

NEW/EMERGING MEASUREMENTS FOR FORAGE QUALITY

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ABSTRACT

A nationally accepted standard hay test for alfalfa hay has included measurement of Acid Detergent Fiber (ADF), Neutral Detergent Fiber (NDF), Dry Matter (DM) and Crude Protein (CP). Total Digestible Nutrients (TDN) has typically been calculated directly from a fiber measurement, usually ADF. However, this is likely to change. While there are a range of points of view on forage testing, it is likely that forage testing will evolve towards greater use of NDF, estimates of NDF digestibility (NDFD), and use of summative equations to predict feeding value. ADF, developed as a preparative step for lignin, will be de-emphasized. Greater inclusion of ash measurements, protein fractions are likely. Techniques such as the gas evolution method may provide important added dimensions to forage measurements. Summative equations, which incorporate several measurements, may provide improved prediction of quality, especially for forages of similar ADF, but with different known performance. Adoption of these analyses will be limited by uncertainty about consistency of measurement and marketing considerations. While markets prefer single measurements of forage quality, the ability to incorporate multiple measurements is critical for improved prediction of quality from forages, since forage quality is by definition multidimensional.

Keywords: hay testing, lab testing, ADF, NDF, CP, digestibility, analyses

INTRODUCTION

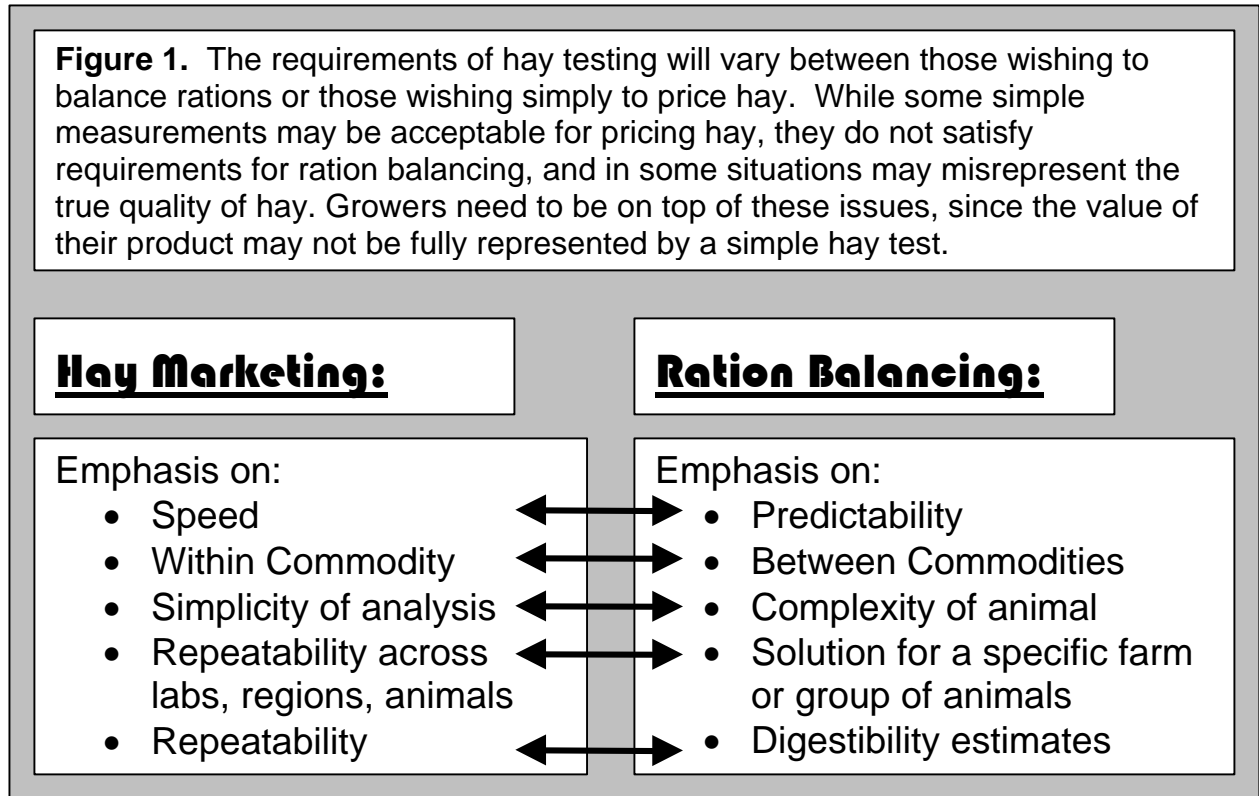
There is little question that the testing of forage crops has acquired increased importance in recent years. This should not be surprising. An average cow today produces 65% more milk than in 1970, and there are individual cows and herds that produce several times that amount. Today's dairy animal consumes a ration vastly different—and much higher in nutritional value—than her great grandmother did. Today, alfalfa hay must be compared with other forages such as corn silage, and many types of concentrates.

Milk production per animal is currently increasing about 2-3% per year (20 year average), and there is little sign that this trend will abate. While in 1972, the minimum 'TDN' value (see footnote for abbreviations) for alfalfa hay was considered to be 52% in California; today that value is 54.5% to 57% TDN values for 'dairy quality' alfalfa hay. To an alfalfa grower, 30-60% of the value of cash hay is determined by quality factors (differences between high and low categories). There is no question that demands for high quality forage for the dairy sector will

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ABBREVIATIONS: TDN: Total Digestible Nutrients, ADF = Acid Detergent Fiber, NDF = Neutral Detergent Fiber, CP = Crude Protein., NFC = Non-Fiber Carbohydrates, NDFD = Neutral Detergent Fiber Digestibility, NFTA = National Forage Testing Association.

continue, and even intensify in the future. This paper examines several important trends in forage testing and how these might impact Western US dairy-forage markets.

This intensification of demand for higher quality for the dairy markets has been primarily focused on lower fiber content. TDN is calculated as a negative linear function of fiber, usually ADF. Relative Feed Value (RFV), used in some areas for marketing, is also a negative function of the fiber measurements ADF and NDF. And while fiber content is an important predictor of animal performance, there are few nutritionists that believe that fiber alone is sufficient to encompass the many factors determining quality in alfalfa hay or other forages. Our current system has limitations that are likely to necessitate changes in the coming years.



FORAGE TESTING AND QUALITY ANALYSIS—MULTIPLE GOALS

It might not be immediately apparent that the requirements for hay testing will differ depending upon the use. While those who market hay place a high degree of emphasis upon simplicity, speed, reliability of results, and transparency of methods. However, ration balancing is an exercise to optimize animal production with a given batch of hay, set of animals, and availability of different feeds (Figure 1). Thus, for ration balancing, emphasis is placed on comparing between commodities (e.g. how much alfalfa or corn silage to feed?), on the true predictability of the measurement, the complex needs of specific animals (e.g. does a close-up cow need more calcium?), with little need to compare with other farms or rations. Determination of quality for marketing requires a high degree of confidence in the repeatability of the numbers. Not all

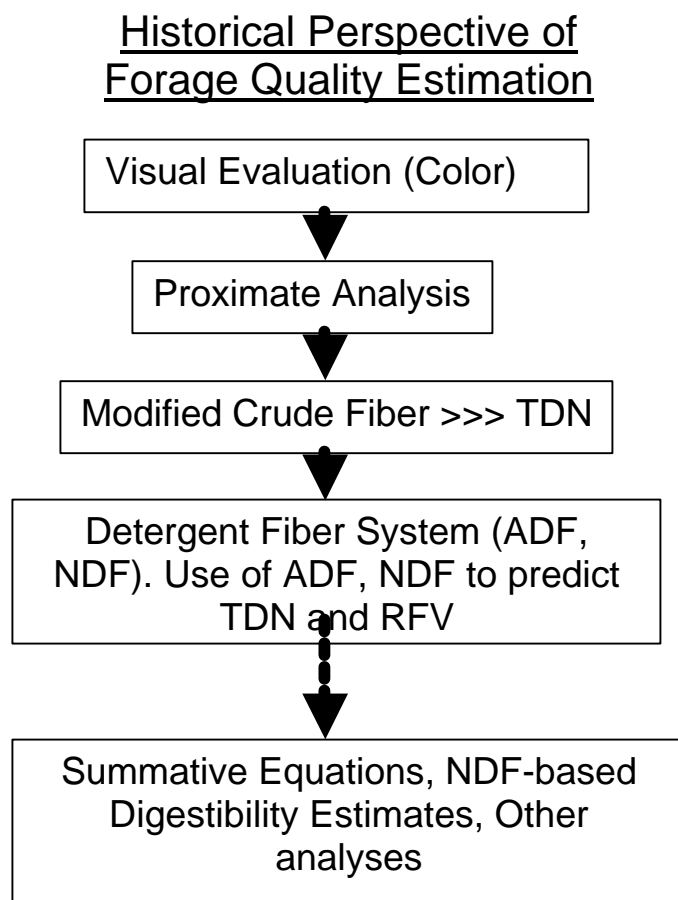
measurements are needed to market hay, since not all attributes carry enough weight to place an economic value on that measurement, but they are still needed for ration balancing.

On the other hand, it is very likely true that several aspects of feeding value are clearly missed by our current standard hay test. I have heard from dairymen the frequent observation that a hay ‘fed better than it’s test’ or a high-test hay ‘feed poorly’ for a Supreme Quality hay. These observations are a good indication that our hay tests do not pick up all aspects of quality. I don’t have solid evidence to support this, but I believe this is particularly true within the ‘middle’ group, those hays between an ADF of about 27 and 31, which may be misrepresented as to their true feeding value. Growers should be particularly concerned about this issue since the value of their hay may be underrepresented. In particular, if there are ‘medium’ quality hays that in reality perform better, it’s important to have methods to determine this.

HISTORICAL PERSPECTIVES and CURRENT PRACTICE

Although there are plenty of opportunities to critique our current system, one has to appreciate the changes in hay analyses that have taken place over the past decades. In the 1920s through the 1950s, hay quality was primarily determined by color. The USDA developed ‘standards’ based upon color, which were used in marketing. It is interesting to read these standards, since what passed as ‘premium’ hay at that time would not likely today be considered even ‘medium’ quality (among other things, the top standard allowed up to 49% seed pods!). Our cutting schedules and other practices have clearly changed. Although color may provide hints as to potential quality, leaf-stem ration is much more important, and there is considerable evidence that green color has a relatively poor relationship to true feeding value.

The measurement of Crude Fiber (CF) and later Modified Crude Fiber (MCF) provided a much-needed rationality to this process. An MCF method to predict TDN was proposed by scientists at UC Davis during the 1950s. By the 1970s, this was in common use in California, and provided a much-needed standardization to forage analysis. During the 1970s, Peter Van Soest at Cornell University developed methods for fiber analysis including ADF and NDF. ADF was developed as a preparative step for lignin



analysis, but rapidly became widely used to predict TDN, and is still used this way today by many nutritionists. The NFTA lists scores of different equations, which predict TDN from ADF or other fiber measurements (this represents a problem too, since TDN becomes difficult to compare). As this is written a 'standard' hay test includes ADF, NDF, CP and DM. However, this system has several shortcomings, which need to be addressed.

WHAT DO NUTRITIONISTS REALLY WANT?

While it is likely that a room full of 100 dairy nutritionists will reveal more than 100 approaches to forage quality, there are several important underlying principles which are likely to be common (see box). The differing opinions and approaches to animal nutrition are probably caused by 1) the genuine complexity of the rumen system itself, and 2) biases based upon genuine regional differences in forages, and 3) differences based upon school of thought and training. Thus a nutritionist that works primarily with 100% alfalfa hay rations may take a different approach than a nutritionist working with a grass-based grazing system, but there are important differences based upon 'schools of thought' as well. A parallel to this can be found in the large and very public philosophical differences in human nutritional thinking (e.g. the 'Atkins diet' vs. 'high grains' diet)!

A major challenge for forage testing is that the most important attributes of quality are not measured, but instead predicted!!

The most important aspect is 'biological energy', expressed as TDN, NEL, or other energy term (see box). The total amount of energy to be extracted is a complex function of animal biology and plant factors, and thus very difficult to routinely measure, and is instead predicted using combinations of measurements. The second most important attribute (especially for high producing dairy cows) is probably intake potential, which again is not measured, but predicted. Forages differ in these two important attributes, but these characteristics cannot be directly measured! A common method of predicting digestible energy is using an ADF-TDN equation. Fiber can be measured as NDF as can minerals, and there are several protein measurements, which may differentiate the digestive fate of the protein fraction. However, it should be clear from this, that some of the most important aspects of forage quality (digestible energy and

What do nutritionists want from alfalfa hay?

While there are many different approaches to ration balancing, many of the desirable attributes can be summarized as follows:

- 1) Digestible Energy (TDN, NEL, Sum Total potential biological energy of the forage)
- 2) High intake Potential (Rate of passage, energy available per unit time, palatability factors)
- 3) Effectively Absorbed Protein (both rumen available and rumen undegradable, or 'bypass')
- 4) Nutritionally Effective Fiber (NDF, long fiber for rumen function, animal health)
- 5) Mineral Balance (sufficient buffering capacity, ion balance between mono-valent and divalent)

intake) cannot by definition be easily measured, but must somehow be predicted. There is a strong need for improvements in the prediction of energy from feedstuffs and methods used to routinely analyze for these factors.

WHAT'S COMING IN FORAGE ANALYSIS?

Over time, it is likely that forage testing will move away from the current system of using ADF to predict TDN. The 2001 NRC 'Nutrient Requirements of Dairy Cows' made no mention of ADF, and relied heavily upon summative equations, or use of multiple measurements to predict quality. While simple quantification of fiber is useful as a first step in determining forage quality, it is of limited use in comparing across forage types. Measurement of ADF does not quantify differences in fiber digestibility, even within forage groups. Forage Intake, a key aspect of quality, is poorly predicted with ADF alone. In 2001, the National Research Council issued revised guidelines for dairy cows (2001, Nutrient Requirements of Dairy Cattle: Seventh Revised Edition, NRC, see: <http://www.nap.edu/catalog/9825.html> for ordering). This was a watershed for several reasons. This document did the following:

- Emphasized measured values vs. table values, a different approach than the previous editions.
- Emphasized intake factors—energy requirements change as level of intake increases.
- Incorporated estimates of ruminant degradation of plant fractions such as fiber and protein
- Emphasized NDF, no mention of ADF-TDN equations for different feedstuffs
- Recognized that effective fiber (NDF) is nutritionally important.
- Includes estimates of NDF digestibility as a part of the estimate of TDN
- Emphasis on summative equations to predict TDN

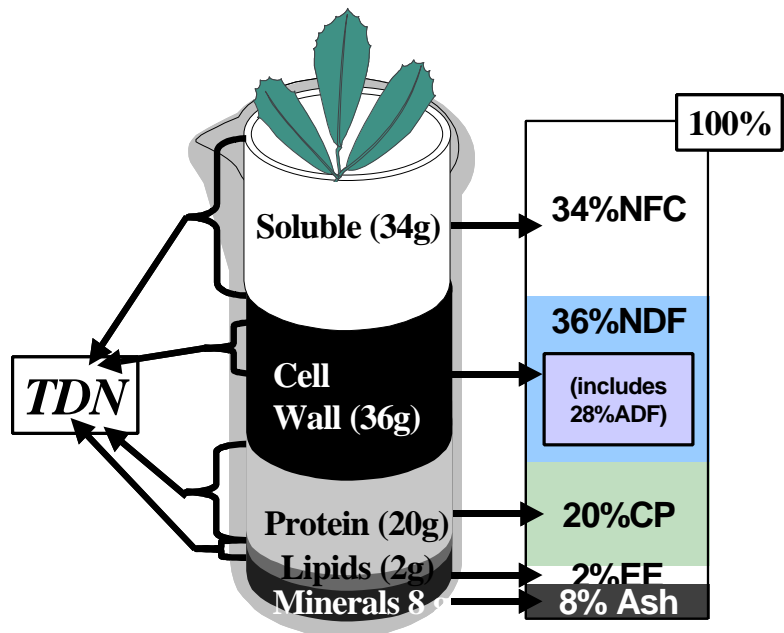


Figure 2. In 100 grams of alfalfa plant material, different components contribute differing amounts to forage quality in this example. The cell solubles (often termed Non-Fiber Carbohydrates, or NFC) contribute 100% towards energy or Total Digestible Nutrients (TDN). NFC can be estimated by difference (100%-NDF-CP-EE-Ash). Most of the protein contributes fully to TDN and Lipids contribute 100% towards energy, but are in very small amounts in alfalfa and grass forages (thus do not normally need to be measured). Minerals (ash) contribute zero towards TDN, and only some portion of the cell wall contributes towards TDN. Measurement of cell wall digestibility and ash are the major components missing from a standard hay test of NDF, ADF, CP and DM. Some nutritionists would also like to see a more sophisticated protein estimates (soluble vs. slowly degraded).

While there is no national unanimity on exactly which equations should be used, this NRC publication represents trends in thinking that resonate with many nutritionists. There will likely be continued discussion about exactly which exact equations should be used. Many of

the newer models for ration balancing will seek to estimate absorbed nutrients based upon digesting kinetics instead of using 'static' feed energy values. All of this provides a profound challenge to the forage testing process.

WHAT IS A SUMMATIVE EQUATION?

A summative equation predicts total digestible nutrients based upon the sum of the various sources of energy in the plant. In Figure 2, for example, the Non-Fiber Carbohydrates are assumed to contribute close to 100% towards TDN. Fat (or Ether Extract) contributes 2.25 as much energy than carbohydrates (since fat has more caloric value), but fat is a very small component of forages (with the exception of corn silage and small grain forage, where it's important). For most forages, it is likely not necessary to measure EE (notable exceptions are corn silage and small grain forage, which have high seed content). A very high percentage of the protein contributes to TDN as well. The fiber contributes to total energy, but is only partially digestible. This is the reason we focus so much on fiber measurements in forage testing. However, currently we do not routinely measure the digestibility of the fiber portion. An estimation of fiber digestibility is necessary, and would be a real improvement in forage testing.

One of the important concepts is that dry matter in feeds can be divided into a fibrous fraction (i.e., NDF) with variable digestibilities and a soluble fraction (i.e., NFC) that is very easily digested, and added to the other sources of energy (CP and lipids). An Example:

$$\text{TDN} = (\text{NFC} * \text{a}) + (\text{CP} * \text{b}) + (\text{EE} * \text{c} * 2.25) + (\text{NDF} * (\text{NDFD} / 100))$$

where: TDN = Total Digestible Nutrients

NFC = Non Fiber Carbohydrates (% of DM) = 100-(NDF +CP+EE+ash)

CP = crude protein (% of DM)

EE = ether extract (% of DM)

NDF = Neutral Detergent Fiber (% of DM)

NDFD = 30-hour in vitro NDF digestibility (% of NDF)

And a,b,c, are constants which estimate the percentage of that value that is contributing towards TDN.

There are various types of summative equations, which include lignin, ash, various components of protein, or other modifications, depending upon the nutritional approach. Besides an estimation of the digestibility of the fiber fraction, the analysis of ash is probably the most useful addition to our current system. Ash contributes nothing to the total digestible nutrients (energy) of the forage. It may range between 6% and 12% in alfalfa hay. Soil contamination, and irrigation with salty water could change the ash (and therefore TDN) dramatically. A percentage increase in ash will detract directly from the TDN content—a difference that is currently not tested. Additionally, the mineral balance in the ash component (especially the balance between monovalent ions such as K⁺ and divalent ions such as Ca⁺⁺) will be of increased interest to nutritionists for close-up (near birth) animals.

'Biological' Digestibility methods. The most crucial 'missing component' of our current hay testing process is an estimation of 'digestibility' of forages, particularly digestibility of the fiber

fraction. This will typically involve subjecting hay samples to biological degradation using rumen fluid, either in the cow, or in an apparatus in a lab. There are a number of approaches to this process, and the standardization of digestibility methods will be a major challenge to their adoption. For starters, the NRC (2001) recommends a 48-hour digestibility, while a number of nutritionists would prefer a 30-hour digestibility, an issue that requires resolution. A differing approach, researched by Peter Robinson at UC Davis, is the 'gas evolution' method, which measures the volumetric evolution of gas in a defined rumen media. This method has been practiced for years in Europe. This has methodological advantages over NDF digestibility methods, since multiple times can be recorded non-destructively. However, it is clear that standardization of digestibility estimates is an important requirement for their adoption.

A GROWER'S POINT OF VIEW

It is clear that many growers would prefer to forget about forage quality altogether. Alfalfa hay growers sometimes view forage quality measurements as being forced upon them by buyers, a perception which is largely correct. Forage quality is defined by animal factors, not production factors. However, growers should not expect the continuing demand for high quality to change. Hay buyers' demands for high quality are no different from consumers' demands for quality in any industry, whether purchasing food, toasters, tractors or pickup trucks.

However, it is not always in the growers' interest to produce the highest quality, since quality and yield are negatively related. Producing high quality hay requires careful attention to weed control, short cutting schedules, and often large sacrifices in yield. We routinely observe trade-offs between yield and quality with many agronomic practices, including variety selection, cutting schedules, and other practices. Thus, to produce high quality hay requires a considerable cost on the part of the grower. The key questions from a grower's viewpoint are: 1) are the price incentives sufficient to justify the higher costs of production for high quality forage? 2) How can I, as a grower, participate in the determination of quality, so I fully understand and help determine the value of my product? For these reasons, growers should be fully engaged in discussion about definitions of forage quality.

COMING CHANGES IN FORAGE QUALITY MEASUREMENTS

The detergent fiber system has been effective in improving the consistency of forage testing, improving prediction compared with subjective visual analysis. However, our current emphasis on ADF, NDF and CP is likely to change. There are several trends in forage testing that are occurring on a national basis. These are:

- Increased use of NDF and de-emphasis of ADF
- Increased emphasis on NDF digestibility or other digestibility estimates to improve prediction of TDN
- Increased routine analysis of 'ash' to improve TDN estimates
- Increased use of 'summative equations'
- Number of analyses increased
- Biological methods (enzymatic, in vitro, in situ) will increase the accuracy of estimating digestibility

The exact form that these changes will take is yet to be determined. There are a number of methodological questions that need to be resolved. However, the gradual inclusion of additional measurements, particularly of NDF digestibility and ash, into our standard hay test are likely to improve our understanding of forage quality that are not currently measured.