

# FUNDAMENTALS OF ALFALFA QUALITY

P.H. Robinson<sup>1</sup>, D.H. Putnam<sup>2</sup> and E.J. DePeters<sup>3</sup>

## ABSTRACT

Attaining high-quality alfalfa hay is a critical aspect of profitability for alfalfa and animal productivity. Attributes of quality include energy, voluntary intake, CP, fiber and minerals. Forage quality has many attributes and should be evaluated through laboratory measurements and subjective observations such as odor mold and weed content. Measurements of plant cell wall (NDF), as well as ADF, CP and ash are the most useful measurements for routine analysis, with additional analyses required for specific purposes. Interpreting the laboratory analyses themselves, as well as calculated values such as TDN, ME and NE is important in understanding laboratory results. Alfalfa growers who invest the time to understand quality factors in cattle performance benefit by their improved ability to successfully market their alfalfa hay at high prices.

**Key Words:** alfalfa, testing, quality

## INTRODUCTION

A major challenge faced by alfalfa growers over the past 30 years has been an increased emphasis on forage quality. The need to produce high-quality alfalfa hay affects marketing and price, as well as yield and stand life, since demands for high-quality alfalfa by the marketplace have been relentless. Although crop yield is still the primary economic factor determining forage crop value per unit of land area, forage quality has become a close second.

Milk production per dairy cow has more than doubled in 50 years, and increased more than 80 percent since the 1970's. Such highly productive cows require feeds with high digestibility, good palatability, high intake potential and high protein levels, thus increasing the demand for alfalfa hay and other high-quality feeds. Growers have responded by producing ever higher-quality alfalfa, with the average quality of alfalfa hay having increased consistently since the 1970's. However, the demand for high-quality forage is likely to intensify further, as dairy managers and nutritionists judge the value of alfalfa hay relative to the other feedstuffs in a ration.

In this article, we examine the definitions of forage quality, as well as the influence of quality on crop value, and issues associated with forage sampling and analysis.

---

<sup>1</sup>P.H. Robinson, UCCE Extension Specialist, UC Davis, Davis, CA 95616; Email: phrobinson@ucdavis.edu; <sup>2</sup>D.H. Putnam, UCCE Extension Specialist, UC Davis, Davis, CA 95616; Email: dhputnam@ucdavis.edu; <sup>3</sup>E.J. DePeters, UC Professor, UC Davis, Davis, CA 95616; Email: ejdepeters@ucdavis.edu; **In:** Proceedings, 37<sup>th</sup> California Alfalfa & Forage Symposium, Monterey, CA, 17-19 December, 2007. UC Cooperative Extension, Agronomy Research and Information Center, Plant Sciences Department, One Shields Ave., University of California, Davis 95616. (See <http://alfalfa.ucdavis.edu> for this and other proceedings).

## **ALFALFA QUALITY IN THE MARKETPLACE**

Dairying in the western United States is largely characterized by a separation between the alfalfa hay producer and dairy farmer user. It is estimated that more than 95 percent of alfalfa grown in this region enters commerce as a hay product, unlike many other regions where alfalfa is primarily fed on-farm and only valued through sales of milk or meat. Thus, in this region, the requirement for high-quality alfalfa hay is largely reflected in the market value of the alfalfa crop itself, and quality is frequently measured by laboratory analysis.

Although hay prices vary considerably from year to year due to supply and demand, forage quality affects price every year. High-quality hay prices averaged \$46 per ton, or 51%, higher in value than the lowest quality in California dairy markets over a recent 11 year period. Differences in price due to quality tend to be higher in a low price year.

### **HAY QUALITY GUIDELINES**

The USDA–Hay Market News Service has developed guidelines for reporting hay as ‘Supreme’, ‘Premium’, ‘Good’, ‘Fair’ or ‘Low’. These are based partly on laboratory assays and partly on subjective evaluation of hay quality indicators by buyers and sellers, such as presence of extraneous materials, including weeds and molds. However, these are guidelines, not standards, and buyers and sellers freely define and re-define quality based on a range of factors, including class of cattle and personal preference. Furthermore, marketing guidelines are likely to change as forage quality concepts change over time.

Historically, several laboratory assays have been used for marketing. These analyses are typically a subset of a wider range of analyses used to predict animal performance in rations. A “standard hay test” in the United States currently consists of analysis of acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein (CP) and dry matter (DM). Total digestible nutrients (TDN) can be calculated from ADF, which is commonly the case in California where TDN is used for marketing. Thus TDN, as used in California, is a function only of ADF, since ADF and NDF are highly correlated in pure alfalfa hays. Other energy values, such as metabolizable energy (ME) and net energy (NE) can be calculated from TDN. Crude protein (CP) is used less frequently in marketing alfalfa hay.

In recent years dairy nutritionists have increasingly used “summative equations” to predict the energy value of alfalfa hay (often NE) using NDF, a measure of NDF digestion, CP, ash and other measures. The use of ADF → TDN equations is largely being abandoned in favor of this approach in the feeding of alfalfa hay.

### **SUBJECTIVE QUALITY FACTORS**

Subjectively determined hay quality factors remain important for predicting hay quality, since not all quality attributes can be predicted from laboratory analyses. Although observational methods are poor at predicting attributes such as fiber concentration, fiber digestibility, energy or CP, hay must be examined visually to assess the importance of weeds (particularly poisonous or noxious weeds), molds or anti-palatability factors such as poor texture (e.g., hard stems/coarseness or the presence of molds), evidence of heating or unpleasant odor. Several of

these factors can affect nutritional value and animal health, and are not determined by common laboratory tests. Thus, a combination of visual and laboratory methods is recommended to fully assess alfalfa forage quality.

### **WHAT IS FORAGE QUALITY?**

Forage quality is defined as the potential to produce a desired animal response from a given intake of forage. Animal response can be measured as milk production, animal growth, meat or wool production and/or general health. However, forage quality is not an intrinsic characteristic of a plant. The definition and optimization of forage quality depends on both species and class of animal, stage of life, and the mixture of other feeds in the ration. Thus, optimal forage quality is a function of both animal and plant factors.

### **FORAGE QUALITY IS MULTIFACETED**

Although it is often tempting to reduce the concept of forage quality to one or two measurements (e.g., CP or TDN), this usually belies a more complicated story. Forage quality is always a complex mixture of nutritional traits. For example, CP is important, but many nutritionists are also interested in the availability (i.e., extent and rate of digestion) of the CP in the rumen since some plant CP might be too rapidly degraded and the nitrogen poorly utilized by rumen microorganisms. In heat damaged or moldy hay, much of the CP can be indigestible by ruminants, and thus of little value.

The potential energy value of a forage crop (often expressed as TDN, ME or NE) is one of the most important attributes of forages. The sources of this energy include rapidly digested soluble sugars, starches, protein, as well as slowly digested fiber, each of which has particular nutritional characteristics. Some energy is released rapidly in the rumen, while other energy is only slowly released after the fiber is digested by rumen microflora.

There are also physical aspects that affect quality (e.g., grind, fiber length, moisture), olfactory issues (e.g., odor, dustiness, chemical attractants that encourage uptake), and contaminants (e.g., toxic weeds, dirt, molds, toxic insects) that affect palatability, intake, and thus overall quality. Forage quality should always be considered a multifaceted attribute of alfalfa, with several features and important concepts.

### **WHAT DO CATTLE REQUIRE FROM FORAGES?**

The principal nutritional feature of forages, that differentiate its quality, are its energy content, intake potential, CP level, fiber level (and ruminal digestion) and mineral level. Although each of these factors is important to all classes of cattle, the importance and relative rank change with cattle type, stage of life and feed ration formulation. In our region, forage quality of alfalfa is most often defined in terms of milk production of high-producing dairy cows, which generally drives the discussion of forage quality, since a large percentage of the California alfalfa crop is used by the dairy sector. However, all of the following factors are relevant to varying degrees to all classes of cattle.

**Energy.** In most cases, the primary consideration of forage quality is its potential energy per unit of dry weight forage. The supply of energy in feeds is a function of digestion and absorption of energy-containing compounds in the plant. This is usually the most important forage quality factor, since biological energy drives the key animal functions of maintenance, growth and milk production. Unfortunately, total biological energy in feeds cannot be directly measured in routine analyses, since it is a function of both the forage and the animal, but is predicted using equations derived from several laboratory analyses.

Energy (i.e., TDN, ME, NE) can be predicted from a linear relationship to a fiber measurement (such as ADF or NDF) in alfalfa, or by summative equations. Although there are many calculations for TDN, the most common TDN equation currently used for marketing in California is the ‘Western States Equation’ developed at UC Davis that estimates TDN from the ADF level of the alfalfa hay. Energy can be more accurately calculated from equations that use more analyses. From a nutritional viewpoint, estimation of energy is typically the most important factor for predicting forage quality, although intake potential is often a close second.

### ***Intake Potential.***

Some forages are digested very rapidly in the rumen, while others require extended periods for equivalent digestion. Other factors that cause cattle to consume more or less of a forage, often termed its ‘palatability’, and are affected by species, taste, condition of the hay, odor, weed content, stem quality and plant maturity. Thus palatability is the animal behavior response to consumption of forage, while intake is a function of both palatability and its rate of digestion in the rumen, as well as its rate of passage from the rumen. Lower intake levels result in lower energy availability per unit time, thereby reducing animal performance. High-fiber alfalfa tends to have both high fiber content and slow fiber digestibility in the rumen that causes cattle can become “filled” and stop eating. This rumen fill limits intake, which ultimately reduces energy intake and animal performance. Thus, potential feed intake of forage is especially important for high-producing dairy cows. Several subjective factors (e.g., visual inspection, touch, smell) may assist in predicting animal acceptance. Palatability is less important in total mixed rations (TMR), since other feeds and additives impact voluntary intake, and becomes less important as its inclusion level in the TMR declines.

The rate of ruminal digestion of fiber (i.e., NDF) is an important indicator of potential intake. There are several approaches to measuring, or predicting, rumen digestibility, including *in vitro* digestible dry matter (IVDDM), gas production estimates, and *in vitro* NDF digestibility (dNDF), all of which are bioassays involving digestion of a sample in rumen fluid. These methods provide information on the rate and extent of DM and/or NDF digestion, which can be used in predictive equations of forage quality.

**Protein.** Since amino acids from proteins are building blocks for muscle and milk, they are important nutritional attributes of forages. Although the concentration of protein (estimated as CP) is important, many nutritionists may also be interested in the amount of alfalfa protein that is digested in the rumen and that which passes undigested from the rumen to be digested in the small intestine. Buffer soluble CP (SolCP) estimates the CP immediately digested in the rumen and acid detergent insoluble CP (ADICP) estimates the indigestible (typically lignified and heat-

damaged) CP. High levels of either are negative to forage quality since excessive digestion of CP in the rumen (i.e., high SolCP) suggests that rumen microbes will not fully utilize the resulting ammonia nitrogen for their growth, and high levels of indigestible CP (i.e., high ADICP) suggests low use of the CP overall since its digestibility in the small intestine will be low. High rumen digestible CP (i.e., high SolCP) can be a problem with very leafy immature alfalfa and low digestibility (i.e., high ADICP) can be a problem in heat damaged alfalfa. Since inexpensive high-CP concentrate feeds are generally available, CP in alfalfa forages is often discounted in alfalfa hay markets.

**Minerals.** Ash is an estimate of the total mineral content in forage, which usually originates from normal mineral uptake by the plant. In general, as ash increases the level of energy declines since minerals do not contain energy. Thus, ash is negative in alfalfa hay energy predictions for ruminants.

However, alfalfa provides several essential minerals in the ash fraction, such phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), chlorine (Cl) and sodium (Na). Although minerals may be supplemented in the diet, the balance (or type) of mineral ions, such as Ca, P, and K in alfalfa may be nutritionally important.

**Other attributes.** There are other, less-well-defined, attributes of forage quality, such as secondary plant compounds, aromas or odor, dust and molds, which affect sensory preferences by cattle, although these may be primarily important as they affect intake and animal health. Toxic weeds or insects (e.g., blister beetle) can be an important anti-nutritional factor in hay. Each year, cattle are sickened from poisonous weeds, excess nitrate (from weeds), or excess micronutrient levels in hay.

### **WHAT CAN BE MEASURED IN ALFALFA HAY?**

Alfalfa plants, when considered as a feed, have several important nutritional characteristics that impact the factors discussed above. However, these nutrients are not uniformly distributed throughout the plant or the harvested crop, and are influenced by both macro- and micro-level morphological differences in plant structure.

**Moisture.** A fresh standing alfalfa crop contains from about 70 to 80% water, which is rapidly reduced to 12 to 18 % by baling. Hay equilibrates to about 10% moisture in hay stacks under ambient western conditions.

Moisture is frequently confused on hay test reports. Although some dry matter (DM) components are soluble, all quality features of alfalfa are contained in the DM, not the water, component of forage. The “as-received” % moisture (or % DM), should only be used to adjust *yield* levels, not forage quality. To understand forage quality, quality measurements should always be compared on a 100% DM basis since moisture can be added or reduced, depending on conditions. Although moisture in hay is not an important nutritional factor, it can indicate excessively wet hay (indicating potential mold problems and/or heating problems, and thereby lower quality), or excessively dry hay (indicating potentially prickly stems or leaf drop).

Dry matter is measured by oven drying for 3 hours at 105°F (41°C). See NFTA Web site ([www.foragetesting.com](http://www.foragetesting.com)) for this and other standard methods. There are some minor errors associated with oven drying since there can be a loss of volatile compounds that are not water, thereby overestimating the moisture content.

**Botanical Level—Leaves and Stems.** Although an alfalfa field may appear as a uniform mass of green, the harvested crop is made up of stems, leaves, flowers and petioles, and each part differs in nutritional value. The most important of these by weight are stems and leaves. Leaves are much more digestible and lower in fiber than stems, and can have 2 to 3 times more CP than stems. Leaf tissue does not accumulate fiber and lignin to the same extent as stem tissue as the plant grows and develops. Thus, the relative weight of leaves and stems is an important visual determinant of quality for alfalfa. If no chemical analysis is available, a subjective evaluation of leaf percentage is a valuable indicator of potential feeding value, with leaf percentage ranging from about 55 to 65% in very-high-quality alfalfa to 35 to 45% in lower-quality alfalfa.

**Fiber Carbohydrates.** Neutral detergent fiber (NDF) measures the cellulose, hemicellulose, lignin and cutin portion of the cell wall fraction (the slowly digestible, and indigestible, components) and is often considered to be an estimate of the total plant structural cell wall fraction. NDF is defined as the residue after 1 hour of boiling in neutral detergent solution. NDF is called aNDF if amylase is used in the analysis, which is the recommended method. NDF commonly ranges from 30 to 50% in alfalfa hay DM.

Acid detergent fiber (ADF) is a sub-fraction of NDF, and measures the cellulose, lignin, and cutin portion, or the more slowly digestible, and indigestible, components of the cell wall. ADF is defined as the residue after 1 hour of boiling with an acid detergent solution. Since ADF is a sub-fraction of NDF, the ADF concentration is always lower, ranging from 22 to 37% of DM in alfalfa hay.

Lignin is a part of both NDF and ADF and is essentially indigestible. However, lignin often “shields” or blocks digestion of hemicelluloses and celluloses to which it is chemically linked. Lignin is defined as the residue after soaking ADF in 72% sulfuric acid for 3 hours, and may be from 5 to 15% of DM of alfalfa hay. This commonly used sulfuric acid lignin assay also captures cutin, the waxy surface of the plant that prevents water loss from the plant.

**Cell Solubles and Non-Fiber Carbohydrates.** Non-fiber carbohydrates (NFC), sometimes called ‘cell solubles’ contribute 100% to the energy content of the forage, with the exception of soluble minerals, and are rapidly digested, thus contributing to high intake potential. Cell solubles may range from 20 to 35% of DM. Young plant cells are quite high in soluble carbohydrates, such as sugars, and high in CP, but low in fiber. As these cells develop and mature, the secondary cell wall becomes more important, and cellulose, hemicellulose and lignin increase and proportionally reduce the cell soluble concentration. Lignification of cells creates complex cell wall structures that are more resistant to enzymatic digestion by rumen microbes. Secondary cell wall development occurs primarily in stems, and is an important determinant of forage quality since plant maturity both increases the cell wall fraction and makes it much more difficult to digest in the rumen.

**Crude Protein.** Typically, alfalfa plants range from 17 to 26% CP on DM, making alfalfa an important source of CP for cattle. However, the quantity of CP digested in the rumen from alfalfa is frequently considered to be too high, and may be a problem due to excess excretion of urinary urea nitrogen from ruminants, which is an environmental concern in California.

Protein in alfalfa is most commonly expressed as CP, which is calculated as the percentage of nitrogen  $\times$  6.25 (reflecting the average nitrogen content of alfalfa protein). Crude protein alone is seldom sufficient to predict animal performance. Measurements of CP digestion in the rumen are helpful in assessing the nutritional value of the CP.

**Fat.** The fat content of alfalfa plants is primarily in the cell membrane portion of the cell and is typically low, averaging about 1.5% of DM as ether extract (EE) in alfalfa hay. However EE is seldom measured in alfalfa hay because there is little triglyceride present, and the organic solvent (e.g., petroleum ether or diethyl ether) also extracts chlorophyll, waxes, volatile oils and resins, which are not energy-containing.

**Minerals.** The mineral content of alfalfa is determined by an ash measurement and can be high, ranging from 6 to 15% of the DM of the plant tissue. Ash is a measure of total inorganic minerals in the forage, as well as soil contamination. To obtain ash, samples are burned at high temperatures (932–1112°F, 500–600°C), and the residue is weighed. Ash can contain minerals from organic compounds, for example P from phytic acid, and some volatile minerals can be lost during combustion. Specific minerals, such as P, K, S, Mg, Ca, S, Se and Mn, are often measured separately to indicate the value of the forage in supplying those nutrients to the cattle or in identifying high levels of concern, particularly for the micronutrients Mo, Se and Mn.

## THE HAY TESTING PROCESS

**Standardization of Hay Quality Measurements.** A key issue impacting dairy nutritionists and hay growers, as well as buyers and sellers, is standardization of hay testing. The process of hay testing begins with accurate hay sampling methods, followed by standard laboratory methods and use of formulas to estimate forage quality based on laboratory measurements. Obtaining different results from various laboratories creates confusion in the marketplace.

**The Importance of Sampling.** It is impossible to overemphasize the importance of sampling in hay quality analysis. Obtaining a representative sample of a given 'lot' of hay is critical, as laboratory assay is only as good as the sample provided to the lab. Tons of highly variable plant material must be represented in a single, tiny, thumbnail-sized sample. This sample must represent the leaf/stem ratio and the legume/grass mix, but also the presence of weeds and soil. Sampling variation is a major problem in hay evaluation and causes millions of dollars in lost revenue each year by buyers and seller, while contributing to lost animal performance. In practice, hay sampling causes more variation in assay results than laboratory variation. However, if sampling protocols are carefully followed, sampling variation can be reduced to an acceptable level, and potential forage quality successfully predicted.

The following steps are widely considered to be the key elements of an effective standardized sampling protocol (further details are available at [www.foragetesting.org](http://www.foragetesting.org)).

## STANDARDIZED HAY SAMPLING PROTOCOL TO ASSURE A REPRESENTATIVE SAMPLE OF HAY

The principle of a good sampling protocol is to obtain an approximately 0.5 pound (227 g) sample that correctly represents the leaf/stem ratio, mixture of weeds and field variation in a defined lot of hay.

**Identify a single lot of hay.** A hay lot should represent a single cutting, a single field and variety, and generally be less than 200 tons.

**Sample at the right time.** Sample as close to point of sale, or as close to feeding, as possible since DM and other measurements are subject to change after harvest and during storage.

**Always use a sharp, well-designed coring device.** Use a coring device 0.38 to 0.75 inches (0.95 to 1.90 cm) in diameter with a sharp tip at 90° to the shaft, not angled. Never send in flakes or grab samples. The probe length should allow probing to a depth of 12 to 24 inches (30 to 61 cm). Hay probes should easily penetrate the bale, represent the leaf/stem ratio, be easy to sharpen and produce approximately 0.5 pounds (227 g) of sample in about 20 cores to a depth of 12 to 24 inches (30 to 61 cm). Some probes (e.g., the 0.75 inch [1.9 cm] Penn State probe) result in excessive samples in 20 cores. See a listing of acceptable probes at [www.foragetesting.org](http://www.foragetesting.org) (NFTA Web site).

**Sample systematically, choosing random bales.** The sampler should walk around the stack as much as possible and sample bales in a systematic fashion. For example, every fourth bale on both sides of the stack. This should prevent inadvertent choosing of bales and provide a random sample. Sample as much of the stack as possible. Don't avoid or choose bales because they look especially bad or good. If 20 cores are taken, they won't make much difference anyway.

**Take enough cores.** We recommend a minimum of 20 cores for a composite sample to represent a hay lot. This is the same for large (e.g., 1 ton [907 kg] bales), or small two-tie or three-tie bales. A larger number of core samples is useful for more variable hay lots.

**Use proper technique.** The probe should be inserted at a 90° angle, 12 to 18 inches (30 to 46 cm) deep, to sample butt ends of each hay bale, between strings or wires, not near the edge. With round bales, sample toward middle of bale on an angle directly toward the center of the bale.

**Sample amount: 'not too big, not too small.'** Sampling should be done so that about 0.5 pounds (227 g) of sample is produced. If the sample is too small, it is likely to be less representative. If the sample is too large, labs may not grind the whole sample. For example, the Penn State sampler tends to provide too large a sample, since it is in 0.75 inch (1.90 cm) diameters. If the wrong amount of sample is produced with 20 cores, a different hay sampler should be used.

**Handle samples correctly.** Seal the composite 20 core sample in a well sealed plastic bag, protect from heat and do not allow samples to be exposed to the sun.

*Certify your hay sample.* An online exam is available at [www.foragetesting.org](http://www.foragetesting.org) to allow individuals to certify their hay samples. This may be particularly important for situations where two parties are interested in results of the sampling. The quiz allows the sampler to “self-certify” that the sample was taken using this protocol.

### **CHOOSING A QUALIFIED NFTA LABORATORY**

Once a good sample is obtained, a laboratory must be chosen. The first criterion for choosing a laboratory is membership in, and certification by, the National Forage Testing Association (NFTA). Laboratory performance is not regulated in the United States by any government agency, but some laboratories voluntarily submit to NFTA performance testing and are sent samples to test their performance. The NFTA board is made up of volunteer laboratories, university and USDA scientists, and hay growers and marketers. A laboratory must match the reference value within a certain range of variation (determined by the NFTA board) to obtain certification. A customer can ask for the actual NFTA grades from the laboratory's certification report and discuss issues such as laboratory practices, and ask the laboratory for their quality assurance standards.