

# Forage Quality and Testing

**Daniel H. Putnam**

*Forage Extension Specialist, Department of Plant Sciences,  
University of California, Davis*

**Peter Robinson**

*Extension Nutritionist, Department of Animal Science,  
University of California, Davis*

**Ed DePeters**

*Professor of Ruminant Nutrition, Department of Animal Science,  
University of California, Davis*

A major challenge faced by alfalfa growers during the past 30 years has been the increased emphasis on forage quality. The need to produce high-quality hay affects marketing and price, as well as yield and stand life. 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 1970s (Fig. 16.1). Such highly productive animals require forages with high digestibility, good palatability, high intake potential, and high protein levels, thus increasing the demand for alfalfa and other high-quality feeds. Growers have responded by producing higher-quality alfalfa; the average quality of hay tested by labs has increased dramatically since the 1970s (Fig. 16.2). The demand for high-quality forage is likely to intensify further, as dairy managers and nutritionists judge the value of alfalfa in comparison to the many other feedstuffs in a ration. Here, we examine the influence of forage quality on crop value, definitions of quality, the influences of agronomic practices on forage



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## Chapter 16

Corresponding Author:

Daniel H. Putnam

[dhputnam@ucdavis.edu](mailto:dhputnam@ucdavis.edu)



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quality, and issues associated with forage sampling and testing.

## Alfalfa Quality in the Marketplace

Dairying in the western United States is characterized by separation between the alfalfa hay producer and dairy farmer. It is estimated that >95 percent of the 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 the sale 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 laboratories.

Although hay prices vary considerably from year to year due to supply and demand factors, forage quality affects price every year (Table 16.1). High-quality hay prices averaged \$46 per ton (907 kg) or 51 percent greater in economic value than the lowest quality in California's dairy markets over an 11-year period (Table 16.1). Quality differences tend to

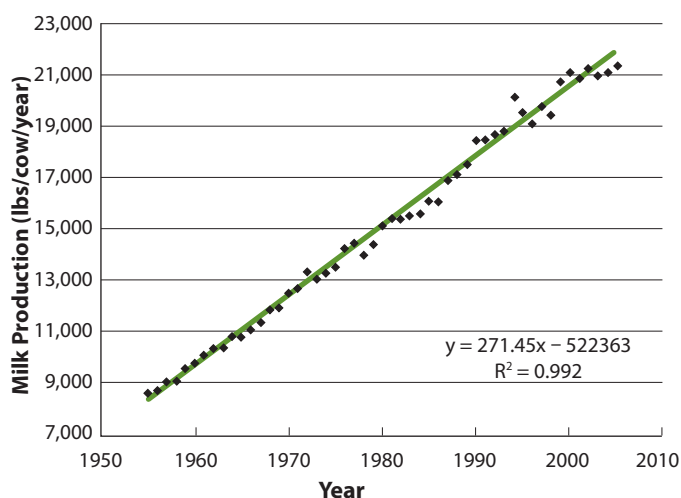
be greater in a low priced year compared with a high priced year.

## Hay Quality Guidelines

The USDA–Hay Market News Service has developed guidelines for reporting hay as Supreme, Premium, Good, Fair, or Utility (Table 16.2). These are based partly on lab tests and partly on subjective evaluation of hay quality indicators by buyers and sellers, such

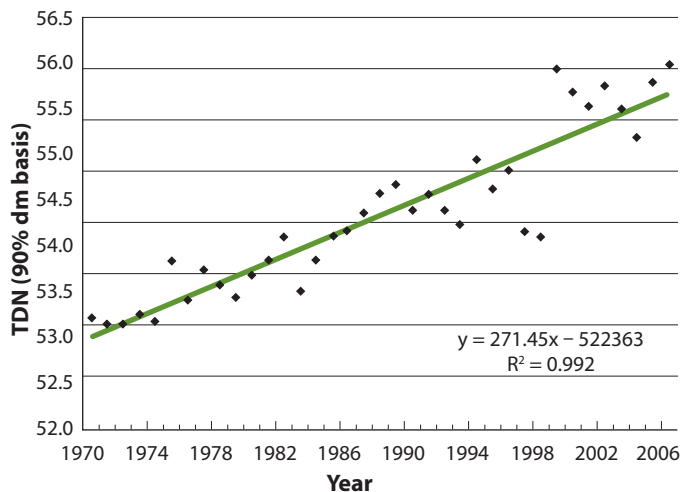
**FIGURE 16.1**

Change in productivity in California dairy cows over a 50-year period (USDA data).



**FIGURE 16.2**

Change in hay test values over time (data from Petaluma Hay Testing Lab, Petaluma, CA).



TDN = total digestible nutrients

### Terminology

- CP = Crude Protein
- ADF = Acid Detergent Fiber
- NDF = Neutral Detergent Fiber
- NDFd = NDF digestibility
- IVDDM = In Vitro Digestible Dry Matter
- EE = Ether Extract
- ADIN = Acid Detergent Insoluble Nitrogen
- DE = Digestible Energy
- ME = Metabolizable Energy
- NE = Net Energy
- NEl = Net Energy of Lactation
- NEg = Net Energy of Gain
- TDN = Total Digestible Nutrients
- DCAD = Dietary Cation-Anion Difference

**TABLE 16.1**

Average price of alfalfa hay, as influenced by quality, across all California markets, 1996–2006. The “Supreme” category was instituted in 1999

| Year           | Marketing Category |              |              |             | Difference*<br>\$/ton | Percentage Difference<br>(top-bottom)<br>% |
|----------------|--------------------|--------------|--------------|-------------|-----------------------|--|
|                | Supreme            | Premium      | Good         | Fair        |                       |  |
| 1996           |                    | 129          | 114          | 100         | 29                    | 29.3                                       |
| 1997           |                    | 151          | 131          | 116         | 35                    | 30.2                                       |
| 1998           |                    | 140          | 122          | 93          | 47                    | 50.3                                       |
| 1999           | 129                | 114          | 91           | 69          | 60                    | 88.8                                       |
| 2000           | 127                | 111          | 93           | 77          | 50                    | 65.0                                       |
| 2001           | 147                | 137          | 124          | 111         | 36                    | 32.4                                       |
| 2002           | 142                | 125          | 107          | 89          | 53                    | 59.6                                       |
| 2003           | 130                | 116          | 97           | 78          | 52                    | 68.4                                       |
| 2004           | 148                | 135          | 119          | 101         | 47                    | 46.7                                       |
| 2005           | 179                | 166          | 146          | 125         | 54                    | 43.1                                       |
| 2006           | 166                | 151          | 132          | 106         | 60                    | 56.9                                       |
| <b>Average</b> | <b>\$146</b>       | <b>\$134</b> | <b>\$116</b> | <b>\$97</b> | <b>\$48</b>           | <b>51.9%</b>                               |

\*Highest price/lowest price due to quality

**TABLE 16.2**

USDA quality guidelines for reporting economic data of alfalfa hay (not more than 10% grass) adapted in 2002 (2006 USDA Livestock, Hay and Grain Market News, Moses Lake, WA). Guidelines are used along with visual appearance to determine quality. All figures are expressed on 100% DM, except as noted.

**Physical Descriptions of Hay Quality** to be used in combination with lab tests for alfalfa hay quality categories (USDA–Market News):

- Supreme:** Very early maturity, pre-bloom, soft, fine stemmed, extra leafy. Factors are indicative of very high nutritive content. Hay is excellent color and free of damage.
- Premium :** Early maturity (i.e., pre-bloom in legumes and pre head-in grass hays), extra leafy, and fine stemmed-factors indicative of a high nutritive content. Hay is green and free of damage.
- Good:** Early to average maturity (i.e., early to mid-bloom in legumes and early head-in grass hays), leafy, fine to medium stemmed, free of damage other than slight discoloration.
- Fair:** Late maturity (i.e., mid- to late-bloom in legumes, head-in grass hays), moderate or below leaf content, and generally coarse stemmed. Hay may show light damage.
- Utility:** Hay in very late maturity (such as mature seed pods in legumes or mature head-in grass hays), coarse stemmed. This category could include hay discounted due to excessive damage and heavy weed content or mold. Defects will be identified in market reports when using this category.

| Category | ADF   | NDF   | RFV <sup>1</sup> | TDN <sup>2</sup> | TDN (90% DM) <sup>3</sup> | CP    |
|----------|-------|-------|------------------|------------------|---------------------------|-------|
| Supreme  | <27   | <34   | >185             | >62              | >55.9                     | >22   |
| Premium  | 27–29 | 34–36 | 170–185          | 60.5–62          | 54.5–55.9                 | 20–22 |
| Good     | 29–32 | 36–40 | 150–170          | 58–60            | 52.5–54.5                 | 18–20 |
| Fair     | 32–35 | 40–44 | 130–150          | 56–58            | 50.5–52.5                 | 16–18 |
| Utility  | >35   | >44   | <100             | <56              | <50.5                     | <16   |

<sup>1</sup>RFV is calculated from ADF and NDF:  $RFV = [88.9 - (.779 \times \% ADF)] \times [(120 / \%NDF) / 1.29]$

<sup>2</sup>TDN = (82.38 - [0.7515 × ADF]) according to Bath and Marble, 1989.

<sup>3</sup>TDN (90% DM) = TDN × 0.9.

ADF = acid detergent fiber; CP = crude protein; DM = dry matter; NDF = neutral detergent fiber; RFV = relative feed value; TDN = total digestible nutrients.

as presence of extraneous materials, including weeds and molds. However, these are guidelines, not standards, and buyers and sellers freely define and redefine quality based on a range of factors, including class of animal and personal preference. Furthermore, marketing guidelines are likely to change as forage quality concepts change over time.

Historically, several lab tests 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 the analysis of acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein (CP), and dry matter (DM) (see “Terminology” sidebar on p. 242). Total digestible nutrients (TDN) and relative feed value (RFV) are calculated from the fiber values of ADF and/or NDF, and are commonly used for marketing. TDN, as commonly used in California, is a function only of ADF, while RFV is a function of both ADF and NDF (see “What Is Calculated” on p. 252). Other predictions, such as ME, NE<sub>1</sub>, and RFQ, can also be calculated.

Although these two common methods for identifying quality in alfalfa markets (RFV and TDN) superficially appear to be different, they are actually quite similar since they are both

based on a measurement of fiber concentration. These are “fiber-based” marketing systems, and generally rank alfalfa hays similarly, since ADF and NDF are highly correlated in pure alfalfa hays. In California markets, the average change in hay price has been calculated to be approximately \$7.00 per unit of ADF, using the hay marketing categories reported by USDA–Market News (Fig. 16.3). Crude protein (CP) is used less frequently in marketing alfalfa hay.

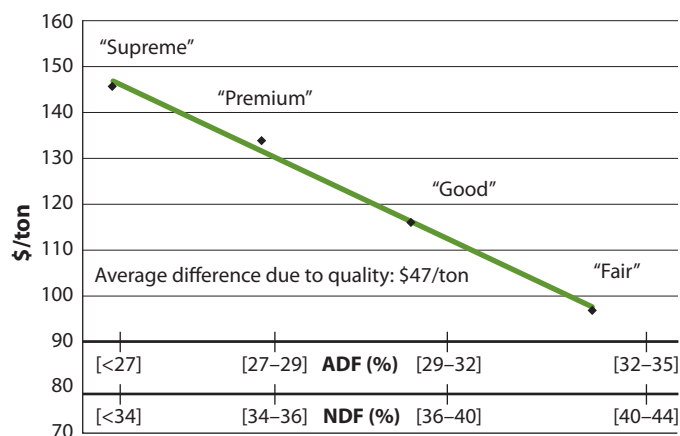
However, in recent years, dairy nutritionists are utilizing “summative equations” to predict the quality of alfalfa hay; these equations incorporate NDF, NDFd, CP, ash, and several other measurements. The use of ADF–TDN equations is largely being abandoned in favor of this approach.

### Subjective Quality Factors

Subjectively-determined quality factors remain important for predicting hay quality, since not all quality attributes can be predicted from laboratory analysis. Although observation methods are poor at predicting fiber concentration, fiber digestibility, energy, or protein, 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 (hard stems or coarseness, or the presence of sooty molds, both of which affect palatability), evidence of heating, or unpleasant odor (Table 16.3). Several of these factors can have significant effects on 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 the forage quality of alfalfa hay.

**FIGURE 16.3**

Average effect of hay quality measurements (ADF or NDF) on price in California; average of all markets, 1996–2006 (Data from USDA–Market News Reports).



ADF = acid detergent fiber; TDN = total digestible nutrients



## 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 could be measured in the form of milk production, animal growth, meat or wool production, 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 mix of 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 forage quality to one or two measurements (for example CP or ME, TDN or RFV), this usually belies a more complicated story. Forage quality is always a complex mix of nutritional traits. For example, CP is important, but many nutritionists are also interested in the availability (extent and rate of digestion) of the protein as it is degraded in the rumen since some plant protein might be too rapidly degraded and the nitrogen poorly utilized by rumen microorganisms. In “tobaccoed” (hay that has turned dark brown through heating) or moldy hay, the CP is often heat-damaged protein, essentially not degradable by ruminants, and thus of little nutritional value.

The total potential biological energy value of the forage crop (often expressed as TDN, ME, or NE) is one of the most important attributes of forages, but sources of energy include rapidly degraded soluble sugars, starches, protein, or slowly degraded 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 cellulose and hemicellulose is broken down 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,

**TABLE 16.3**

Relative effectiveness of visual and laboratory methods of judging forage quality factors. Some quality factors are best evaluated visually, whereas other factors require a lab test

| Quality Factor           | Visual Examination | Lab Test  |
|--------------------------|--------------------|-----------|
| Leaf:Stem Ratio (Leaf %) | Good               | Fair      |
| Leaf-Stem Attachment     | Excellent          | Poor      |
| Mold/Dustiness           | Excellent          | Poor      |
| Texture (coarse, soft)   | Excellent          | Poor      |
| Weed Content             | Excellent          | Fair      |
| Noxious Weeds            | Excellent          | Poor      |
| Odor                     | Excellent          | Poor      |
| Fiber Concentration      | Poor               | Excellent |
| Fiber Digestibility      | Poor               | Excellent |
| Protein Concentration    | Poor               | Excellent |
| Protein Degradability    | Poor               | Excellent |
| Mineral Content          | Poor               | Excellent |

and thus overall quality. Forage quality should always be considered a multifaceted attribute of alfalfa, with several key features or important concepts. What are these principal features of forages?

## What Do Animals Require From Forages?

In a discussion with animal nutritionists, several principles or concepts emerge as important requirements from forages. The principal nutritional features of forages are digestible energy content, intake potential, protein, ruminally effective fiber, and minerals or ash. Although each of these factors is important to all classes of livestock, the importance and relative rank will likely change by animal 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, these factors are relevant in varying degrees to all classes of animals.



## 1. Digestible Energy (DE)

In most cases, the primary consideration for forage quality is the potential digestible energy per dry matter weight unit (lb, kg, or Mg) of 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 animal functions of maintenance, growth, and milk production. Unfortunately, the total potential biological energy in feeds cannot be easily measured directly in routine analyses, since it is a function of both the forage and the animal, but is predicted with equations derived from several laboratory analyses.

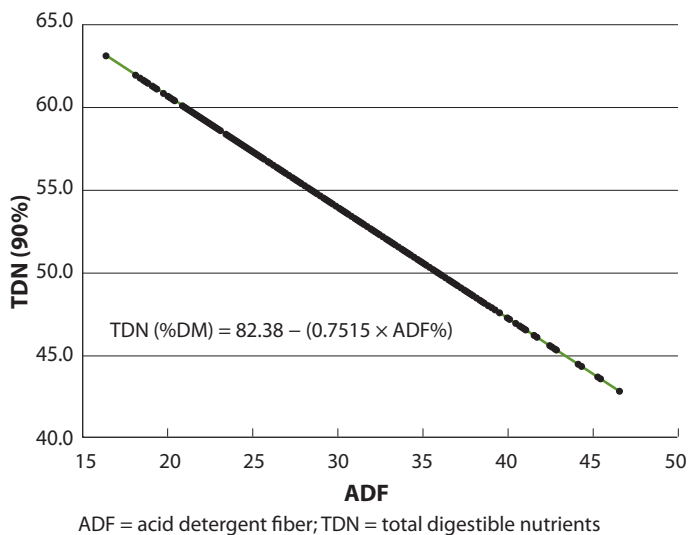
In plants, digestible energy comes from both rapidly available and slowly available sources. The rapidly available forms include sugars, starches, and pectins, which are released quickly in the rumen and contribute energy to the animal, primarily as volatile fatty acids such as acetate, propionate, and butyrate that are absorbed through the rumen wall. However, considerable energy in forages is contained in the cell wall portion (cellulose, hemicellulose), which is made available

only through enzymatic breakdown by rumen microorganisms. These are also subsequently converted into volatile fatty acids and absorbed by the animal. Although starches, sugars, and pectins are essentially 100 percent digestible, the fibrous energy component in the alfalfa cell wall is typically in the range of 30 to 60 percent digestibility. Protein also contributes to energy since it contains carbon skeletons. Lipids (oils or fats) contain considerable energy (2.2 times that of carbohydrates), but small quantities are typically contained in alfalfa forages, although lipids are more important in corn silage and other forages that contain grain.

Energy (TDN, NE, NE<sub>l</sub>, or ME) can be predicted from a linear relationship to a fiber measurement (ADF or NDF) in alfalfa (Fig. 16.4), or by summative equations. Although there are many calculations for TDN, the most common TDN currently used for marketing in California is given in Figure 16.4. Energy is more accurately calculated from summative equations that use NDF, NDFd, ash, EE, CP, and other factors to predict energy. It is important to determine the method of calculation when comparing the energy values among and between forages. From a nutritional viewpoint, estimation of digestible energy is typically the most important factor for predicting quality of forages, although intake is often a close second.

**FIGURE 16.4**

For marketing purposes, TDN has been historically calculated directly from ADF value in California and other western states. TDN is calculated on a 100% DM basis, but is sometimes expressed on a 90% DM basis, since western hay equilibrates to approximately 90% DM. This is changing since nutritionists now largely use summative equations based on NDF.



## 2. Intake Potential

Some forages are digested very rapidly in the rumen, while other feeds require extended periods for complete digestion. Additionally, there are factors that cause animals to consume more or less of a forage, often termed “palatability,” that are affected by species, taste, condition of the hay, odor, weed content, stem quality, and plant maturity. Palatability is the animal behavior response to the consumption of forage. Intake is a function of both palatability and rate of digestion in the rumen, and rate of passage from the rumen. Lower intake levels result in lower energy availability per unit of time, reducing animal performance and lowering the forage quality. High-fiber alfalfa often has both high fiber content and slow fiber digestibility—therefore animals can become

“filled” and stop eating. This rumen fill limits intake, which ultimately reduces energy intake and animal performance. When feed or energy intake is below requirements, milk production generally declines. Thus, potential feed intake of a forage is especially important for high-producing dairy cows. However, too-rapid rates of degradation result in poor rumen function and negatively affect animal health, causing acidosis and other health problems. Several subjective factors (e.g., visual inspection, touch, smell) may assist in predicting animal acceptance, but palatability may be less important in total mixed rations (TMRs), since other feeds and additives impact voluntary intake by ruminants.

However, the rate of ruminant degradation of the fiber fraction (NDF) is an important indicator of 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 (NDFd), 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 NDF digestion, which can be used in predictive equations. Intake potential is one of the most important quality factors for lactating dairy cows.

### 3. Protein

Since amino acids from proteins are building blocks for muscle, milk, and animal enzymes, they are important nutritional attributes of forages. Although the concentration of protein (estimated by CP) is important, many nutritionists may also be interested in the amount of alfalfa protein that is degraded in the rumen or passes undegraded from the rumen and is digested in the small intestine. Rumen degraded protein (RDP) provides an estimate of CP availability in the rumen. Acid detergent insoluble CP (ADICP) estimates the undigestible (typically lignified and heat-damaged) CP. While heat damaged and undegraded protein is a negative factor, excessive degradation of CP in the rumen is also a negative quality factor if the rumen microbes do not fully utilize the ammonia nitrogen (N) for microbial protein.

This excess ammonia N is absorbed through the rumen wall, and much of the ammonia is converted to urea via an energy-dependent process, and the urea is excreted in the urine.

High rumen degradable protein can be a problem with very leafy immature alfalfa. Since inexpensive high-CP concentrate feeds are generally available, CP in alfalfa forages is often discounted compared with its energy content in alfalfa hay markets. However, as the cost of CP supplements rises, the economic value of protein in forages will become greater, particularly “rumen escape protein,” absorbed in the lower intestine that is often most effectively utilized by ruminants.

*Since amino acids from proteins are building blocks for muscle, milk, and animal enzymes, they are important nutritional attributes of forages.*

### 4. Ruminally Effective Fiber

The provision of ruminally effective fiber with a high level of digestibility is a major attribute provided by alfalfa hay in ruminant rations. Forage growers are faced with a quandary with this issue: As indicated above, digestible energy and intake potential are considered to be the most important quality factors. Energy and intake are inversely related to fiber concentration (ADF, NDF) in the hay. Thus, generally, as the percentage of ADF or NDF goes up, digestible energy and intake go down. As a result, dairy managers frequently demand low-NDF or low-ADF alfalfa hay.

However, reduction of fiber to very low levels can create problems in rumen function since dietary fiber stimulates rumination, chewing, and saliva production; the latter helps to stabilize rumen pH. High-producing ruminants can suffer physical problems with rumen health when “effective fiber” is too low in their diet. Thus, the fiber in alfalfa provides positive physical and chemical attributes to ruminant rations. However, if the digestibility of the fiber is too low, both DE and intake are negatively affected, thus the quandary for forage growers.

It is clear that both the concentration of the NDF and the rates of digestion of the fiber fraction are important attributes of forage quality, but the value of effective-fiber (vs. low-fiber, high-energy) hay varies, depending on the levels in the diet and class of animals to which it is being fed.

## 5. Ash and Minerals

Ash is an estimate of total mineral content in a forage, which could originate from normal mineral uptake by the plant, for example, phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), chlorine (Cl), and sodium (Na) from excessive salt accumulation, or contamination with soil. In general, as ash increases, the level of digestible energy declines, since minerals do not contain energy. Thus, ash is considered to be a negative

*Ash is an estimate of total mineral content in a forage, which could originate from normal mineral uptake by the plant or from excessive salt or contamination by soil.*

factor in predictions of energy for ruminants, and lower-ash alfalfa should generally contain higher energy.

However, alfalfa provides several essential minerals contained in the ash fraction. 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 important nutritionally. For example, high K is a negative attribute for dairy animals just before and just after calving (often termed the “close-up” or “transition” period), since excessive K contributes to an increased incidence of milk fever. Additionally, excessive concentrations of micronutrients (such as selenium [Se] or molybdenum [Mo]) can be toxic when present in high amounts in the diet. Conversely, hays can provide necessary micronutrients that otherwise might be limiting in diets. Nutritionists frequently are interested in the balance of mineral nutrients in forages (e.g., Dietary Cation–Anion Difference [DCAD], see below).

## 6. Other Factors

There are other, less-well-defined attributes of quality, such as secondary plant compounds, aromas or odor, dust, and molds, that affect sensory preference by animals, but these may be important primarily as they affect intake (factor 2) and general animal health. Toxic weeds or insects (e.g., blister beetle) can be important anti-nutritional or toxic factors, and important quality factors in hay. Each year, many animals are sickened or die from poisonous weeds, excess nitrate (from weeds), or excess micronutrient concentrations in hay (see Puschner 2006). These are all attributes under the umbrella of “forage quality.”

It should be clear from the above discussions that forage quality is a complex trait that includes a range of factors.



## What’s in a Forage Plant?

Alfalfa plants, when considered as a feed, have several botanical, morphological, and physiological characteristics that impact the factors cited above. Nutrients are not uniformly distributed throughout the plant or the harvested crop. They are influenced by both macro- and micro-level morphological differences in plant structure and changes in plant composition (Fig. 16.5).

## Moisture

A fresh standing alfalfa crop contains from about 70 to 80 percent water, which is rapidly reduced to 12–18 percent moisture at baling. Hay equilibrates to about 10 percent moisture in hay stacks under ambient western conditions. Moisture is typically 60–65 percent for haylage.

Moisture is frequently confused on hay test reports. Although some dry matter components are soluble, all quality features of alfalfa are contained in the DM component, not the water component of forage. Thus, the “as-received” percentage of moisture (or percent DM) should only be used to adjust *yield* levels, not forage quality. To understand quality, quality measurements should always be compared on a



100-percent DM basis since moisture can be added or reduced, depending on conditions. Although moisture in hay is not an important nutritional factor by itself, it can indicate excessively wet hay (indicating potential mold problems, and thereby lower quality), or excessively dry hay (indicating potentially harmful prickly stems or leaf drop).

### 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 2–3 times more CP than stems (Fig. 16.5). Leaf tissue does not accumulate fiber and lignin to the same extent as stem tissue as the plant

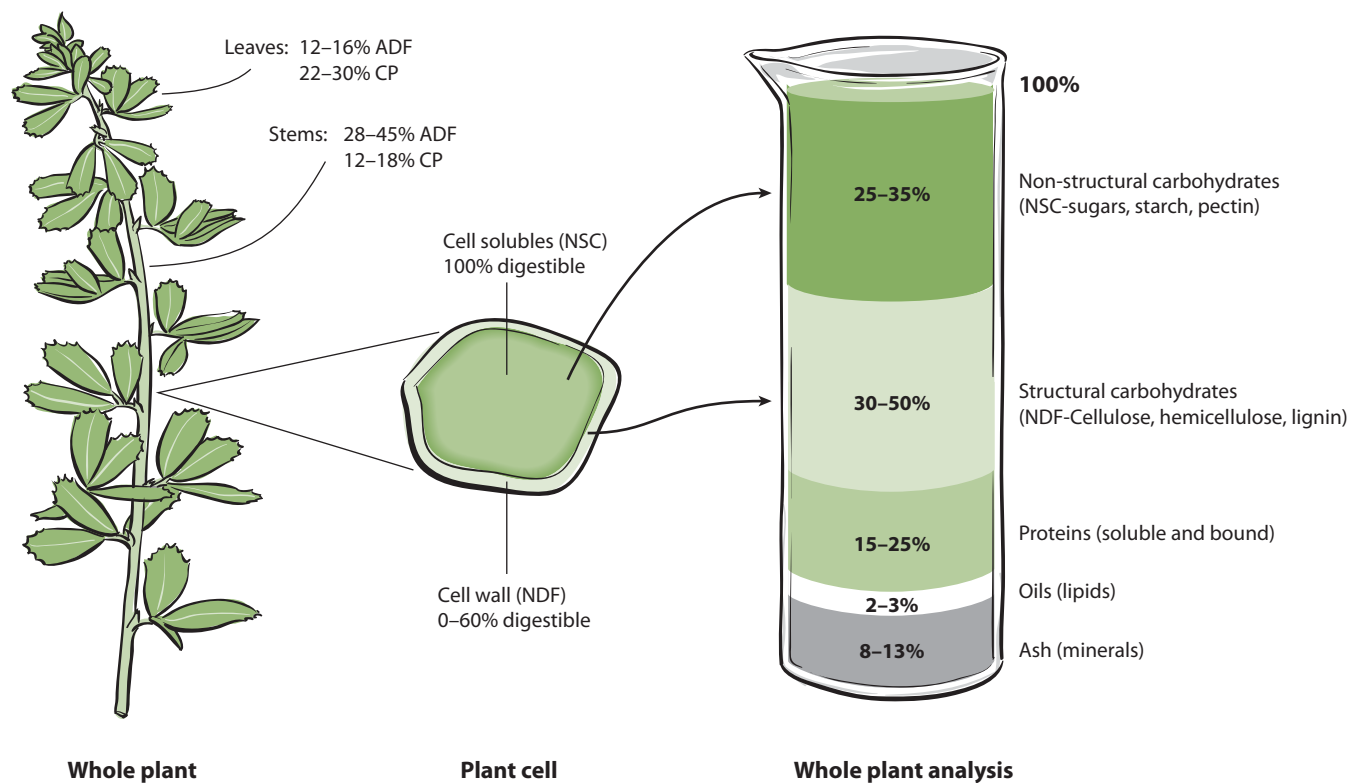
grows and develops. Thus, the relative weight of leaves and stems is probably the most important determinant of quality for alfalfa. If no analysis is available, a subjective evaluation of leaf percentage is a valuable indicator of potential feeding value (Table 16.3). Leaf percentage ranges from about 55 to 65 percent in very-high-quality alfalfa to 35 to 45 percent in lower-quality alfalfa.

### Microscopic Level—Cell Walls

On a microscopic level, each plant consists of millions of cells. Each cell consists of distinct components that differ in their nutritional characteristics, most prominently those compounds that are free or easily digested in the vacuoles or cytoplasm (cell solubles), and the cell wall material itself. A universal characteristic of higher plants is the presence of a cell wall (Fig. 16.5). This is the most fibrous component of the plant and provides structure

**FIGURE 16.5**

Alfalfa forage consists of structural components that differ dramatically in forage quality. Leaves are much lower in fiber and can have two to three times more protein than stems. Within the cell, the cell solubles or nonfiber carbohydrates (sugars and starches) are 100 percent digestible, whereas the cell wall or fiber portion are only partially digestible. NDF approximates total cell wall, and ADF approximates the most difficultly digested portions of the cell: cellulose and lignin.



to stand up and grow, and allows movement of water through the xylem. The cell wall may be as much as 60 percent of the DM of the cell (ranging from 30 to 50 percent in alfalfa).

From an animal nutrition viewpoint, cell wall material has a large influence on forage quality, since it is typically the least digested, and thus the focus of most lab measurements. As the plant matures, cell wall content generally increases, which reduces overall plant digestibility and therefore decreases forage quality.

### Cell Solubles and Nonfiber Carbohydrates

Nonfiber carbohydrates (NFC), sometimes called “cell solubles,” contribute 100 percent to the energy content of the forage (with the exception of soluble minerals), and are rapidly digested, thus contributing to high intake.

Cell solubles may range from 20 to 35 percent of DM. Young plant cells are quite high in soluble carbohydrates, such as sugars and starches, and high in protein, 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.

*Non-fiber carbohydrates (NFC), sometimes called “cell solubles” contribute 100 percent to the energy content of the forage.*

Lignification of cells creates complex cell wall structures that are more resistant to enzymatic breakdown 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.

### Protein

Typically, alfalfa plants range from 17 to 26 percent CP; thus alfalfa is an important source of protein for animals. However, the quantity of

protein degraded in the rumen from alfalfa is frequently considered to be too high in alfalfa. This may be a problem due to excess excretion of urinary urea N from ruminant feeding systems, which can be an environmental concern.

### Fat

The fat content of alfalfa plants is primarily in the cell membrane portion of the cell and is typically fairly insignificant, averaging about 1.5 percent ether extract (EE) for alfalfa hay.

### Minerals

Mineral content of alfalfa is approximated by the ash measurement and can be significant, ranging from 6 to 15 percent of the DM of the plant tissue.



## What Is Measured?

Since forage quality has chemical, biological, and dynamic properties, both measured and calculated methods must be used to predict alfalfa forage quality. The first subject of interest to nutritionists is often the measurement of the plant cell wall component, since cell walls are present in large quantities in the plant and are the most difficult component to digest. Measurements of cell wall are often accompanied by measurements of cell wall digestibility, CP, ash, and fat, which are followed by calculations of nonfiber carbohydrate and other relative quality and energy estimates. Standard hay assays include:

**Dry Matter (DM):** DM is the percentage of a sample that is not water. All other forage quality components are typically expressed and compared on a 100-percent DM basis. Dry matter is measured using 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 minor errors associated with oven drying since there can be a loss of volatile compounds that are not water, overestimating the moisture content. These small errors are more important in silages.

**Neutral Detergent Fiber (NDF):** NDF approximately measures the cellulose, hemicellulose, lignin, and some ash portion of the cell wall fraction (the slowly digestible, and indigestible, components) and is often equated with an estimate of the total plant cell wall fraction (minus the pectin). NDF is defined as the residue that remains after 1 hour of boiling in neutral detergent fiber solution. NDF is called aNDF if amylase and sulfite are used in the analysis, which is the recommended method. NDF commonly ranges from 30 to 50 percent in alfalfa hay.

**Acid Detergent Fiber (ADF):** ADF is a subset of NDF, and approximately measures the cellulose, lignin, and cutin component, or the least-digestible components of the cell wall. ADF is defined as the fibrous component of the plant that remains after 1 hour of boiling with an acid detergent solution. Since ADF is a component of NDF, the ADF concentration is always lower, ranging from 22 to 37 percent in alfalfa hay.

#### **Neutral Detergent Fiber Digestibility**

**(NDFD):** *In vitro* NDF digestibility is a measurement of the digestibility of the NDF fraction in a ruminant system for a specified incubation length of time. NDFD quantifies the amount of NDF remaining after a defined number of hours of incubation in rumen fluid (typically, 24, 30, 48, or 72 hours) in a controlled lab test, and is expressed as a percentage of NDF. NDFD may also be measured using *in vivo* (within the animal itself) methods in feeding studies or using *in situ* methods (bags in rumen). Digestibility of NDF in western alfalfa hays may range from 30 to 55 percent.

#### **Digestible Neutral Detergent Fiber (dNDF):**

The dNDF level is measured in the same way that NDFD is measured but is expressed as a percentage of dry matter, not as a percentage of NDF.

**Crude Protein (CP):** Protein in alfalfa is most commonly expressed as CP, which is calculated as the percentage of nitrogen (N)  $\times$  6.25 (reflecting the average nitrogen content of alfalfa amino acids). The correction factor of

6.25 assumes that the amino acids in alfalfa protein contains 16 percent N (the actual amount may be closer to 15.8 percent N, but 6.25 is used as a standard). Crude protein alone is seldom sufficient to predict animal performance. Measurement of amino acids may occasionally be helpful, and measurements of CP degradability in the rumen are considered very helpful. Crude protein ranges from 16 to 26 percent of DM in alfalfa hay.

**Ash:** Ash is a measure of total inorganic minerals in the forage as well as soil contamination. To obtain the ash percentage, samples are burned at high temperatures (932–1112°F, 500–600°C), and the remainder is weighed. Ash can contain minerals from organic compounds, for example P from phytic acid, plus some volatile minerals can be lost during the combustion process. Ash contains no energy. Specific minerals, such as P, K, S, Mg, Ca, Se, and manganese (Mn), are often measured separately to indicate the value of the forage in supplying those nutrients, or in identifying high levels of concern, particularly for the micronutrients Mo, Se, and Mn.

Although the above measurements are most frequently used, several other measurements may also be seen on laboratory reports and are used by nutritionists.

**Lignin:** Lignin is a part of NDF and ADF and is essentially undigestible. However, lignin often “shields” or blocks digestion of hemicelluloses and celluloses to which it is chemically linked. Lignin may be from 5 to 15 percent of the DM of alfalfa hay. Lignin measurements tend to be less repeatable than ADF or NDF.

**Lipids or Fats (EE):** The fat in alfalfa is primarily in cell membrane material and is measured as ether extract (EE). Ether extract 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 triglycerides.

**Total Nonstructural Carbohydrate (TNC) or Nonstructural Carbohydrates (NSC):** TNC (or NSC) is a measure of the starch and sugar contained in forages. This has a lower value than NFC since NFC contains compounds other than starch and sugars.

***In-Vitro* Dry Matter Digestibility (IVDMD):** IVDMD is the quantity of DM digested when a known amount of alfalfa is anaerobically incubated with buffered rumen fluid typically in a test tube after a defined length of time (typically 24–72 hr). This method provides an estimate of the extent of DM digestion. It is seldom measured and used as a routine method for estimating forage quality.

***In-Vitro* Gas Production:** This is the quantity of gas produced when a known amount of ground sample is anaerobically incubated with buffered rumen fluid over a defined length of time (e.g., from 0 to 48 or 72 hr). A continuous curve with multiple readings is possible. The multiple measurements allow estimation of the extent of digestion and also the rate of digestion. Gas quantities can be used to predict Digestible Energy (DE) or Metabolized Energy (ME) content.

**Ruminant *In-Situ* Measurements:** Digestibility of forages can be measured with nylon bags inserted directly into the rumen of fistulated cows. Bags can be withdrawn from the rumen after different lengths of incubation time. *In situ* (also called *in sacco*) methods are often used to estimate disappearance of DM, CP, and NDF. If samples are collected over a range of incubation times, both the extent and rate of disappearance can be estimated.

**Acid Detergent Insoluble Nitrogen (ADIN) and Acid Detergent Insoluble Crude Protein (ADICP):** ADIN and ADICP are measured as the insoluble N remaining after a known amount of sample is boiled in acid detergent solution. The N remaining in the ADF residue is assumed to be unavailable to the animal. It is a good estimator of indigestible CP, mostly lignified and heat damaged protein, and is generally expressed as a percentage of the CP content

of the forage. Formation of ADICP can occur during “heating” in moist hay (i.e., browning). This can be expressed either as ADIN or as ADICP (which is the insoluble N  $\times$  6.25).

**Rumen Undegraded Protein (RUP):** RUP measures the quantity of CP that is not degraded by microbes in the rumen. Often called “rumen escape protein,” it is typically measured with *in situ* bag methods—the protein which does not disappear from the ruminant nylon bag is considered rumen undegraded protein.



## What Is Calculated?

Not all forage quality characteristics can be measured; some very important quality factors must be predicted from laboratory measurements since they are so difficult to measure routinely. These are primarily the energy and intake potential of the forage, which may be predicted using several approaches. It is very important to understand the source of the calculated numbers on laboratory reports to allow correct interpretation, since these can sometimes be calculated differently.

**Non-Fiber Carbohydrates (NFCs):** NFCs are those energy-containing compounds (primarily sugars, starches, and pectins) that are highly soluble and nearly 100 percent digestible by ruminants. Non-fiber carbohydrates are calculated as the difference between the total DM and the NDF, CP, ash, and EE concentrations of the forage. This is similar (but not precisely the same) as NSC (see above), which can be measured directly. The NFCs may range from 20 to 35 percent in alfalfa forage and is a major contributor to the digestible energy contained in forages.

**Digestible Energy (DE):** DE is the quantity of total intake energy in a forage that is not lost in feces.

**Metabolizable Energy (ME):** ME is the quantity of energy in a forage that is not lost in feces, urine, or rumen gasses, and is available to the animal for use.

**Net Energy for Maintenance (NE<sub>m</sub>):** NE<sub>m</sub> is a prediction of the quantity of energy in a forage required to maintain a stable weight.

**Net Energy for Gain (NE<sub>g</sub>):** NE<sub>g</sub> is a prediction of the quantity of energy in a forage available for body weight gain above that of maintenance.

**Net Energy for Lactation (NE<sub>l</sub>):** NE<sub>l</sub> is a prediction of the quantity of energy in a forage available for maintenance plus milk production during lactation, and for maintenance plus the last two months of gestation for dry, pregnant cows.

**Dietary Cation–Anion Difference (DCAD):** DCAD in the 2001 NRC recommendations is calculated as the difference of concentrations of cations and anions as milliequivalents:  $\text{meq} (\text{Na} + \text{K} + 0.15 \text{ Ca} + 0.15 \text{ Mg}) - (\text{Cl} + 0.605 \text{ S} + 0.5 \text{ P})/100 \text{ g}$  of dietary DM.

**Total Digestible Nutrients (TDN):** TDN conceptually is the sum of DE contained in nonstructural carbohydrates (cell solubles), digestible NDF, crude protein, and fat. However, in practice, TDN is predicted from ADF or NDF alone (Fig. 16.4), but formulas for TDN vary widely. The “western states” equation, as published by Bath and Marble (1989), is  $\text{TDN (\% of DM)} = 82.38 - (0.7515 \times \text{ADF}\%)$ . Currently, TDN is more frequently predicted using summative equations by nutritionists.

**Relative Feed Value (RFV):** RFV is a marketing index for ranking cool-season grass and legumes and is calculated from ADF and NDF. The RFV is conceptually based on both digestibility and intake potential, but is mathematically highly correlated to NDF. See the NFTA Web site ([www.foragetesting.org](http://www.foragetesting.org)) for calculation.

**Relative Forage Quality (RFQ):** RFQ is an index for marketing forages, similar to RFV, but includes a component related to intake potential. The RFQ is calculated from NDF, NDFD, CP, EE, and NFC and is an index for marketing forages proposed as an improvement over RFV since it emphasizes intake potential. The RFQ is calculated from NDF, NDFD, CP, EE, and NFC. See NFTA Web site ([www.foragetesting.org](http://www.foragetesting.org)) for calculation.

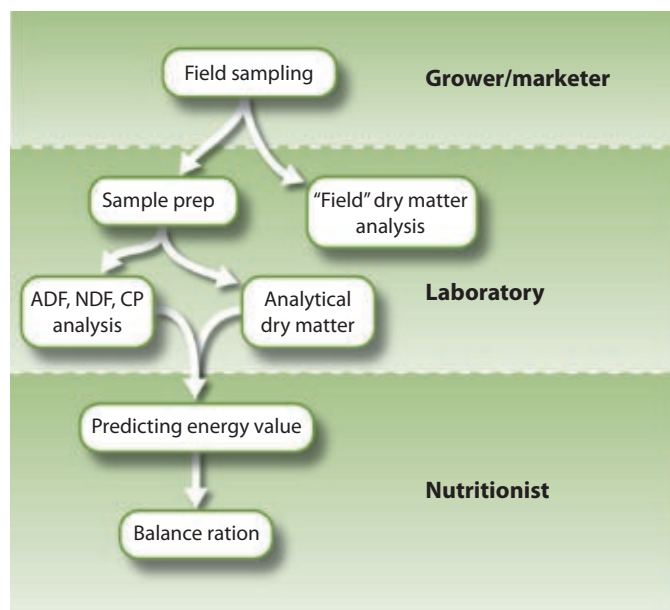
## The Hay Testing Process

### Standardization of Hay Quality Measurements

A key issue impacting dairy nutritionists and hay growers, as well as buyers and sellers, is the standardization of hay testing. The process of hay testing begins with accurate sampling methods, followed by the standardization of laboratory methods and use of empirical formulas to estimate forage quality based on laboratory measurements (Fig. 16.6). Obtaining differing results from various laboratories creates confusion in the marketplace.

**FIGURE 16.6**

The hay testing process. Growers and marketers are responsible for sampling methods, laboratories are responsible for good lab methods, and nutritionists are responsible for providing prediction equations and interpretation of data.





## The Importance of Sampling

It is impossible to overemphasize the importance of sampling for hay quality analysis. Obtaining a representative sample of a given “lot” of hay is critical. Remember, a laboratory test is only as good as the sample provided to the lab. *Here’s the dilemma:* Tons of highly variable plant material must be represented in a single, tiny, thumbnail-sized sample (Fig. 16.7). For many analyses, the sample actually analyzed by the laboratory is only 0.5 grams (0.018 oz)! This sample must represent not only the proper leaf–stem ratio and the legume/grass mix, but must also reflect the variable presence of weeds and soil variation.

Sampling variation is a major problem in hay evaluation and causes millions of dollars in lost revenue each year by either buyer or seller, and also contributes to reduced animal performance. In practice, hay sampling causes more variation in results than does laboratory variation. However, if sampling protocols are carefully followed, sampling variation can be reduced to an acceptable level, and the potential forage quality successfully predicted.

The following steps are widely considered to be the key elements of an effective stan-

dardized 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.

- 1. 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 (181 Mg).
- 2. Sample at the right time.** Sample as close to point of sale, or as close to feeding, as possible since dry matter and other measurements are subject to change after harvest and during storage.
- 3. Always use a sharp, well-designed coring device.** Use a coring device 0.375 to 0.750 inches (0.95 to 1.9 cm) in diameter with a sharp tip at 90 degrees to the shaft, not

angled. *Never* send in flakes or grab samples. The probe length should allow probing to a depth of 12–24 inches (30–61 cm). Hay probes should (1) easily penetrate the bale, (2) fairly represent the leaf–stem ratio, (3) be easy to sharpen, and (4) produce approximately 0.5 pounds (227 g) of sample in about 20 cores to a depth of 12–24 inches (30–61 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).

### FIGURE 16.7

Hay sampling protocols are critical to provide accurate quality measurements. Sampling methods must correctly represent the leaf–stem component, percentage of weeds, as well as variation due to soil type over a field in hay lots. Units for sampling should not exceed 200 tons, and should be from a single field/single cutting. See <http://alfalfa.ucdavis.edu> for hay sampling protocols.



- 4. 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.

- 5. 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.

- 6. Use proper technique.** The probe should be inserted at a 90-degree angle, 12–18 inches (30–46 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.

- 7. 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 (1.9 cm) diameters. If the wrong amount of sample is produced with 20 cores, a different hay sampler should be used.

- 8. 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.

- 9. 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 the 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

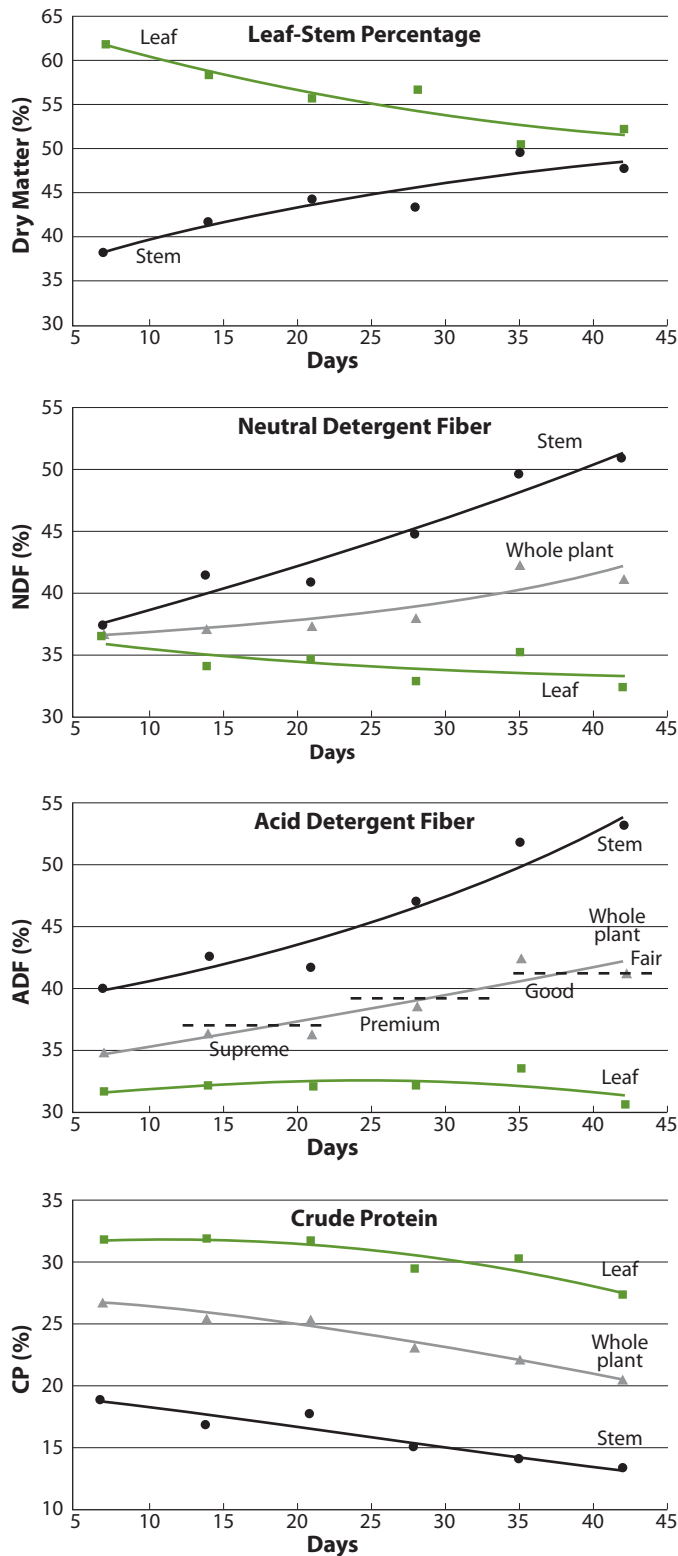
Once a good sample is obtained, a qualified laboratory must be chosen. The first criterion for choosing a high-quality laboratory is membership in and certification by the National Forage Testing Association (NFTA). Laboratory performance is not regulated in the United States by any government agency—laboratories voluntarily submit to the NFTA performance testing program 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.

Additionally, 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. In addition, customers may conduct their own split-sample test of laboratories. To test two laboratories, either grind and carefully split the sample with an appropriate device, or better yet, ask for your ground sample back to split and send to another laboratory (never split unground samples to test laboratory performance). Don't work with a laboratory that is unwilling to assist you in testing their performance.

*The first criterion for choosing a high-quality laboratory is membership in and certification by the National Forage Testing Association (NFTA).*

**FIGURE 16.8**

Changes in alfalfa leaf–stem dry matter percentage, acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein concentrations of the first growth period, Yolo Co., CA. Marketing categories are shown as a function of ADF (USDA–Market News). Data from T. Ackerly (M.S. Thesis, UC Davis, 2000).



## Agronomic Factors that Influence Forage Quality

The major agronomic factors that affect alfalfa quality are cutting schedules (plant maturity at harvest), weed and pest management, harvest effects, and seasonal or weather patterns. Less important effects are variety, time of day of harvest, fertilizers, and irrigation. Sometimes these factors interact in complex ways. But these factors typically affect quality via a few fundamental mechanisms, including plant maturity at harvest, leaf percentage, mixtures with weeds, and environmental effects.

### Plant Maturity at Harvest

It is a universal axiom of alfalfa forage production that as a plant grows and develops, forage quality declines. Therefore, the stage at which the plant is harvested is usually the most critical factor determining forage quality. This is such an important issue that we have dedicated a whole chapter in this series to cutting schedules (see “Harvest Strategies for Alfalfa,” Chapter 13), and thus it will be given only cursory treatment here.

The change in forage quality due to plant maturity is the result of two major and powerful mechanisms: First, the leaf percentage declines as the plant grows, as a percentage of the plant biomass (Fig. 16.8). This is due primarily to the increase in stem weight that occurs during growth—since the plant produces mostly stems after about 12 to 15 days (Fig. 16.8). Second, the quality of the stem fraction declines precipitously as the plant continues to grow. The ADF and NDF concentrations go up, whereas CP goes down, particularly in the stem component (Fig. 16.8). This is due to what is happening at the cellular level; the young, tender primary cell wall is strengthened by the highly lignified secondary cell wall in the stem. The rate of growth of the stem (weight increase per day), and the rate of lignification of the stem (increase in lignin percentage or NDF/ADF percentage), is also highly influenced by time of year, temperature, and other factors, such as variety.

Staging growth of the plant according to vegetative and reproductive development

is an important way to identify high-quality alfalfa. Stages include vegetative, early bud, late bud, early flower, late flower, and seed production (see further details in Chapter 3 “Alfalfa Growth and Development”). The profound effect of cutting schedule and maturity on quality and yield can be seen in Table 16.4. Plant height is also closely related to forage quality. Measuring sticks, such as the UC Intermountain Alfalfa Quality Stick (see <http://alfalfa.ucdavis.edu>), have been developed to help predict quality from height, but these have not proven to be robust across Mediterranean and arid environments.

**Leaf Percentage**

The leaf percentage of hay is a major determinant of quality. Leaves may have two to three times the CP content of stems and sometimes half the fiber concentration. In some forages, leaves consist of two-thirds of the feeding value, although they may be less than 50 percent of the DM. The decline in forage quality is mainly due to stems, which decline about 0.5 percentage points in digestibility (IVDDM) per day, and increase dramatically in NDF and ADF, whereas leaves decline only very slightly over time (Table 16.4).

Although plant maturity has a dramatic effect, there are also many other factors that influence leaf percentage. These include insect and disease damage, variety, irrigation, harvest and curing effects, as well as environment.

Thus, any agronomic practice that impacts leaf–stem ratio or plant maturity at harvest will affect forage quality.

**Yield–Quality–Persistence Tradeoff**

Although forage quality is dramatically improved by short cutting schedules (e.g., 21-day intervals), yield is also dramatically

**Factors and Principles that Influence Alfalfa Quality**

**Primary Mechanisms      Agronomic Factors**

- Plant maturity at harvest
- Leaf percentage
- Mixture with weeds
- Environmental effects
- Cutting schedules
- Rain damage
- Time of day for harvest
- Harvesting effects
- Variety
- Stand density
- Soil type and fertility
- Irrigation
- Pest interactions

reduced, as is stand life, allowing for increases in weed infestation (Table 16.4—note that the forage quality data in this table does not reflect the weed component of the mix). The tradeoff between yield, quality, weeds, and stand life is a major and complex issue for forage producers and is of tremendous economic importance. The optimum profitability point as determined by cutting schedule is rarely the point where maximum quality is obtained, nor at the point

**TABLE 16.4**

Effect of maturity at harvest and harvest interval on alfalfa yield, quality, leaf percentage, weeds, and stand life

| Maturity at Harvest | Harvest Interval (days) | Yield (T/acre) | ADF  | CP   | Leaf (%) | Weeds (%) | Stand Percentage* |
|---------------------|-------------------------|----------------|------|------|----------|-----------|-------------------|
| Pre-Bud             | 21                      | 7.5            | 26.3 | 29.1 | 58       | 48        | 29                |
| Mid-Bud             | 25                      | 8.8            | 29.5 | 25.2 | 56       | 54        | 38                |
| 10% Bloom           | 29                      | 9.9            | 32.2 | 21.3 | 53       | 8         | 45                |
| 50% Bloom           | 33                      | 11.4           | 32.7 | 18.0 | 50       | 0         | 56                |
| 100% Bloom          | 37                      | 11.6           | 35.5 | 16.9 | 47       | 0         | 50                |

Source: Marble (1974). Proceedings, 4th California Alfalfa Symposium, Dec. 4–5. UC Cooperative Extension.

\*Percentage of alfalfa stand after three harvest years.

ADF = acid detergent fiber; CP = crude protein.

where maximum yield is obtained. See Chapter 13, “Harvest Strategies,” for a full discussion of this issue.

### Cutting Schedule

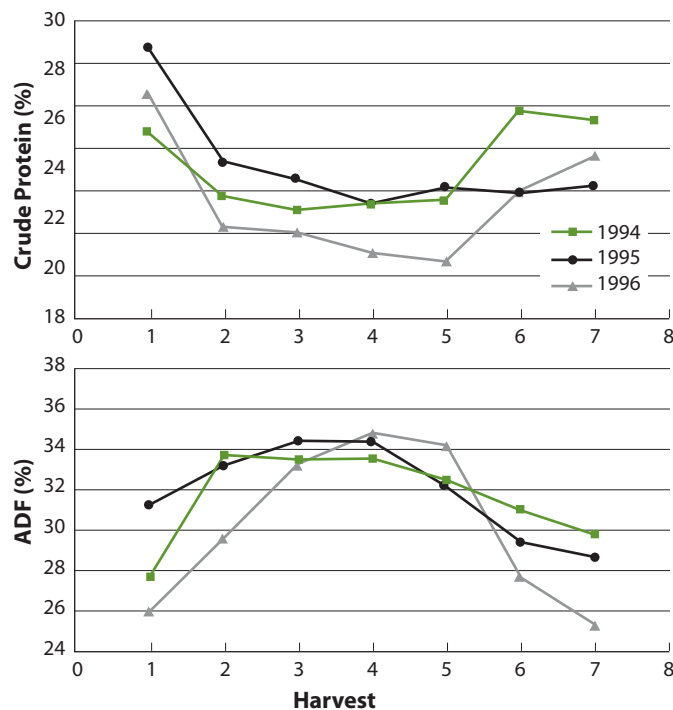
Cutting schedule is, overwhelmingly, the most powerful method under a grower’s control to manipulate forage quality, since both maturity and leaf percentage are impacted. Growers have generally gravitated toward early- to late-bud harvests to attain high forage quality, but at great expense of yield and persistence (Table 16.4). If yield, stand persistence, and weeds were not important, the earliest cutting dates would typically provide the highest quality forage (Table 16.4), but these dates would rarely provide optimum economic returns. The vigorous cutting schedules commonly practiced to attain high quality may ultimately work against high-quality production since stands may thin and weeds may invade (Table 16.4). Clearly, a more integrated approach balancing yield, quality, persistence, and economics is required.

### Environment and Temperature

Alfalfa forage quality is generally highest in spring (i.e., first and second cuttings) and late fall, and lowest in summer, but forage quality also changes due to temporary weather patterns. Data collected over 3 years using eight to ten mostly nondormant varieties in Fresno County, California, show large differences over the season and among years (Fig. 16.9). Seasonal and environmental differences were far greater than the differences among varieties. Seasonal and yearly variations have their effect primarily through temperature, but day length and light intensity are also important. The high temperatures of summer increase growth rate (primarily stem growth), hasten plant maturity, and increase lignification of the cell wall. High temperatures also hasten respiration rates, which in turn reduce the quantity of soluble carbohydrates in the stems and leaves. Respiration turns sugars and starches into carbon dioxide and produces energy to produce other compounds in the plant, such as cell wall material or protein. Thus, high rates of respiration have the dual effect of lowering the highly digestible “sugar pools” in the plant and hastening growth and maturity.

**FIGURE 16.9**

Seasonal influences on crude protein (top) and acid detergent fiber (bottom) values. Data average of ten nondormant varieties, 1994–1996, Kearney Ag. Center, Fresno Co., CA.



### Weeds and Species Mixtures

Although weeds can theoretically have neutral, positive, or negative effects on alfalfa forage quality, the overwhelming effect is negative. Most weeds, especially grassy weeds, increase the NDF concentration (fiber) and lower intake, protein, and digestibility. Ironically, many weeds can increase yields of sparse alfalfa stands, since they “fill in” bare areas, but this yield increase rarely compensates for the lower quality of the forage.

The primary characteristics of weeds that influence quality are the species of weed and maturity at harvest. Some weeds, such as pigweed (*Amaranthus retroflexus* L.), lambsquarters (*Chenopodium album* L.), and volunteer cool-season grasses, may provide good forage quality if harvested early but can also contain high nitrate levels, contributing a significant risk to animal health. Some weeds, like common groundsel (*Senecio vulgaris* L.) and fiddleneck (*Amsinckia menziesii* [Lehm.] Nelson & J. F. Macbr.), are toxic to animals



and thus substantially lower the feeding value, even if the energy or protein are not affected. Green and yellow foxtail (*Setaria viridis* [L.] Beauv. and *Setaria pumila* [Poiret] Roemer & Schultes), foxtail barley (*Hordeum jubatum* L.), yellow starthistle (*Centaurea solstitialis* L.), and Russian thistle (*Salsola tragus* L.) can all contribute to lowered palatability and lower animal acceptance, sometimes causing pain and injuring the mouths of the animals. Even in cases where weeds do not reduce the chemically analyzed feeding value, they may reduce the marketability of the hay due to the perception of the buyer. In practice, inability to control weeds is one of the most common causes of low forage quality of alfalfa.

### Harvest Effects

The process of drying, raking, handling, and baling hay has long been known to affect forage quality. Alfalfa leaves dry much faster than stems. Since growers must wait until stem moisture is sufficiently low for baling, hay is often harvested at a point where leaves are too dry for handling. Leaf shatter is a significant hazard in western states and can reduce forage quality by reducing leaf–stem ratio. Any method, be it mechanical or chemical conditioning, wider swath width, or skillful raking that speeds the drying process of stems, may improve forage quality.

The greatest risk for leaf shatter is during raking process and baling, although any field operation may increase leaf shatter, depending on conditions. Field operations (such as intensive conditioning or wide windrows) that hasten drying of stems help preserve forage quality. Some hay preservatives may enable growers to bale under more moist conditions, thereby conserving leaf material. However, they are generally not believed to be cost-effective under most California conditions. Where extremely dry baling conditions prevail, re-wetting windrows to soften leaves just before baling can be beneficial. Dew can provide much-needed softness and leaf retention, and therefore many growers bale at night or in early morning during summer months to maximize leaf retention. Applying good harvesting skills to maintain forage quality remains a major challenge to growers.

Switching to greenchop or haylage can improve leaf retention, approaching 100 percent, since the forage is wilted, not dried, before handling. A major advantage of haylage is the ability to get the crop off the field rapidly in the spring when rains threaten, and in some cases, an additional harvest is possible. However, production of haylage may entail DM and quality losses during ensiling that may be equal to, or greater than, those losses resulting from baling. Losses of quality are least with greenchop, but dry matter intake can be lowered due to high moisture content of fresh forage.

### Conditioning and Particle Size or Maceration Effects

Traditional conditioners, if well adjusted, can have a significant effect on quality since they hasten stem drying. This allows growers to more closely match the drying rate of leaves and stems and to retain leaf material. Conditioning also slows respiration of carbohydrates, reducing quality loss.

Maceration, which is a “shredding” or very intensive conditioning, may have dramatic effects on forage quality. Maceration ruptures the forage cells, rather than just crushing or conditioning the stems. In experimental studies, drying rates are reduced to as little as a day, and a “mat” is produced that can then be picked up and baled, cubed, or ensiled. Maceration changes microparticle size, making cells more available for rumen fermentation. The immediate availability of the soluble fraction of forage, as well as the rate of fermentation of the NDF fraction, have been shown to be dramatically affected by maceration in studies at the USDA Dairy Forage Research Center in Madison, Wisconsin, and at the University of California at Davis (UC Davis). If commercialized, this technology may have a major effect on forage production and quality. See

*Switching to greenchop or haylage can improve leaf retention, approaching 100 percent, since the forage is wilted, not dried, before handling.*

Orloff et al. 1997, ([www.alfalfa.ucdavis.edu](http://www.alfalfa.ucdavis.edu)) for details.

Note: if blister beetles are present, hay should not be conditioned or crushed to lessen the chances of toxicity in the hay (see “Managing Insects in Alfalfa,” Chapter 9).

### Time of Day

Observations from the 1940s have shown changes in soluble carbohydrate levels in alfalfa due to time of day. More recent data from Idaho, California, Utah, and other states have pointed to the advantage of harvesting alfalfa in

*Data from Idaho, California, Utah, and other states have pointed to the advantage of harvesting alfalfa in the late afternoon.*

the late afternoon, which takes advantage of the temporary accumulation of soluble carbohydrates associated with photosynthesis during the day. Accumulation of sugars (and other soluble components) in the cells may lower the apparent fiber and the crude protein concentration due simply to the greater quantity of accumulated cell solubles. As the

alfalfa plant rapidly photosynthesizes in the late morning, sugars and starches may accumulate in plant tissue. At night, these compounds are respired and utilized by the plant, increasing the fiber concentration.

If hay is cut in the afternoon, and respiration in windrows is minimal, then the higher concentration of soluble carbohydrates may contribute up to 1 to 1.5 percent to the energy (ME, DE, or TDN) of the forage. There is evidence that animals prefer afternoon-harvested hay in either grazed forage or hay. The advantages of afternoon harvest would likely be greatest under cool, bright-sunshine conditions, and under conditions where the forage is highly conditioned to increase drying rates and minimize respiration in the windrow after harvest. Afternoon harvests are not necessarily appropriate in circumstances where rain damage is the more important concern, and every hour of drying time is important.

### Rain Damage During Harvest

Rain reduces the level of available carbohydrates or available energy by leaching soluble components from the plant. It also decreases forage quality by increasing leaf shatter. Since soluble components are typically 100 percent digestible, leaching decreases the energy value significantly, as well as protein content and dry matter. The extent of leaching is influenced by stage of maturity, forage moisture at the time of the rain, amount and intensity of rain, and condition of the hay during the rain event. Rain can increase dry matter losses caused by leaching and leaf shatter from 10 to over 50 percent, depending on the amount of rainfall.

### Variety

Research from a number of locations has shown differences in quality between some, but not all, varieties under the same cutting schedule. Varieties differ primarily due to changes in leaf percentage, or because of slower growth rates, which are often a function of fall dormancy, or due to more subtle changes in cell wall structure, such as lower lignin or higher rates of cell wall degradation in the rumen. Multifoliolate varieties (varieties that produce more than three leaflets per leaf) can, in some cases, result in higher quality forage, but this is not always so. The key issue is leaf percentage and stem quality, not number of leaves. Stem quality and leaf percentage may be equal or greater with some trifoliolate leaf type varieties compared to so-called multi-leaf or multifoliolate varieties. Some trifoliolate varieties have also been developed to have a superior forage quality.

Fall dormancy has a powerful effect on quality of varieties in a Mediterranean environment. In a three-year study at UC Davis, nondormant varieties were significantly lower in quality than dormant varieties (Fig. 16.10). There was an approximately 0.6 percent increase in either ADF or NDF or a 0.6 percent decrease in CP per unit fall dormancy (FD) from FD rating 3 through 9 (the higher the number, the more nondormant the variety). Growers have found that planting of more dormant cultivars has become an important strategy for improving quality. However, the growth rates of more dormant varieties may be

significantly below those of other adapted varieties in a region. Under most circumstances, growers must be prepared to accept lower yields with these varieties (see “Choosing an Alfalfa Variety,” Chapter 5), particularly under longer-seasoned, warmer conditions (e.g., Southern California). Yield is still the predominant economic factor for alfalfa growers, but under some economic conditions, such as low price years, growers have been willing to sacrifice some yield for higher forage quality.

**Stand Density**

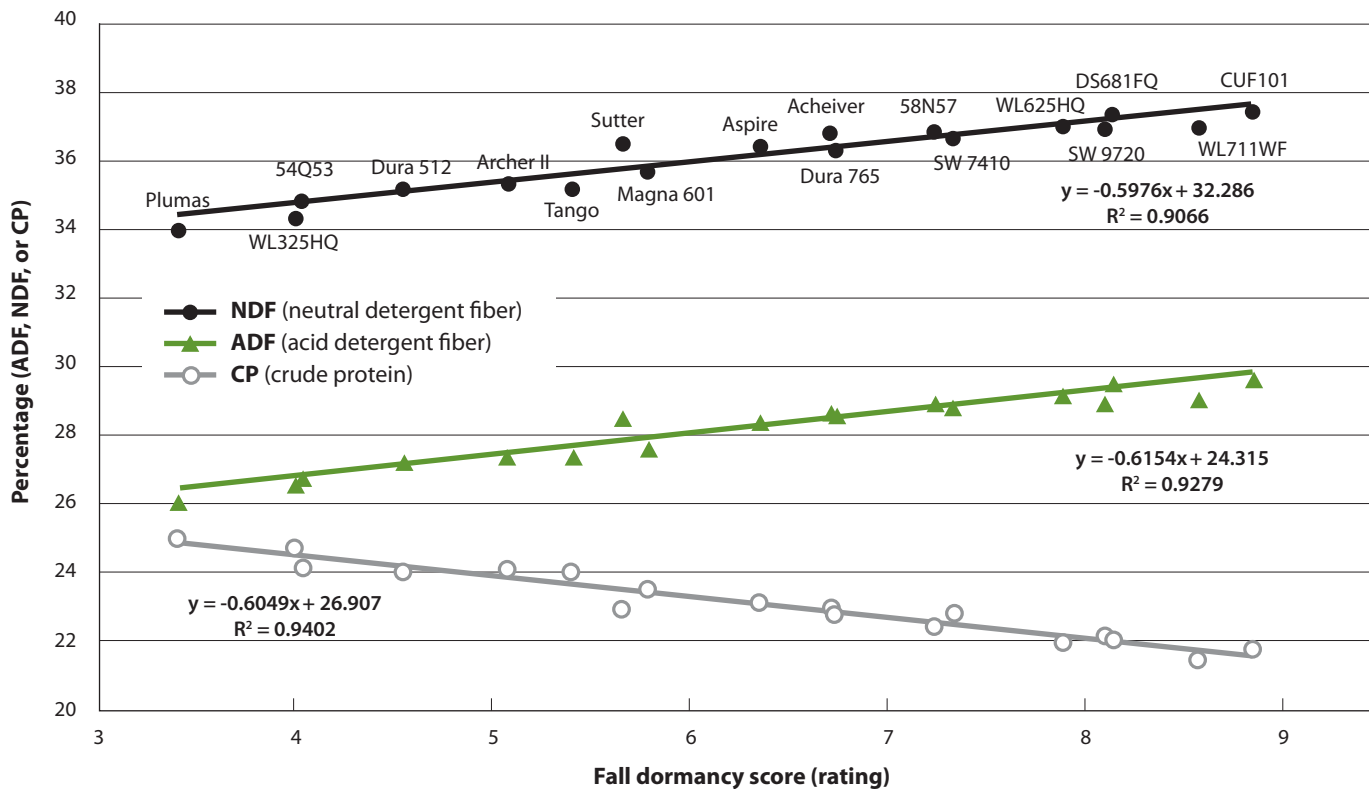
Leaf percentage, CP, ADF, and lignin are not largely affected by stand density per se. Evidence from studies in Wisconsin, Idaho, Oregon, and Wyoming have shown that leaf percentage, CP, ADF, and lignin were not affected by initial seeding rates. This is because at higher plant densities, the numbers of stems per crown is greatly reduced; thus the

number of stems per unit area does not differ significantly between very high and moderately low densities. However, stem thickness may be slightly greater under low densities. Counteracting this effect, however, is the possibility that light penetration into the lower sections of the alfalfa canopy may improve leaf retention compared with thick stands.

A more important factor is the effect of stand density on weeds. When stand densities fall below a certain number (between four and six plants per square foot [0.929 m<sup>2</sup>], depending on the age of the stand), open spaces become available for the growth of weeds. The weeds, in turn, can have a substantial impact upon forage quality. This is likely the most important consideration of alfalfa stand density in relationship to forage quality. Maintaining a high stand density is desirable for high yields, weed management, and high quality.

**FIGURE 16.10**

Effect of fall dormancy ratings on forage quality (ADF, NDF, and CP) of 18 varieties grown at Davis, California. Data points represent an average of 3 years, three cutting schedules, all harvests, about seven harvests/year (2002–2004). Lower fall dormancy of alfalfa varieties reduces ADF and NDF, and increases protein on the average, but this should be evaluated against the generally inferior yields of these varieties under Mediterranean and desert conditions.



### Soil Type

It has long been known that alfalfa produced on certain soils, primarily heavy clay or salty soils, produces higher quality alfalfa than that produced on sandy or loamy soils. This has been attributed to greater plant stress on those soil types, and slower growth rates, perhaps due to lack of oxygen in the root zone or salt effects. Because stress often reduces growth rates, this primarily reduces stem growth, not leaf growth. The stress seems to produce a shorter, finer-stemmed, leafier alfalfa than alfalfa harvested at the same harvest interval on sandy or loamy soil. It should be noted, however, that climatic influence might be a more important factor than soil type in comparing regions.

### Fertilizers

As a rule, fertilizers are likely to have either no effect, or decrease the quality of alfalfa.

*As a rule, fertilizers are likely to have either no effect, or decrease the quality of alfalfa.*

Most fertilizers improve yields of alfalfa when the elements contained in the fertilizer are in short supply in the soil (see “Alfalfa Fertilization Strategies,” Chapter 6). Thus, if P, K, S, or micronutrients are low in soil or tissue tests, yields of alfalfa will improve with application of those fertilizers. In most cases, however, the improvement in yield

that results from application of fertilizers will result in more rapid growth rates, which is more likely to decrease, not increase, forage quality as a result of increased stem growth and more rapid lignification of the stem.

Research in California, Wisconsin, and Oregon has clearly shown that there is either no difference, or a decline in alfalfa quality, when K fertilizers were used on K-deficient sites. These results are not surprising, considering the importance of K in improving alfalfa growth and yield. Similar results have been seen with P and S. These studies indicate the importance of fertilizing for maximum yield. Additionally, a well-fertilized crop will be better able to sustain the short cutting schedules necessary for producing high-quality forage.

However, fertilizers generally do not improve quality.

Another important factor is the potential negative effect of plant nutrients on quality. It's important not to over-apply fertilizers. Dairy nutritionists emphasize the importance of minimizing the amount of K contained in hay fed to close-up cows (pregnant cows nearing birth), to prevent problems with calcium nutrition and milk fever. With excess K in the soil, “luxury consumption” occurs. Alfalfa is well known for luxury consumption of K, where the K concentration of the forage increases without an increase in yield. This is clearly not desirable, either from the grower's point of view (waste of fertilizer with no return), or from the nutritionist's point of view, due to the danger of excess K in the forage. This is a serious problem near dairies, where excess soil K cannot be controlled. This problem has been increasingly recognized, and a niche market for low-K hay has emerged—some dairies will pay \$5 to \$10 more per ton (907 kg) for such “low-potassium” hay.

Some growers feel that nitrogen (N) fertilizers may improve the quality of alfalfa. However, there is little evidence to support this practice for either yield or quality. Nitrogen fertilizers are unlikely to improve ME, NE, or TDN, or reduce fiber. There are some instances of N fertilizers causing slight improvements in CP concentration, but an equal or greater number of field trials show no effect of N fertilizers on CP. Nitrogen fertilizers are likely to contribute to the nonprotein N fraction in the plant, which is mostly metabolized and excreted by the animal. This has a metabolic cost and may contribute to environmental problems caused by the increased N in the animal waste. Additionally, N fertilizers encourage grassy weeds more than alfalfa, which may lower quality. Although applications of N fertilizers may make the plants look greener, it is not recommended to apply N fertilizers to alfalfa in attempts to improve forage quality or yield.

### Irrigation Management

Irrigation management is probably the most important yield-limiting factor in western states. Over-applications of water, too little water, or lack of drainage are major problems

with alfalfa production. However, water stress often *improves* forage quality, since the leaf-stem ratio can be improved due to lack of growth of the stem component. However, yields are linearly related to water availability and are dramatically reduced by water stress. The loss in alfalfa yield is too great to justify allowing water stress as a means of improving quality.

### Insects and Diseases

Insect and disease pests can have a positive or a negative effect on forage quality, but the effect is typically negative since their feeding habits include consuming leaves, thereby decreasing the leaf percentage. Sucking insects, such as aphids, may reduce soluble carbohydrates, therefore reducing forage quality. Insects that intensively suck plant sap, such as the silver-leaf whitefly (*Bemisia argentifolii* Bellows & Perring) in the Imperial Valley and cowpea aphid (*Aphis craccivora* Koch) in the Central Valley, cause widespread stickiness on the plant surface; this in turn encourages fungi (sooty molds) to develop, which lowers palatability and consumer acceptance. Generally, insects must be controlled to maintain high-quality alfalfa and prevent leaf loss (see “Managing Insects in Alfalfa,” Chapter 9).

## Summary

Attaining high-quality alfalfa forage is a critical aspect of profitability for alfalfa and animal productivity. Attributes of quality include digestible energy, voluntary intake, protein, ruminally effective fiber, and minerals. Forage quality has many attributes and should be evaluated through both laboratory measurements and subjective observations (odor, mold, weed content, etc.).

Measurements of plant cell wall (NDF) and its degradability (NDFD), crude protein (CP), and ash may be 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 ME, DE, NE<sub>l</sub>, TDN, and RFQ, is important for understanding laboratory tests. Cutting schedules, weed management, and harvest management are the most powerful methods for improving quality under the control of growers, but seasonal effects (spring, summer, fall) can be major determinants of forage quality. Variety, time of day of harvest, insect management, and water stress can influence quality but are usually less important than cutting schedules, harvest management,

time of year, or climate.

Fertilizers generally do not improve quality, but quality can differ somewhat by soil type.

Alfalfa growers who invest the time in understanding quality factors for animal performance benefit by their improved ability to successfully market their hay.







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