Forage Quality: What is it?
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This bulletin will familiarize you with the meaning of forage quality, the major components and nutrients that comprise forage quality and nutrient values typical of "high-" and "low-" quality forage samples. More and more emphasis is being placed on the nutritive value of forages, because forage quality information can be used to:

- Formulate nutritionally balanced, maximum profit rations for livestock.
- Develop feed inventories based on quality and quantity of available forages.
- Evaluate forage management practices.
- Determine equitable prices for forages based on feeding value.

DM (Dry Matter)

The first distinction to make when considering forage quality is the division between water and water-free material, which is commonly termed dry matter (DM). Several laboratory methods can determine DM and moisture, the most common of which is weighing a sample before and after drying it in an oven. Percent moisture plus percent DM equals 100. Ranges of desirable DM and moisture percentages for several forages are listed in Table 1.

Table 1.
Desirable DM and moisture contents of forages.

Forage	Dry matter (%)	Moisture (%)
Baled hay		
untreated	80-88	12-20
treated with preservative	70-75	25-30
Hay crop silage		
top-unloading upright silo	35-40	60-65
bottom-unloading upright silo	45-55	45-55
bunker and horizontal bag silo	30-35	65-70
Corn silage	32-37	63-68

Forage quality values can be reported on an as-fed (wet or fresh), air-dry or DM basis.

As-fed values represent the nutrient content of the feed as it is fed. Nutrient values expressed on this basis are lower than when expressed as either air-dry or DM, because the water content of the feed dilutes the nutrient content.

Air dry forages are assumed to contain 10 percent moisture or 90 percent DM.

Dry matter values are expressed on the basis of nutrients in a forage that is 0 percent moisture or 100 percent dry matter. The nutrient concentration on a DM basis is that contained in the DM portion of the feed.If you know the nutrient value on an "as-fed" or "as-is" basis, you can convert the value to a DM basis using this formula:

$$\text{Nutrient (DM basis)} = \frac{\text{Nutrient (as-fed basis)} \times 100}{\text{DM\%}}$$

Example: What is the crude protein value on a dry matter basis if haylage (as-fed) has 59% moisture and 7.6% crude protein?

Step 1 - Determine DM content

$$\begin{aligned} \text{DM\%} &= (100 - \text{\% moisture}) \\ &= 100 - 59 \\ &= 41\% \end{aligned}$$

Step 2 - Determine crude protein on DM basis

$$\text{Crude protein \% (DM Basis)} = \frac{7.6 \times 100}{41}$$

Answer: 18.5%

It is important to express nutrient values on a DM basis for use in formulating livestock rations, because intake is predicted as pounds of dry matter. Also, equations used for calculating energy or other components from a nutrient analysis require nutrients to be expressed on a DM basis.

CP (Crude Protein)

Crude protein (CP) consists of: (a) available and unavailable or bound protein and (b) non-protein nitrogen such as amino acids, amines and ammonia. The term "crude protein" rather than "protein" is used because crude protein is determined by measuring the total nitrogen (N) concentration rather than the true protein concentration in a forage or feed. The total measured nitrogen is then multiplied by the factor 6.25 to obtain the crude protein concentration in a forage sample. The factor 6.25 is based upon the fact that proteins contain about 16 percent nitrogen (100 ÷ 16.0 = 6.25). Protein is essential for all livestock, and forages are often evaluated based on their crude protein concentration.

Average crude protein concentrations for some common forage legumes and grasses are listed in Tables 2 and 3. Generally, legumes have higher crude protein concentrations than grasses when cut for hay. Less mature forages are generally higher than more mature forages in crude protein.

Table 2.
Typical crude protein (CP) concentrations of some common forage legumes.

	Alfalfa			Red clover			
	Pre-bloom	Early bloom	Full bloom	Early bloom	Full bloom	Birdsfoot trefoil	Alfalfa-grass mixture
CP(%)	22	18	15	19	15	16	12-17

Table 3.
Typical crude protein (CP) concentrations of some common forage grasses.

	Cool-season grasses*				Small grain silage		
	Vegetative	Early-late bloom	Corn silage dent	Corn stover	Barley	Oats	Sorghum-sudangrass, late
CP(%)	15-19	8-15	8-9	6	10	13	9

*Orchardgrass, smooth bromegrass, timothy.

Heat-Damaged Protein

When hay is stored too wet, heating may occur. On the other hand, if haylage is ensiled with too little moisture and too much oxygen, heating and "caramelization" can occur. Heat causes some of the available protein in these forages to chemically bind to sugars. The compounds that form may be completely unavailable to the animal. Heat-damaged forages are brown to black and have a sweet caramel-tobacco aroma. The amount of heat-damaged protein in a forage can be measured by determining the amount of crude protein in the acid-detergent fiber fraction.

This heat-damaged protein is also referred to as acid detergent fiber-nitrogen (ADF-N), acid detergent insoluble nitrogen (ADIN), fiber bound protein, bound protein, unavailable protein or acid detergent insoluble protein (ADIP). Whatever you call this heat-damaged protein, it is important that you include it in the measurement of crude protein. Note, however, it is protein that will do your livestock little good — they can't digest it.

Because of this problem, some forage tests report adjusted crude protein (ACP). The crude protein measurement is adjusted for the amount of heat-damaged protein in the sample. Such an adjustment to the crude protein value should be made only when heat-damaged protein is more than 10 percent of the total crude protein. Although there is probably some heat-damaged protein in all forages, it is not considered significant unless it exceeds a 10 percent threshold.

Example for adjusting crude protein:

Assume that the measured crude protein = 20.2% and heat-damaged protein = 2.4%.

Step 1: Determine percentage of total crude protein that is heat-damaged protein:
2.4 ÷ 20.2 = 11.9% (11.9% of crude protein is heat-damaged)

If the result of this division were less than 10%, there would not be a concern. However, in this example, heat-damaged protein was greater than 10%, so you must proceed to Step 2.

Step 2: If total from Step 1 is over 10%, adjust crude protein for heat-damage:
20.2 - 2.4 = 17.8% adjusted crude protein.

This value is sometimes called available protein.

ADF, NDF (Fiber)

In general, "fiber" refers to the bulky characteristic and components of a forage. The fiber fraction of a feed contains the less digestible portions of the plant and is therefore negatively associated with forage feeding value. Fiber contents are used to determine energy content, intake potential and digestibility of forages.

The original method of evaluating forages for fiber content, known as the Weende method, was developed more than 100 years ago. This method separated carbohydrates in forages into two groups, crude fiber and nitrogen free extract. The crude fiber was that portion of the forage resistant to digestion in weak acid and alkali. We know now that crude fiber is not an accurate measure of the nutritive value of a forage, because it tends to underestimate good-quality forage and overestimate the value of poor-quality forages.

The detergent fiber system was developed to overcome some of these problems. This system separates forage components into two groups: cell contents (neutral detergent solubles) and cell walls (neutral detergent fiber, or NDF). The cell wall fraction provides structural support to the plant for upright growth. The NDF fraction is subdivided into acid detergent solubles and acid detergent fiber (ADF).

Neutral detergent fiber is the percentage of cell wall material or plant structural components in a feed. The total fiber content of a forage is contained in the NDF fraction. NDF is measured by dissolving a forage sample in a neutral detergent solution. The fraction of the sample that does not dissolve is the NDF fraction. Chemically, NDF includes cellulose, hemicellulose, lignin and heat-damaged protein. NDF is closely related to the intake potential of a forage. This is an inverse relationship, i.e., the lower the NDF percentage, the greater the intake potential. More mature plant material will have a higher NDF concentration. At comparable stages of maturity, grasses have higher NDF concentrations than legumes. Very high quality legume hay would have an NDF content of 40 to 46 percent.

Acid detergent fiber contains cellulose, lignin and heat-damaged protein. It is the insoluble fraction in an acid detergent solution. ADF is closely related to digestibility of a forage. Again, this is an inverse relationship, and the lower the ADF percentage, the greater the digestibility of a feed or forage. ADF can be used to predict the energy value of a forage. Like NDF, more mature plant material will contain higher ADF concentrations. Very high quality legume hay would have an ADF content of 30 to 36 percent. Table 4 presents average NDF and ADF percentages for some different types and maturities of forages.

Table 4.
Average NDF and ADF concentrations of common forages.

Forage	NDF (%)	ADF (%)
Alfalfa		
Pre-bloom	<40	<31
Early bloom	40-46	31-35
Mid-bloom	47-53	36-40
Full bloom	54-60	41-42
Alfalfa-grass mixture	45-52	36-40
Red clover, full bloom	56	41
Cool-season grasses*		
Vegetative	60-65	32-35
Early-late bloom	65-70	35-40
Corn silage	42	31

*Orchardgrass, smooth bromegrass, timothy.

TDN, DDM, NE (Energy)

The energy content of a forage is one of its most important nutritive characteristics. The energy content of a forage or feed will have a major influence on how much milk or meat can be produced from that forage. The most common measures of energy are digestible dry matter (DDM), total digestible nutrients (TDN) and-net energy (NE). Equations have been developed that relate each of these three measures to acid detergent fiber (ADF).

Digestible dry matter (DDM) is an estimate of the percentage of the forage that is digestible. In some research forage quality laboratories, DDM is analyzed either by using an *in vitro* (artificial rumen) or *in vivo* (actual animal digestion trial) procedure. In both of these cases, a sample of the forage is actually mixed with fluid from an animal's rumen, and the percentage of the sample digested by microbes in the rumen fluid is measured. Because *in vivo* trials are very costly and require many pounds (or tons) of forage, most DDM values reported by commercial laboratories are calculated based on *in vitro* results. More recently, formulas have been developed that relate DDM to ADF. The national standard formula for alfalfa and alfalfa-grass mixtures is:

DDM% = 88.9 - (.779 x ADF%)

Early maturity legume hay and haylage would have a typical value for DDM in the range of 65 percent or more. Corn silage would have typical DDM values of 60 to 70 percent (see Table 5).

Total digestible nutrients (TDN) is the sum total of all digestible organic nutrients (protein, fat, fiber and non-fiber carbohydrates) of a forage that are available to the animal. TDN is expressed in terms of percent or pounds per 100 pounds of feed. TDN values in feed test reports are calculated from equations that relate total digestible nutrients to ADF. Two of the commonly used formulas are presented below. These are the formulas used by the MSU Forage Testing Laboratory:

For alfalfa: %TDN = 96.35 - (ADF% x 1.15)

For corn silage: %TDN = 87.84 - (ADF% x 0.7)

TDN is a close approximation of *in vivo* DDM. Table 5 presents typical TDN values for various forages.

Table 5.
Typical energy (DDM, TDN, NEL) values for various forages.

	DDM	TDN	NEL
	——% of DM——		Mcal/lb
Legume hay and haylage (early maturity)	61-65	56-62	.61-.67
Legume hay and haylage (late maturity)	55-60	48-55	.53-.60
Legume-grass mixed hay and haylage	57-60	50-55	.52-.57
Grass hay and silage	50-55	50-55	.50-.56
Corn silage	61-70	63-70	.62-.70
High-moisture shelled corn	80-90	80-90	.84-.95

Net energy is expressed in terms of megacalories per unit weight (Mcal/lb). For dairy animals, only one NE term is used, NE_L (net energy for lactation). For beef animals, however, efficiency of energy use for maintenance is greater than efficiency of energy use for gain, so two separate terms are used — net energy for maintenance (NE_m) and net energy for gain (NE_g). ADF is the single plant component most highly related to NE_L, and this is an inverse relationship. As ADF increases, NE_L decreases. Several formulas that relate ADF to NEL for different forage species have been developed. Some of these formulas that are used in the MSU Forage Testing program are presented below:

Alfalfa:
NE_L (Mcal/lb) = 1.044 - (ADF% x 0.0123)

Corn silage:
NE_L (Mcal/lb) = .3133 x (2.86-(35.5/(100)-(ADF% x 1.67))

Legume-grass mixture:
NE_L (Mcal/lb) = 1.044 - (ADF% x 0.0131)

See Table 5 for typical NE_L values for different forages.

RFV (Relative Feed Value)

Relative feed value (RFV) is an index used to rank forages based on digestibility and estimated intake potential. Relative feed value attempts to measure the overall nutritive quality of a forage using a single number. Several hay auctions presently use RFV as the primary source of information for buyers and sellers of hay. As quality of a forage increases, RFV also increases. The ratio between RFVs of different hays can be related to their economic worth.The formula for calculating RFV is:

RFV% = (DDM x DMI)/1.29, where DDM = 88.9 - (.779 x ADF%) DMI (% of BW) = 120/(forage NDF%)

RFV takes into account both the digestibility of the forage (digestible dry matter, or DDM), and the intake potential (dry matter intake, or DMI). Intake potential, or the amount of forage dry matter that an animal will consume, is affected by how fast forages are digested and pass through the digestive tract. The fiber fraction that appears to be most closely related to the DMI of forages is NDF (neutral detergent fiber). The reliability of using NDF to predict total DMI (forage plus grain) is uncertain, so forage NDF values should be used to compare potential DMI and RFV of forages and not total rations.

Standards for using RFV as criteria to grade hay have been proposed by the Hay Marketing Task Force of the American Forage and Grassland Council (AFGC). These standards are being used in several states in hay marketing. The AFGC standards for legumes and grasses are presented in Table 6.

Table 6.
Market hay grades for legumes, legume-grass mixtures, and grasses — AFGC Hay Marketing Task Force ("A continuum from legume pre-bloom to grass headed and/or heavily weathered forage")[a].

	Description					
Grade	Species and Stage	CP	ADF	NDF	DDM	RFV
Prime	Legume, pre-bloom	>19	<31	<40	>65	>151
1	Legume, early bloom, 20% grass-vegetative	17-19	31-35	40-46	62-65	125-151
2	Legume, mid-bloom, 30% grass-early-head	14-16	36-40	47-53	58-61	101-124
3	Legume, full bloom, 40% grass-headed	11-13	41-42	54-60	56-57	86-100
4	Legume, full bloom, 50% grass-headed	8-10	43-45	61-65	53-55	77-85
Fair	Grass-headed and/or rain-damaged	<8	>45	>65	<53	<77

[a]Description adopted by U.S. Alfalfa Hay Quality Committee.

Relative feed value, in combination with crude protein, should be used when hay is being bought or sold according to nutritive quality. The question of feeding forages to dairy animals based on RFV is one that has not been completely answered. In some cases, it has been recommended that high-producing dairy cows be fed forages with RFVs above 118, but more work in the area of RFV and its relation to animal performance will be needed before absolute recommendations can be made.

Summary

There are many ways to judge the "quality" of a forage. You can view its color and smell or feel it, or you can subject forage to chemical analyses. For the most accurate evaluation, you can feed it to large or small animals. One of the most promising methods of forage quality analysis is near infrared reflectance spectroscopy (NIRS). Using NIRS, a complete evaluation of a forage, including dry matter, crude protein, fiber, energy and relative feed value, can be accomplished in only a few minutes and at a reasonable cost. The accuracy of NIRS depends upon the accuracy of the chemical analyses that are used to calibrate the instrument. For animals to produce profitably, they must be fed balanced rations. Because forages vary widely in nutrient composition, it is impossible to adequately balance rations when forages are not routinely tested.

For more information on forage quality, consult the following MSU Extension bulletins, available from your county Cooperative Extension Service office. Single copies of each are free to Michigan residents.

E-1413, "Alfalfa: Quality Means Profit"

E-1994, "Chemical Preservation of Forages: Techniques and Economics"

E-1995, "Chemical Conditioning of Forages: Techniques and Economics"

E-2118, "Sampling Forages for Quality Testing"

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