

Forage Terminology

Plant Structure

Forages or roughages are difficult feeds to define. Some have described forages as bulky feeds that have relatively low digestibility. Such a definition, however, has major exceptions. Corn silage is definitely a forage, but can be over 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 (Fig. 1). 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 used 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 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 species with similar digestive tracts have very limited ability to digest plant cell wall compounds. This is unfortunate, as cellulose is one of the most abundant materials on earth. Forage eaters, however, have bacteria and other microbial populations in their digestive tracts that can partially digest these compounds into usable nutrients. Animals that have the ability to use forages as the primary portion of their diet do not have the enzymes necessary to digest the cellulose and hemicellulose compounds found in forage. They must rely on the microbial populations within their digestive system.

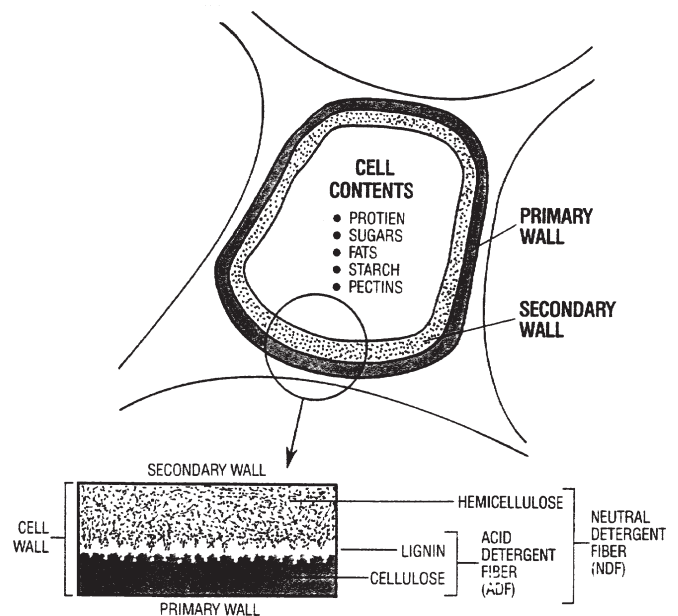


Fig. 1. Diagram of a plant cell showing wall structure.

With advancing growth and maturity, forage cells insert a non-carbohydrate 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 non-digestible substance and its presence will inhibit the availability of 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

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the brick wall, but also lacking mortar. The brick and block could both be broken down by the microbial populations within 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 and digest.

Types of Forage Evaluation

Visual Appraisal

Forages are often evaluated by sight, smell, and feel. While there are definite limitations for measuring quality with visual appraisal, it is an important tool in helping to evaluate forages. Color, leaf content, stem texture, maturity, contamination from weeds, molds or soil, and observations on palatability are examples of useful visual determinations. Visual inspections are important because they can identify problems in the forage that may not be determined by standard forage analysis.

While being an excellent and necessary “first line” forage evaluation tool, visual appraisal does not give adequate nutritional information for the producer who is trying to feed the most-efficient, least-cost ration possible. Visual appraisal should be used in conjunction with some other forage analysis.

Conventional Chemical “Wet Chemistry” Analysis

Traditional laboratory methods involve various chemical, drying, and burning procedures to determine the major chemical components within the forage. This is the older, well established method of forage analysis. Wet chemistry procedures are presently the most widely used for forage evaluation in this country. They 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. The forage analysis can only be as good as the sampling, handling, and analytical procedures used.

Proximate Analysis

For over 100 years, the proximate analysis system was used to evaluate forages and other feedstuffs. This wet chemistry set of procedures, done in its entirety, 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 (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 energy (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 dry matter and percent crude protein. Ash (total mineral content) and ether extract are not commonly determined in a typical forage analysis. The original crude fiber analysis has been largely replaced with the newer detergent analysis. Some tests still use crude fiber or modified crude fiber as a way of evaluating the fiber content of forages, so crude fiber values are still commonly reported in feed tables.

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. It would be impossible to compare different forages without using the percent dry matter as a base line. Dry matter is also very important as the moisture content will give clues as to how a forage will preserve when stored by baling or fermentation.

Protein Analysis

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

When a laboratory uses wet chemistry, crude protein will most likely be measured by the standard Kjeldahl procedure. This measures total nitrogen which is then multiplied by 6.25 to arrive at the crude protein value for the forage. The 6.25 figure is used because most forages have about 16 percent nitrogen in the protein (100 divided by 16 = 6.25). The crude protein value includes both true protein and non-protein nitrogen compounds. True plant protein is roughly 70 percent of the protein in fresh forages, 60 percent of the total in hay forage, and lower 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.

There is always a portion of the crude protein in forages that is unavailable but that percentage will increase if heating has occurred. If the bound or insoluble protein is greater than 12 percent of the crude protein, there has been enough heating to reduce protein digestibility. If the bound protein is over 15 percent, there has been extensive heating 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.

The steps used to calculate the percentage of bound protein and 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 divided by 17.68 = 13.35%

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

2. Calculate % ACP.

$$\% \text{ ACP} = \frac{\text{CP}\% \times [100 - (\% \text{ bound} - 12\%)]}{100}$$

$$\% \text{ ACP} = \frac{17.68 \times [100 - (13.35 - 12)]}{100} = 17.44$$

Note the ACP value in this case is lower than crude protein, 17.68, because the bound protein value was 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 (e.g., ADIN = 0.29% (dry basis). Bound crude protein would be: 0.29 x 6.25 = 1.81%). Some laboratories report percent ACP as crude protein minus bound protein. Technically, this is incorrect as it does not account for the normal amount of bound protein in the forage.

Crude Fiber Analysis

Crude fiber determination was the primary analytical procedure used to analyze forage samples for 40 years.

The crude fiber analysis uses alkali and acid treatments to isolate the cell wall residue (crude fiber) that represents undigestible portions of the forage. It was later learned, however, 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 is still used in portions of the country to evaluate alfalfa.

Detergent or Van Soest Method of Cell Wall Determination

A newer wet chemistry method for evaluating the cell wall content of forages was developed in the 1960s by Peter Van Soest at the USDA Beltsville Nutritional Research Facility (Table 1). This system was developed because it was determined the crude fiber system did not differentiate the components of the cell wall well enough to generate accurate energy estimates over a wide range of forage species and maturities. The crude fiber system was criticized for often underestimating good quality forages and overestimating poor quality forages. Fig. 2 shows how the crude fiber and the newer detergent systems fractionate forages.

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

Fraction	Components included	Nutritional availability	
		Ruminant	Non-ruminant
Cell contents	Sugars, starch, pectin	Complete	Complete
	Soluble carbohydrates	Complete	Complete
	Protein, non-protein 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, J. Animal Science, 26:119.

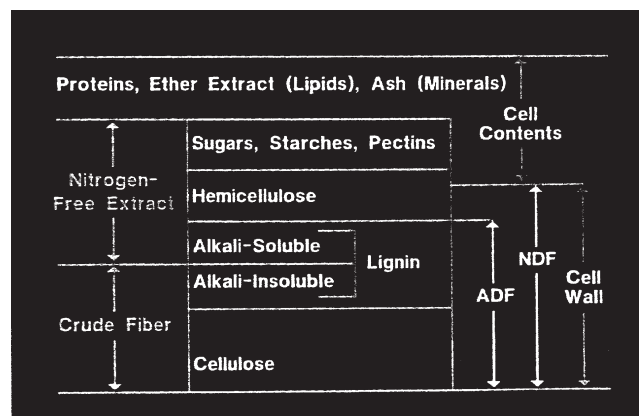


Fig. 2. Forage analysis showing nitrogen-free extract and crude fiber vs. Van Soest (ADF and NDF).

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

Forage	Percent, dry matter basis				
	Cell contents	NDF	ADF	CF	Lignin
Alfalfa					
late vegetative	60	40	29	22	7
early bloom	58	42	31	23	8
mid-bloom	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
Coastal bermuda-grass	24	76	38	33	6
Orchardgrass					
mid-bloom	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
mid-bloom	33	67	36	31	5
late bloom	30	70	40	33	7
Corn silage					
stover	32	68	55	31	7
well eared	49	51	28	24	4
few ears	47	53	30	32	5

Key: NDF=neutral detergent fiber, ADF=acid detergent fiber, CF=crude fiber.

Source: United States-Canadian tables of feed composition, third revision. 1982.

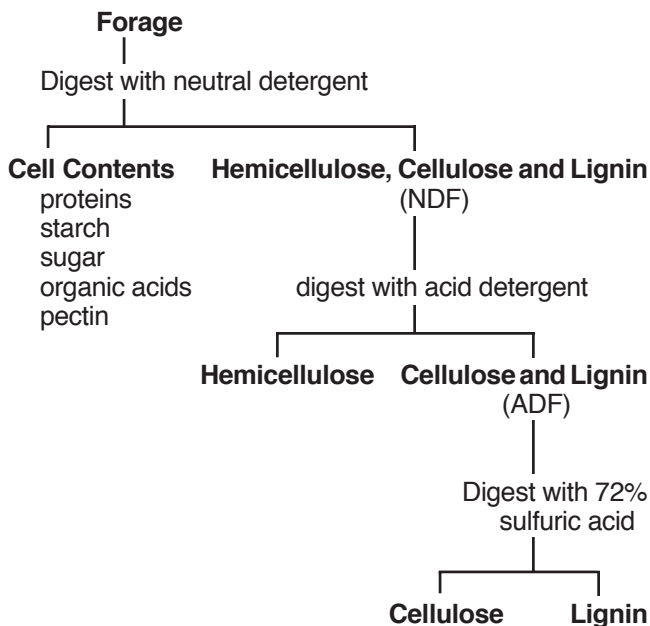


Fig. 3. The detergent (Van Soest) procedure to partition forages.

The Van Soest or detergent system of forage analysis is now 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 is then filtered. The soluble portion contains these highly digestible cell contents:

- Sugars
- Starch
- Pectins
- Lipids
- Soluble carbohydrates
- Protein
- Non-protein nitrogen
- Water soluble vitamins/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 and is commonly referred to as the cell wall fraction (Table 2). Neutral detergent fiber (NDF) has been shown to be negatively correlated with dry matter intake. In other words, as the NDF in forages increases, animals will be able to consume less forage. NDF increases with the advancing maturity of forages. Using NDF, a better prediction of forage intake can be made and, therefore, better rations 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 (Fig. 1). Acid detergent fiber is important because it has been shown to be negatively correlated with how digestible a forage may be when fed. As the ADF increases, the forage becomes less digestible. Acid detergent fiber is sometimes 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.

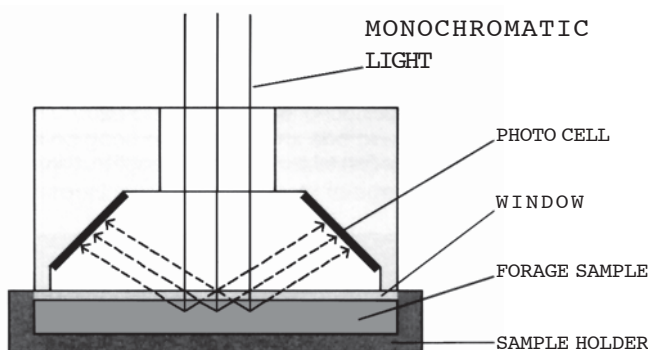
Lignin, the indigestible non-carbohydrate component that decreases cellulose and hemicellulose availability, can be determined by further treatment with a stronger acid. Fig. 3 shows a schematic of the detergent system of a forage analysis.

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 and colorimetric procedures are most commonly used to determine the mineral content of the forage.

Near Infrared Reflectance Spectroscopy (NIRS) Analysis

Near infrared reflectance spectroscopy is a rapid and low-cost computerized method to analyze forage and



Source: University of Minnesota

Fig. 4. Diagram of how NIRS reads a prepared plant sample.

grain crops for their nutritive value. Instead of using chemicals, as in conventional methods, to determine protein, fiber, energy, and mineral content, NIRS uses near-infrared light (Fig. 4).

This newer method of analysis involves the drying and grinding of samples that are then 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. Reflected wavelengths are detected by the eye and signals are sent to the brain to identify the color.

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 (25 times faster than conventional laboratory procedures) and less expensive than wet chemistry methods. Accuracy depends on good sample collection and storage and consistent drying, grinding, and mixing of samples before 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 error.

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. They are, however, commonly used by scientists 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 where small nylon 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.

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 is then digested in an enzyme solution to simulate digestion in the small intestine. Both *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 (Table 3). 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.

$$\text{Apparent dry matter digestibility} = \frac{\text{Dry matter intake} - \text{Dry matter in feces}}{\text{Dry matter intake}} \times 100$$

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

Dry matter feed intake for 14 days = 252 pounds
 Dry matter fecal output in 14 days = 93.5 pounds

$$\text{Apparent dry matter digestibility} = \frac{252 - 93.5}{252} \times 100 = 62.9\%$$

Table 3. Four forages showing total digestible nutrient and net energy values.¹

Forage	% TDN	Net energy, Mcal per pound		
		Maintenance	Gain	Lactation
Coastal bermuda-grass, 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

¹All values on a dry matter basis.

Source: NRC, Nutrient requirements of dairy cattle, 1989.

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

$$\% \text{ TDN} = \% \text{ digestible crude protein} + \% \text{ digestible crude fiber} + \% \text{ digestible starch and sugars} + \% \text{ digestible fats} \times 2.25. \text{ (The fats are multiplied by 2.25 because they contain that much more energy per unit weight.)}$$

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 in 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, 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. It is very common to see the terms net energy-maintenance (NEM), net

energy-gain (NEG) and net energy-lactation (NEL) on laboratory or NIRS forage reports. These terms are commonly used in formulating today's rations. Fig. 5 shows the losses subtracted out to arrive at these energy terms.

The total energy content of a feed can be determined by totally burning the sample and measuring the heat produced to obtain the gross energy value of the feed. It does not, however, 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.

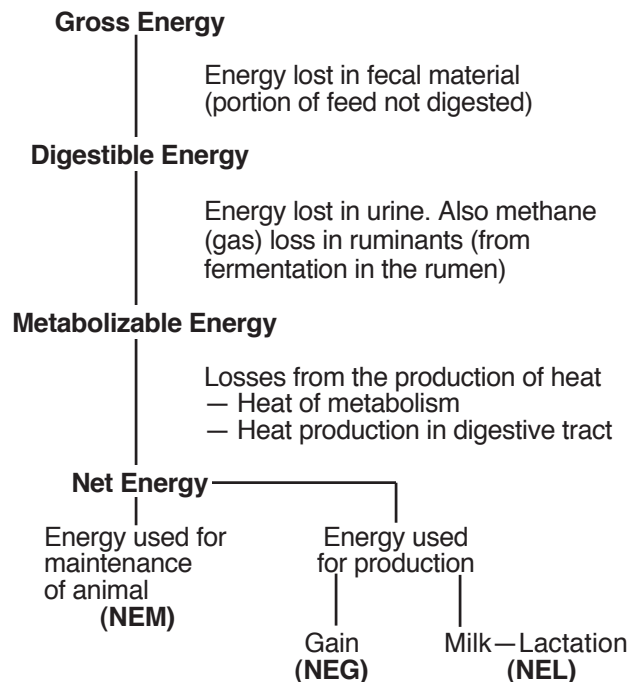


Fig. 5. Energy losses when forages are fed.

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. There are three net energy values for each feed 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. In most dairy formulations, the same value is used for both NEM and NEL.
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, are normally used in ration formulation.

4. Laboratory digestibility and net energy values are not produced from digestion trials or metabolism studies. The feeding value of forages has been shown to be negatively associated 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:

$$\% \text{ DDM} = 88.9 - (0.779 \times \% \text{ ADF})$$

Example:

If % ADF = 31%:

$$\% \text{ DDM} = 88.9 - (0.779 \times 31) = 64.75\%$$

Dry Matter Intake (DMI)

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

$$\text{DMI (as a percent of body weight)} = \frac{120}{\% \text{ NDF}}$$

Example:

NDF value for a forage is 40%: $\text{DMI} = \frac{120}{40} = 3.0\%$ of body wt

Relative Feed Value (RFV)

The dry matter intake potential (DMI) may not be reported as such, but 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.

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

Example:

From the previous examples, DDM = 64.75%

DMI = 3.0%

$$\text{Relative feed value} = \frac{64.75 \times 3.0}{1.29} = 151$$

Relative feed value has no units but 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. 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 to the forage with 53 percent NDF and 41 percent ADF. Note that the forage with a RFV of 100 would not be considered excellent-quality forage. Dairy producers with high producing cows often look for alfalfa with an RFV of 124 or greater (see Table 4).

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. It should be noted that

Table 4. 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
Fescue, late vegetative	12	36	64	88
Fescue, early bloom	10	39	72	76
Orchardgrass				
early vegetative	18	31	55	109
Orchardgrass				
early bloom	15	34	61	95
Sorghum-sudangrass, veg	15	29	55	112
Sorghum-sudangrass, headed	8	40	65	83
Wheat straw	4	54	85	51

Key: CP=crude protein, ADF=acid detergent fiber, NDF=neutral detergent fiber, RFV=relative feed value.

because the same formulas are not used by all laboratories, it may not be possible to compare the values from one laboratory with those of another.

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 .01114) - 0.054

4. Estimating percent digestible dry matter (DDM):

$$\% \text{ DDM} = 88.9 - (\text{ADF \%} \times 0.779)$$

5. Estimating dry matter intake as a percent of body weight (DMI):

$$\% \text{ DMI} = \frac{120}{\% \text{ NDF}}$$

6. Relative feed value (RFV):

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



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