# FORAGE QUALITY: IMPACTS ON CATTLE PERFORMANCE AND ECONOMICS

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## INTRODUCTION

The value of a feedstuff is a complex function of its nutrient composition (net energy, protein, vitamins, minerals, etc.) chemical-physical characteristics of its fiber (fragility of the cell walls), acceptability (palatability), and associative interactions with other dietary ingredients. In the case of forages, their associative effects on utilization of other dietary ingredients is of greatest importance. For this reason, forages are often referred to as functional feeds. Indeed, forages are not usually cost-competitive alternatives for supplying the diet with energy, protein, or minerals. Their inclusion in formulations for feedlot and dairy cattle is dictated primarily on the basis of their function as roughage. A big step toward understanding the alternative value of different forages in diet formulations for feedlot and dairy cattle is to better appreciate their limits as functional feedstuffs.

### Attributes of fiber that affect feeding value

The specific attributes of fibrous components in forage that contribute most to its function as roughage are comprised in the term "effective fiber", specifically effective neutral detergent fiber or eNDF. This term describes the properties of forage that stimulate chewing, regurgitation and rumination. It reflects the physical-chemical qualities of the fiber, including initial particle size, density, and fragility or ease of particle-size reduction through chewing and digestion. The eNDF of forage not only represents its particular functionality in promoting digestive function, but also represents the character of the forage that can limit energy intake, and thus have a negative influence on performance.

Plant cell walls are comprised of a complex array of carbohydrate fractions including hemicellulose, cellulose, and lignin that impart rigidity and structural stability needed for growth. These fractions are referred to collectively as neutral detergent fiber or NDF. Although cellulose is the predominant component of plant fiber, it is important to recognize that the cellulose microfibrils are tightly bound by covalent bonding in a matrix of other fiber components, particularly hemicelluloses and lignin (Jeffries, 1990). Analogous to reinforced concrete, digestion of cellulose is limited by this hemicellulose-lignin encasement.

Of primary concern with respect to fiber digestion is the consequent effect on energy intake and hence, animal performance. The rumen has an upper limit on its physical capacity. As the rate of fiber digestion decreases, the amount of slowly digestible OM in the rumen increases. When referring to digestive characteristics, the terms "digestibility" and "digestion" are two

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commonly misused terms. Digestibility" is qualitative, referring to the susceptibility to degradation. In contrast, digestion refers to the extent of degradation. The extent of ruminal fiber digestion is a function of rate of digestion (**$K_d$**) and rate of passage (**$K_p$**) [digestion, % = $K_d/(K_d + K_p)$]. A primary factor influencing rate of ruminal fiber digestion is the accessibility of substrate to the fibrolytic process, in particular, the physical chemical interactions of cellulose, hemicellulose and lignin. This is a unique characteristic of individual forages or fiber sources, and is influenced by stage of maturity, age post-harvesting, method of preservation, and processing.

The problem however, is not "digestibility" of the forage, but rather, the length time needed for the degradative process. The nature of the fiber, the rate of particle size reduction and rate of passage are the more limiting aspects, especially in dairy formulations where forage inclusion rates are necessarily high. The NRC (1996) tabular values for alfalfa and bermudagrass demonstrate this point. Early bloom alfalfa, and fresh bermudagrass have TDN values of 60% and 64% respectively. Digestion of NDF from alfalfa hay is 45%, while that of bermudagrass is 65%! Bermudagrass is more digestible, and on that basis, appears to be the better choice. However, although the fiber components in alfalfa are less digestible, the physical characteristics of the fiber causes it to be very brittle and break easily, permitting a rapid rate of passage from the rumen. Bermudagrass on the other hand, takes nearly twice as long to pass from the rumen. While the energy value of bermudagrass is superior to that of alfalfa, its feeding value may not be superior.

Retention time of fiber in the rumen, or the length of time that fiber is exposed to the fibrolytic process is influenced by initial fiber particle size, rate of particle size reduction (chewing, rumination), particle density, and rate of digestion. The basis for particle retention is not altogether certain. Larger particles may become trapped in or on a floating ruminal mat, thus restricting access to the reticulo-omasal orifice. Larger particles may also be screened by omasal lamina and returned to the rumen, increasing retention time of larger particles (Church, 1988). Although particles of 5 cm may pass through the reticulo-omasal orifice (Welch, 1986), most particles leaving the rumen are smaller than 1 mm. Welch (1986) observed that more than half (55.2%) of the ruminal DM passed through a .8-mm sieve. While mastication during feed ingestion and rumenal fermentation play key roles in the diminution of particulate matter, rumination is the most important activity in reducing the particle size of undigested coarse material. Selected stems from several different species and maturities of hay (2 cm of size) showed no change in physical form when incubated in ruminal fluid of fistulated steers in nylon bags for 10 d (Welch, 1982). Lengths of plastic ribbon 7-cm long with a .90 specific gravity required extensive rumination (particle size reduction) before they could pass from the rumen (Welch, 1982).

It is tempting to attribute size selection to the reticulo-omasal orifice. Mc Bride et al, cited by Welch, 1986, photographed the orifice using fiber optics and found that in feeder cattle the maximum opening was more than 4 mm, and more than 2 cm in cows (Welch, 1982); making it difficult to explain the separation solely on the basis of orifice action, per se. Since more than 50% of ruminal DM will pass a 600 m sieve, other mechanisms, including particle density, and integrity of the ruminal mat are also likely to play important roles. Whatever the mechanism, it is clear that feed particles must be reduced to a size of less than 1 mm before they are likely to pass on to the lower digestive tract. The relationship between initial particle size of fiber (before being eaten) and ruminal retention time is given by the following equation: $Kp = 3.21 - .016eNDF$, where eNDF refers to the initial particle size of forage (before ingestion; NRC, 1996).

**Models for assessing the forage value**

Popular models for assessing the comparative feeding value of forages include: Forage Quality Index (**FQI**), Relative Feed Value (**RFV**), and Relative Forage Quality (**RFQ**; Moore and Undersander, 2002):

FQI = TDN intake, g/(29.0 * $BW^{0.75}$), where TDN intake = 0.01 * TDN, % * (120.7 - (0.83 * NDF,%) , and TDN, % = 32.2 + (0.49 * $OMD_{in\ vitro}$).

RFV = DMI * DDM / 1.29, where DMI = 120/ NDF, %, and DDM = 88.9 - (0.779 * ADF, %).

RFQ = 0.813 * TDN intake, % BW, where $DMI_{Legume}$ = 120/NDF + (NDFD – 45) * .374 / 1350 * 100, $DMI_{grass}$ = -2.318 + 0.442*CP -0.0100*CP2 - 0.0638*TDN + 0.000922*TDN2 + 0.180*ADF - 0.00196*ADF2 - 0.00529*CP*ADF, $TDN_{legume}$ = (NFC*0.98) + (CP*0.93) + (Fatty acids*0.97*2.25) + ($NDF_{nitrogen\ free}$ * 48-hour in vitro NDFdigestion/100) – 7, and $TDN_{grass}$ = (NFC * 0.98) + (CP * 0.87) + (Fatty acids *0.97*2.25) + ($NDF_{nitrogen\ free}$ * (22.7 + (0.664 * 48-hour in vitro NDFdigestion))/100) – 10.

These models were designed to assess feeding value under grazing condition, or when forage is the major feed ingredient. All three approaches assess differences among forages from the standpoint maximal DMI and digestibility. The National Forage Testing Association adopted RFV. Although, all three approaches tend to rank forages similarly (Moore and Undersander, 2002).

Why hasn’t the RFV model achieved general acceptance by nutritionist in diet formulations involving complete mixed diets? In the first place, the model is not sufficiently accurate in assessment of practical differences between forages of similar classification. The predictors of forage-limited DMI (120/%NDF) and digestiblity (88.9 - 0.779 * ADF, %) explain very little (1 and 20%, respectively) of the variation in observed DMI and digestibility (Sanson and Kercher, 1996; Moore and Coleman, 2001). Secondly, the RFV model does not appraise forages with respect to their primarily role as “roughage”.

**Relative Feed Value doesn’t define forages as to their “functionality” as roughages**

Feedlot cattle may be finished on all-concentrate diets. However, ADG and gain efficiency are improved by including small amounts of forage (Stock et al., 1990). Pitt et al (1996) observed that in feedlot cattle, ruminal pH was a predictable function of the effective NDF (**eNDF**, %) content of the diet ($pH = 5.425 + 0.0422eNDF$). Thus, the benefit to added forage is reduced incidence of acidosis (Clark and Davis, 1984; Popp et al., 1997), leading to increased feed intake (Price et al., 1980) and ADG (Wise et al., 1968). High energy finishing diets containing less than 6% forage NDF may result in marked depressions in energy intake and ADG (Alvarez et al., 2004). On the other hand, the inclusion of too much forage in the diet may also limit energy intake and ADG. When finishing diets contain greater than 9% forage NDF, ruminal bulk fill may begin to limit energy intake (Alvarez et al., 2004).

In opposition to the RFV or RFQ models, ruminal NDF digestion is not an intrinsic function of the forage, per se, but rather a complex function of the complete diet. Ruminal fibrolytic capacity (growth of cellulolytic bacteria) diminishes with decreasing ruminal pH (Slyter, 1976; Shriver et al., 1986; Russell and Wilson, 1996), and ruminal pH is dependent of dietary NDF level (Pitt et al., 1996). So it is, that ruminal fiber digestion may be more limited by ruminal fibrolytic capacity (condition of ruminal pH) than by the native degradability of the fiber (digestive quality of the fiber). Indeed, Alvarez et al. (2004) observed that most ($R^2 = 0.96$) of the variation in ruminal ADF digestion (**RDADF**, %) was explained by changes in ruminal pH ($RDADF = 28.725 - 0.535pH + 1.225pH^2$).

The rumen has an upper limit on its physical capacity. As the rate of ruminal fiber digestion decreases, the amount of slowly digestible OM remaining in the rumen increases. Zinn and Salinas (1999) observed that maximal DMI in cattle is a predictable function of initial shrunk weight (**IW**, kg) of cattle when placed in the feedlot, or calving weight of dairy cows, current weight or average weight during interval of interest (**BW**, kg), dietary NDF (%), forage eNDF (expressed as a percentage of forage NDF), and ruminal NDF digestion (**RDNDF**, %): DMImax, Kg/d = (0.001 * (0.098 * IW) + 26.24) * (BW^.75) / (0.01NDF(1 - 0.01RDNDF) / ((0.77 - 0.00386eNDF) * (0.042NDF - 0.037 - 0.00031NDF$^2$)). Accordingly, with a 220 kg calf fed a growing diet containing 21% NDF, a 20% reduction in ruminal fiber digestion is expected to depress ADG by 10% (1.15 vs 1.28 kg/d). With a 630 kg lactating cow fed a diet containing 30% NDF (80% eNDF), decreasing ruminal NDF digestion from 45% to 35% would drop maximum DM intake from 25 to 21 kg/d, resulting in a 21% decrease in milk yield (37 vs 47 kg/d).While this model is a reliable predictor of $DMI_{max}$, it requires accurate estimates of ruminal NDF digestion and eNDF. Accordingly, when the level of forage inclusion in the diet is sufficiently high to limit DMI, cattle preformance will be improved by enhancing the rate of ruminal fiber digestion and/or the rate of passage of fiber from the rumen. Thus, when nutritionists are faced with the dilemma of substituting a “reputation” forage (one for which they already have considerable experience) with an alternative less familiar forage, the primal questions is “Will the substitution negatively impact energy intake and digestive function?”.

**Evaluating forages quality**

As stated previously, it is the cell wall fraction that contributes to forages functional role as roughage. Due to comparatively high price of forages per unit energy, the nutritionist’s goal is to provide the minimum amount of forage that will safely permit maximal performance response. In the case of feedlot cattle, finishing diets are formulated to contain 6 to 9% forage NDF. In the case of lactating high producing dairy cattle, diets are formulated to contain a total of 29 to 32% NDF. But, whatever the target level selected, the important point to be understood is that forages are included in formulations for feedlot and dairy cattle to achieve a specified NDF level, not forage level.

Digestion of non-cell wall organic matter fractions (nonstructural carbohydrates plus protein and lipid) is comparatively high (greater than 80%) in forages, averaging 85%. However, digestion of the cell wall fraction (NDF) is much lower, typically ranging between 40 and 70%, with an average of roughly 60%. Thus, selection of forages to reduce their NDF content, is an obvious means for enhancing the energy value of the forage. However, this may in the final analysis, result in nothing more than a costly dilution of the forage fiber. In contrast, selection of forages for improved fiber digestibility, and not reduced fiber levels can be very beneficial. An example of this type of selection is brown midrib corn. Silage from brown midrib corn has only slightly lower NDF levels than conventional corn silage, yet due to lesser (35%) lignification, ruminal fiber digestion with brown midrib corn variety is greater (16%) than that of conventional varieties, permitting greater DMI (Greenfield et al., 2001). Surprisingly, the net energy value of brown midrib is not enhanced appreciably (Tine et al., 2001).

By definition, a forage is a feedstuff containing 35% or greater NDF. Accordingly, what is classified as “Supreme” alfalfa hay (<27% ADF, 34% NDF) is so low in fiber so as to not qualify technically as a forage. Corn silage is generally considered a high quality forage. However, it is actually comprised of stalks, husks and cob containing 65 to 70% NDF, and 25 to 50% corn grain. If one were to take bermudagrass (a lower quality forage) and combine it 50:50 with ground corn, its NDF value would be similar (42%), but its energy value would be 4% greater than that of a very high quality corn silage containing 50% grain. Indeed, when forages are substituted into the diet on an equal NDF basis, differences among forages in feeding value become small, or non-appreciable. For example, Ware and Zinn (2004) compared alfalfa hay (early bloom), sudangrass, and rice straw as fiber sources in a steam-flaked corn-based finishing diet for feedlot cattle. Diets were formulated so that test forages contributed 8% NDF (ie., 19.1, 12.2, or 10.2% forage as alfalfa hay, sudangrass, or rice straw, respectively). There were no treatment effects on ADG, DMI, gain efficiency, and net energy value of the diet. Likewise, Plascencia et al. (2003) observed that when either sudangrass or elephant grass replaced 45% of the NDF provided by alfalfa hay in a lactation diet for Holstein cows, there were no forage source effects on DMI, milk yield, and milk efficiency, although percentage milk fat was greater when grass hays contributed a portion of the forage NDF. Nevertheless, net energy values of individual feed ingredients in a dietary formulation are largely additive (the net energy value of the complete diet is equal to the sum of the net energy value of the individual feed ingredients). Thus, when forages are compared on an equal forage level basis, gain efficiency and dietary net energy values are consistent with the energy value of the respective forage (Alvarez et al., 2000; Ware et al., 2004).

## CONCLUSIONS

The NDF level of forage not only represents its particular functionality in promoting digestive processes, but also represents the character of the forage that can limit energy intake, and thus have a negative influence on performance. The rumen has an upper limit on its physical capacity. As the rate of fiber digestion decreases, the amount of slowly digestible OM in the rumen increases. Retention time of fiber in the rumen, or the length of time that fiber is exposed to the fibrolytic process is influenced by initial fiber particle size, rate of particle size reduction (chewing, rumination), particle density, and rate of digestion. Currently adopted laboratory approaches (QI, RFV, RFQ) for assessing forage quality are not well accepted by nutritionist. The models are not sufficiently accurate in assessment of practical differences between forages of similar classification, and they do not appraise forages with respect to their primarily role as “roughage”. Forages are included in the diet to reduced incidence of acidosis. Due to comparatively high prices of forages per unit energy, the nutritionist’s attempt to provide the minimum amount of forage that will safely permit maximal performance response. Forages are included in formulations for feedlot and dairy cattle to achieve a specified NDF level, **not** forage level. Selection of forages to reduce their NDF content, is an obvious means for enhancing the energy value of the forage. However, this is often nothing more than a costly dilution of the forage fiber. When forages are substituted into the diet on an equal NDF basis, differences among forages in feeding value become small, or non-appreciable. Nevertheless, net energy values of individual feed ingredients in a dietary formulation are largely additive. Thus, when forages are compared on an equal forage level basis, gain efficiency and dietary net energy values are consistent with the energy value of the respective forage.

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