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FORAGE QUALITY TESTS AND INTERPRETATION

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Forage quality refers to how well animals consume a forage and how efficiently the nutrients in the forage are converted into animal products. The right forage tests, accurately conducted, can provide a good estimate of forage quality. Forage quality information is important for:

1) Formulating nutritionally balanced rations.
2) Developing and allocating forage inventories.
3) Evaluating forage management practices (growing, harvesting and storage).
4) Marketing and pricing forages.

Recommended tests for determining forage quality are: dry matter (DM), crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), calcium (Ca), and phosphorus (P). Energy values (TDN or net energy) and relative feed values (RFV) can be calculated from these core analyses. Additional macro and micro mineral analyses are suggested but not necessary on a routine basis. An available protein analysis or another measure of protein tied up through heat damage should also be done on any forage suspected of being heated during storage.

Forage Quality

A number of factors both singly and interactively affect forage quality. Understanding and controlling some of these factors can help improve forage quality.

Species. Plant species can account for a wide variation in forage quality. Compositional differences between species are reflected in the CP and NDF tests. Legumes are higher in CP but lower in NDF than grasses or grain silages (Table 1). Species with low NDF contents have higher potential intakes and therefore are generally higher in quality than high NDF species. Weeds may or may not change forage quality depending on species, stage of maturity and soil fertility.

Maturity. As plants mature, they increase in fiber and lignin content. Increasing fiber (ADF and NDF) reduces digestibility and intake potential. Lignin is essentially indigestible and therefore, the increasing lignin content that comes with increasing maturity also reduces digestibility. For each one percentage unit increase in lignin, digestible dry matter (DDM) decreases three to four percentage units.

Environment. Climatic conditions during growth and harvest of plants can greatly affect forage quality. The most apparent environmental factors are temperature, light and rainfall.

Forage plants at the same maturity will be higher in fiber and CP when growth occurs during high temperatures compared to cool or normal temperatures. Forages grown in hot climates will have a lower digestibility than forages grown in cooler climates at identical CP contents.

Sunlight has a variable affect on plant nutrient values. Plants grown in bright light generally have a higher digestibility than plants grown in shade. Cloudy weather may increase CP content of plants.

Moisture stress reduces plant growth but generally increases leaf to stem ratios. Plants grown under moisture stress are usually higher in digestibility (lower in fiber) and higher in antiquality factors (alkaloids, nitrates and prussic acid) than plants grown under normal moisture conditions.

Insect and disease damage. Both of these conditions result in leaf losses which decrease CP and increase fiber content of plants.

Soil fertility. Fertilization of grasses with nitrogen (N) will increase CP content. However, fertilization with other nutrients usually has little effect on the nutrient content of forages. Extremes in soil mineral levels are required to cause mineral deficiencies or toxicities in ruminant animals.

Harvesting and storage. Losses of highly digestible nutrients occur during forage harvesting and storage. Keeping these losses to a minimum is essential in attaining high quality forages. Leaf losses during harvest result in CP losses and decreases in DDM. Rainfall on cut forage results in leaching of highly digestible nutrients. Storage conditions allowing for molding and heating can substantially reduce plant nutrient contents and animal acceptability.

Table 1. Nutrient content of some common Minnesota forages and grains.

	CP		ADF		NDF		Ca		P		RFV	
N[a] Type	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
	% of dry weight											
HAY												
320 Legume	18.0	10-25	38.0	24-50	50.7	30-70	1.44	.7-2.00	.27	.2-.4	109	68-216
175 Legume-grass	15.6	7-24	39.3	31-48	55.4	40-72	1.21	.4-1.8	.26	.2-.3	98	68-150
29 Grass-legume	13.6	6-20	40.4	32-53	59.2	49-79	.96	.4-1.6	.25	.2-.3	90	56-120
72 Grass	10.3	5-17	40.4	32-52	63.7	51-80	.63	.2-1.3	.22	.1-.3	84	60-111
HAY-CROP SILAGE												
194 Legume	19.0	12-27	39.2	17-51	46.7	23-63	1.25	.5-1.8	.30	.2-.4	116	76-311
61 Legume-grass	16.5	10-24	40.8	33-52	50.5	38-66	1.04	.4-1.6	.28	.2-.4	105	68-153
8 Grass-legume	14.6	9-18	39.3	35-42	53.5	47-62	.77	.2-1.3	.27	.2-.3	109	91-115
5 Grass	13.1	11-18	42.8	38-47	57.4	50-61	.61	.1-1.3	.28	.3-.3	90	80-103
CORN SILAGE												
11 Inoculated	7.9	6-10	28.0	22-39	48.2	38-67	.27	.2-.4	.33	.3-.4		
3 NPN	11.0	9-12	25.1	24-26	46.6	46-48	.25	.2-.3	.33	.3-.4		
102 Normal	8.0	6-17	28.0	13-39	47.7	30-62	.26	.1-.4	.30	.1-.4		
Sweet corn	8.0		36.0		59.0		.42		.40			
Popcorn	9.0		32.0		51.0		.30		.28			
Stover	6.0		39.0		67.0		.40		.38			
SORGHUM SUDAN												
Average	9.0		40.0		65.0		.50		.21			
SMALL GRAINS												
16 Oatlage	11.8	8-16	41.6	35-46	57.7	48-67	.48	.1-1.10	.28	.2-.3		
GRAINS												
Barley	13.0		7.0		19.0		.0		.40			
Corn, high moisture												
91 Shelled	10.3	9-15	3.2	2-7	8.3	4-15	.0		.30			
43 Ear	10.2	8-14	8.3	3-14	18.0	8-32	.0		.27			
9 Snapped	9.9	9-11	11.0	8-13	24.2	18-29	—		—			

[a]Number of samples—values obtained from Minnesota NIRS Extension project during 1986 or 1987.

Expressing Forage Test Results—Dry, Wet, or Air-Dry Basis

Forage test results can be reported on an as-fed, air-dry, or DM basis. The definitions of these bases are listed below:

Basis	Definition
As-fed, Wet	Nutrients expressed on these bases represent the nutrient content of the feed as it is fed.
or Fresh	Nutrient values expressed on these bases are lower than when expressed on either an air-dry or DM basis as the water or moisture content of the feed dilutes out the nutrient content.
Air-Dry	Feeds are assumed to contain 10 percent moisture or 90 percent DM.
Dry Matter (DM)	Moisture free (0 percent) or 100 percent dry basis. All moisture has been removed and nutrient concentration is that contained in the DM portion of the feed.

Converting forage nutrients to a DM basis can be done using the following formula:

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

Nutrient values should be on a DM basis for use in formulating livestock rations. Also, equations for calculating energy or other components from nutrient analysis require nutrients to be expressed on a DM basis. The following example shows how to convert test results from as-fed to DM basis:

Corn Silage Analysis (as-fed)
Moisture—62%
Crude protein—3.1%

Step 1. Determine DM content.
DM% = (100 − % moisture)
38% = (100 − 62)

Step 2. Convert CP analysis to a DM basis.

$$\text{CP\% (DM basis)} = \frac{3.1\% \times 100\%}{38\%}$$

CP% (DM basis) = 8.16

Interpreting Forage Test Results

Dry Matter (DM)

DM is the percentage of forage which is not water (DM% = 100 − % moisture). Knowing DM content of forages is important for:

1. Ration formulation. Nutrient requirements of animals are expressed on a DM basis. Also, animal intake is regulated more by DM intake than volume of feed consumed.

2. Comparison of forages. Nutrients are contained in the DM portion of forages.
3. Predictor or indicator of storage problems. Forages ensiled too dry or hay baled too wet can heat, reducing protein availability and/or becoming moldy. Ensiling forages too high in moisture can result in excessive losses through seepage and undesirable fermentation.

Suggested Moisture Ranges for Forages

Forage	Moisture %
Hay—baled	Less than 20
Haylage—stave silo	50 to 60
—oxygen-limiting silo	45 to 55
Corn silage	62 to 68

Crude Protein (CP)

Mixtures of true proteins, composed of amino acids, and nonprotein nitrogen make up the CP content of forages. The CP content of forages is determined by measuring the amount of N and multiplying by 6.25. The general term "protein" refers to CP which includes both available and unavailable CP.

When harvested early and stored properly, legume and legume-grass forages are excellent sources of CP (Table 1). However, forage quality includes more than just CP. Using CP as the only measure of forage quality can be misleading. Figure 1 shows the variation in ADF and NDF content of legume hays containing between 18.5 and 20.5% CP. Both ADF and NDF contents almost doubled within hays having only a 2% unit range in CP. Therefore, tests in addition to CP are necessary to determine forage quality.

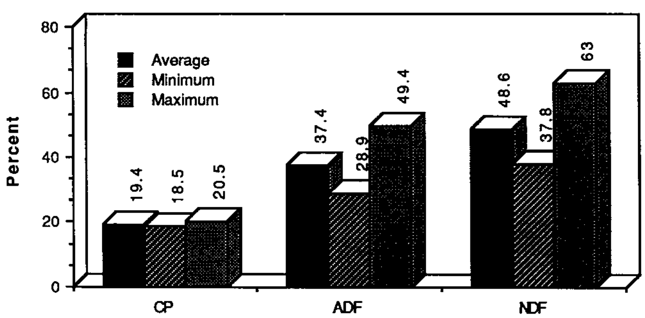

Figure 1. Range in fiber tests of legume hay samples with crude protein limits.

Adjusted Crude Protein (ACP)

Excess moisture in hays and too little moisture in the presence of too much oxygen in haylages result in heating and caramelization. Some true proteins become tied up with carbohydrates during the heating process, which makes them unavailable to the animal. Heat-damaged forages are characterized by being brown to black in color and having a sweet caramel-tobacco aroma. Cows often relish heat damaged forages because sugars become condensed and turn into syrup during heating.

The amount of unavailable or heat-damaged protein in forages can be measured either by determining the amount of CP or N in the ADF fraction or by digesting the feed in pepsin, an enzyme found in the intestine of animals. The analysis for N in the ADF fraction is commonly referred to as ADFN or acid detergent insoluble N (ADIN), whereas the pepsin analysis is usually referred to as pepsin insoluble N. Bound protein is another term sometimes used in referring to heat damaged proteins.

Adjusted CP (ACP) is the amount of CP available to an animal for utilization after being corrected for unavailable protein. In unheated forages, 12 percent or less of the CP is in the ADF fraction. For example, alfalfa containing 20 percent CP may have 2.4 percent CP or less in the ADF fraction. When the percentage of CP in the ADF fraction increases above 12 percent, this indicates harvesting and storage conditions were not ideal and some reduction in CP availability has occurred. The higher the percent CP in the ADF, the more extensive is the reduction. Use ACP values in formulating livestock rations.

The following example illustrates how ACP is calculated:

Alfalfa-Grass Haylage	DM Basis
CP%	16.5
ADFN%	.4

Step 1. Calculate CP in ADF from ADFN.

$$\text{CP\% in ADF} = \text{ADFN\%} \times 6.25$$
$$2.5\% = .4 \times 6.25$$

Step 2. Determine ADFCP as percentage of the total CP.

$$\text{ADFCP\%, \% of total CP} = \frac{\text{CP\% in ADF}}{\text{CP\%}} \times 100$$
$$15.2\% = \frac{2.5\%}{16.5\%} \times 100$$

Step 3. Calculate ACP%.

$$\text{ACP\% of DM} = \frac{\text{CP\%} \times [100-(\text{ADFCP\%}-12\%)]}{100}$$
$$16.0\% = \frac{16.5\% \times [100-(15.2\%-12\%)]}{100}$$

Note: If ADFCP is 12 percent or less of CP, ACP = CP.

Fiber

The bulky characteristics of forage come from fiber. Forage feeding values are negatively associated with fiber since the less digestible portions of plants are contained in the fiber fraction. Fiber contents are used to calculate energy content, digestibility, and potential intake of forages.

The detergent fiber analysis system separates forages into two parts: cell contents or neutral detergent solubles, which include sugars, starches, proteins, nonprotein nitrogen, fats and other highly digestible compounds; and the less digestible components found in the fiber fraction. The fiber fractions are contained in the cell walls of plants and provide structural support for upright growth. Figure 2 illustrates these various fractions of plant cells and their chemical components.

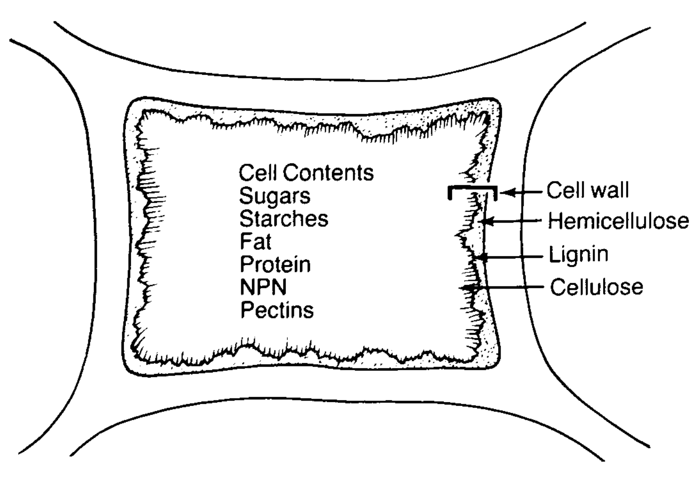

Figure 2. Plant cell fractions and chemical components.

The total fiber content of a forage is contained in the neutral detergent fiber (NDF) or cell wall fraction. Chemically, this fraction includes cellulose, hemicellulose, lignin, and heat-damaged protein. Because of these chemical components and their association with the bulkiness of feeds, NDF is closely related to feed intake and rumen fill in cows.

Digestibility of NDF in forages ranges from 20 to 80 percent, depending on forage species and stage of maturity. Cell contents, on the other hand, are nearly 100 percent digestible. Cell contents are determined by subtracting NDF from 100.

The acid detergent fiber (ADF) fraction contains cellulose, lignin, and heat-damaged proteins. It is closely related to indigestibility of forages and is used in calculating energy content.

Lignin is another component found in cell walls of forages and is measured by either acid detergent lignin (ADL) or permanganate lignin (PML) procedures. Lignin is almost completely indigestible and therefore, as the lignification of forages increases, digestibility decreases.

A list of the fiber fractions along with their chemical components and digestibilities are in Table 2. The main factors affecting feeding value of forages relative to fiber are species and date of cutting. Grasses are higher in NDF than legumes but lower in lignin. Thus, grasses have lower potential intakes than legumes but contain more digestible cellulose because of less binding from lignin. Early cut, bud, or late vegetative stage legumes are low in fiber, contain less lignin than when mature, and have the highest potential intake of any forages.

Table 2. Fiber fractions, components, and digestibilities.

Fraction	Components	Digestibility
Cell walls (NDF)	Hemicellulose	20-80%
	Cellulose	50-90%
	Lignin	0-20%
	Heat damaged protein	Variable
	Keratin	
ADF	Cellulose	50-90%
	Lignin	0-20%
	Heat damaged protein	Variable
ADL	Lignin	0-20%
Cell solubles (100-NDF%)	Starches	95-100%
	Fats	
	Soluble proteins	
	Nonprotein nitrogen	
	Sugars	
	Pectins	

Minerals

The total mineral content of feedstuffs is called ash. Forages normally contain 3 to 12 percent ash on a DM basis. Organic matter is determined by subtracting ash from 100.

Minerals can be divided into two groups. Macro are those required by animals in relatively large amounts and include calcium, phosphorus, potassium, magnesium, sulfur, and salt (sodium chloride). Micro or trace minerals are required in small amounts and include iron, iodine, cobalt, copper, manganese, zinc, and selenium.

Forages should be routinely tested for calcium and phosphorus. Other macro minerals, along with trace minerals, should be tested for once or twice per year.

Calculating Energy Values

There are several measures or terms to describe the energy value of a feed. The most common measures for lactating or dry dairy cows are total digestible nutrients (TDN) and net energy-lactation (NE_L). Measuring the energy content of a feed requires very sophisticated equipment and animal metabolism trials. However, it has been found that the energy content of a feed is inversely related to the fiber content and therefore, numerous equations have been developed to predict the energy value of a feed from its fiber content. There is no one absolutely accurate equation for predicting energy values of all forages or even for prediction of energy within a forage classification such as legumes, grasses, corn silage, etc. The following equations are those being used by the Minnesota Extension NIRS project for predicting the energy content of different forages.

Total Digestible Nutrients (TDN)

TDN is a measure of energy and is defined as:

$$\text{TDN\%} = \text{Digestible CP} + \text{Digestible CF} + \text{Digestible nitrogen free extract} + (\text{Digestible fat} \times 2.25)$$

The TDN values shown on forage analysis reports are calculated primarily from CF or ADF. Estimates of TDN can be made using the following formulas:

Legume and Grass Forages

$$\text{TDN\%} = \text{DDM\%}$$

$$\text{TDN\%} = 88.9 - (.779 \times \text{ADF\%})$$

Corn Silage

$$\text{TDN\%} = 87.84 - (\text{ADF\%} \times .7)$$

Net Energy (NE)

Net energy is a more comprehensive measure of energy than TDN. Three measures of NE are used: NE_L (lactation), NE_m (maintenance), and NE_g (gain). All are expressed as megacalories (Mcal) per 100 pounds of feed DM. The NE_m and NE_g are used primarily in formulation of beef rations, whereas only NE_L is used in formulation of dairy cow rations. Feed energy is used equally well for maintenance and milk production but less efficiently for body weight gain.

NE_L can be calculated directly from TDN:

$$NE_L\ (\text{Mcal/lb}) = (\text{TDN\%} \times .01114) - .054$$

For small grain silage, NE_L can be estimated using the following equation:

$$NE_L\ (\text{Mcal/lb}) = .3133 \times [2.86 - (\frac{35.5}{100 - (\text{ADF\%} \times 1.67)})]$$

Equations for estimating NE_L of corn grain are:

Ear Corn

$$NE_L\ (\text{Mcal/lb}) = 1.04 - (\text{ADF\%} \times .02)$$

Shelled Corn

$$NE_L\ (\text{Mcal/lb}) = .905 - (\text{ADF\%} \times .003)$$

Calculations for NE_m and NE_g are more complex and require calculating ME (metabolizable energy) first.

$$\text{ME (Mcal/kg)} = \frac{1.808 \times \text{TDN\%}}{50}$$

$$NE_m\ (\text{Mcal/lb}) = \frac{(1.37 \times ME) - (.138 \times ME^2) + (.0105 \times ME^3) - 1.12}{2.205}$$

$$NE_g\ (\text{Mcal/lb}) = \frac{(1.42 \times ME) - (.174 \times ME^2) + (.0122 \times ME^3) - 1.65}{2.205}$$

Relative Feed Value (RFV)

Each of the previously described forage tests and energy measures can be used directly in ration balancing, but trying to use all these tests to evaluate quality differences in legume, grass and mixtures of legume-grass forages is confusing. Relative feed value is an index which combines important nutritional factors (potential intake and digestibility) into one number for a quick, easy and effective method of evaluating feeding value or quality.

The formula for calculating RFV uses the estimated digestibility and potential intake of a forage calculated from ADF and NDF fractions, respectively.

Digestible Dry Matter (DDM)

Both animal and laboratory trials have shown ADF is highly related to the digestibility of a forage. Factors which increase ADF content such as increasing maturity, weathering, rain damage and weeds decrease digestibility. The National Alfalfa Hay Quality Committee's accepted equation for predicting DDM of legumes, grasses and legume-grass mixtures from ADF is:

$$\text{DDM \%} = 88.9 - (.779 \times \text{ADF\%})$$

Dry Matter Intake (DMI)

The amount of forage or feed DM an animal will consume is affected by how fast forages are digested and pass through the intestinal tract. The fiber fraction which appears to be most clearly related to the DMI of forages is NDF. However, the exact NDF level in rations necessary to achieve optimum performance is uncertain. Wisconsin research indicates maximum feed intake in alfalfa-based dairy rations occurs when NDF is 1.2 pounds per 100 pounds of body weight.

$$\text{DMI (\% of body weight)} = \frac{120}{\text{Forage NDF (\% of DM)}}$$

Calculation of RFV is made by multiplying DDM by DMI and then dividing by 1.29. The number derived from the RFV calculation has no units and is used only as an index for evaluating quality of hay or haylage made from legume, grass or legume-grass mixtures. At the present time, the RFV concept should not be used to evaluate quality of corn silage or forages other than those listed above.

$$\text{RFV} = \frac{\text{DDM} \times \text{DMI}}{1.29}$$

Standards for RFV as a criterion to grade hay have been proposed by the Hay Marketing Task Force of the American Forage and Grassland Council. The standards for legumes and grasses are listed in Table 3. These standards only include digestibility and intake, the most limiting performance factors for high producing dairy cows. The RFV does not include CP because CP is influenced by factors unrelated to those affecting RFV, but CP should be considered in pricing forages. High producing dairy cows require forages with RFV's above 124.

Summary

Both visual appraisal and a forage test are necessary to determine the quality of a forage. Forages should be inspected for absence of mold and good green color. Recommended forage tests include DM, CP, ADF, NDF, Ca, and P. Descriptions of forage quality for marketing or evaluating forages should include RFV. Optimum animal performance at lowest feed costs will be achieved when forage quality is related to animal performance and rations are balanced using forage test results.

Table 3. Forage quality standards for legumes, grasses and legume-grass mixtures.[a]

Quality standard[a]	RFV[b]	ADF[c]	NDF[c]	DDM, %[d]	DMI % of BW[e]
		--------------- % of DM	--------------		
Prime	>151	<31	<40	>65	>3.0
1	151-125	31-35	40-46	62-65	3.0-2.6
2	124-103	36-40	47-53	58-61	2.5-2.3
3	102-87	41-42	54-60	56-57	2.2-2.0
4	86-75	43-45	61-65	53-55	1.9-1.8
5	<75	>45	>65	<53	<1.8

[a]Standard assigned by Hay Market Task Force of AFGC.
[b]Relative feed value (RFV) calculated from (DDM × DMI) ÷ 1.29. Reference RFV of 100 = 41% ADF and 53% NDF.
[c]ADF = acid detergent fiber, and NDF = neutral detergent fiber.
[d]Dry matter digestibility (DDM, %) = 88.9 − (.779 × ADF%)
[e]Dry matter intake (DMI, % of body weight) = 120 ÷ forage NDF (% of DM).

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