. However there are a number of NDF terms which refer to derivations of the NDF procedure, as well as different ways to express the biological or functional relevance of NDF (Fig. 1).

NDFom

This term refers to a variant of NDF in that the total residue from the NDF procedure is corrected for residual ash by combusting the sample in a furnace at 550°C. The reason for this variant is primarily to eliminate double accounting of ND insoluble ash in both the NDF and ash fractions of a forage. However the biological and practical debate of whether this ‘correction’ is really necessary continues.

aNDF

This term refers to a variant of NDF in which a heat stable alpha amylase is added during boiling with the neutral detergent solution. The reason for this variant is to eliminate problems of filtration associated with forages (such as corn and small grain silages) which can contain substantial levels of starch which are inefficiently solubilized by neutral detergent. Samples which filter poorly due to poor starch solubilization overestimate NDF by capturing some starch in the residue.

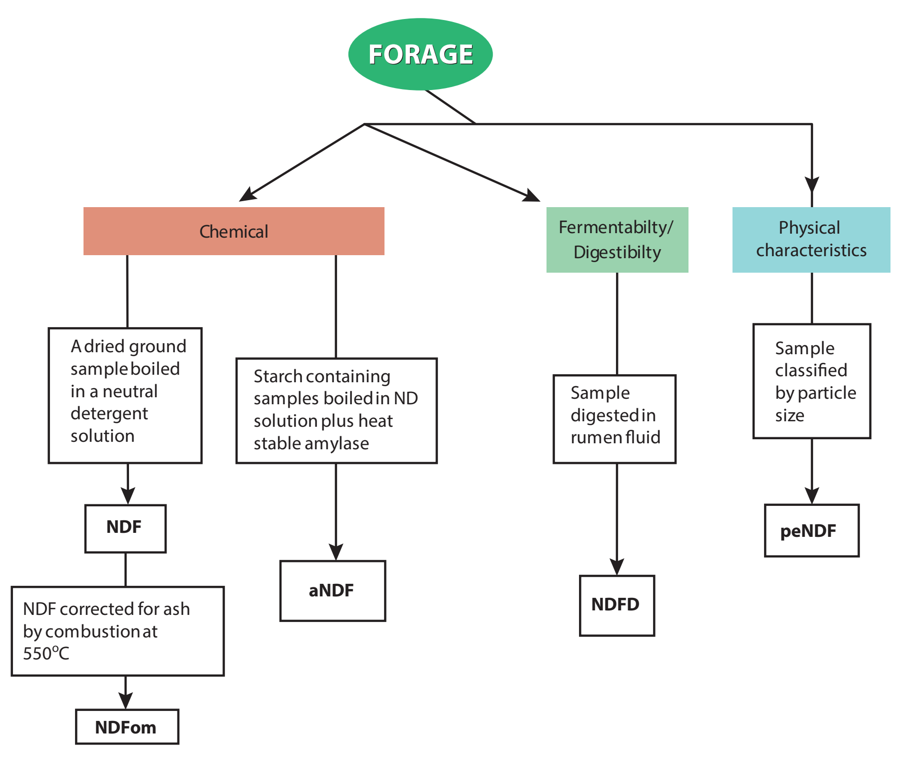

Figure 1. Forage NDF analysis schematic.

aNDFom

This term refers to a variant of NDF which combines aNDF and NDFom.

dNDF or NDFD

This term refers to the proportion of the NDF (or aNDF or NDFom depending on procedure) which is fermented in an *in vitro* system for a specified time of incubation. In this procedure, rumen fluid is collected from ruminally cannulated cows and then small quantities of dried and ground forage are incubated with it for a fixed time period. The reason for this procedure is to estimate ruminal fermentability of NDF in cattle, and so allow comparison of NDF fermentabilities among forages as well as to facilitate calculation of estimates of the energy value of the forage. The most common times of incubation are 24 h (often to estimate the extent of fermentation in cows at very high intakes), 30 h (often to estimate the extent of fermentation in cows at low intakes), 48 h (to estimate the extent of fermentation to support NRC (2001) software) and 96 h (a historical value used to estimate the practical extent of NDF fermentation). These dNDF (or NDFD) values by time are indicated by adding subscripts (e.g. dNDF$_{30}$).

peNDF

This term refers to the proportion of the NDF (or aNDF or NDFom) which is considered to have *physical effectiveness*, or the ability to stimulate ingestive and ruminative chewing in cattle. The latter is particularly important since ruminative chewing stimulates salivary secretions which buffers the rumen and facilitates an environment supportive of fiber fermentation. To date there is no recognized procedure to measure peNDF, notwithstanding research efforts to define it based upon the particle size of the forage. These approaches have been fraught with problems since forage particles have length and width dimensions and so defeat attempts to create particle size definitions. Thus tabular values of peNDF are hypothetical and generally a series of 'common sense' estimates of the physical effectiveness of an NDF within a forage expressed as a % of NDF. For example, long wheat straw may be 100% peNDF whereas chopped wheat straw might be 80% (or less) depending upon the chop length. The reason for this NDF definition is to facilitate ration formulation since it is known that reducing the particle size of a fiber destroys its physical characteristics while having no impact on its chemical composition. Put slightly differently, peNDF is a ruminant nutrition fudge factor which allows successful ration formulation since formulations based upon NDF analyses alone can result in disastrous rations with all small, or all large, particle size NDF sources.

eNDF

This term refers to the proportion of the NDF (or aNDF or NDFom) which is considered to have actual *effectiveness* in the rumen, or the ability to stimulate an optimal ruminal environment. Notwithstanding research efforts to define eNDF based upon its impact on rumen pH, this approach has been largely unsuccessful and so eNDF remains a largely hypothetical concept which is not used in ration formulation.

Importance of forage fiber in dairy rations

Rations of lactating dairy cows generally contain 28–35% of dry weight as NDF and rations of non-lactating cows can contain 50% or more. In most rations of domesticated ruminants, except feedlot cattle, NDF is the single largest chemical component of the ration. Thus its characteristics, both chemical and physical, are important to the overall chemical and physical characteristics of the ration – which are the characteristics that determine overall animal performance.

Ration NDF has two important functions:

1) It provides the structural fiber required by ruminants to stimulate ingestive and ruminative chewing which in turn stimulates saliva production. Saliva is very important because it contains buffers which prevent rumen pH from declining thereby inhibiting bacterial growth and fermentation of substrate. Ruminative chewing is strongly stimulated by NDF, particularly NDF in long particles, in the ration. Structural fiber also provides the 'bulk' required to create a stable rumen mat which is needed to hold ingested feeds in the rumen thereby preventing them from escaping the rumen too quickly to be digested.

2) Digestion of NDF in the rumen creates volatile fatty acids which, when absorbed from the rumen, are a substantial source of energy to the animal's metabolism. NDF is a major contributor to total digestion in a ration. For example, it contributes about 25% of total digested organic matter in rations of high producing lactating dairy cows.

However therein lies the conundrum because, to have structural value, NDF needs to have a large particle size which is important to stimulating ruminative chewing. However to contribute to the animals' energy balance, the NDF must be digested which tends to destroy its structural value. In practice this conundrum is often resolved by feeding sources of NDF which are high in small particles (and more rapidly fermented in the rumen while having less structural value) as well as sources of NDF high in larger particles (such as straws which are less rapidly fermented in the rumen while having more structural value).

So how should we estimate the energy value of a forage?
It has long been recognized that high quality forage is the key base for successful (i.e. supportive of high animal performance) ruminant rations. In this context 'high quality' means forage with a high energy value (driven by a high digestibility) which supports high intake. The two key factors which determine the energy value of a forage for cattle are its content of fat, due to its high energy value, and the digestibility of its total structural fiber (i.e. NDF), due to its high level in forages. The former can be dealt with by chemical analysis, although the latter has proven to be more difficult because chemical composition alone is a poor predictor of fiber fermentability (i.e. the rate at which a fiber ferments, which is a key factor in determining its actual fermentability in an animal's rumen).

The most common approach to estimate the energy value of feedstuffs has been to calculate its total digestible nutrient (TDN) value using an equation based on analyzable components of feedstuffs. Although the TDN equation has changed over the past 130 years as feedstuff analyses have improved, the principles have remained unchanged. TDN is calculated based on digestible crude protein (CP), digestible fat, digestible NDF, and digestible non-fiber carbohydrate (NFC). The TDN value can then be used to estimate the net energy for lactation (NE_l) value of individual feedstuffs.

The equation in Table 2 estimates the TDN value of feedstuffs for cattle fed at a low level of intake, which is a level of intake sufficient to maintain the body weight of the animal, referred to as the maintenance level of intake or '1xM'. The equation also predicts the NE_l values of

Table 1. Predicting the energy value of forages from analyses.

	Required assays for Energy Calculations								Energy Calculations (DM basis)					
Sample	**DM**	**OM**	**Fat**	**CP**	**SCP**	**ADICP**	**NDF**	**dNDF**	**TDN (1XM)**	**DE (1XM)**	**ME (1XM)**	**NE_l (1XM)**	**Energy Discount**	**NE_l (3XM)**
Description	%	--------	% DM	--------	% CP	% CP	% DM	% NDF	%	Mcal/kg	Mcal/kg	Mcal/kg	% unit M	Mcal/kg
Forage 1	24.9	88.6	1.1	8.2	55.0	13.4	49.8	46.6	58.27	2.57	2.14	1.43	8.03	1.20
Forage 2	28.2	96.3	6.5	24.4	62.0	7.4	31.4	56.9	83.02	3.66	3.25	2.09	5.81	1.85
Forage 3	92.4	95.0	3.7	19.5	19.0	7.0	41.2	27.8	63.86	2.82	2.39	1.58	6.95	1.36

DM=dry matter; OM=organic matter; CP=crude protein; SCP=buffer soluble crude protein; ADICP=acid detergent insoluble protein; NDF=neutral detergent fiber; dNDF=*in vitro* NDF digestibility; TDN=total digestible nutrients; DE= digestible energy; ME=metabolizable energy; NE_l= net energy of lactation.

http://animalscience.ucdavis.edu/faculty/robinson feedstuffs for cattle fed at a higher level of intake, which is a level of intake sufficient to maintain the body weight of the animal and produce about 30 kg/d (66 lb/d) of milk, referred to as the production level of intake, or '3xM'.

Many commercial laboratories provide the assays required in the equation in Table 2 (and in the spreadsheet in Table 1). The *in vitro* NDF assay which has essentially become an industry standard is the '30 h *in vitro* NDF', which was selected because it best correlates to digestion of dried and ground feeds in dairy cows fed at 1xM. Once in hand, this value can be entered into a spreadsheet to estimate the energy value of the forage. The user enters only the analytical information and the program estimates the various energy values, which can then be used for feed evaluation, feed pricing and ration formulation.

Table 2. Estimation of the TDN (1xM) in % Dry Matter – The UC Davis approach.

$$\text{TDN (1xM)} = ((\text{CP-SCP-ADICP})*0.98) + (\text{SCP}*0.80) + ((\text{EE-1})*0.98*2.25) + (\text{aNDFom}*\text{dNDF30}) + (0.98*(100\text{-ASH-EE-NDF-CP})))$$

Where: CP = crude protein (% of DM)
SCP = buffer soluble CP (% of DM)
ADICP = acid detergent insoluble CP (% of DM)
EE = ether extract (% of DM)
aNDFom = ash-free NDF assayed with amylase (% of DM)
dNDF30 = *in vitro* NDF digestibility at 30 h (% of NDF)
ASH = ash (% of DM)

The estimation of the NE_l value at 3xM is calculated from the TDN value at 1xM and the energy 'discount' which is estimated from some of the same components used to estimate TDN value at 1xM. These equations, while allowing estimation of the energy value of virtually any forage, are rather complicated, and so a spreadsheet is available to make the calculations (Table 1).

Conclusion

The structural fiber in forages, analyzed as neutral detergent fiber (NDF), is key to its nutritional quality, where 'quality' of a forage is defined in terms of its structural value to support ruminative chewing and of its energetic value to the animal. Unfortunately a high energy value and a high structural value seldom exist in the same forage structural fiber. However, because rations for cattle are combinations of forages and other feeds, it is possible to create rations which combine fibers with high structural quality and fibers that have high energetic value. Unfortunately, this effort is limited to some extent by poor methodologies to analytically define structural value (or physical effectiveness) of forage fibers and a poor understanding of the chemical factors which determine differences in rumen fermentability of fibers among forages.

References available online at www.farmwest.com

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