Understanding Forage Quality

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Understanding forage quality

Forage quality is defined in various ways but is often poorly understood. It represents a simple concept, yet encompasses much complexity. Though important, forage quality often receives far less consideration than it deserves.

Adequate animal nutrition is essential for high rates of gain, ample milk production, efficient reproduction, and adequate profits (see sidebar). However, forage quality varies greatly among and within forage crops, and nutritional needs vary among and within animal species and classes. Producing suitable quality forage for a given situation requires knowing the factors that affect forage quality, then exercising management accordingly. Analyzing forages for nutrient content can be used to determine whether quality is adequate and to guide proper ration supplementation.

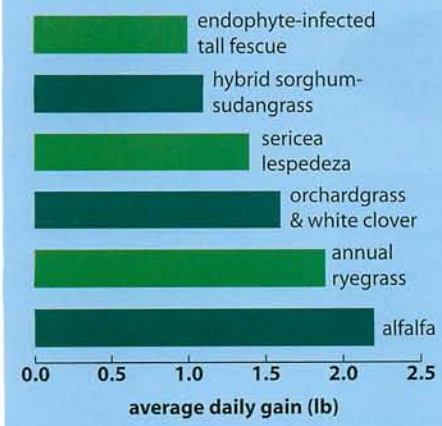
In recent years, advances in plant and animal breeding, introduction of new products, and development of new management approaches have made it possible to increase animal performance. However, for this to be realized, there must be additional focus on forage quality. The purpose of this publication is to provide information about forage quality and forage testing that can be used to increase animal performance and producer profits.

IMPORTANCE OF FORAGE QUALITY

Forage quality has a direct effect on animal performance, forage value, and, ultimately, on profits. The following graphs show the links between quality, performance, and returns.

Weight gain

Stocker beef cattle gains from different forages, *Alabama*

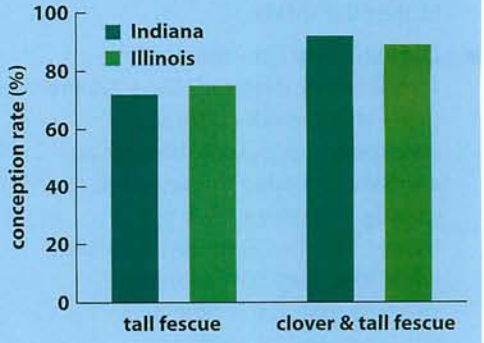


Milk production

Production from 8 tons/acre of alfalfa hay of either low or high quality, *Wisconsin*

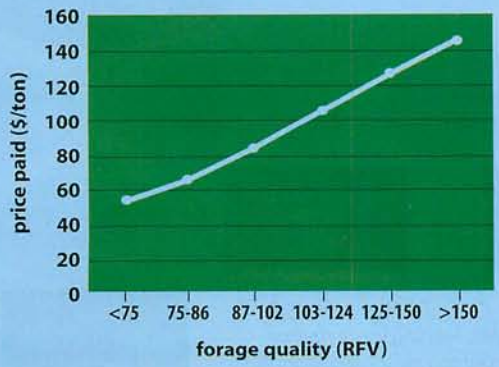
Reproductive efficiency

Conception rates of cows grazing fescue or fescue/clover, *Indiana & Illinois*

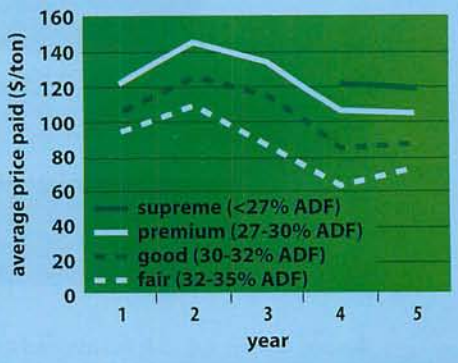


Hay sale prices

Prices paid in quality-tested hay auctions, *Wisconsin*, 1984-98



Effect of forage quality on hay price average all California markets (1996-2000)

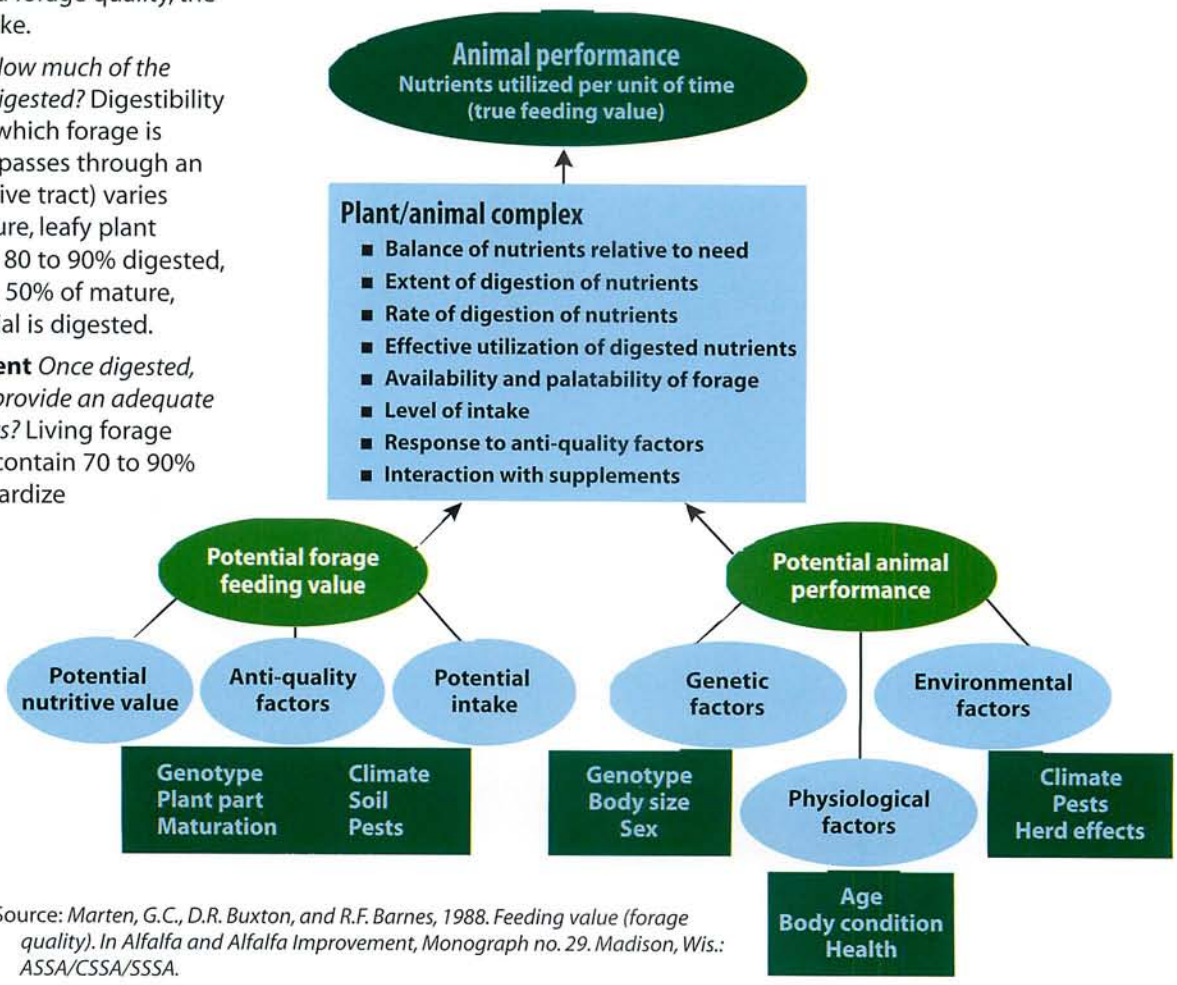


What is forage quality?

Forage quality can be defined as the extent to which a forage has the potential to produce a desired animal response. Factors that influence forage quality include the following.

- **Palatability** *Will the animals eat the forage?* Animals select one forage over another based on smell, feel, and taste. Palatability may therefore be influenced by texture, leafiness, fertilization, dung or urine patches, moisture content, pest infestation, or compounds that cause a forage to taste sweet, sour, or salty. High-quality forages are generally highly palatable.
- **Intake** *How much will they eat?* Animals must consume adequate quantities of forage to perform well. Typically, the higher the palatability and forage quality, the higher the intake.
- **Digestibility** *How much of the forage will be digested?* Digestibility (the extent to which forage is absorbed as it passes through an animal's digestive tract) varies greatly. Immature, leafy plant tissues may be 80 to 90% digested, while less than 50% of mature, stemmy material is digested.
- **Nutrient content** *Once digested, will the forage provide an adequate level of nutrients?* Living forage plants usually contain 70 to 90% water. To standardize analyses, forage yield and nutrient content are usually expressed on a dry matter (DM) basis. Forage dry matter can be divided into two main categories: (1) cell contents (the non-structural parts of the plant tissue such as protein, sugar, and starch); and (2) structural components of the cell wall (cellulose, hemicellulose, and lignin).
- **Anti-quality factors** Various compounds may be present in forage that can lower animal performance, cause sickness, or even result in death. Such compounds include tannins, nitrates, alkaloids, cyanoglycosides, estrogens, and mycotoxins. The presence and/or severity of these elements depend on the plant species present (including weeds), time of year, environmental conditions, and animal sensitivity. High-quality forages must not contain harmful levels of anti-quality components.
- **Animal performance** is the ultimate test of forage quality, especially when forages are fed alone and free choice. Forage quality encompasses "nutritive value" (the potential for supplying nutrients, i.e., digestibility and nutrient content), how much animals will consume, and any anti-quality factors present. Animal performance can be influenced by any of several factors associated with either the plants or the animals (figure 1). Failure to give proper consideration to any of these factors may reduce an animal's performance level, which in turn reduces potential income.

Figure 1. Factors that affect animal performance on forage.



Source: *Marten, G.C., D.R. Buxton, and R.F. Barnes, 1988. Feeding value (forage quality). In Alfalfa and Alfalfa Improvement, Monograph no. 29. Madison, Wis.: ASSA/CSSA/SSSA.*

Factors affecting forage quality

Many factors influence forage quality. The most important are forage species, stage of maturity at harvest, and (for stored forages) harvesting and storage methods. Secondary factors include soil fertility and fertilization, temperatures during forage growth, and variety.

Species differences

Legumes vs. grasses

Legumes generally produce higher quality forage than grasses. This is because legumes usually have less fiber and favor higher intake than grasses. One of the most significant benefits of growing legumes with grasses is improvement of forage quality.

A comparison of timothy and alfalfa from the second cut of a mixed stand (figure 2) illustrates typical species differences in quality. Alfalfa, at early bloom, had 16% crude protein (CP) compared with 9.5% in timothy. However, applying substantial amounts of nitrogen fertilizer to grasses can make their CP levels comparable to legume forage.

In the same comparison, timothy had considerably higher levels of neutral detergent fiber (NDF) than alfalfa. Typically, higher NDF (total fiber) levels and a slower rate of fiber (cell wall) digestion for grass forages results in lower voluntary intake compared with legumes. Faster digestion allows more forage (and thus more nutrients) to be consumed.

Cool-season vs. warm-season grasses

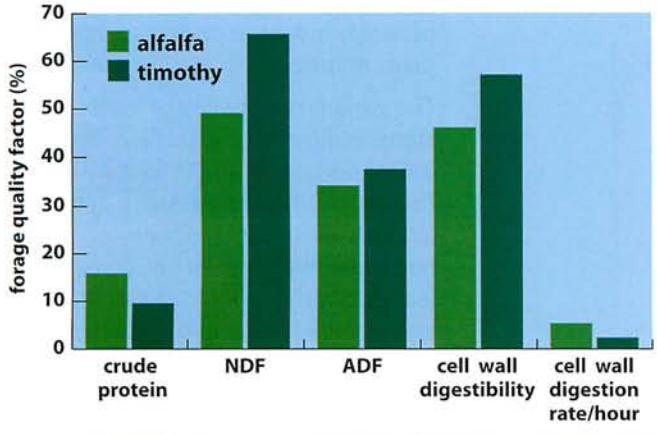
There is considerable variation in forage quality among the grasses used as cultivated forages in the United States. Forage grasses are divided into two broad categories: cool season (adapted to temperate regions) and warm season (best adapted to tropical or subtropical environments). Cool-season grasses include orchardgrass, Kentucky bluegrass, perennial and annual ryegrass, and tall fescue. Bermudagrass, bahiagrass, dallisgrass, and corn are examples of warm-season grasses.

Cool-season species are generally higher in quality than warm-season grasses. The digestibility of cool-season grass species averages about 9% higher than warm-season grasses. Minimum crude protein levels found in warm-season grasses are also lower than those found in cool-season grasses. Within each category, annual grasses are often higher in quality than perennials. Due to differences in leaf anatomy (tissue arrangement or structure), warm-season grasses convert sunlight into forage more efficiently than cool-season grasses, but their leaves contain a higher proportion of highly lignified, less digestible tissues.

Temperature

Plants grown at high temperatures generally produce lower quality forage than plants grown under cooler temperatures, and cool-season species grow most during the cooler months of the year. However, forage of any species tends to be lower in quality if produced in a warm region rather than a cool region. For example, in one study annual ryegrass grown at temperatures of 50° to 59°F produced forage made up of 59% leaf material, but only 36% leaf matter when grown at 68° to 77°F.

Figure 2. Forage quality of alfalfa and timothy components of a mixture.



Source: *Collins, M. 1988. Composition and fibre digestion in morphological components of an alfalfa–timothy sward.* Anim. Feed Sci. Tech. *19:135–143.*

Table 1. Effect of plant maturity on intake and digestibility of cool-season grass hays by lactating cows *(summary of several studies involving various grasses).*

cutting date	growth stage	hay intake per day	hay digestibility	relative digestible DM intake
		% body weight/day	%	
June 3–4	vegetative	2.64	63.1	166
June 11–12	early boot	2.36	65.7	154
June 14–15	late boot	2.45	62.6	153
June 16–18	early head	2.28	58.5	133
July 1	bloom	2.30	52.7	121
July 5	bloom	2.13	52.2	111
July 7–8	bloom	2.05	52.2	107
July 9–10	late bloom	1.95	51.5	100

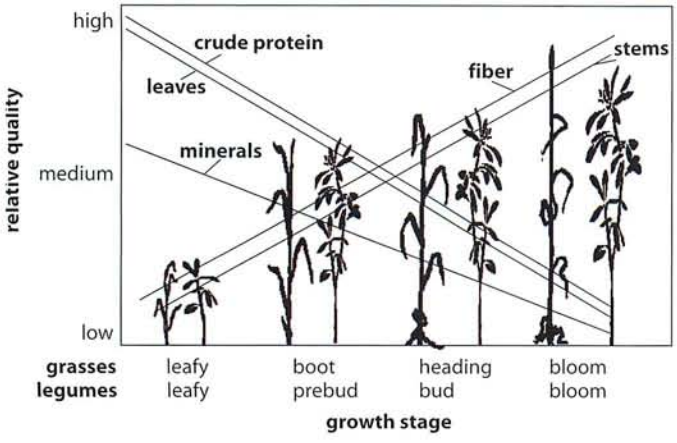
Source: *Stone, J.B., G.W. Trimberger, C.R. Henderson, J.T. Reid, K.L. Turk, and J.K. Loosli. 1960. Forage intake and efficiency of feed utilization in dairy cattle.* J. Dairy Sci. *43:1275–1281.*

Table 2. Leaf and stem quality of alfalfa and timothy components of a mixture.

plant component	% of the whole plant	CP	NDF	ADF
		%		
Alfalfa				
upper leaf[a]	30.7	23.9	27.7	18.5
lower leaf	12.8	21.8	25.9	16.6
upper stem[a]	6.5	13.4	52.6	38.6
lower stem	50.0	9.6	67.8	52.9
Timothy				
leaf	29.6	18.3	49.1	25.5
stem	70.4	5.8	72.5	42.6

[a]*Upper leaf and stem were taken from the last five internodes on each stem.*
Source: *Collins, M. 1988. Composition and fibre digestion in morphological components of an alfalfa-timothy sward.* Anim. Feed Sci. Tech. *19:135–143.*

Figure 3. Effect of plant maturity on forage intake and digestibility.



Source: *Adapted from Blaser, R., R.C. Hammes, Jr., J.P. Fontenot, H.T. Bryant, C.E. Polan, D.D. Wolf, F.S. McClaugherty, R.G. Klein, and J.S. Moore. 1986. Forage–animal management systems. Virginia Polytechnic Institute, Bulletin 86-7.*

Maturity stage

Maturity stage at harvest is the most important factor determining forage quality of a given species (table 1 and figure 3). Forage quality declines with advancing maturity. For example, cool-season grasses often have dry matter (DM) digestibilities above 80% during the first 2 to 3 weeks after growth initiation in spring. Thereafter, digestibility declines by 1/3 to 1/2 percentage units per day until it reaches a level below 50%.

Maturity at harvest also influences forage consumption by animals. As plants mature and become more fibrous, forage intake drops dramatically. Typical DM digestibility and intake values for cool-season grass hays harvested at different stages of maturity are shown in table 1. Numerous studies have shown similar effects in many different species.

Intake potential decreases and NDF concentration increases as plants age. This is because NDF is more difficult to digest than the non-fiber components of forage. Also, the rate at which fiber is digested slows as plants mature. Therefore, digestion slows dramatically as forage becomes more mature.

Leaf-to-stem ratio

Reduced leaf-to-stem ratio is a major cause of the decline in forage quality with maturity, and also the loss in quality that occurs under adverse hay curing conditions. Leaves are higher in quality than stems, and the proportion of leaves in forage declines as the plant matures.

The variation in quality of leaves and stems is illustrated in table 2. The oldest portion of alfalfa stems had less than 10% CP compared with 24% in alfalfa leaves. Stems of both species had much higher fiber levels than leaves, but the older, lower alfalfa leaves were similar in quality to the upper, younger leaves. However, older alfalfa stem tissue was considerably lower in quality than young stem tissue.

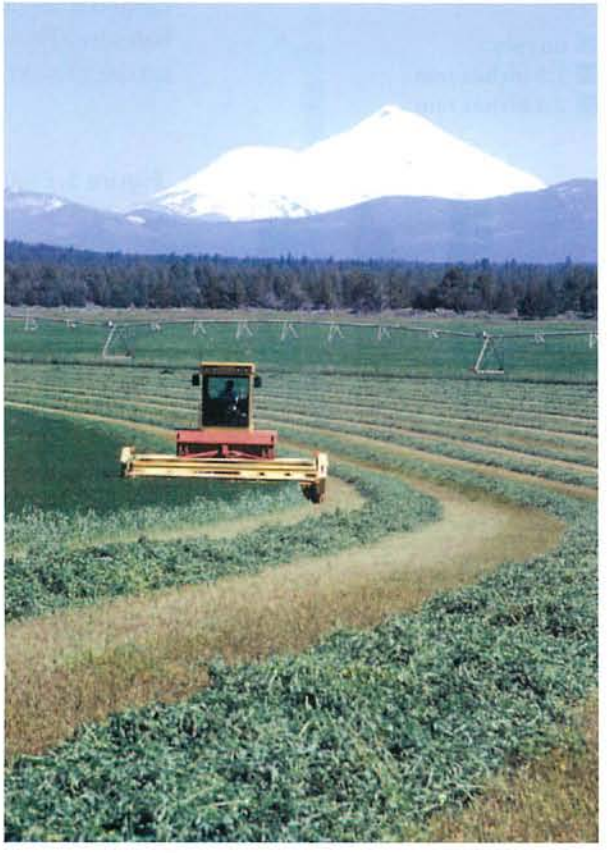
Reproductive growth lowers leaf-to-stem ratio, and thus forage quality. Most cool-season grasses require a period of cool temperatures (vernalization) for flowering, so they produce reproductive stems only in the spring. Thus, the forage quality of regrowth of these grasses is greater and changes less over time because they have higher leaf-to-stem ratios than first-growth forage. Legumes and some grasses such as bermudagrass can flower several times each season, so their forage quality patterns are less closely linked to season.

Grass–legume mixtures

Grass–legume mixtures generally have higher crude protein concentration and lower fiber concentration than pure grass stands. In Georgia, mixtures of seven legumes with bermudagrass (receiving no nitrogen fertilizer) ranged from 11 to 13% CP compared with only 11% CP in pure bermudagrass receiving 90 pounds/acre of nitrogen annually. In another study, first-cutting alfalfa containing about 30% timothy had a CP level of 17.5% compared with 20.5% in alfalfa with no grass.

Fertilization

Fertilization of grasses with nitrogen (N) often substantially increases yield and also generally increases CP levels in the forage. In one study, fertilizing switchgrass with 70 pounds/acre of nitrogen raised CP from 5.3 to 6.4%, and increased voluntary intake by 11%. (Fertilizing alfalfa and other legumes with nitrogen to improve quality is not recommended.) Fertilization usually has little or no effect on digestibility. Fertilization with phosphorus (P), potassium (K), or other nutrients that increase yield may actually slightly reduce forage quality when growth is rapid. Excessive levels of some elements such as potassium may in some cases decrease the availability of other elements such as magnesium (Mg) in the diet.



Daily fluctuations in forage quality

As early as the 1940s, changes in soluble carbohydrate levels in alfalfa were linked to time of day. Plants accumulate soluble carbohydrates during daylight and then use them overnight. Thus, soluble sugars are lowest in the morning and highest after a day of bright sunshine. Recent studies in low rainfall climates have shown higher forage quality when alfalfa is harvested in the late afternoon rather than in the morning. It appears that the advantage of afternoon harvest is greatest on cool, sunny days and when the forage is highly conditioned to increase drying rates and minimize respiration in the windrow. However, afternoon harvests may not be advisable in high rainfall areas where every hour of good drying time is needed in curing hay.

Variety effects

There are many examples of plant breeding improving forage quality. The variety 'Coastcross-1' bermudagrass is about 12% higher in digestibility than 'Coastal' bermudagrass, supporting 30% higher average daily gains by beef steers. In species such as timothy that have a wide range of maturity dates, later-maturing varieties tend to be slightly lower in digestibility because early types make more of their growth under lower temperatures. Some silage corn varieties have higher grain content and/or stover digestibility than others.

The development of multifoliate alfalfa varieties (having more than three leaflets per leaf) is a strategy aimed at increasing forage quality, but some multifoliate varieties have no higher leaf percentage than traditional trifoliate varieties. Some trifoliate varieties exhibit superior quality, but care should be taken to assure that a "high-quality" variety is not substantially lower in yield.

Harvesting and storage effects

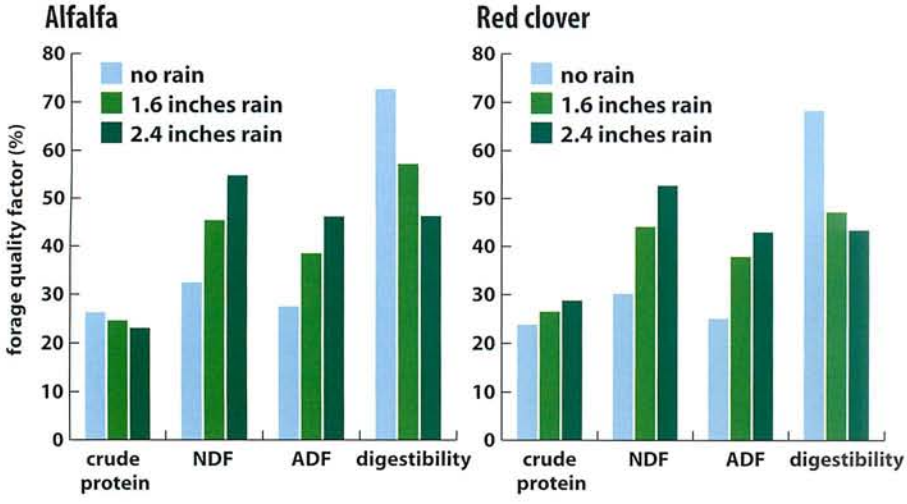
Leaf shatter, plant respiration, and leaching by rainfall during field drying of hay can significantly reduce forage quality, particularly with legumes. Figure 4 illustrates typical effects of rainfall during the drying process. Moderate rain damage reduced alfalfa CP levels slightly and digestibility dramatically, but NDF and ADF levels increased sharply. Red clover hay quality was also greatly reduced by rain, even though crude protein increased. The total amount of crude protein did not increase; the percentage of crude protein in the remaining dry matter was higher due to leaching of highly soluble constituents. However, leaching also increases the proportion of unavailable ADIN (see glossary) in the hay.

Rainfall during curing damages legume leaves most. For alfalfa hay exposed to both drying and leaching losses, more than 60% of the total losses of dry matter, CP, ash, and digestible DM were associated with the leaves. Rain during field drying has less impact on the forage quality of grasses than legumes. In one study, alfalfa hay that received rain was 12 percentage units less digestible than fresh forage, compared with a difference of only 6 percentage units for grass hay produced under similar conditions. Damage from rain increases as forage becomes dryer, and is especially severe when rain occurs after it is ready to bale.

Quality losses also occur due to weathering, plant respiration, and microbial activity during storage. In high rainfall areas, losses can be large for round bales stored outside, due to weathering of the outer layers. In an Indiana study, digestibility and crude protein content of the unweathered center portions of round bales of mixed grass hay stored outside for 5 months was 59% and 13.5%, respectively, while the weathered outer portions of bales had a digestibility of 43%, and a crude protein content of 16.4%. In the same study, the digestibility and crude protein content of unweathered centers of alfalfa/grass bales were 57% and 14.3%, respectively, and 34% and 16.9% for the weathered outer portions of bales, respectively.

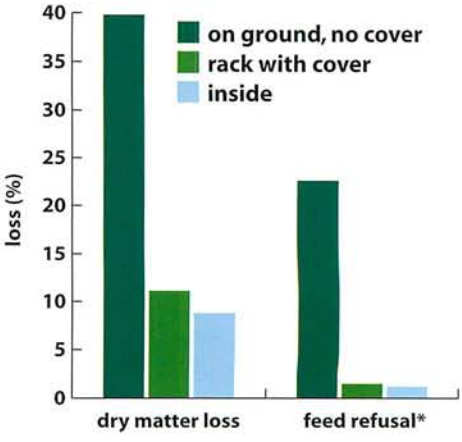
In a study in Louisiana (figure 5), baled ryegrass stored outdoors on the ground lost 40% of the initial DM during 1 year of storage. Protected bales lost an average of 10% of the initial DM during the same period. Refusal during feeding to mature cows ranged from only 1% for inside-stored bales to 22% for bales stored outside on the ground.

Figure 4. Change in forage quality of alfalfa and red clover hays exposed to rain during curing.



Source: *Collins, M. 1983. Wetting and maturity effects on the yield and quality of legume hay.* Agron. J. *75:523-527.*

Figure 5. Changes during storage of ryegrass round bales in Louisiana.



**Refusal measurements were made after 7 months of storage.*

Source: *Verma, L., and B.D. Nelson. 1983. Changes in round bales during storage. Trans. ASAE. 26:328-332.*

Some storage and feeding losses are inevitable. Estimated losses from harvested forage stored at various moisture contents are provided in figure 6.

Sensory evaluation of hay

Much can be learned from a careful sensory examination of hay. First, the **plant species** present can be determined. Does the hay consist almost exclusively of a particular forage crop? Does the forage crop tend to be higher in quality than other forages? Does the hay contain weeds? If so, what percentage is weeds and how much nutritional benefit do they provide to livestock? Could they be toxic?

The **maturity** of the hay, one of the main factors determining forage quality, can be visually assessed. The number and maturity of seed heads and blooms, and the stiffness and fibrousness of the stems are indicators of plant maturity.

Leafiness is particularly important; the higher the leaf content, the higher the forage quality. Leafiness can be affected by plant species, by stage of maturity at harvest, and (especially in legume hays) by handling that results in leaf loss.

Texture is a consideration. Softness usually results from early cutting, high leaf content, and a suitable moisture level at baling. When hay is "very soft" and pliable, it is difficult to distinguish between stems and leaves just by feeling the hay. "Soft" hay is soft to the touch, but stems can be detected easily. "Slightly harsh" hay has stems that are a little rough. "Harsh or brittle" hay is dry, stemmy, and unpleasant to the touch. "Extremely harsh" hay can injure an animal's mouth, lowering intake.

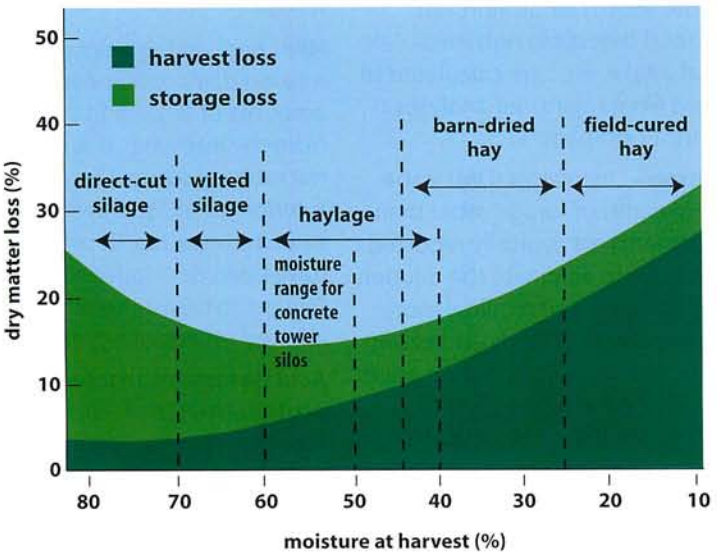
Color helps sell hay to the average buyer. Color alone is not a good indicator of forage quality, but it can be an indicator of harvest and storage conditions. A bright green color suggests that hay was cured quickly and protected during storage. Slow curing prolongs plant respiration, which reduces forage quality. Hay that is rain damaged after being partially dried will lose color due to leaching. Mold growth on leaves and stems or exposure to sunlight will also bleach hay. Baling at moisture contents at or above 20 to 25% may cause high bale temperatures that result in tan to brown or black colors (commonly called "tobacco hay").

A pleasant **odor** indicates hay was cured properly. Moldy, musty odors may occur in hay stored at moisture contents above 16 to 18% (above 14% for 1-ton square bales). Animals may respond to off-odors by going off feed. Odors caused by heating (>125°F) result from hay being baled at too high a moisture content or from ensiling forage that is too dry. Interestingly, hay with a slightly caramelized odor is often quite palatable to livestock, even though the quality is reduced. (The odor of silage can indicate good or bad fermentation; if it smells of butyric acid—similar to rancid butter—it may lack palatability, and low animal intake is likely.)

Dusty hay is usually the result of soil being thrown into the hay by rake teeth hitting the soil. The presence or absence of molds, dust, and odor are referred to as **organoleptic** qualities.

Visual inspection can also detect **foreign matter** (anything that has little or no feed value). Tools, sticks, rocks, wire, items of clothing, dead animals, and cow chips have all been found in hay and are obviously undesirable. Dead animals in hay can cause botulism, a deadly disease that can kill farm animals.

Figure 6. Estimated dry matter loss during harvest and storage of hay-crop forages at various moisture levels.



Source: *Michigan State University*

HOW TO PROPERLY SAMPLE HAY

Use a good probe—The hay probe should have an internal diameter of at least 5/8 inch. The cutting edge should be at right angles to the shaft, and kept sharp. Dull probes will not obtain a representative sample. Core samplers that cut through a cross-section of a bale provide the best representation of stems and leaves. Avoid using open augers as they selectively sample leaves.

Sample at random—It is important to select bales at random from throughout the hay "lot" (defined in sidebar on page 10). Avoiding some bales and choosing others based on appearance will bias the sample. For stacked hay, samples should be taken from bales at various heights in the stack.

Take enough core subsamples—Taking at least 20 core samples from a hay lot minimizes sample variation.

Use the proper technique—For rectangular bales of all sizes, insert the hay probe 12 to 18 inches deep at a right angle into the center of the ends of bales. For round bales, the probe should be inserted at right angles to the outside circumference of the bales.

Handle samples correctly—Combine core samples from a given lot into a single sample and store in a sealed plastic freezer bag. Samples should be protected from heat or direct sun, and promptly sent to a laboratory for analysis. The sample should weigh approximately 1/2 to 3/4 pound. With larger samples, many labs will not grind the entire sample. Too small a sample will not adequately represent the hay lot.

Split samples correctly—To test the performance of a particular laboratory (or the sampling technique), a fully ground and thoroughly mixed sample should be split and submitted. Unground samples should not be split.

Laboratory analysis of forage

Accurate laboratory testing of feed and forage is required to provide the information needed to formulate animal rations. Testing to assess quality also provides a basis for commercial hay sales.

A forage analysis should reflect the average quality of the material being tested. Only a few grams of material represent tons of forage, so it is essential to obtain a representative sample. Therefore, sampling technique is extremely important (see sidebars on how to properly sample hay, silage, and pasture forage).

Laboratory analytical techniques

Laboratory analyses are used to determine the nutritive value of forages. A typical forage analysis includes measurements of dry matter, crude protein, and fiber (acid detergent fiber and neutral detergent fiber). Sometimes ash is measured, and when heat-damaged protein is suspected, acid detergent insoluble crude protein should be measured. Many other results provided on laboratory reports (digestible energy or protein, net energy, total digestible nutrients, potential intake, etc.) are calculated or estimated from measured analyses. See figure 11 on page 17.

Dry matter—Dry matter (DM) is the portion (weight) of forage other than water. Nutrients are typically reported on a DM basis to eliminate the dilution effect of moisture and to allow more direct comparison of feeds and easier formulation of diets. To compare prices and nutritive value among lots of forage, they should be adjusted to a DM basis. Sometimes hay is compared or sold on a 90% DM basis, which closely resembles the average DM of air dried feeds.

For hay, excessively low moisture (less than 10%) could indicate brittleness (and thus low palatability) or excessive leaf loss (linked with lowered forage quality), while high moisture (greater than 14 to 18%) indicates a risk of mold. For silage, excessively low moisture (below 45%) can indicate heat damage, while high moisture (above 70%) can indicate poor fermentation and potential intake problems.

Detergent fiber analysis—Acid detergent fiber (ADF) and neutral detergent fiber (NDF) are frequently used as standard forage testing techniques for fiber analysis. NDF approximates the total cell wall constituents including hemicellulose, whereas ADF primarily represents cellulose and lignin. ADF is often used to calculate digestibility, and NDF is used to predict intake potential. As fiber increases, forage quality declines.

Protein—Protein is a key nutrient that must be considered both in amount and type for various animal diets. It is commonly measured as crude protein (CP), which is 6.25 times the nitrogen content of forage. Crude protein is used because rumen microbes can convert non-protein nitrogen to microbial protein, which can then be used by the animal. However, this value should be used with some care, as it is not applicable to non-ruminants or when high levels of nitrate are present in the forage.

High-performing animals, especially milking dairy cows, need larger amounts of protein to be absorbed from the intestines than rumen microbes produce. Therefore, they need a certain amount of bypass protein (or RUP) in the ration. Recently, calibrations have been developed that allow RUP in forages to be estimated using near infrared reflectance spectroscopy.

Acid detergent insoluble crude protein (ADICP)—This estimates the nitrogen that has low digestibility in the rumen and the intestine. It is important for determining the value of heat-damaged hay and silage. A little ADIN is good because it increases bypass protein, but too much may reduce total protein availability.

Digestible energy estimates—Energy values can be determined directly only by feeding trials. Laboratory reports provide calculated values. There are four basic approaches:

A. The most common has been to measure a single fiber fraction (usually ADF) and use it to calculate an estimated digestibility, total digestible nutrients (TDN) or net energy for lactation (NE_l).

B. Summative equations are predictions of TDN or NEl from multiple measures of forage composition. These measures often include NDF, NDF nitrogen, crude protein, ether extract, lignin, and neutral detergent fiber nitrogen. These predictions are more accurate than those of single fiber fractions, but are much more time consuming and expensive. Beware of laboratories that output "summative equations" but don't measure all components.

C. Some scientists have begun looking for additional factors to better describe the energy content of forage. The most common additional measure at present is to determine nonfibrous carbohydrate (NFC) or starch content.

D. *In vitro* and *in situ* digestibility are generally considered the best analyses to use to predict animal performance. Both use rumen fluid to digest the samples either in a beaker or test tube (*in vitro*) or in a porous bag placed in the rumen via a fistula or port in the animal's side (*in situ*).

In 2001, the National Research Council recommended measuring digestible fiber (dNDF) and then calculating total digestible nutrients (TDN) as a much better estimate of energy content of the forage than acid detergent fiber. Digestible NDF can be estimated two ways: by measuring lignin or by measuring *in vitro* digestion. As shown in figure 7, the two methods give different results. It is believed

HOW TO PROPERLY SAMPLE SILAGE

Sampling during harvesting

Collect three to five handfuls of chopped forage from the middle of a load during unloading, place in a plastic bag, and refrigerate immediately. Follow the same procedure for several loads. Combine samples from a single harvested field and mix well. Place the entire sample in a clean plastic bag or other container, and seal tightly. Label each container with your name and address as well as the date, sample number, and forage type. Store the sample in a cool place (do not freeze) until you send it to a laboratory for analysis. Repeat for each field, variety, or hybrid. If filling tower silos or silo tubes, keep a record of where each lot is in the silo or tube. Feeding colored plastic strips through the blower at the end of each lot may help identify the lots later.

Silos with seepage should be resampled upon feeding because loss of soluble compounds due to seepage will increase dry matter, acid detergent fiber and neutral detergent fiber, and decrease crude protein. Resample silos at feeding that were filled with forage at less than 50% moisture that may have heated excessively, causing increased acid detergent fiber and acid detergent fiber insoluble nitrogen. Recheck dry matter of silages at feed out. Fiber and protein are not likely to change much during storage, except as mentioned above, but moisture can change significantly.

Ensiled material from a tower silo

Do not sample the spoiled material on the top or bottom of the silo; wait until 2 to 3 feet of silage have been removed. Collect a 1 to 2 pound sample from the silo unloader while it is operating. Collect samples from opposite sides of the silo. Combine the samples and mix well. Place the entire sample in a plastic bag and handle as discussed above.

Ensiled material from a bunker silo

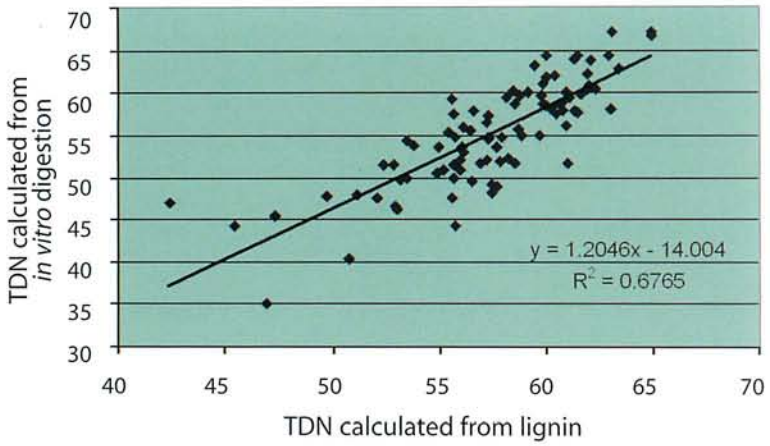
If feeding with a TMR (total mixed ration) mixer—Load silage from bunker into TMR mixer and mix well. Take several grab samples to collect a 1 to 2 pound total sample. Place in a plastic bag and handle as discussed above.

If not feeding with a TMR mixer—Collect a 1 to 2 pound total sample from the different vertical layers of the silo face. Grab several handfuls from freshly exposed forage after the day's feeding has been removed. Do not sample the spoiled material on top of the silo. Combine handfuls and mix well. Place the entire sample in a clean plastic bag or other container, and seal tightly. Store immediately in a cold place until shipping. Label each container as indicated earlier. Place in a plastic bag and handle as discussed above.

that measuring dNDF by *in vitro* digestion is much more indicative of animal performance than measuring it by lignin analysis.

Intake estimates—Voluntary intake, a prime consideration in feeding, is often estimated based on neutral detergent fiber (NDF) content. NDF consists of the slowly digested and nondigestible fibrous portion of the plant which is most of the cell wall material (figure 8). As the NDF level increases, voluntary feed intake tends to decline. However, if NDF of the ration is too low, health problems such as acidosis, displaced abomasums, and foundering may occur.

Figure 7. Comparison of TDN calculated from lignin and *in vitro* digestion for alfalfa and grasses. (The diagonal line indicates values for identical results.)



IDENTIFICATION OF A FORAGE LOT

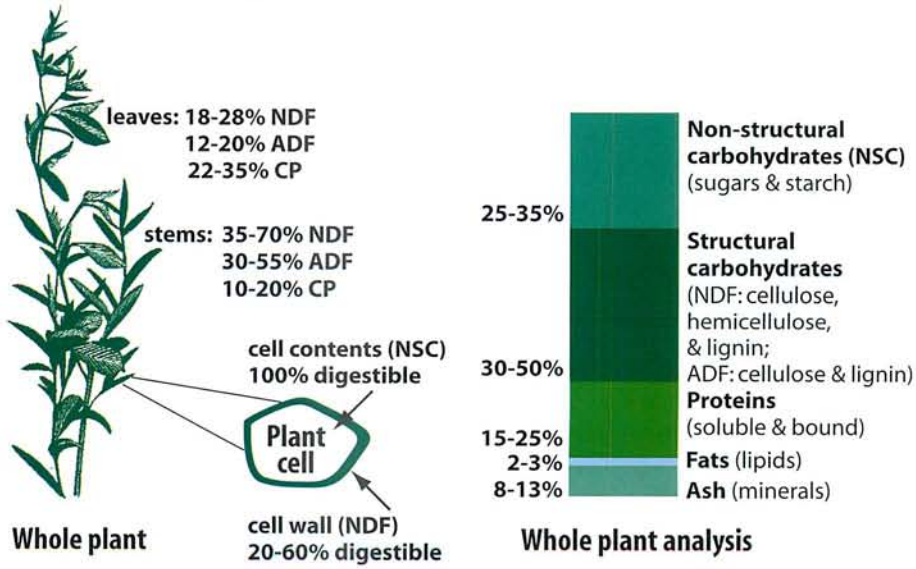
A lot is defined as forage taken from the same farm, field, and cut under uniform conditions within a 48-hour time period. A lot can represent several truck or wagon loads, but all the forage should have been harvested and stored under identical conditions. For accurate test results, hay or silage should be stored by lots, and separate samples taken from each lot. Any special conditions that result in quality differences in a lot, such as rain damage during harvest or excessive weed populations, should be noted to allow later assessment of the reasons for quality variations.

Laboratory proficiency

The accuracy of forage analysis depends on the analytical procedures used and the precision of laboratory techniques. The National Forage Testing Association (NFTA) certifies the proficiency of laboratories with regard to accurately testing hay and corn silage for DM, CP, ADF, and NDF. It is advisable to use a NFTA certified laboratory. For a current listing of certified laboratories, as well as more information about proficiency testing, visit NFTA's web site (www.foragetesting.org).

When evaluating a forage test report, keep in mind that none of the values, either measured or calculated are absolute. There is variability in hay stacks or silage, and some variation associated with lab analysis. Normal lab variation, not including errors associated with poor sampling of forages, are considered to be: CP (+/-0.5), NDF (+/-0.9), and ADF (+/-0.7). For example, a reported value of 20% CP should be considered to be anywhere between 19.5 and 20.5% under normal circumstances. Relative feed value (see glossary) will vary within 8 points.

Figure 8. Structural components of alfalfa.



Source: *Adapted from Putnam, Dan, 2000. Producing high quality alfalfa: Factors that influence alfalfa forage quality. Proc. CA Plant and Soil Conference, Jan. 19-20. Stockton, CA.*

Understanding laboratory reports

Various labs present analysis results in different ways, but the following items should be included.

Laboratory identification Should include contact information (address, fax, phone).

Lab certification This seal indicates the lab has passed the NFTA proficiency test.

Client identification Helps ensure information is reported to correct person or organization.

Feed description The client needs to provide accurate and detailed information about the forage or feed to aid in interpretation.

Sample identity and description Report should list lot identification number, sampling date, sample method and handling, and condition of the sample on arrival.

Analytical results Results should be reported on a 100% dry matter (DM) basis. Additional columns may be included for reporting results on an as-is (as-received) or an air-dry (90% DM) basis.

Calculated results There should be a clear distinction between results determined analytically and those calculated from analytical determinations.

Comments and signature There should be an area where laboratory personnel can indicate concerns or provide other feedback about the sample or results.

Feed analysis report

ABC Feed Analysis Laboratory
Anywhere Street
Any City, ST 00000
Phone: 000-000-0000 Fax: 000-000-0000
Email: ABCLabs@IP.com Web: www.ABC.com

Client name:	Joe Client	Feed identification:	A-1-720
Address:	123 Anystreet	Feed type:	Alfalfa
City, State, Zip	Anytown, AS 12345	Grower or feed origin:	Doe farm
Phone:	123-456-7890	Field location:	South 720
Email:	JC@localnet.com	Cutting and harvest date:	First, 05/25/01
		Feed preservation:	Wilted for silage
Date sample analyzed:	05/29/01	Sampler:	John Doe
Date results reported:	05/31/01	Date sample taken:	05/25/01
Lab identification code:	00-000123	Date sample shipped:	05/26/01
Invoice/accession code:	4567	Date sample received:	05/28/01

Sample method and handling: Grab samples of chopped material from 12 loads.
Sample condition as received: Chopped material of adequate amount in good condition.

Nutrients, units	Method	As received	100% DM	90% DM
Analytical determinations				
Oven moisture, %	In-house 105-16	65.0	0.0	10.0
Oven dry matter, %	In-house 105-16	35.0	100.0	90.0
Crude protein, %	AOAC 990.03	8.4	24.0	21.6
Acid detergent fiber, %	Handbook 379	10.2	29.0	26.1
aNDF, %	NFTA, 1993	13.3	38.0	34.2
Total nonstructural carbohydrates, %	Smith, 1983	4.2	12.0	10.8
Fat, %	AOAC 920.39A	1.4	4.0	3.6
Ash, %	AOAC 942.05	3.5	10.0	9.0
Minerals				
Calcium, %	NIR ISI equation	0.81	2.30	2.07
Phosphorus, %	NIR in-house equation	0.12	0.33	0.30
Calculated values				
Neutral det. soluble carbohydrates, %	Mertens, 1988	8.4	24.0	21.6
Total digestible nutrients, %	Bath & Marble, 1989	21.2	60.6	54.5
Net energy of lactation, Mcal/lb	Mertens leg. ADF	0.24	0.68	0.61
Relative feed value	NFTA, 1993	56.8	162.0	146.0

Comments:

Signature:

HOW TO PROPERLY SAMPLE PASTURE FORAGE

Sampling pasture forage is especially challenging because the quality of pasture forage is constantly changing. Also, selective grazing by animals affects the quality of their diets.

If pastures are rotationally stocked, collect forage randomly from several spots so the entire pasture will be represented. It may be helpful to observe how the animals are grazing their present pasture, then collect a sample to the same stubble height from the next pasture.

For a continuously stocked pasture, forage should be collected from several locations. Note whether animals are spot grazing and try to sample what they are eating. The pasture can be sampled monthly or as needed.

Mix the collected forage, then fill the sample bag. If not mailed immediately, refrigerate or air dry.

Matching forage quality to animal needs

Animal performance is determined by feed availability, feed nutrient content, intake, extent of digestion, and metabolism of the feed digested, but availability and intake most often determine animal performance. A cow never produced milk or a steer never grew on feed that it didn't eat!

With regard to the nutritive content of forage, digestible energy (digestibility) is the most common limiting factor. However, there are times when protein and minerals are the nutrients that limit animal performance, especially in grazing situations when supplementation is impractical.

The amounts of digestible energy, protein, vitamins, and minerals needed for maintenance is low relative to other animal processes. In general, forages that contain less than 70% NDF and more than 8% crude protein will contain enough digestible protein and energy, vitamins, and minerals to maintain older animals. Thus, even many low quality forages and crop residues can meet the maintenance needs of some classes of animals, if protein and minerals are adequate.

Reproduction

Reproduction requires relatively small increases in nutrient requirements. Conception of females is often enhanced by "flushing" (increased energy intake during the breeding season). Males also need additional energy for the increased activity during the breeding season. Thus, during breeding, animals should receive forages that are 10 to 20% higher in digestible energy, and lower in NDF, than those fed to animals on a maintenance ration. During the breeding season, males often lose weight that must be recovered later.

The fetus and uterine tissues require little energy, protein, or minerals during the first two-thirds of pregnancy. Therefore, early pregnancy (gestation) is a time when nutritional requirements of animals are low.

During the last third of pregnancy, nutrient requirements increase because fetal weight increases rapidly. Also, females typically need to store fat during pregnancy that will be used to meet the high-energy demand of early lactation. Not only do nutrient requirements increase, the internal body space for the digestive tract is greatly reduced during the latter stages of pregnancy. Thus, in the last 10% of pregnancy it is important to increase dietary nutrition substantially (<50% NDF and at least 10 to 12% crude protein).

Growth

The bodies of very young animals are rapidly developing muscle and bone. Muscle is primarily protein, and bone is mostly minerals (calcium and phosphorus), so growing animals have much higher requirements for crude protein and minerals than older animals.

Extra energy is also needed for the development of both muscle and bone, but younger animals have less internal body capacity to accommodate consumption of bulky forage than older animals. Higher requirements and less capacity result in the need for greater nutrient density in the diets of young, growing animals, especially until they reach about 50% of their mature weight.

Nutrient and energy density of the diet should be highest shortly after birth (16 to 18% crude protein and 30 to 40% NDF), and gradually decrease to 12% crude protein and 55% NDF by the time they reach 50% of mature weight. Milk produced by the mother is an excellent supplement for young animals that allows them to perform well when consuming forages.

After weaning, the protein in forages may be too soluble and may lack the amino acid balance needed for muscle development, or calcium and phosphorus levels in forage may not be adequate. Thus, supplementing forage diets with protein and minerals often improves the rate of growth in young animals.

Fattening

Body fat becomes the major component of weight gain as an animal matures, because the development of muscle and skeleton greatly diminishes. Fat is a concentrated source of energy; therefore, the fattening of animals requires a diet that is dense in digestible energy and lower in protein, minerals, and vitamins. Fattening diets typically contain 8 to 10% crude protein and less than 25% NDF, which is difficult to achieve with all-forage diets because the fiber concentration in forages limits their digestible energy density.

Lactation

Lactation places the greatest nutrient demand on animals. On a dry basis, milk contains about 20 to 25% protein, 25 to 30% fat, and high levels of minerals and vitamins to ensure the rapid growth of offspring. Whereas growth and fattening may require nutrients at one and a half to two times the maintenance level, lactation of beef cows or sheep may require nutrients at two to two and a half times maintenance, and lactating dairy cows, ewes, and goats may require nutrients at up to four to five times maintenance levels. Such high nutrient demands necessitate the feeding of high quality forages and/or feeds.

Lactating dairy animals require a delicate balance of fiber: too much fiber lowers energy density and limits intake, resulting in low milk production; too little fiber reduces production of fat-corrected milk, increases fattening of the female, and increases incidence of digestive and metabolic disorders. To maximize forage use in the rations, fiber intake must be pushed to the maximum limit of the animal that will still allow it to realize its milk production potential. Since too much fiber intake becomes the limiting factor in this situation, feeding high quality forage is critical when attempting to maximize forage intake by animals with high levels of milk production.

Diets of nursing cows and sheep at peak lactation need to contain 12 to 14% crude protein and less than 55% NDF. However, high-producing lactating dairy cows, ewes, and goats require diets that are 16 to 18% crude protein, 25 to 30% NDF, and contain significant levels of calcium and phosphorus. As in the case of fattening animals, this is difficult to attain with forages alone.

In most cases, the intake potential and digestible energy content of the forage determines the productivity of an animal. However, when forage quality is low and forages are the only source of nutrients, protein and minerals may limit animal performance.

An illustration of how well various categories of forage crops tend to provide digestible dry matter to selected classes of livestock is provided in figure 9. More detail on nutrient needs of animals can be found in the publications of the National Research Council, available from National Academy Press.

Economic impacts of forage quality

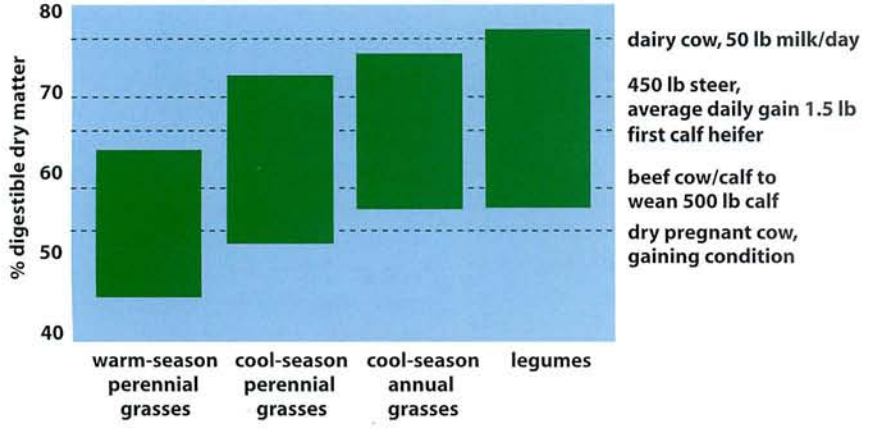
There is widespread recognition that forage generally supplies a relatively low-cost source of nutrition for livestock. However, the relationship between forage quality and the level of profit realized from forage-related enterprises is often underappreciated.

Pasture forage quality

Grazing can provide low-cost nutrition because livestock, rather than expensive machinery, harvest the forage. However, failure to make adjustments to changes in pasture growth rate during the grazing season may lead to either overgrazing (which reduces forage growth and may thin forage stands) or undergrazing (which lowers overall forage quality and increases forage waste). Consequently, grazing management can be extremely important.

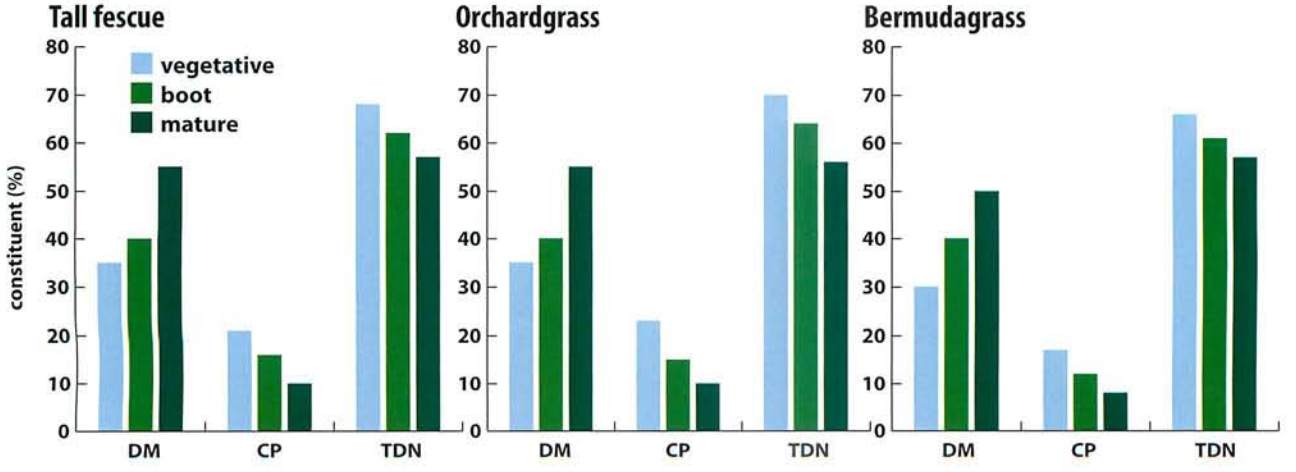
The influence of maturity on forage quality provides another reason for using pasture when feasible (figure 10). The data compares the percent dry matter, crude protein, and total digestible nutrient of selected grasses at three stages of growth: vegetative (as in a properly grazed pasture), boot (when most hay should be harvested), and mature (when much hay actually is harvested). For each species, forage quality was highest at the vegetative stage. Thus, grazing not only avoids mechanical harvesting costs, but also often offers the advantage of higher forage quality as compared to stored feed.

Figure 9. Forage digestibility ranges and their suitability for different classes of livestock.



Source: *Adapted from H. Lippke and M.E. Riewe. 1976. Principles of grazing management. In Grasses and Legumes in Texas (E.T. Holt, ed.) Texas Agric. Exp. Stn. Res. Monograph RM6C:169–206.*

Figure 10. Forage quality dry matter (DM), crude protein (CP), and total digestible nutrients (TDN) percentages at varying growth stages.



Source: *Adapted from Kennedy, Mark, and John Jennings. 1997.* Forage quality in Management Intensive Grazing in the Ozarks. *Jointly published by the Top of the Ozarks and the Southwest Missouri R C & D Councils, the Missouri Department of Natural Resources, and the Natural Resources Conservation Service.*

Hay quality

Hay quality varies due to numerous factors discussed earlier in this publication. Such differences should in turn be reflected in sale prices when hay is marketed. This occurred at hay auctions in Wisconsin and California (illustrated in "Importance of Forage Quality" sidebar on page 1).

Other considerations

Improving forage quality can result in other benefits that affect profit. Animal health, including resistance to parasites and diseases, is favored by a high plane of nutrition. In addition, the reproductive efficiency of animals is often higher when nutritive intake is high. High quality forage also often reduces or eliminates the need for supplemental feeds, which usually are more expensive than non-forage sources of nutrition.

Additional information

The following web sites contain information about forage quality.

American Forage and Grassland Council: www.afgc.org

Forage Information System: www.forages.orst.edu

National Forage Testing Association: www.foragetesting.org

US Dairy Forage Research Center: www.dfrc.wisc.edu

KEY CONCEPTS TO REMEMBER

- The ultimate measure of forage quality is animal performance.
- Factors having the greatest impact on forage quality are forage species, stage of maturity at harvest, and (if forage is mechanically harvested) harvesting and storage techniques.
- Forage quality varies greatly among and within forage crops, and nutritional needs vary among and within animal classes and species. Knowing forage quality and animal nutritional needs is necessary to formulate rations that result in desired animal performance.
- Leaves are higher in quality than stems; young stems are higher in quality than old stems; and green leaves are higher in quality than dead leaves. In most cases, higher quality is also associated with legumes as compared to grasses; and with cool-season plants as compared to warm-season plants.
- Rain during field drying damages legume hay more than grass hay. Also, the dryer the hay when rain occurs, the greater the damage. However, delayed harvest due to concern about rain probably results in more forage quality loss than does rain damage.
- Fertilizing with nitrogen generally increases the crude protein level of grasses, but fertilization usually has little or no effect on the digestible energy of forage.
- Sensory evaluation of forage provides important information, but laboratory testing is required to formulate rations.
- A laboratory analysis uses only a few grams of material to represent tons of forage. Therefore, sampling technique is *extremely* important.
- The numbers provided on a forage test report are valuable but not absolute. Reported results vary somewhat due to differences within a hay lot (or other feed material sampled), sampling technique, and laboratory procedures.
- While protein and minerals can limit animal performance, digestible energy is more likely to be the limiting factor from forage.
- The more mature and fibrous (lower in quality) a forage, the longer it takes to be digested and the less an animal will consume.
- Major losses in forage quality often occur due to poor storage and feeding techniques. *Producing* forage with good nutritive value is not enough; good animal performance results when animals *consume* forage that is suitably high in nutrients and low in fiber.

Glossary

Acid detergent fiber (ADF) The residue remaining after boiling a forage sample in acid detergent solution. ADF contains cellulose, lignin and silica, but not hemicellulose. Often used to calculate digestibility, TDN and/or NE_l. Contrast with *crude fiber* and *neutral detergent fiber*.

Acid detergent fiber insoluble nitrogen (ADFIN) See *acid detergent insoluble nitrogen* (preferred term).

Acid detergent fiber crude protein (ADFCP) See *acid detergent insoluble crude protein.*

Acid detergent insoluble crude protein (ADICP) The same feed fraction as ADIN that has been converted to crude protein equivalent by multiplying ADIN * 6.25. Same as *acid detergent fiber crude protein*. ADICP is preferred.

Acid detergent insoluble nitrogen (ADIN) Nitrogen in acid detergent fiber residue. ADIN greater than 15% of nitrogen is an indicator of heat damage. Formation of ADIN is also called non-enzymatic browning (because the hay or silage turns brown) or the Maillard reaction. Should be expressed as a percent of the dry matter, not of ADF. Same as *acid detergent fiber insoluble nitrogen*.

Adjusted crude protein (ACP) A calculated value adjusting total crude protein for heat-damaged protein. Adjusted crude protein estimates the protein available for animal use and should be used for formulating rations when ADIN is greater than 15% of the total nitrogen.

Ash (also called total ash) A measure of the total mineral content; the residue remaining after burning a sample. Values above 10% for grasses or 14% for legumes usually indicate soil contamination of forage. Ash, ADF-ash, and NDF-ash will be different values because ADF and NDF procedures remove some minerals.

As fed See *as is.*

As is Values expressed based on moisture content of forage when it was received in the laboratory. Same as *as fed* and *as received.*

As received See *as is.*

Available crude protein (ACP) Same as *adjusted crude protein.*

Bypass protein See *rumen undegraded protein.*

Cellulose A structural carbohydrate; a long-chain polymer of glucose that is the main constituent of plant cell walls. It is the most abundant carbohydrate in nature and is slowly and partially digestible by ruminants.

Crude fat An estimate of the fat content of feeds that is measured by ether extraction. Crude fat contains true fat (triglycerides) as well as alcohols, waxes, terpenes, steroids, pigments, ester, aldehydes, and other lipids. See *ether extract* and *fat*.

Crude fiber (CF) The original fiber method using sequential acid and alkali extraction (developed by Henneberg and Sttohmann in 1865). Crude fiber includes most of the cellulose, but only a portion of the lignin and no ash. Therefore it underestimates true fiber, is less than ADF, and is seldom used for forage analysis. Contrast with *acid detergent fiber* and *neutral detergent fiber*.

Crude protein (CP) This value is 6.25 times the nitrogen content for forage or 5.7 times the nitrogen content for grain.

Degraded intake protein (DIP) See *rumen degraded protein.*

Digestible cell wall See *digestible neutral detergent fiber* (preferred term).

Digestible neutral detergent fiber (dNDF) The portion of neutral detergent fiber digested by animals at a specified level of feed intake. The dNDF of feeds may be determined by *in vivo* feeding trials or estimated by lignin analysis, *in vitro* or *in situ* digestibility, or by near infrared reflectance analysis. Expressed on DM basis. Compare with *neutral detergent fiber digestibility*.

Digestible energy (DE) The energy in a forage or feedstuff that is not excreted in feces.

Dry matter (DM) The percentage of the sample that is not water.

Dry matter digestibility (DMD) The portion of the dry matter in a feed that is digested by animals at a specified level of feed intake. Called *in vivo* DMD if determined by feeding animals in a digestion trial. There is no laboratory method for measuring DMD directly; it is often estimated by measuring *in vitro* digestibility, *in situ* digestibility, near infrared reflectance analysis, or calculated from acid detergent fiber (which is the least accurate method).

Escape protein See *rumen undegraded protein.*

Ether extract (EE) Portion of dry matter extracted with ether. Used to measure crude fat. See *crude fat* and *fat*.

Fat Triglycerides of fatty acids that are a high density source of energy for animals. Fat is measured by determining content of fatty acids or is estimated in forages as ether extract minus one. Fats and fatty acids contain 2.25 times the energy found in carbohydrates and are highly digestible by animals. See *ether extract* and *crude fat*.

Hemicellulose Long chains of sugar compounds associated with plant cell walls.

***In situ* digestibility** Digestibility determined by incubation of a ground forage sample in a porous nylon bag within the rumen of an animal for a fixed time period.

***In vitro* digestibility** See *in vitro dry matter digestibility* (preferred term).

***In vitro* dry matter digestibility (IVDMD)** Digestibility determined by incubation of a ground forage sample with rumen fluid in beaker or test tube for 24 to 48 hours, followed either by addition of acid and pepsin and further incubation for 24 hours (IVDM or IVDMD) or by boiling in neutral detergent fiber solution. See *dry matter digestibility*.

***In vitro* NDF digestibility (IVNDFD)** See *digestible neutral detergent fiber.*

Lignin Undigestible plant component, giving the plant cell wall its strength and water impermeability. Lignin also reduces digestibility.

Metabolizable energy (ME) The energy in a forage that is not lost in feces, urine, or rumen gases.

Metabolizable protein (MP) The rumen undegraded protein and microbial protein that passes into the intestine and can be broken down into amino acids.

Modified crude fiber (MCF) A modification of the crude fiber in which the ashing step is deleted. Modified crude fiber is crude fiber plus ash.

Moisture The percent of the sample that is water.

Figure 11. Feed and forage composition.

analytical fractions				chemical constituents	other analyses
moisture				water	
	ash			various minerals plus sand	
dry matter	organic matter	NDF	ADF	cellulose	
				lignin	
				fiber-bound N* heat-damaged N*	ADICP, NDICP
				hemicellulose	
		NDS	NDSC	fructans glucans pectic substances	NDSF
				sugars starches organic acids	
			crude protein	NPN (amino acids, amines, urea)	
				true protein degradable	RDP (DIP)
				true protein undegradable	RUP (UIP)
			ether extract	esterified fatty acids pigments and waxes	

percentage of feed or forage

*Fiber-bound nitrogen and heat-damaged nitrogen are also found in crude protein and RUP.

Source: *John Moore. Professor Emeritus of Animal Sciences, University of Florida.*

Net energy for gain (NEg) An estimate of the energy value of a feed used for body weight gain above that required for maintenance.

Net energy for lactation (NE_l) An estimate of the energy value of a feed used for maintenance plus milk production during lactation and for maintenance plus the last two months of gestation for dry, pregnant cows.

Net energy for maintenance (NEm) An estimate of the energy value of a feed used to keep an animal at a stable weight.

Neutral detergent fiber (NDF) Residue left after boiling a sample in neutral detergent solution. Called aNDF if amylase and sodium sulfite are used during the extraction (this is recommended procedure). The NDF in forages represents the indigestible and slowly digestible components in plant cell walls (cellulose, hemicellulose, lignin, and ash). Contrast with *crude fiber* and *acid detergent fiber*.

Neutral detergent fiber digestibility (NDFD) The portion of neutral detergent fiber digested by animals at a specified level of feed intake. May be determined by *in vivo* feeding trials or estimated by lignin analysis, by *in vitro* or *in situ* digestibility, or by near infrared reflectance analysis. Expressed on NDF basis. Compare with *digestible neutral detergent fiber*.

Neutral detergent insoluble crude protein (NDICP) Nitrogen in neutral detergent fiber residue. Estimates the portion of the undegradable protein that is available to the animal.

Neutral detergent soluble carbohydrates (NDSC) See *nonfibrous carbohydrates*.

Nonfibrous carbohydrate (NFC) An estimate of the rapidly available carbohydrates in a forage (primarily starch and sugars). This value is calculated from one of the following equations: NFC = 100% – (CP% + NDF% + EE% + Ash%) or, if corrected for NDFCP, NFC% = 100% – [CP% + (NDF% – NDFCP%) + EE% + Ash%] Contrast with *total nonstructural carbohydrate*.

Non-protein nitrogen (NPN) The portion of the total nitrogen that is not in protein. If high, NPN is an indicator of potential for nitrate toxicity.

Nonstructural carbohydrate (NSC) See *total nonstructural carbohydrate*; contrast with *nonfibrous carbohydrate*.

Nutritive value (NV) Protein, mineral, and energy composition, availability of energy, and efficiency of energy utilization.

Organic matter (OM) The portion of the dry matter that is not ash (mineral).

Organic matter digestibility (OMD) The portion of the organic matter that is digestible.

Protein A long chain of amino acids essential for plant and animal life. Animals meet protein needs by breaking down plant and microbial (from the rumen) protein and reassembling as animal protein.

Relative feed value (RFV) An index for ranking cool-season grass and legume forages based on combining digestibility and intake potential. Calculated from ADF and NDF. The higher the RFV, the better the quality. It is used to compare varieties, match hay/silage inventories to animals, and to market hay.

Relative forage quality (RFQ) An index for ranking cool-season grass and legume forages based on TDN and intake potential. Calculated from NDF, CP, EE, NDFD, ADF, and NFC. It matches animal performance better than RFV across a wide range of forages.

Rumen degraded protein (RDP) That portion of total protein that is degraded to ammonia in the rumen. Same as *degraded intake protein*. *Rumen degraded protein* is the preferred term.

Rumen undegraded protein (RUP) That portion of the protein not degraded in the rumen. Often called *bypass protein, escape protein,* or *undegraded intake protein. Rumen undegraded protein* is the preferred term.

Soluble intake protein (SIP) That portion of total protein rapidly degraded to ammonia in the rumen.

Soluble protein Protein soluble in a specified solution. Can be used to estimate rumen degraded protein and rumen undegraded protein.

Total digestible nutrients (TDN) The sum of crude protein, fat (multiplied by 2.25), non-structural carbohydrates, and digestible NDF. Often estimated by calculation from ADF, but formulas used vary.

Total nonstructural carbohydrate (TNC) A measure of the starch and sugar in forages. It has a lower value than nonfibrous carbohydrates because NFC contains compounds other than starch and sugars. Same as *nonstructural carbohydrate*; contrast with *nonfibrous carbohydrate*.

Undegraded intake protein (UIP Same as *rumen undegraded protein*.

Voluntary intake Consumption of a forage when forage availability is not limiting.

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