UNDERSTANDING NUTRITIVE VALUE: ALTERNATIVE FORAGES

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INTRODUCTION

There is a tendency to consider forages largely in terms of their energy value or TDN. However, the feeding value of forage is actually a more complex function of its nutrient composition, chemical-physical characteristics of its fiber, acceptability (palatability), and associative interactions it might have with other dietary ingredients. Because forages are not usually cost-competitive with concentrate feedstuffs as energy sources, their inclusion in formulations for feedlot and dairy cattle is dictated more particularly on the basis of their function as roughage. Feedstuffs that contribute extra nutritional benefits, separate and distinct from their nutrient supply, are referred to as “functional feedstuffs”. 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

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 (see Figure 1.).

Fiber digestion vs. digestibility

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

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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 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 is needed for the degradative process. The nature of the fiber, the rate of particle size reduction and rate of passage are its most 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. 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 is not 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 (see Figure 2). 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 Φm 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 Impact of Forage on Energy Intake

How differences in fiber components affect the functionality of forages is poorly understood, or appreciated. Hence, currently applied standards are overly simplistic. For example, the National Forage Testing Association adopted an approach for comparing forages known as relative feed value (RFV). The RFV is calculated from predicted values for DMI (DMI, % of BW = 120 / (NDF, % of DM) and digestible dry matter (DDM) based on laboratory analyses for acid detergent fiber [ADF; DDM, % of DM = 88.9 - .779 * (ADF, % of DM)]. Accordingly, RFV = DMI * DDM / 1.29. Like other comparable systems (forage quality index; relative forage quality), the RFV makes not attempt at distinguishing among forages as to their "functionality" as roughages. It does not differentiate among forages with respect unique properties of the fiber that might limit its rate of passage from the rumen. The approach assumes that forage is the sole dietary ingredient and that NDF intake will be constant at 1.2% of body weight. In short, the system compares forages as energy sources when they are the sole dietary ingredient. Consequently, RFV (and related systems) has received very limited consideration by nutritionist in diet formulations for feedlot and dairy cattle, where the primary purpose for forage inclusion is to prevent digestive dysfunction. The bottom line: forage is not included in the diet for its *nutritive* qualities independently of its *functional* qualities.

A primary concern with respect to fiber digestion is its relationship with energy intake and hence, animal performance. 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. Many models have been developed over the past decade, in an effort to explain the risks associated with intake of the various forages. 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)). With a 220 kg calf fed a growing diet containing 21% NDF, a 20% reduction in ruminal fiber digestion is expected to depress the 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 enhance by inhancing 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 Alternative Forages

In order to see more clearly the principles indicated above, let’s look at a recent evaluation of sudangrass and elephant grass hays as partial replacements for alfalfa hay in diets for lactating Holstein cows (Alvarez et al., 2002; Plascencia et al., 2003). Elephant grass (Pennisetum purpureum) is a tall leafy perennial that is characteristic for its high biomass yield (>300 kg/hectare). The nutrient composition of elephant grass has comparatively little variation between cuttings, even when cut infrequently (Chaparro and Sollenberger, 1997). In these studies researchers evaluated Promor A, a new elephant grass variety selected for its superior agronomic characteristics (growth, tillering, closing in, ratooning ability, drought tolerance and ease of cutting), and for its higher CP:NDF ratio. Cows were fed a steam-flaked corn-based diet containing (DMB): 1) 49% alfalfa hay; 2) 24% alfalfa hay and 16% sudangrass hay; 3) 24% alfalfa hay, 8% sudangrass hay, and 8% elephant grass hay; and 4) 24% alfalfa hay and 16% elephant grass hay. Diets were formulated to contain 26% NDF and 20% eNDF (DMB). Compoistion of experimental diets are shown in Table 1.Four lactating Holstein cows with cannulas in the rumen and proximal duodenum were used in a 4 x 4 Latin square experiment to evaluate the effects of forage substitutions on digestive function. Twelve cows were used and a 4 x 4 Latin square to evaluate treatment effects on lactational performance. The results of these two trials are shown in Tables 2-4. Substitution of a portion (40%) of alfalfa hay for grass hay in diets for lactating cows slightly decreased ruminal microbial efficiency. However the impact on ruminal and total tract digestion of OM and NDF were small. Because of differences in NDF content of alfalfa hay versus grass hays, substitution of a portion of the alfalfa hay with grass hay results results in less total dietary forage, permitting greater dietary energy density. Based on diet formulation on the intake model presented about (Zinn and Salinas, 1999), expected DMI and 3.5% milk yield was 21.1 and 33.1 kg/d, respectively, for the alfalfa hay diet and 20.9 and 33.7 for the grass hay replacement diets. According to the model, the alfalfa hay diet was slightly limiting lactational performance, while the grass hay containing diets was projected to allow for an additional 143 kg extra milk during a 305-d lactation. Results shown in Table 3 were in close agreement with projected performance based on the intake model. Partial replacement of alfalfa hay for either sudangrass or elephant grass did not limit DMI and lactational performance.

In like manner, Alvarez et al (2000) observed that in feedlot cattle fed a steam-flaked corn-based growing diets containing 20% forage (DMB) as Promor A, alfalfa hay (early bloom), or sudangrass hay, DMI and ADG were greater for diets containing grass hay. The observed net energy value of Promor A (1.19 and .63 Mcal/kg for maintenance and gain, respectively) was slightly lower than predicted (1.32 and 0.75 Mcal/kg, respectively) based on its crude protein and fiber content [$NEm = 0.64 + (3.18CP / NDF)$]. Prediction equations of the type tend to overestimate the energy value of feedstuffs that are unusually high in ash (Promor A contained 15.4% ash). Virtually all of the improvement in ADG was attributable to superior palatability or acceptability of elephant grass versus sudangrass and alfalfa hay.

CONCLUSIONS

Feeding value of forage is complex function of its nutrient composition, chemical-physical characteristics of its fiber, acceptability, and associative interactions that it might have with other dietary ingredients. Forages are comparatively expensive energy sources. Consequently they are included in formulations for feedlot and dairy cattle primarily on the basis of their function as roughage. Due to slower rates of degradation and passage from the rumen, the fiber component of forages can be a major limitation on dry matter intake and cattle performance. Thus, when nutritionists are faced with the dilemma of substituting a “reputation” forage with an alternative less familiar forage, the primary concern is how the substitution impacts energy intake and digestive function. Although complex in nature, practical models are in place for aiding nutritionists in better assessing the risks involved in selecting alternative forages.

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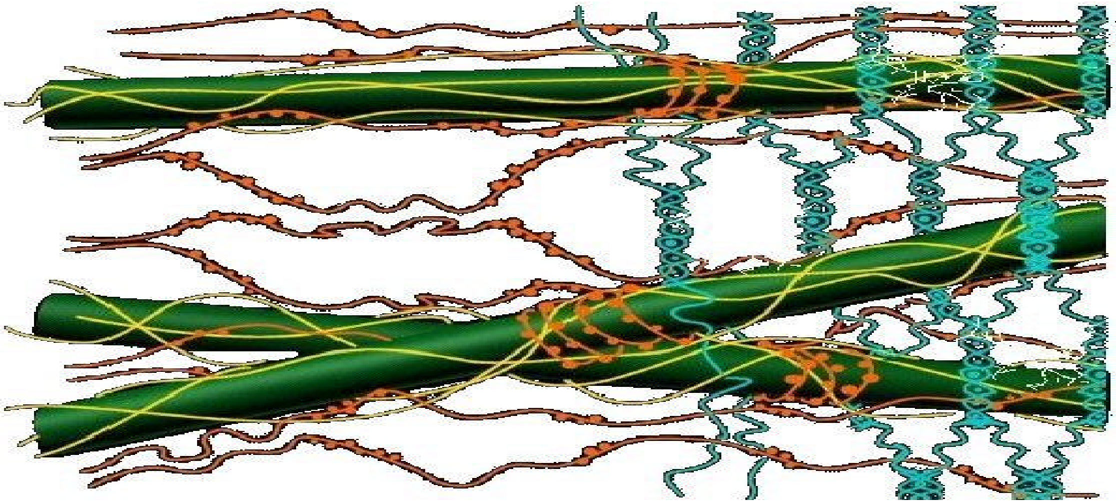
Figure 1. Representation of fiber matrix. (adapted from Tomme et al., 1995)



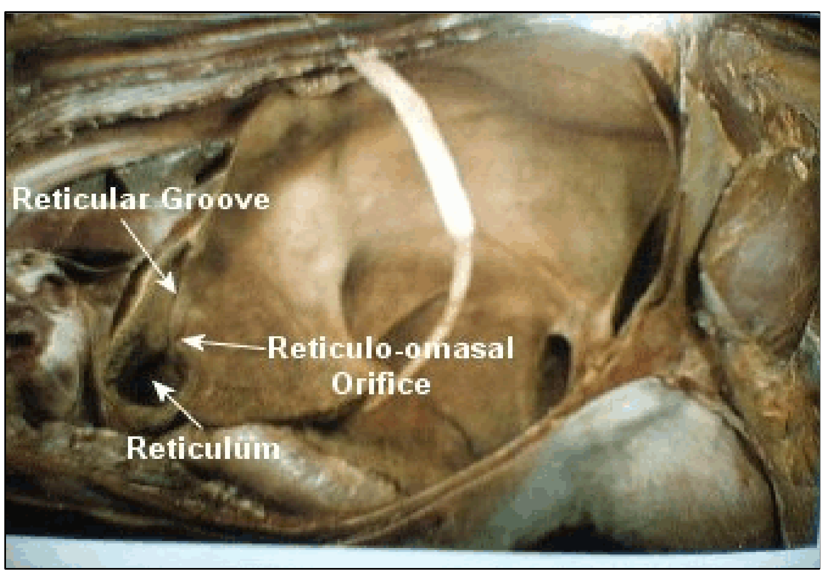


Table 1: Composition of experimental diets fed to cows (Trials 1 and 2)[a].

	Alfalfa	Promor A grass:Sudangrass ratio		
Item	Hay	0:100	50:50	100:0
Ingredient composition, % (DM basis)				
Alfalfa hay	49.00	24.00	24.00	24.00
Sudangrass hay		16.00	8.00	
Promor A hay (Elephant grass)			8.00	16.00
Steam-flaked corn	34.55	40.70	40.70	40.70
Yellow grease	2.00	2.00	2.00	2.00
Fishmeal	1.00	1.50	1.50	1.50
Canola meal	6.00	8.00	8.00	8.00
Cane molasses	6.00	6.00	6.00	6.00
Limestone	.30	1.00	1.00	1.00
Trace mineral salt[b]	.50	.50	.50	.50
Magnesium oxide	.20	.20	.20	.20
Dicalcium phosphate	.45	.10	.10	.10
Nutrient composition, DM basis[c]				
NE_L, Mcal/kg	1.77	1.83	1.83	1.83
Crude protein, %	17.5	15.0	15.4	15.8
UIP, %	4.8	5.1	5.2	5.3
Metabolizable methionine, g/d	39	41	41	41
Metabolizable lysine, g/d	125	127	127	128
NDF, %	27.8	27.8	26.93	26.0
ADF, %	19.1	17.6	17.0	16.5
NSC, %	41.8	44.3	44.3	44.3
Ether extract, %	5.1	5.1	5.1	5.1
Calcium,%	1.06	1.00	1.00	1.00
Phosphorus,%	.41	.40	.40	.40
Potassium, %	1.22	1.21	1.21	1.21
Magnesium, %	.39	.40	.38	.37
Sulfur, %	.30	.27	.27	.27

1Figure 2. Rumen Interior (adapted from Ashdown et al., 1984)

[a]Chromic oxide (.35%) added to diets in Trial 1 as a digesta marker.

[b]Trace mineral salt contained: $CoSO_4$, .068%; $CuSO_4$, 1.04%; $FeSO_4$, 3.57%; ZnO, 1.24%; $MnSO_4$, 1.07%; KI, .052%; and NaCl, 92.96%.

[c]Based on tabular values for individual feed ingredients (NRC, 1996). Tabular values for elephant grass are not provided by NRC (1996). Elephant grass has a mineral content comparable to sudangrass hay, however, it is higher (48%) in CP, and lower (8%) in NDF.

Table 2. Influence of partial substitution of alfalfa for hay grass (sudangrass, elephant grass) on digestive function in diets for lactating dairy cattle (Alverez et al., 2002).

		Treatments [a]			
		Sudangrass:Elephantgrass, ratio			
Item	Control	100:00	50:50	00:100	SEM
Intake, g/d					
DM	15055	15054	15347	15115	122
OM	13617	13818	13657	13418	119
NDF	4065	4230	3699	3643	32
N	390	327	384	366	3
Flow to the duodenum, g/d					
OM[c]	9008	8345	8486	8290	263
NDF	2983	2717	2576	2480	209
N[bd]	417	362	401	380	10
NAN[ed]	396	345	381	362	9
MN	200	169	197	169	12
Feed N[f]	197	177	183	193	6
Ruminal digestion, % of intake					
OM	48.3	51.7	52.6	50.9	2
NDF	26.1	35.7	30.4	32	5.5
Feed N[g]	49.7	45.8	52.6	47.6	1.7
MN efficiency [ch]	30.4	23.9	27.4	24.8	1.9
N efficiency[fi]	1.01	1.06	0.99	0.98	0.03
Postruminal digestion, % of flow to duodenum					
OM	52.6	50.9	51.1	53.1	2.5
NDF	19.6	13.9	12.5	10.8	7.9
N	70.5	68.8	69.7	69.3	0.6
Total tract digestion, % of intake					
DM	67.1	67.1	66.7	67.9	0.9
OM	68.7	70.3	69.9	71.4	1
NDF	41.7	45.4	40.2	43.5	2.5
N[b]	68.6	65.3	68.6	68.4	0.8
DE, Mcal/kg[e]	2.71	2.85	2.78	2.9	0.04
Digestible Energy, %[e]	64.6	67.3	66.8	68.5	1

[a] Treatments: Control, 49% alfalfa hay; 100:00, 24% alfalfa hay and 16% sudangrass hay; 50:50, 24% alfalfa hay, 8% sudan grass hay, and 8% elephant grass hay; and 00:100, 24% alfalfa hay and 16% elephant grass hay.

[b] Linear effect of grass hay, $P < .05$. [h] Microbial N, g/kg OM fermented.

[c] Alfalfa vs grass effect, $P < .10$. [i] Nonammonia N leaving the abomasum/N intake.

[d] Quadratic grass hay effect, $P < .10$. [g] Quadratic grass hay effect, $P < .05$.

[e] Alfalfa vs grass effect, $P < .05$.

[f] Linear effect of grass hay, $P < .10$.

Table 3. Milk yield and change of body condition score in Holstein cows fed the experimental diets (Plascencia et al., unpublished)

Item	Alfalfa hay	Promor A: sudangrass hay ratio			SD
		0:100	50:50	0:100	
Cows	8	8	8	8	
Wight, kg					
Initial	571	566	561	568	14
Final [a]	576	581	559	573	21
DM intake, kg	21.77	22.08	22.15	21.40	2.73
Milk yield, kg/d	31.71	31.31	33.72	32.20	3.56
FCM (3.5%), kg/d	33.82	33.19	34.30	33.64	4.07
Milk yield/DMI	1.56	1.52	1.59	1.60	.29
Body condition score					
Initial	2.78	2.75	2.90	2.81	.11
Final [b]	2.84	2.75	2.81	2.88	.13

[a] Quadratic component ($P<0.10$).

[b] Linear component ($P<0.10$).

Table 4. Characteristics of milk composition from Holstein cows fed the experimental diets

Item	Alfalfa hay	Promor A: sudangrass hay ratio			SD
		0:100	50:50	0:100	
Cows	8	8	8	8	
Milk composition,%					
Protein	3.14	3.08	3.14	3.12	.09
Fat [a]	3.63	3.66	3.67	3.70	.08
Lactose [b]	4.84	4.79	4.88	4.78	.10
Solids non fat	8.59	8.58	8.61	8.50	.25
Total solids	12.22	12.24	12.28	12.20	.20
Casein	2.51	2.43	2.49	2.46	.08

[a] Alfalfa vs grass hay ($P<0.05$).

[b] Quadratic component ($P<0.10$).