Defining Forage Quality; What is it?

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ABSTRACT

The first step in discussing forage quality is to arrive at a consensus on exactly what constitutes "quality". For the purposes of this discussion forage quality will be defined as "the ability of a forage to provide nutrients to livestock". We will then evaluate the factors that affect the ability of a given alfalfa sample to meet the nutritional needs of an animal and discuss how laboratory analyses relate to animal performance.

Key Words: alfalfa, forage quality, nutritive value, energy, fiber, protein

INTRODUCTION

Numerous approaches have been taken in defining forage quality over the past 200 years, unfortunately, a single, all-inclusive definition has so far evaded us. The difficulty in arriving at a single definition of forage quality is because forage quality, much like beauty, is in the eye of the beholder. Horse owners, and those hay producers that supply them with alfalfa, commonly use physical characteristics such as color, leafiness and stem thickness in describing the "quality" of alfalfa. Commercial hay producers may define a "quality" alfalfa as one that gives the greatest net profit. For the purpose of this discussion, however, I am going to display my personal biases as an animal nutritionist and suggest that we define forage quality as the ability of a forage to provide nutrients to livestock. One of the main reasons that I favor nutritive value as the definition of forage quality is that the only reason we produce alfalfa is for use as a livestock feed. And the reason we feed livestock (dairy and beef cattle, sheep, horses, etc.) is so they will produce a product (meat, milk, wool) or service (transportation or traction) for us. Therefore, defining quality as nutrient availability makes sense because the production of these products or services is directly related to the nutrient availability of the forage.

To simplify matters, I will restrict my discussions and examples to lactating dairy cattle, as I believe they are the ruminant of choice among the current audience. It is important to remember, however, that many of the principles I will be discussing also apply to beef cattle, sheep, llamas, etc.

WHAT NUTRIENTS?

If we are going to discuss the ability of alfalfa to provide nutrients, it would be helpful to know exactly which nutrients we are talking about. Years of scientific study have provided us with extensive information on the specific nutrients required by lactating dairy cattle and in most cases, the quantities of them that are required to reach a given level of production. A quick glance through a nutrition text book or the National Research Council publication entitled

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"Nutrient Requirements of Dairy Cattle" will provide us with a list composed of: water, energy, protein, fiber, minerals and vitamins. Requirements for each of these nutrients can be calculated for animals of very specific descriptions (age, body weight, level of milk production, etc.) and are commonly used by nutritionists to formulate rations (Table 1). Although nutritionists must consider all nutrients to completely balance a ration, for the purpose of brevity I will restrict myself to three (energy, fiber and protein) for further discussion on forage quality.

Table Nutrient requirements for a 1300 pound Holstein cow at four levels of milk production.

Milk Production (LB/D)	Energy (Mcal/D)	Fiber [NDF] (%)	Crude Protein (LB/D)	Minerals Ca	Minerals P	Vitamins A	Vitamins D
				---(%)---		(1,000 IU)	
120	47.3	25	1.0	0.66	0.41	1,450	450
90	38.0	25	8.5	0.65	0.42	1,450	450
60	28.7	28	6.0	0.60	0.38	1,450	450
Dry	10.1	35	0.9	0.39	0.24	1,000	140

Taken From: Nutrient Requirements of Dairy Cattle, 6th. Rev. Ed., 1989. National Research Council, National Academy Press, Washington, D.C. 1989.

Identifying the specific nutrients required is important in our discussion because this tells us what components of alfalfa we need to be measuring to characterize forage quality. Let's take a look at each of our three nutrients and learn a little more about what they are, how they are measured and how they affect our definition of forage quality.

ENERGY

Commonly the nutrient most limiting in the diets of lactating dairy cattle, energy is also the nutrient most apt to need supplementation in diets containing high levels of alfalfa. The importance of energy to animal production and its impact on limiting the level of alfalfa that can be fed to dairy cattle would suggest that energy may be the most important criteria to use in evaluating the "quality" of alfalfa. Unfortunately, energy is the most difficult nutrient to measure in alfalfa and in almost all cases must be estimated from some other plant constituent. The difficulty in measuring energy comes from the fact that almost all components of an alfalfa plant contribute some quantity of energy during digestion, but the exact contribution varies greatly and can seldom be accurately predicted. This highlights the main problem associated with using nutritive value as a measure of forage quality; namely that we are forced to use laboratory analyses for specific chemical components (such as sugar, starch, nitrogen or fiber) to estimate nutritional values. As table 2 demonstrates, the nutritional value of some chemical constituents, such as sugar and starch, can be easily estimated because they are almost completely digested and contribute to only one nutritional entity - energy. The energy that can be obtained from other constituents, however, such as protein, hemicellulose and cellulose are harder to predict because they vary greatly in digestibility.

Table 2. Contribution of various plant constituents to the nutritive value of alfalfa.

	Component	Fiber	Energy	Protein
Cell Contents				
	Sugar	No	Yes	No
	Starch	No	Yes	No
	Protein	No	Varies	Yes
	Lipid	No	Varies	No
Cell Wall				
	Pectin	No	Yes	No
	Hemicellulose	Yes	Varies	No
	Cellulose	Yes	Varies	No
	Lignin	Yes	No	No

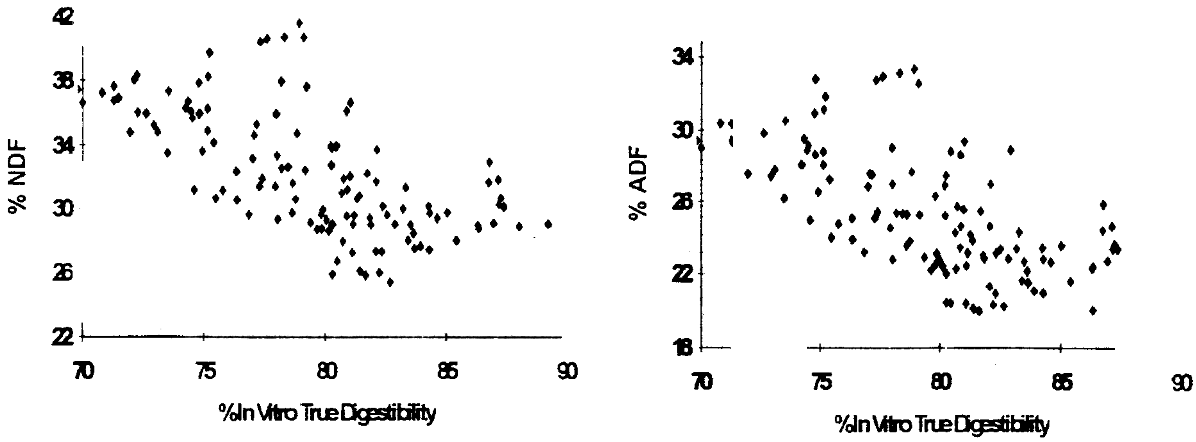
A key consideration in determining how much energy will be available from a given alfalfa sample is knowing to what extent the sample will be digested by the rumen microbes. Although such evaluations (refered to as *in vitro* analyses) can be conducted in the laboratory, these analyses are not available through most commercial labs. Currently most nutritionists use mathematical equations based upon fiber concentration (NDF or ADF) to predict the energy value of alfalfa. These equations are based upon the observation that as fiber concentration goes up, digestibility tends to decrease and thus energy availability declines.

Table 3. Currently used energy prediction equations based upon fiber concentration and a comparison of results for an alfalfa sample containing 35% NDF and 27% ADF.

Source	Equation	Estimated TDN (%)	Estimated NEl (Mcal/LB)
California			
	TDN (%) = 82.38 - (0.7515 X ADF)	62	
Wisconsin (D.R. Mertens)			
	TDN (%) = 86.2 - (0.513 X NDF)	68.2	
	TDN (%) = 84.2 - (0.598 X ADF)	68.1	
	NE_l (Mcal/LB) = 1.054 - (0.0098 X NDF)		0.711
	NE_l (Mcal/LB) = 1.011 - (0.0113 X ADF)		0.706
New York			
	NE_l (Mcal/LB) = 1.085 - (0.015 X ADF)		
Pennsylvania			
	NE_l (Mcal/LB) = 1.044 - (0.0119 X ADF)		

Table 3 presents several of the most common equations used by nutritionists, and as can be seen, depending upon the equation that is used, the estimated energy value can vary significantly. A key assumption underlying the use of these equations is that there is a direct relationship between fiber concentration and digestibility. As Figure 1 shows, recent research has demonstrated that this relationship is far weaker than previously though and reminds us to use caution when basing energy estimates on fiber concentration. The importance of energy in properly formulating rations for lactating dairy cattle, and therefore evaluating the "quality" of alfalfa, demands that more accurate methods for determining the energy concentration of alfalfa (and all feedstuffs) be developed. This will almost certainly require that our standard chemical analyses (NDF and ADF) be replaced with nutritional analyses such as in vitro or in situ techniques. Development of such a technique, that is inexpensive and repeatable across laboratories will greatly enhance our ability to use energy availability as a major consideration in defining forage quality.

Figure 1 Relationship of fiber concentration (NDF and ADF) with digestibility of alfalfa.



PROTEIN

After energy, protein is the nutrient of greatest concern among most nutritionists. A familiar term to most of us, protein has been used as a measure of forage nutritive value for almost 200 years. Nutritionally we use the term crude protein, because the analytical technique that is used to measure protein does not really measure protein, but rather total nitrogen, including nitrogen present in the from of true proteins, peptides, amino acids, ammonia, nitrates and urea. Alfalfa is considered an excellent source of protein not only because it is high in crude protein concentration, but also because most of the crude protein fraction is composed of true proteins. The long-term popularity of using crude protein as a measure of forage nutritive value is probably due to several factors, including ease of obtaining accurate laboratory analyses and the readily observed response of lactating dairy cattle to changes in dietary crude protein levels. Using crude protein content as the sole means of characterizing the nutritional value of alfalfa has some unique limitations, however, as extremely high levels of protein in alfalfa is not always nutritionally desirable.

The problem with feeding high levels of crude protein is that in some cases rumen degradation of proteins generates excessive levels of nitrogen in the rumen that are absorbed into the cows circulatory system. Removing these high levels of nitrogen from the blood stream increases the filtering load placed on the kidneys and requires the use of energy that could otherwise be used for milk production. If elevated blood nitrogen levels continue for an extended period of time, the cow's immune system may begin to fail and reproductive disorders such as reduced conception rate or spontaneous abortions may occur.

Understanding the importance of the relative proportions of degradable and undegradable protein has resulted in a refinement of the crude protein system to account for these fraction and to permit their use in formulating rations and evaluating forage quality. The degradable fraction of crude protein is referred to as degradable intake protein (DIP) and the undegradable portion is called undegradable intake protein (UIP) or "bypass" protein. Much emphasis has been placed on the need for increasing the UIP levels in the diets of dairy cattle to insure that adequate levels of protein are reaching the small intestine of the cow and are not being wasted in the rumen. It is important to remember, however, that rumen microbes do require nitrogen and decreasing protein degradability may limit the ability of the microbes to function properly in the rumen.

Because the protein in alfalfa is highly degradable (up to 80%), some scientists have argued that increasing the UIP fraction would improve the feeding value of alfalfa protein. In diets where alfalfa represents 50 to 70% of the total ration protein, such as we have in the Midwest, this argument has great merit. In diets typically fed to lactating cattle in California, however, high levels of byproduct feeds are often fed that are high in UIP and alfalfa serves as the primary source of DIP for the rumen microbes. This highlights the fact that our definition of forage quality is not only affected by the composition of the forage and the requirements of our livestock, but also depends upon how the forage will be combined with other feed ingredients.

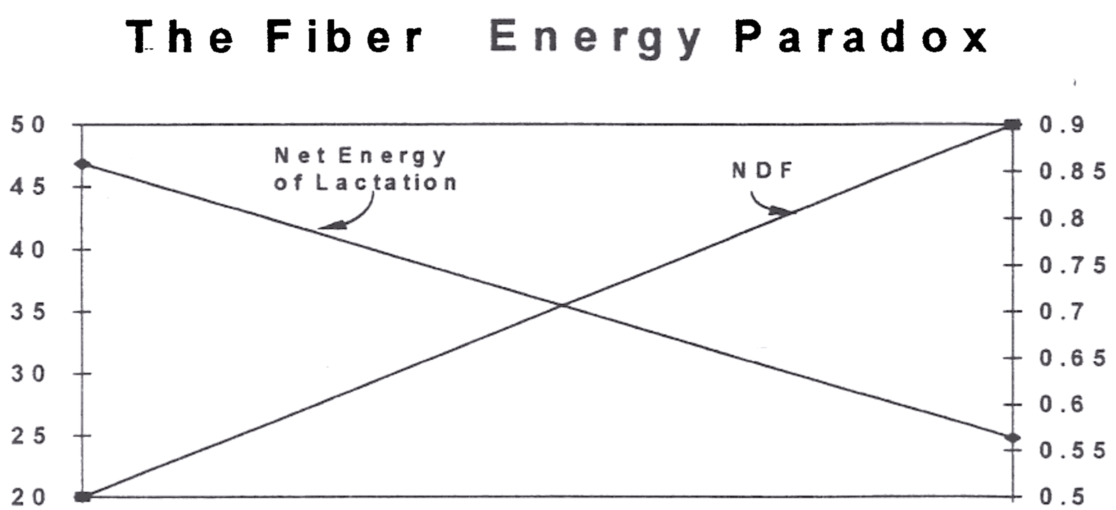
FIBER

Sometimes viewed as an undesirable component in alfalfa because of it's limiting effect on intake and negative association with energy density, fiber is required by lactating dairy cattle because it is essential for maintaining proper rumen function. Fiber is composed primarily of hemicellulose, cellulose and lignin, and is contained in the cell wall of plants where it provides support, in much the same way as our skeleton supports us. Because it is designed for rigidity and strength, the compounds used in forming fiber are very tough and are resistant to degradation. While this is desirable in the living plant, the difficulty in degrading fiber is undesirable in the rumen where the slow rate and incomplete extent of microbial degradation of fiber can greatly limit energy intake.

High fiber levels tend to limit energy intake in two ways, one through a limitation in dry matter intake due to an accumulation of undigested fiber in the rumen and secondly through the reduction in digestibility associated with increased fiber concentrations. Laboratories commonly offer two analyses for fiber concentration, neutral detergent fiber (NDF) and acid detergent fiber (ADF). Neutral detergent fiber represents the total fiber (hemicellulose, cellulose and lignin) contained in a sample and has been shown to be highly related to dry matter intake (low NDF = high intake). The ADF analysis was developed use in predicting digestibility and contains only cellulose and lignin, under the assumption that hemicellulose was highly digestible and would reduce the ability to accurately predict digestibility. Research has shown that hemicellulose and cellulose are virtually identical in their digestibilities, therefore it has been found that NDF and ADF are equally accurate (inaccurate?) at predicting digestibility (Figure 1). Because it recovers the total fiber fraction, NDF is still the preferred analysis for use in predicting voluntary intake.

Based upon the negative effects associated with fiber, it would seem that reducing fiber levels in forages (and animal rations) as much as possible would be of great benefit. However, it is important to remember that dairy cattle (and all ruminants) have highly specialized digestive systems that are designed to function on high fiber diets. Removing fiber from the diet causes serious physiological and metabolic problems that can have devastating consequences. As Figure 2 demonstrates, this presents a challenge to nutritionists who need to reduce dietary fiber levels to increase dry matter intake and provide adequate energy for high producing dairy cattle, while still maintaining adequate fiber for proper rumen health.

Figure 2. Relationship of fiber concentration to energy availability in alfalfa.



Using fiber as a measure of forage quality presents a special challenge, as it is a desirable component with undesirable attributes. This tells us that in developing systems to characterize forage quality based on fiber, we must begin to think in terms of looking for an optimum level of fiber in our alfalfa, not a minimum as we currently do. For example, evaluating alfalfa using a predicted TDN value based on an ADF analysis (as is currently done in California) indicates that the best alfalfa we could have would contain no fiber (0% ADF), and would have a TDN value of 82.4%. The lack of sufficient fiber to stimulate rumen function, however, would make this a very difficult forage to feed without causing metabolic problems in dairy cattle. The specific optimum fiber level for alfalfa varies greatly from situation to situation depending upon the animals to which it is being fed and the fiber content of the other ingredients of the diet. The key thing to remember is that both fiber and energy are required by dairy cattle and both need to be considered in determining the "quality" of alfalfa.

SO WHAT DOES ALL THIS MEAN?

While defining forage quality based upon the ability of the forage to supply nutrients for livestock seems like a simple enough idea, the complexity of the ruminant digestive system, variation in nutrient requirements among groups of animals and differences in feeding programs require that such a system be very sophisticated. As we have discussed, estimating energy availability is not an exact science and requires some intelligent "fudging" in the real world. We also know that increasing the crude protein levels of alfalfa may not always improve the nutritional value of the forage and that we need to be concerned about the relative proportions of degradable and undegradable protein. Reducing fiber concentrations of alfalfa tends to increase intake and energy density, however, dairy cattle require fiber in their diets and can suffer serious metabolic disorders if not provided with adequate fiber.

Combining all of these observations makes it clear that defining forage quality based upon nutrient availability is actually quite a complex undertaking and requires some understanding of ruminant nutrition. It also indicates that simple approaches to categorizing forage quality based upon concentrations of a single entity, such as crude protein (N) or TDN (estimated from fiber), are not sophisticated enough to determine how effective a given alfalfa sample will be at providing the nutrients required by your cows given your specific feeding program.

In conclusion, the take home message of this discussion is that forage quality can and should be described in terms of available nutrients. The key to making this definition work is a realization that extremes in composition (high protein and low fiber) do not necessarily equate to higher forage quality. For every feeding situation, there is an optimum balance of nutrients that are required and our view of forage quality needs to be based upon meeting this optimum balance, not exceeding it.