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Forage Nutrition for Ruminants

Reviewed by
Karl Hoppe, Extension Livestock Systems Specialist
Zac Carlson, Extension Beef Specialist

Plants utilized in feeding livestock have long been a fundamental link in the food chain. Native grasses supported grazing animals well before man began to domesticate livestock. Forages always have been an extremely important source of nutrients in livestock rations. Ruminants, with their symbiotic relationships with microbes, are able to utilize forages as a primary portion of their diet. Through their conversion into milk and meat products, forages continue to be one of the primary sources of nourishment in the human diet.

Feed costs represent the single largest expense in most livestock operations. Producing and properly preserving high-quality forages can help reduce the costs associated with feeding concentrates and supplements. Astute producers recognize the economic significance of producing high-quality forage crops.

The primary methods of harvesting and preserving forage crops include silage making, hay making, green chopping and pasturing. Each of these methods of forage harvest and/or preservation has benefits and limitations. Any given operation may use each of the methods at varying times, depending on the availability of resources. Producers must review each management practice and evaluate their own production situation to determine which method to use to gain the maximum economic return.

Forage Terminology

Plant Structure

Forages have been described as bulky feeds that have relatively low digestibility. However, corn silage is a forage, but it can be more than 70 percent digestible. Perhaps the best way to understand forages is to look at the properties that make them unique.

Forages contain significant portions of plant cell-wall material. From the standpoint of a forage user, the amount and type of plant cell wall is extremely important because it greatly influences how a particular forage will be utilized by animals to produce meat or milk.

A young plant cell has a single outer layer referred to as the primary cell wall. Later, as the plant matures, a second layer is laid down on the inside of the cell. This is called the secondary cell wall.

The secondary wall is thicker and gives the plant cell tensile strength. The main structural components of the primary and

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secondary walls are the complex carbohydrates, cellulose and hemicellulose. Together, the primary and secondary cell walls make up a large portion of the forage (40 to 80 percent).

Humans and other monogastric species have limited ability to digest plant cell wall compounds.

Forage eaters, however, have bacteria and other microbial populations in their digestive tracts than can ferment these compounds into usable nutrients. Animals that have the ability to utilize forages as the primary portion of their diet do not have the enzymes necessary to digest the cellulose and hemicellulose compounds found in forages themselves. They must rely on the microbial populations in their digestive system.

With advancing growth and maturity, forage cells insert a noncarbohydrate material, known as lignin, into the primary and secondary walls.

This complex compound gives the plant additional tensile strength and rigidity. Lignin can be thought of as the primary skeleton of the plant cell. It is important from a nutritional perspective because it is a nondigestible substance and its presence limits the ability of the microorganisms to ferment the cellulose and hemicellulose portions of the forage.

A simplified analogy is to think of the young plant cell wall as a wall containing two layers. The initial primary cell wall is the outer brick wall, lacking mortar. The secondary cell wall is like cinder blocks on the inside of the brick wall, but also lacking mortar. The brick and block could be broken down by the microbial populations in the digestive tract of the animal.

Lignin represents the mortar that is added later to cement the cell building blocks together. As the plant advances in maturity, more and more lignin is added to the complex of brick and blocks, making them more difficult to break down.

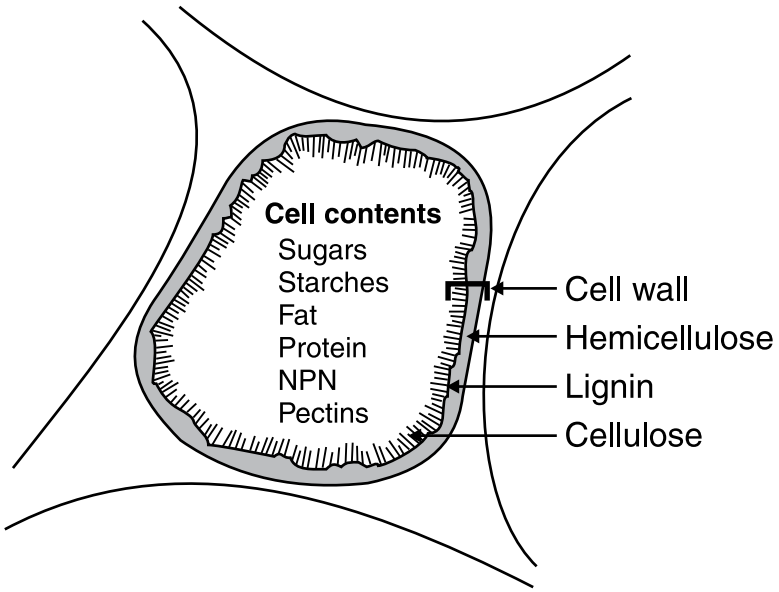

Figure 1. Diagram of a plant cell showing cell wall structure.

Forage Evaluation

Visual Appraisal

Measuring quality with visual appraisal, such by as sight, smell and feel, has distinct limitations, but they are important tools for evaluating forages. Color; leaf content; stem texture; maturity; contamination from weeds, molds or soil; and observations on palatability are examples of useful visual determinations.

"Wet Chemistry" Analysis

Traditional laboratory methods involve various chemical, drying and burning procedures to determine the major chemical components in the forage. This is the older, well-established method of forage analysis.

Wet chemistry procedures are the most widely used for forage evaluation in this country. The procedures are based on sound chemical and biochemical principles and take considerably more time to complete than the newer electronic methods. Accurate results are dependent on good sampling techniques when the samples are gathered, proper handling of the samples after collection and good analytical procedures in the laboratory conducting the evaluation.

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The forage analysis is only as good as the sampling, handling and analytical procedures used.

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Proximate Analysis

This wet chemistry set of procedures analyzes for the following:

- Dry matter content (100 percent minus moisture content)
- Crude protein (total nitrogen is measured)
- Ether extract (lipids and fats)
- Ash (mineral content)
- Crude fiber (most of the cellulose and some lignin)

Using this analysis, the proximate system estimates the following:

- Nitrogen-free extract (sugars, starch and some of the hemicellulose and lignin)
- Total digestible nutrients (estimate of digestibility)

While the proximate system has some limitations for the analysis of forages, portions of it are widely used today. Most typical forage analyses use the dry-matter and crude-protein procedures from the proximate system to determine percent of dry matter and crude protein. Ash (total mineral content) and ether extract are not determined commonly in a typical forage analysis. The original crude fiber analysis has been replaced with the newer detergent analysis.

Dry-matter Determination

Dry matter is the percentage of the forage that is not water. Dry-matter content is important because all animal requirements are made on a dry-matter basis. Comparing different forages without using the percent of dry matter as a baseline would be impossible. The dry matter of fermented feeds (haylage and silage) often is underestimated because of the volatile fermentation products that are used by the animal. Dry matter is also very important because the moisture content will give clues as to how a forage will preserve when stored by baling or ensiling.

Protein Analysis

Protein is an important nutrient supplied by forages. In legumes, protein is the primary nutrient supplied and is likely the principle reason a particular forage is being fed. Understanding what protein analysis tells about the quantity and quality of the protein in the forage is important.

When a laboratory uses wet chemistry, crude protein most likely will be measured by the standard Kjeldahl procedure. This measures total nitrogen, which then is multiplied by 6.25 to arrive at the crude protein value for the forage. The 6.25 figure is used because most proteins contain about 16 percent nitrogen (100 divided by 16 = 6.25). The crude protein value includes true protein and nonprotein nitrogen compounds. True-plant protein is roughly 70 percent of the protein in fresh forages, 60 percent of the total in hay forage and less than 60 percent in fermented forages. Ruminant animals are able to utilize a portion of both types of protein.

Many laboratories report a digestible protein value. This is a calculated number, such as 70 percent of the crude protein or crude protein minus 4.4. It is an estimate of protein digestibility only and has limited value in formulating rations.

When excessive heating has occurred in the forage, such as in poorly managed silage or hay, a portion of the crude protein may be unavailable. The crude protein analysis gives no indication that excessive heating may have rendered a portion of the protein unavailable. If heat damage is suspected, an analysis for bound protein or unavailable or insoluble protein should be requested. Laboratories typically report the bound protein as ADF-CP, unavailable or insoluble crude protein.

A portion of the crude protein in forages always is unavailable; the percentage will increase if heating has occurred. If the bound or insoluble protein is greater than 12 percent of the crude protein, enough heating has occurred to reduce protein digestibility. If the bound protein exceeds 15 percent, extensive heating has occurred in the forage.

In formulating rations, the normal amount of bound protein has been taken into account when determining protein requirements for animals. Unless heating in the feed has occurred, the crude protein value can be used in formulation of the ration. If the amount of bound protein is higher than 12 percent, available crude protein (ACP) should be used.

Crude Fiber Analysis

Crude fiber determination was the primary analytical procedure used to analyze forage samples for many years. Crude fiber analysis uses alkali and acid treatments to isolate the cell wall residue (crude fiber) that represents undigestible portions of the forage. Researchers

The steps used to calculate the percentage of bound protein and available crude protein (ACP) are:

1. Find the percentage of the crude protein that is bound. Bound protein may be expressed as ADF-CP or Insoluble CP.

   Example:

   Crude Protein = 17.68%
   ADF-CP = 2.36%

   % bound = 2.36 ÷ 17.68 = 13.35%

   Because this value exceeds 12 percent, it indicates heating has occurred in the forage and available protein should be calculated and used.

2. Calculate percentage of ACP.

   Example:

   % ACP = [CP% x (100 – (% bound – 12%))] ÷ 100

   % ACP = [17.68 x (100 – (13.35 - 12))] ÷ 100 = 17.44

   Note: The ACP value in this case is lower than crude protein, 17.68, because the bound protein value is greater than 12 percent.

   If the forage analysis reports the bound protein as bound nitrogen (ADIN), the bound crude protein can be determined by multiplying by 6.25.

   Example:

   ADIN = 0.29% (dry basis)

   Bound crude protein is: 0.29 x 6.25 = 1.81%

Some laboratories report percent ACP as crude protein minus bound protein. Technically, this is incorrect because it does not account for the normal amount of bound protein in the forage.

later learned that ruminants could digest a portion of the crude fiber. Even with its faults, the crude fiber system provides valuable information concerning the nutritive value of forages. A modified version of the crude fiber analysis (MCF) that includes the insoluble ash still is used in portions of the country to evaluate alfalfa.

Detergent or Van Soest Method of Cell Wall Determination

A newer method for evaluating the cell wall content of forages was developed in the 1960s by Peter Van Soest at the U.S. Department of Agriculture-Agricultural Research Service's Beltsville Agricultural Research Center (BARC) in Maryland. This system was developed because research determined that the crude fiber system did not differentiate the components of the cell wall well enough to generate accurate energy estimates for a wide range of forages species and maturities. The crude fiber system was criticized for often underestimating good-quality forages and overestimating poor-quality forages. Figure 2 shows how the crude fiber and the newer detergent systems fractionate forages.

The Van Soest or detergent system of forage analysis is the most common way to partition forages. The forage sample is boiled in a special detergent at a neutral pH of 7.0. The material then is filtered. The soluble portion contains these highly digestible cell contents:

- sugars
- starch
- pectins
- lipids (fat)
- soluble carbohydrates
- protein
- nonprotein nitrogen
- water-soluble vitamins and minerals

Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF)

The insoluble portion of the forage (neutral detergent fiber) contains the cellulose, hemicellulose, lignin and silica. It commonly is referred to as the cell wall fraction. Research shows neutral detergent fiber (NDF) is negatively correlated with dry-matter intake. In other words, as the NDF in forages increases, animals will consume less forage. NDF increases with the advancing maturity of forages. A better prediction of forage intake can be made using NDF; therefore, better rations can be formulated.

The fraction of the forage cell wall that is most commonly isolated and reported is the acid detergent fiber (ADF). This may be the most important determination of the forage analysis.

Acid detergent fiber is the portion of the forage that remains after treatment with a detergent under acid conditions. It includes the cellulose, lignin and silica (Figure 2). Acid detergent fiber is important because it is negatively correlated with how digestible a forage may be when fed. As the ADF increases, the forage becomes less digestible.

Acid detergent fiber sometimes is misinterpreted as indicating the acid content of fermented forages. The term acid detergent fiber has nothing to do with the acid content of a forage. The name is derived from the procedure used to determine the cellulose and lignin content.

Lignin, the indigestible noncarbohydrate component that decreases cellulose and hemicellulose availability, can be determined by further treatment with a stronger acid. Figure 3 shows a schematic of the detergent system of a forage analysis. Table 1 classifies the digestibility of forage fractions using the Van Soest method. The average cell contents and cell wall fractions for forages common to our area are listed in Table 2.

Neutral Detergent-soluble Carbohydrates (NDSC)

The carbohydrates soluble in neutral detergent include the most digestible portion of the plant and are the most difficult to describe nutritionally.

In contrast to nonstructural carbohydrates (NSC), also referred to as non-fiber carbohydrates (NFC), the carbohydrates in question are actually neutral detergent-soluble carbohydrates (NDSC).

The NDSC include structural and fiber carbohydrates (Figure 4). As a class, NDSC are highly digestible (see Van Soest, Figure 3) and rapidly fermented. However, they are a compositionally diverse group, which has tended to preclude their direct measurement by chemical analysis.

Table 1. Classification of forage fractions using the Van Soest method.

		Nutritional Availability	
Fraction	**Components included**	**Ruminant**	**Non-ruminant**
Cell contents	• sugars, starch, pectin	complete	complete
	• soluble carbohydrates	complete	complete
	• protein, nonprotein N	high	high
	• lipids (fats)	high	high
	• other solubles	high	high
Cell wall (NDF)	• hemicellulose	partial	low
	• cellulose	partial	low
	• heat-damaged protein	indigestible	indigestible
	• lignin	indigestible	indigestible
	• silica	indigestible	indigestible

Source: Van Soest, JAS 26:119.

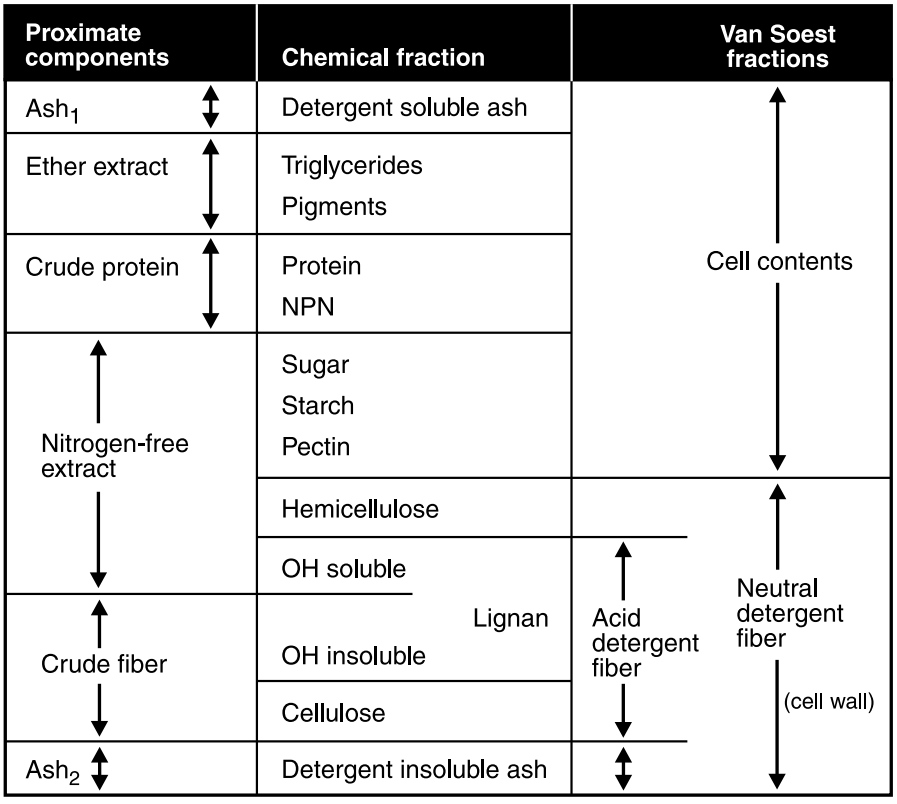


Figure 2. Fractions of feed dry matter.

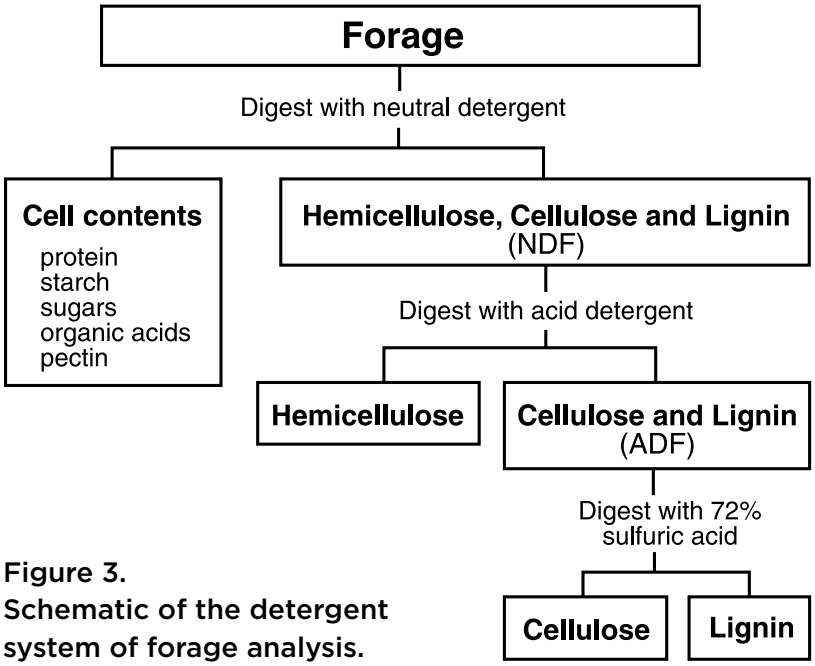


Figure 3.
Schematic of the detergent system of forage analysis.

Table 2. Average cell contents and cell wall fractions in common forages.

Forage	Cell Contents	NDF	ADF	Crude Fiber	Lignin
Percent, Dry-matter Basis					
Alfalfa					
late vegetative	60	40	29	22	7
early bloom	58	42	31	23	8
midbloom	54	46	35	26	9
full bloom	50	50	37	29	10
Red clover	44	56	41	9	10
Birdsfoot trefoil	53	47	36	31	9
Brome					
late vegetative	35	65	35	30	4
late bloom	32	68	43	37	8
Orchardgrass					
midbloom	32	68	41	33	6
late bloom	28	72	45	37	9
Sorghum-sudangrass	32	68	42	36	6
Timothy					
late vegetative	45	55	29	27	3
midbloom	33	67	36	31	5
late bloom	32	68	55	31	7
Corn silage					
stover	32	68	55	31	7
well eared	49	51	28	24	4
few ears	47	53	30	32	5

Source: U.S.-Canadian tables of feed composition, third revision. 1982.

NDSC is calculated as the difference between NDF and noncarbohydrate fractions by the equations:

100 – (crude protein + NDF + ether extract + ash)

or

100 – ((crude protein + (NDF – NDIN) + ether extract + ash))

The second equation corrects for protein in the NDF and avoids subtracting the protein twice.

Because it is calculated by difference, all of the errors from the component analyses accumulate in NDSC.

The source of crude protein in a feed may be a source of error in the NDSC calculation. Crude protein is simply an estimation of protein mass arrived at by multiplying nitrogen content y 6.25. When the nitrogenous compounds present are not one-sixteenth nitrogen, factors other than 6.25 may be appropriate. However, no practical way is available to determine the correct multiplier. The effect of miscalculating crude protein mass in the NDSC calculation is of special concern with feeds high in nonprotein nitrogen.

One of the greatest challenges to using NDSC in ration formulation is its diversity of components. The NDSC includes organic acids, sugars, disaccharides, oligosaccharides, starches, fructans, pectic substances, ß-glucans and other carbohydrates soluble in neutral detergent.

Different carbohydrates predominate in the NDSC of different feeds. Beyond their

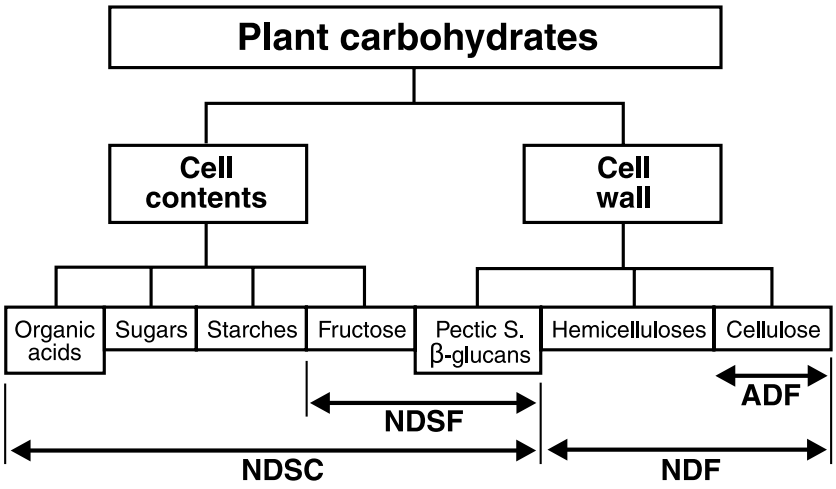
composition, these carbohydrates also vary in their digestion and fermentation characteristics (Table 3).

Organic acids, such as acetate and lactate, do not support microbial growth to the extent of other carbohydrates. The rate of starch fermentation in the rumen is highly variable and changes with the processing method, source and other ration components. Pectic substances support a microbial yield similar to starch, but their fermentation is depressed at low pH.

Thus far, differences in NDSC among feeds have been used in a qualitative fashion for ration formulation because no practical way is available to measure the component carbohydrates. Recent work offers a way of analyzing feeds to separate neutral detergent-soluble fiber from starches, sugars and organic acids. Although this improves upon the current situation, more work needs to be done to determine how to formulate rations optimally using the different fractions and how to separate organic acids from sugars and starches to better predict nutrients available to the animal.

Mineral Analysis

Forage analyses typically report the content of major minerals. The minerals typically determined are calcium and phosphorus. In laboratories using wet chemistry, atomic absorption, inductively coupled plasma (ICP) and colorimetric procedures are used most commonly to determine the mineral content of the forage.



Pectic S = pectic substances; ADF = acid detergent fiber; NDF = neutral detergent fiber; NDSC = neutral detergent-soluble carbohydrates; NDSF = neutral detergent-soluble fiber.

Figure 4. Carbohydrate composition of chemically analyzed fractions.

Table 3. Characteristics of neutral detergent-soluble carbohydrates (NDSC).

NDSC Fraction	Predominant Composition	Digestible by Mammalian Enzymes[1]	May Ferment to Lactic Acid[1]	Fermentation Depressed at Low pH[1]	Common Sources
Organic acids	acetate propionate, lactate, butyrate	yes	no	no	silage, feed, additives, whey
Sugars and disaccharides	glucose, fructose, sucrose (glucose + fructose)	yes	yes	no	molasses, citrus pulp, sugar beet pulp
Starch	glucose	yes	yes	no difference	corn and small grain products, bakery waste, potatoes
Fructans	fructose	no	yes	unknown	temperate cool season grasses, Jerusalem artichoke
Pectic substances	galacturonic acid, arabinose, galactose, rhamnose, etc.	no	no	yes	legume forages, citrus pulp, beet pulp, soybean hulls
ß-glucans	glucose	no	no	yes/unknown	small grains

[1] Relative to starch.

Reference: M.B. Hall, U.S. Forage Research Center

Near-infrared Reflectance Spectroscopy (NIRS) Analysis

Near-infrared reflectance spectroscopy is a rapid and low-cost computerized method to analyze forage and grain crops for their nutritive value. Instead of using chemicals, as in conventional methods, NIRS uses near-infrared light to determine protein, fiber, energy and mineral content.

This method of analysis involves the drying and grinding of samples, which then are exposed to infrared light in a spectrophotometer. The reflected infrared radiation is converted to electrical energy and fed to a computer for interpretation. Each major organic component of forages (and grain) will absorb and reflect near-infrared light differently. By measuring these different reflectance characteristics, the NIRS unit and a computer determine the quantity of these components in the feed.

The procedure is similar to the human ability to visually distinguish color when light strikes a material that absorbs some wavelengths and reflects others.

The detection of specific nutrients is possible because reflectance spectra from forage samples of established nutrient values (by wet chemistry procedures) are programmed into the computer. When a similar feed sample is evaluated by NIRS, the computer compares the wavelength reflections caused by the sample and matches them to previously tested samples.

The NIRS method of determining forage nutritional content is very rapid and less expensive than wet chemistry methods. Accuracy depends on good sample collection, storage and consistent drying, grinding and mixing of samples prior to analysis. The calibration set that is used must be developed from an adequate number of wet chemistry samples similar to those being analyzed. Without proper calibration, the NIRS analysis can have serious errors.

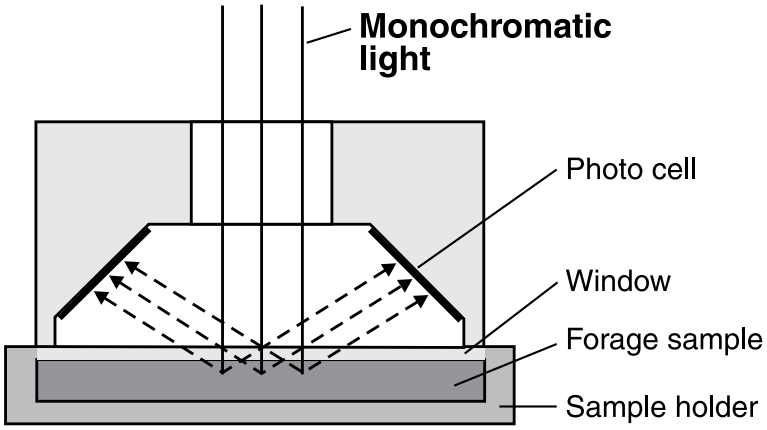


Figure 5. Diagram of how NIRS reads a prepared plant sample.

The typical forage analysis generated with NIRS is similar to that using proximate and detergent analysis.

In addition, NIRS typically reports bound protein, available crude protein, potassium and magnesium values.

In Vitro and In Vivo Disappearance Evaluation

In vivo (in animal) and in vitro (in glass or in test tube) procedures are seldom used for farm forage analysis. However, scientists commonly use them to evaluate forage quality. Most often, dry-matter disappearance in a specific period of time is measured, and this value will indicate how digestible a forage may be.

The term in situ (in bag) may be used to describe the procedure in which small polyester bags containing samples of forage are placed in the rumen of live animals consuming similar diets to the forage being evaluated. This is done through a sealed external opening into the rumen of an animal, called a canula.

In vitro is usually a two-step procedure done in test tubes. First the forage sample is digested using rumen fluid from a donor animal to simulate rumen digestion. The sample then is digested in an acidic enzyme solution to simulate digestion in the true stomach (abomasum).

In situ and in vitro are excellent techniques for forage evaluation when more expensive and time-consuming digestion or feeding trials are not possible.

Digestion trials are an excellent way to evaluate forages or other feeds for nutrient availability.

In this procedure, the forage is fed to several animals. The amount of forage fed and feces produced in a 10- to 14-day period is recorded and sampled for analysis.

An estimate of digestibility can then be calculated as follows:

((dry-matter intake – dry-matter output feces) ÷ dry-matter intake) x 100 = apparent dry-matter digestibility

Example: In a digestion trial using six animals, the average feed intake and fecal production were:

((48 lb. – 17.8) ÷ 48) x 100 = 62.9% apparent dry-matter digestibility

Because an analysis can be done on the feed and feces, determining the digestibility for each nutrient in the feed is possible. For example, the protein digestibility could calculate to be 75 percent digestible while the cell wall fractions may be only 59 percent digestible. In scientific research, this procedure is followed to determine total digestible nutrients (TDN).

The actual formula is:

% digestible crude protein +
% digestible crude fiber +
% digestible starch and sugars +
% digestible fats x 2.25 = % TDN

The fats are multiplied by 2.25 because they contain that much more energy per unit weight.

Total digestible nutrients may be estimated when the forage analysis is determined using the proximate analysis. This is done using average digestion numbers from previous digestion trials.

While TDN values are common on forage analysis reports, TDN is not commonly used in ration formulation because it does not account for all the losses that can occur in the fermentation and metabolism when forages are fed. These losses can be large for forages, so improved energy estimate systems have been developed.

Energy Terminology

Consumed forage can be thought of as a fuel and the animal that consumes it as a vehicle. No vehicle is 100 percent efficient at burning fuel. No animal uses 100 percent of the forage to produce the products we derive from them.

By accounting for losses during digestion, absorption and utilization, better predictions of the usable energy content of feeds can be made. Seeing the terms net energy-maintenance (NEM), net energy-gain (NEG) and net energy-lactation (NEL) is very common on laboratory or NIRS forage reports. These terms are used commonly in formulating today's rations. Figure 6 shows the losses subtracted to arrive at these energy terms.

The total energy content of a feed can be determined by bomb calorimetry (completely burning) the sample and measuring the heat produced to obtain the gross energy value of the feed. However, it does not indicate how digestible the feed is. For example, wood chips and corn grain have about the same gross energy value, but if both were fed, the digestibility would be very different. Table 4 compares some common forages.

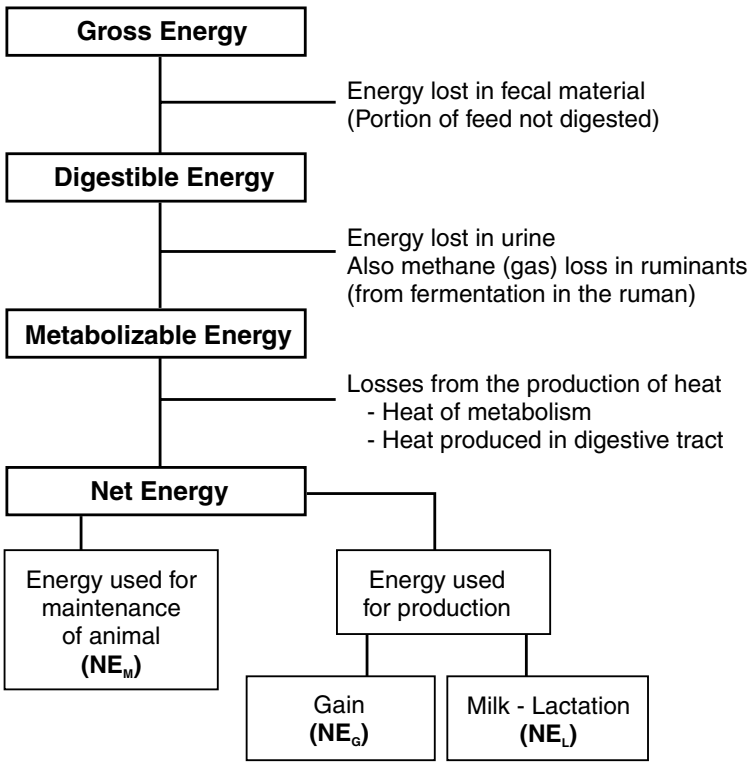


Figure 6. Energy losses when forages are fed.

Table 4. Four forages showing total digestible nutrient and net energy values.[1]

Forage	% TDN	Net Energy, Mcal Per Pound		
		Maintenance	Gain	Lactation
Bermudagrass, 43 to 56 day growth	43	0.33	0.09	0.42
Alfalfa hay, full bloom	55	0.52	0.26	0.56
Alfalfa hay, late vegetative	63	0.64	0.38	0.65
Corn silage, well eared	70	0.74	0.47	0.73

[1]All values on a dry-matter basis.
Source: NRC, Nutrient Requirements of Dairy Cattle, 1989, 2001.

Important Points

1. Net energy values for forages are best for ration formulation because they account for the major losses in digestion and utilization of the feed.
2. Each feed has three net energy values because animals use feeds with different efficiencies, depending on how the energy is being utilized. Net energy-gain is the least efficient and will have the lowest value. NEM and NEL are utilized with about equal efficiencies because milk is predominantly water (about 87 percent). In most dairy formulations, the same value is used for NE_M and NE_L.
3. Total digestible nutrients, which are calculated from digestion trials, do not account for all the losses. Forages tend to have a large loss of energy due to fermentation in the rumen of the animal. Unless it is below the thermal neutral zone of the animal, this heat loss represents total loss to the animal. For this reason, TDN tends to overestimate the energy value of forages.

   Therefore, net energy values, not TDN, normally are used in ration formulation.
4. Laboratory digestibility and net energy values are not produced from digestion trials or metabolism studies. The feeding value of forges has been shown to be associated negatively with cell wall contents (as the ADF and NDF values go up, energy values decrease). Because of this, energy values, estimates of digestibility and relative feed values reported on laboratory analysis are calculated using the ADF content in the forage. Neutral detergent fiber content is used to estimate the amount of forage an animal will be able to consume.

The fact that ADF and NDF values are used to generate many of the relative feeding values further emphasizes the importance that cell wall content has on animal performance.

Forage Terms

Digestible Dry Matter (DDM)

Many forage analyses will include a value called digestible dry matter. While different laboratories may use different formulas to calculate this value, one common formula is:

88.9 – (0.779 x % ADF) = %DDM

Example:

If % ADF = 31%:
88.9 – (0.779 x 31) = 64.75%

Dry-matter Intake (DMI)

Feeding studies have shown that as the percent of NDF increases in forages, animals consume less. Therefore, the percent of NDF can be used to estimate dry-matter intake. The formula used for the calculation is:

120 ÷ %NDF = DMI
(as a percent of body weight)

Example:

NDF value for a forage is 40%:
120 ÷ 40 = 3% of body weight DMI

Relative Feed Value (RFV)

The dry-matter intake potential (DMI) may not be reported as such, but it may be used to calculate a term called relative feed value (RFV). This combines dry-matter intake and the digestible dry-matter (DDM) values of the forage.

(%DDM x %DMI) ÷ 1.29 = RFV

Example:
From the previous examples
DDM = 64.75%, DMI = 3.0%
(64.75 x 3) ÷ 1.29 = 151

This estimates the intake of digestible dry matter relative to a forage that contains 1.29 percent of body weight as digestible dry matter and represents the quality of an average to below average forage.

Relative feed value has no units, but it is a way to compare the potential of two or more like forages for energy intake. Forages with NDF values of 53 percent and ADF values of 41 percent represent the value of 100 RFV (typical first-cutting alfalfa in full bloom).

Forages with values greater than 100 are of higher quality. If a forage has a value lower than 100, it is lower in value compared with the forage with 53 percent NDF and 41 percent ADF. Note that the forage with an RFV of 100 would not be considered excellent-quality forage. Dairy producers with high-producing cows often require RFVs of 150 or greater.

Relative feed values do not take into account the protein content of the forage. Protein content has to be evaluated separately. Table 5 shows forages with different relative feed values and expected CP levels.

Table 5. Relative feed values of various forages.

Forage	CP	ADF	NDF	RFV
		%		
Alfalfa, pre-bud	23	28	38	164
Alfalfa, bud	20	30	40	152
Alfalfa, mid-bloom	17	35	46	125
Alfalfa, mature	15	41	53	100
Alfalfa-grass, bud	19	30	45	135
Alfalfa-grass, mid-bloom	15	38	55	100
Alfalfa-grass, mature	12	42	52	101
Brome, late vegetative	14	35	63	91
Brome, late bloom	8	49	81	58
Bermudagrass, early	12	32	70	85
Bermudagrass, late	8	43	78	66
Corn silage, well eared	9	28	48	133
Corn silage, few ears	8	30	53	115
Cornstalks	6	43	68	76
Sorghum-sudangrass, vegetative	15	29	55	112
Surghum-sudangrass, headed	8	40	65	83
Wheat straw	4	54	85	51

Relative Feed Quality (RFQ)

Recently approved, relative feed quality (RFQ) is an improved version of RFV. Developed by the University of Wisconsin, it adds measures for fiber digestibility as well as quantity.

The proposed new RFQ index, originally called digestible relative feed value (dRFV), will replace RFV, which was implemented in 1978. Although RFV is used widely, what has become apparent is that hay lots with identical RFV scores don't necessarily produce the same amount of milk. As a result, the RFV index has come under increasing scrutiny as scientists have learned more about fiber digestibility.

A forage's energy content has a lot to do with the digestibility of its fiber, and forages similar in most other quality parameters can vary widely in fiber digestibility. The current RFV formula uses ADF to estimate energy content. However, ADF only explains about 55 percent of the variation in the digestibility of a forage.

The proposed RFQ will predict the energy content and potential intake of forages, just as RFV does. The difference: With RFQ, NDF digestibility will be included in both calculations.

That's because digestibility impacts the energy content of a forage as well as the amount animals will eat. To avoid confusion and ensure broad acceptance of the switch to RFQ, the scientists kept the numbers and scale the same as with RFV. Dairy-quality hay will still score above 150, for example.

On average, alfalfa will get the same scores as it does now. Individual samples, though, may differ by up to 50 points when evaluated by RFQ instead of RFV. But the results will more accurately reflect the forage's true value.

In general, grasses will get higher scores under RFQ. They tend to be high in NDF, so they score too low when all fiber is assumed to be equally digestible. Changing RFV likely will broaden its applicability.

RFV is appropriate only for alfalfa and cool-season grasses, although it often is used more widely.

The new index probably can be used on corn silage and perhaps other types of forage, too.

RFQ Index

RFQ = (DMI, % of BW) x (TDN, % of DM) ÷ 1.23

When the divisor, 1.23, is used to adjust the equation to have a mean and range similar to RFV (Moore and Undersander, 2002, Proc. Natl. Forage Testing Assn.).

1) For alfalfa, clovers and legume/grass mixtures, the equations for TDN and DMI will be:

   Total digestible nutrients for alfalfa, clovers and legume/grass mixtures are calculated from NRC 2001 recommendations using in vitro estimates of digestible NDF as follows:

   TDN_{legume} = (NFC x 0.98) + (CP x 0.93) + (FA x 0.97 x 2.25) + (NDFn x (NDFD ÷ 100) – 7

   where: CP = crude protein (% of DM)

   EE = ether extract (% of DM)

   FA = fatty acids (% of DM) = ether extract – 1

   NDF = neutral detergent fiber (% of DM)

   NDFCP = neutral detergent fiber crude protein

   NDFn = nitrogen-free NDF = NDF – NDFCP, else estimated as NDFn = NDF x 0.93

   NDFD = 48-hour in vitro NDF digestibility (% of NDF)

   NFC = nonfibrous carbohydrate (% of DM) = 100 – (NDFn + CP + EE + ash)

   Dry matter intake calculations for alfalfa, clover and legume/grass mixtures will be:

   DMI_{legume} = 120 ÷ NDF + (NDFD – 45) x .374 ÷ 1350 x 100 with NDFD adjustment. 45 is an average value for fiber digestibility of alfalfa and alfalfa/grass mixtures.

   DMI is expressed as % of body weight (BW), NDF as % of DM and NDFD as % of NDF

2) **For warm- and cool-season grasses, the equations for TDN and DMI will be:**

   Total digestible nutrients for warm- and cool-season grasses are calculated as:

   TDN_{grass} = (NFC x 0.98) + (CP x 0.87) + (FA x 0.97 x 2.25) + (NDFn x NDFDp ÷ 100) – 10

   Where terms are as defined previously and NDFDp = 22.7 + .664 x NDFD

   Dry-matter intake calculations for warm- and cool-season grasses will be:

   DMI_{Grass} = -2.318 + 0.442 x CP - 0.0100 x CP^2 – 0.0638 x TDN + 0.000922 x TDN^2 + 0.180 x ADF – 0.00196 x ADF^2 – 0.00529 x CP x ADF

   DMI is expressed as % of BW, and CP, ADF and TDN are expressed as % of DM

Predictive Equations for Alfalfa Quality

Predictive equations for alfalfa quality (PEAQ) is a method to predict the forage quality of standing alfalfa. It was developed by agronomists at the University of Wisconsin - Madison.

The two equations predict ADF and NDF when the height of the tallest stem is measured and the maturity stage of the most advanced plant is determined.

The equations have been validated not only in Wisconsin but also in numerous other environments from California to New York. Because regression equations are difficult and somewhat time-consuming in a production field situation, tables have been developed using computer spreadsheet programs that help make for rapid in-field estimates of NDF or relative feed value (RFV).

Additionally, several seed companies have developed "PEAQ sticks" that can be used easily to determine plant height and forage quality. The original "five maturity stage" system used with PEAQ has been simplified to a "three maturity stage" system without a loss of precision.

Estimating Alfalfa RFV in the Field Using PEAQ

Step 1

Select a representative 2-foot-square area in the field.

Step 2

Determine the stage of growth for the most mature alfalfa plant stem in the selected area by referring to Table 6, Alfalfa growth stages. An example log sheet has been provided on Page 14.

Step 3

Select the tallest most mature alfalfa plant within the 2-foot-square area. Measure the height from the soil surface (next to the plant crown) to the top of the

Many state and county Extension staff are using PEAQ along with other methods to help farmers predict the optimum harvest time for alfalfa.

This has proved especially useful for first cutting.

stem (not the tip of the highest leaf blade). Straighten the stem for an accurate measure of its length and record your measurement in inches.

Note: The tallest stem may not be the most mature stem. Do your measurements on the tallest stem with the most mature stage of growth.

Step 4

Based on the length of the tallest and most mature stem, use Table 7, *Predictive Equation of Alfalfa Quality (PEAQ)*, to estimate relative feed value (RFV) based on plant height and maturity value.

Step 5

For best results, repeat steps 1 to 4 in multiple (four or five) representative areas in your field and average the results. Sample more times for fields larger than 30 acres.

Note: This procedure estimates alfalfa relative feed value for a standing crop. PEAQ does not account for changes in quality because of wilting, harvesting, weather damage and storage. To estimate harvested relative feed values, subtract 15 to 20 RFV units (assuming good wilting and harvesting conditions) from the calculated values. This procedure is most accurate for a good stand of pure alfalfa with healthy growth.

Table 7. Predictive Equation of Alfalfa Quality (PEAQ).

Height of tallest stem (from soil surface to stem tip)	Stage of Most Mature Stem		
	LATE VEGETATIVE Vegetative (<12") No buds visible.	BUD STAGE 1 or more nodes with visible buds. No flowers visible.	FLOWER STAGE 1 or more nodes with open flower(s).
16	237	225	210
17	230	218	204
18	224	212	198
19	217	207	193
20	211	201	188
21	205	196	183
22	200	190	178
23	195	185	174
24	190	181	170
25	185	176	166
26	180	172	162
27	175	168	158
28	171	164	154
29	167	160	151
30	163	156	147
31	159	152	144
32	155	149	140
33	152	145	137
34	148	142	134
35	145	139	131
36	142	136	128
37	138	133	126
38	135	130	123
39	132	127	121
40	129	124	118
41	127	122	115
42	124	119	113

The PEAQ system for estimating alfalfa quality in the field was developed by agronomists at the University of Wisconsin - Madison.

Table 6. Alfalfa growth stages.

Maturity Value	Description
Late vegetative (L)	Stem length >12 inches
Bud stage (B)	1 or more nodes with visible buds. No flowers visible.
Flower stage (F)	1 or more nodes with open flower(s).

Keep in mind: To target 150 RFV alfalfa in storage, start cutting at 170 RFV to compensate for harvesting losses, which can account for 10 percent to 15 percent reduction in quality from respiration and leaf loss.

PEAQ Log Sheet

Date	Field Identification	Plant Height	Maturity Value	Est. RFV	Comments
5/23	North 80	29	B	160	example entry

Formulas Used in Forage Analysis Reports

Various laboratories may use different formulas for reporting calculated values for forages. Some of the more common ones are shown.

Note that because the same formulas are not used by all laboratories, comparing the values from one laboratory with those of another may not be possible.

1. **Estimating Percent Digestible Protein (DP):**

   Corn silage: % DP = (% crude protein x 0.908) – 3.77
   or
   = crude protein x 0.70

   Alfalfa: % DP = % crude protein – 4.4
   or
   = % crude protein x 0.72

2. **Estimating Percent TDN:**

   Legumes and grasses: = 88.9 – (0.79 x ADF%)

   Corn silage: = 87.84 – (0.70 x ADF%)

3. **Estimating Net Energy-Lactation, Mcal/lb:**

   Alfalfa: = 1.044 – (ADF% x 0.0123)

   Grasses: = 1.50 – (ADF% x 0.0267)

   Alfalfa – grass mixtures: = 1.044 – (ADF% x 0.0131)
   or
   = (TDN% x 0.1114) - 0.054

4. **Estimating Percent Digestible Dry Matter (DDM):**

   % DDM = 88.9 – (ADF% x 0.779)

5. **Estimating Dry-matter Intake as a Percent of Body Weight (DMI):**

   % DMI = 120 ÷ % NDF

6. **Relative Feed Value (RFV):**

   RFV = (%DDM *[from No. 4 above]* x %DMI *[from No. 5 above]*) ÷ 1.29

7. **Relative Feed Quality (RFQ):**

   RFQ = (TDN *[from No. 2 above]* x DMI *[from No. 5 above]*) ÷ 1.23

References

In addition to sources cited, materials were adapted with permission from Pioneer Forage Manual, which no longer is in print.

Replaces AS991, "Know Your Forages"

This publication was authored by J.W. Schroeder, former dairy specialist, NDSU, 2006.

For more information on this and other topics, see www.ndsu.edu/extension

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