Dairy Goat Nutrition: Feeding for Two
(How to properly feed the goat and her rumen)

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Introduction

Feed costs account for more than 55% of dairy goat production costs. As a result, many producers have become engrossed in reducing costs to feed a goat per day rather than optimizing their feeding efficiency. *The cheapest ration is not usually the most production-efficient ration*. This statement may sound like a contradiction, but relates to the understanding of how the goat and her rumen interact from a nutrient requirement perspective. The dairy goat, like other ruminant animals including the cow and sheep, has a unique digestive tract that allows the animal to consume and utilize fibrous foods which otherwise would be unavailable to nonruminant animals. This ability is the result of a symbiotic (i.e., mutually beneficial) relationship between the goat and billions of microorganisms that inhabit the rumen or pregastric compartment. Bacteria and protozoa that inhabit the rumen have the capability to ferment material, which would be indigestible to the goat alone, and produce end products used to produce high quality products such as meat, milk and mohair. Dairy goat producers need to take full advantage of this goat-rumen interrelationship in order to produce milk most efficiently. In addition, feeding both the goat and rumen properly will result in a healthier animal overall. If you are not taking advantage of the rumen, then you might as well be feeding pigs! The focus of this presentation is to acquaint you with a conceptual approach to nutrient requirements of the dairy goat and her rumen and how they are appropriately met in an effort to produce milk as efficiently as possible.

Applied Rumen Anatomy

The rumen is actually only one chamber of a complex, bacterial fermentation system located before the true digestive stomach compartment. This is in contrast to the bacterial fermentation system located after the stomach as found in horses. Bacterial fermentation is a digestive process where bacteria living in the digestive tract partially breakdown complex dietary ingredients to produce end products, which can be used by the host animal to meet its nutrient needs. We may be more familiar with bacterial fermentation as the process by which beer and wine are produced. In addition to fermentation end products, the host animal obtains most of its dietary protein needs from the digestion of bacteria growing in its digestive tract. This bacterial digestion occurs only in ruminant animals since the fermentation process comes before the stomach.

The reticulum is a smaller fermentation compartment, in front of and intimately associated with the ruminal compartment. The reticulum is primarily responsible for assisting in rumination contractions and distributing feed within the reticulo-rumen. The rumen is the primary fermentation vat, being between 5 to 10 gallons in volume in a mature goat. Muscular contractions aid in the constant mixing of feed materials with bacteria laden fluids to promote fermentation and in regurgitation of feed materials, which results in particle size reduction from chewing and copious amounts of saliva production. Bicarbonate in saliva is primarily responsible for maintaining only a slightly acid pH in the rumen, given the tremendous amount of acids being produced during fermentation. Also as a result of the continuous fermentation process, rumen temperature is slightly greater than the goat's and can contribute to helping maintain normal body temperature during cold weather or making the goat more uncomfortable during hot weather. The rumen has a specialized lining that contains many finger-like projections called papillae, which absorb end products of fermentation, volatile fatty acids (VFAs). These VFAs, namely acetate, propionate, and butyrate, are available to the goat to be used for production of glucose (propionate), fat (acetate, butyrate) or oxidized for energy. This rumen lining can be easily damaged by severe or prolonged declines in rumen pH, a result of excessive grain or insufficient fiber feeding.

When the rumen is appropriately fed, it will contain a small gas cap, middle fibrous mat layer, and a lower liquid layer. The gas cap consists of carbon dioxide and methane, both end products of fermentation and prevent exposure of bacteria to oxygen. The fibrous mat layer is composed of long dietary fiber material that helps stimulate rumination and ruminal contractions. Dietary fiber of sufficient length (> 1 inch) to form the mat layer is termed effective fiber. The tremendous number of bacteria found in the rumen are distributed within the fibrous mat and liquid layers. Besides the type of raw material the microorganism requires for metabolism, reproductive rate also determines where the organism will be found in the rumen. Bacteria and protozoa that do not reproduce quickly in relation to rate of passage through the rumen must attach to fibrous material if they are to remain in the rumen. When effective fiber is not adequately provided, these microorganisms will be wiped out of the rumen and will result in abnormal fermentations and potentially digestive upsets and off-feed situations.

The third ruminal chamber is the omasum, which is approximately the size of a volleyball and located on the right side of the goat. The omasum is responsible for regulating particle passage rate from the rumen and water absorption from ingesta. Under normal rumen conditions, particles greater than 2 mm in size do not leave the rumen. Very little other information is known about this organ. When large fiber particles or whole corn kernels are found in the manure, this is a good indication of improper rumen function and should be evaluated. The abomasum, or fourth rumen chamber, is similar to our own stomach. Digestive enzymes and hydrochloric acid are secreted which initiate breakdown of complex proteins and starches for further digestion in the small intestine.

Rumen Microbiology

Over 150 different species of microorganisms have been identified in the rumen. These organisms range from bacteria, the most abundant, to protozoa, fungi, and viruses. Although there is a wide variety of bacteria found in the rumen, they can be loosely grouped into five major categories (Table 1). A basic understanding of nutrient and environmental requirements of these different microbial groups is necessary to fully appreciate how feeding programs may impact on rumen health. Substrates, nutrient requirements, fermentation end products, and pH tolerance are shown for these different microbial groups (Table 1). One important concept to glean from this table is the observation that fiber fermentation (i.e., the bacterial breakdown of plant cell wall) occurs only at higher pH levels.

A healthy rumen is one that has a balanced interaction between all the special groups of bacteria. In abnormal rumen environments, usually one group of bacteria has overwhelmed all other groups and dominates fermentation activity. For example, rumen acidosis is the result of feeding too much grain (sugars and starches), which allows the starch digesters to overwhelm the rumen environment and eliminate fiber fermentation. Reduced dietary amounts of either effective or total fiber reduces rumination activity and salivary buffering resulting in acidic conditions impeding fiber fermentation. In addition, with loss of the rumen mat, fiber fermenting bacteria will be washed out of the rumen. This is the crux of the problem in dairy goat feeding, providing sufficient grain to support milk production without excessive amounts which suppress fiber fermentation, milk fat test, and rumen activity.

Nutrient Requirements: Goat and Rumen

All living organisms require essential nutrients to support their metabolic processes, which keeps them alive. General classification of required nutrients include: water, the most essential, energy, protein, minerals, and vitamins. Minerals can be further subdivided into macrominerals and microminerals based on the daily amounts required. Vitamins are separated into fat or water soluble sources. Daily amounts of these essential nutrients required are based on the physiologic state of the doe (e.g., maintenance, growth, lactation, pregnancy) and environmental conditions. Bacteria have similar requirements for maintenance and growth (i.e., reproduction).

Table 1. Characteristics of the different categories of microorganisms found in an anaerobic fermentation system.[1]

Class of Organism	Primary Substrate	Specific Requirements	Primary Endproduct	pH Tolerance
Fiber Fermenting Bacteria	Cellulose, Hemicellulose, Pectins	Ammonia Iso-acids Cofactors	Acetate Succinate Formate, CO_2	Neutral 6.2-6.8
General Purpose Bacteria	Cellulose Starch	Ammonia Amino Acids	Propionate, Succinate, Butyrate Ammonia	Acid 5.5-6.6
Nonstructural CHO Bacteria	Starch Sugars	Amino Acids Ammonia	Propionate Lactate Butyrate Ammonia	Acid 5.0-6.6
Secondary Feeders	Succinate, Lactate Fermentation Endproducts	Amino Acids	Ammonia Iso-acids Propionate	Neutral 6.2-6.8
Protozoa	Sugars, Starch Bacteria	Amino Acids	Acetate Propionate Ammonia	Neutral 6.2-6.8
Methane Producing Bacteria	CO_2, H_2 Formate	Coenzyme M Ammonia	Methane	Neutral 6.2-6.8

[1]Adapted from Chase, L.E. and C.J. Sniffen, Cornell University.

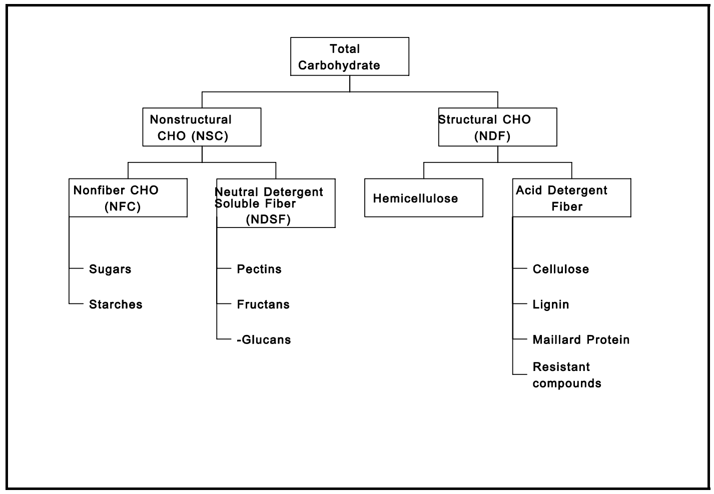
Differences between the dairy goat and microbes are seen in where they derive their nutrients (Table 2). The dairy goat derives a majority of her energy and protein from microbial end products or the microbes themselves. Bacteria contain approximately 60% protein, which is of high quality and digestibility. In other words, the more we make the bugs grow in the rumen system, the less additional more expensive feedstuffs we need to provide the doe. Microbial protein production alone can support up to 50 lbs of milk production in the dairy cow. The first goal of a dairy goat feeding program should be to maximize microbial protein production and then secondly, meet additional nutrient requirements over-and-above those not met by microbial fermentation end products. This type of feeding approach would theoretically be the most economical and efficient.

Bacteria require a number of essential nutrients for the synthesis of protein, similar to that of the doe. However unlike the doe, bacteria can use a greater variety of potential nitrogen sources to synthesize amino acids, the building blocks of proteins. In addition, bacteria can synthesize both essential and nonessential amino acids unlike the doe, which needs to be supplied with preformed essential amino acids. Figure 1 presents an overview of the processes required to synthesize microbial protein.

Microbial protein production is a function of dietary ingredients, which can be broken down (i.e., degraded or fermented) in the rumen by the microbes. If any of the required building blocks are in limited supply, microbial protein production will be determined by the availability of the most limiting substrate. In many goat rations based on low quality forages, energy (ATP) and protein are in limited supply. Ammonia (NH_3) may be provided from nonprotein nitrogen sources, amino acids, peptides, or proteins where utilization
of a nitrogen source is dependent upon the specific population of bacteria. For example, fiber fermenting bacteria can only use NH_3 as their nitrogen source. Energy production (generation of ATP) will be dependent **Table 2.** Substances that supply essential nutrient needs for the dairy goat and rumen microbial population.

NUTRIENT	GOAT	BACTERIA
Energy	VFA's Glucose	Complex Carbohydrates Sugars, Starches, Amino Acids
Protein	Amino Acids Microbial Protein	Ammonia, Amino Acids, Peptides
Minerals	Dietary	Dietary
Vitamins	Dietary Bacterial	Dietary Synthesized

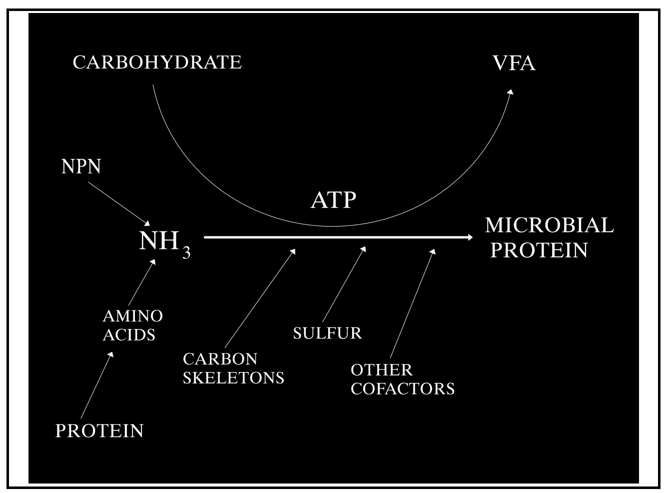
upon the available carbohydrate source (i.e., sugar, starch, or fiber) and its rate of degradation. Plant cell wall material, especially from very mature plants, is very slowly degraded and therefore is a less readily available source of energy in the rumen.



Microbial protein production is more complex than just providing the necessary amounts of substrate in the diet. The rumen is a dynamic system that constantly has fermentation end products, liquid, bacteria, and particles being removed and new substrate added. So not only do we need to address concepts of substrate requirements, availability of substrate relative to other substrates needs to be addressed as well.

Applied Feed Analysis

Microbial protein can only be synthesized when all necessary substrates are available in the rumen in a synchronized manner. Both energy (ATP) and nitrogen, the critical substrates, need to be available at the same relative time and in appropriate amounts to allow for maximal utilization of dietary ingredients and maximize protein synthesis. This process is essential to the efficiency and dietary adaptability of the ruminant organism. Remember, the bulk of dietary protein digested in the gastric stomach of the ruminant animal is of bacterial origin.



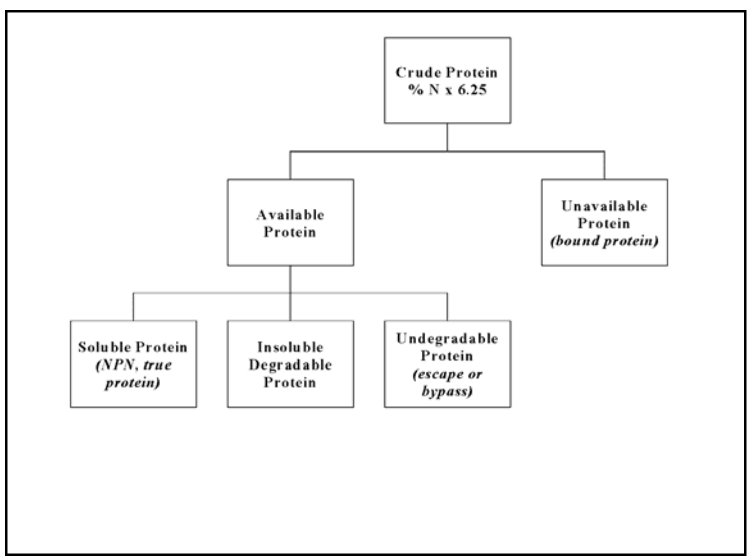
Plant carbohydrates are separated on the basis of their association to the plant cell wall (Figure 2). Carbohydrates that make up the cell wall are termed structural carbohydrates and are slowly fermented, if at all. Therefore, energy (ATP) yield from these sources would be minimal and slow compared to nonstructural carbohydrates. Nonstructural carbohydrates (NSC) are those compounds not associated with the cell wall, with the exception of pectin. These carbohydrates are primarily sugars and starches and are very rapidly fermented to acids. In contrast to structural carbohydrates, nonstructural carbohydrates can rapidly provide large amounts of energy for microbial protein production. However, fermentation of nonstructural carbohydrates also results in lactic acid production, which if excessive can have detrimental effects on rumen fermentation.

A variety of factors, which may or may not be under our control, can influence both rate and degree of bacterial breakdown of carbohydrates. As a plant matures, there is an increase in the lignin content of cell wall material making it less available. Degree of lignification and distribution of lignin within the cell wall will affect rate of digestion of plant carbohydrates. How a plant grows based on rainfall, soil temperature, fertility, cloud cover, location, and cutting strategies all can influence availability of carbohydrates within the plant. Particle size reduction (grinding) increases surface area for bacterial attachment and breakdown and is very beneficial in increasing cell wall digestion. Steam, extrusion, and popping will alter starch configuration to make it more available. Fermentation (ensiling) will make lesser available carbohydrates more available. As particles pass through the rumen faster, less time is available for bacterial attachment and degradation. Rate of passage is directly related to dry matter intake and will have an impact on extent of digestion of slower degraded carbohydrates and proteins.

Dietary crude protein is also separated into fractions on the basis of rumen degradability and solubility (Figure 3). Proteins that are rumen degradable would be able to provide nitrogen for microbial protein production. Rumen solubility suggests that the protein source would be more rapidly available. For example urea, a nonprotein nitrogen source, is 100% soluble and degradable and therefore would very rapidly provide ammonia for microbial protein production. In meeting our goal of maximum microbial protein production, we also need to match rates of degradation of carbohydrate and protein sources to make rumen energy and nitrogen available in somewhat equivalent amounts for most efficient microbial protein yield and overall dietary protein incorporation. If we can reduce the amount of protein used in the ration and yet maintain or improve milk yield, the goat becomes much more efficient and <u>profitable</u>!

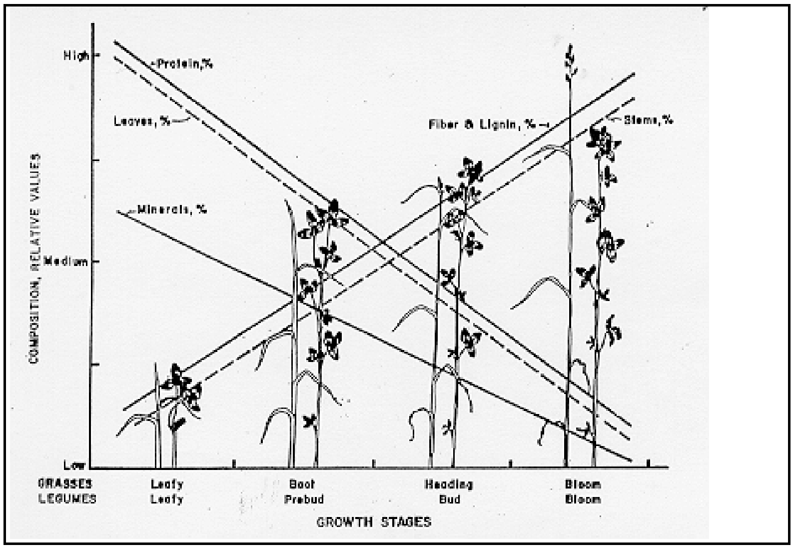
When putting together a goat feeding program, we need to address many of these factors in attempting to make sure that rumen availability of energy and nitrogen are coordinated in order to achieve maximal microbial protein production. We need to blend energy and nitrogen sources with similar rumen availability properties to ensure equal availability. If we maintain maximal microbial protein synthesis, not only will the amount of additional dietary protein be reduced, but the goats will have increased dry matter intake and remain healthier, all contributing to increased milk producing efficiency. When nitrogen and energy sources are not matched, diseases such as grain overload, milk fat depression, or other rumen dysfunctions may occur.

Applied Feed Analysis - Understanding Forage Quality



From the above description, the goat digestive tract is designed to utilize forage materials. Goats require a wide variety of nutrients, including energy, protein, minerals and vitamins, to support bodily functions. Feeds are not equal in their ability to support animal functions of maintenance, growth, reproduction and lactation. Feed nutritive value is a function of the availability of energy and essential nutrients in support of animal performance. Three components of nutritive value are: 1. <u>Digestibility</u> - ability of the animal to break down the feed in the digestive tract; 2. <u>Intake</u> - how much of the feed the animal is able to consume, limited by fiber content as well as other factors; and 3. <u>Energetic efficiency</u> - ability of the animal to obtain energy from the feed that can be used for production/maintenance purposes. How well a particular forage meets these nutrient needs will determine the amount and composition of supplements, if necessary, to meet the goat's nutrient needs. High quality forages will require minimal supplementation compared to poor quality forages.

Forages, whether hay, silage, or pasture, have always provided the foundation of the goat ration. However, forage quality varies tremendously. A multitude of factors can influence forage quality including: plant species, plant maturity, environmental conditions, fertilization, water availability, time of cutting, and storage practices. As a result, hay from the same farm and field can vary significantly within a year and between years. You can not assume that since you buy your hay from the same person year after year that it is the same quality forage each time! Unfortunately, hay quality does not necessarily direct the price. Often good and poor quality hays are sold for the same price, especially in years where hay production was limited. Your feed dollar is best spent on good quality hay. Factors that affect forage or feed ingredient quality include the following:



1. Plant species - legume hay generally higher in protein (16-20%), energy (NE_l = .63 Mcal/lb) and minerals (1-2% Ca) than grass hays (8-13% protein, NE_l = .49 Mcal/lb, .3-.75% Ca)

    a. Leaf-to-Stem Ratio - since leaves contain more energy and protein than stems, good leafy hay of any type is desired.
    b. Reserve substances - seeds and plant starches, highly available and digestible
    c. Resistant substances - cell wall material and other compounds (lignin, tannins, cutins) that help the plant survive in the environment; poorly digested and reduce feed quality
    d. Nutrient content interrelationships - ratios between energy, protein, fiber in the feed relative to specific nutrient requirements.

2. Stages of maturity/date of cutting. Plant maturity is the single most important factor that determines forage quality. The later the date of harvest, the lower the protein and energy content of both legume and grass hays, but the higher the dry matter content (Figure 4). Best time to harvest varies but end of budding to early bloom stage is a good rule for most species.

3. Environmental Effects - environmental temperature and daylight are the two most important factors influencing plant growth. Sunlight increases digestible carbohydrate content of the plant, while temperature increases plant cell wall formation and lignification. The interaction between temperature and daylight can explain the differences from cutting to cutting.

4. Methods of Processing - a variety of methods can be used to increase the availability and digestibility of a feed source. Fiber sources are usually ground and pelleted to increase

intake. Cereal grains are ground, flaked, popped, steam-flaked or other cooking procedure to increase the digestibility of the starch in the grain.

5. Storage practices - exposure of feed ingredients, especially forages, to moisture and oxidation (light, minerals) will result in a variable rate (3 to 40%) of nutrient loss. Most of these loses are highly available carbohydrates resulting in dramatic decreases in feed digestibility.

Forages are necessary to provide sufficient effective fiber to maintain rumen function and health. However, with ever increasing levels of milk production, fiber becomes a serious limitation to meeting energy needs. Feeding more grain to compensate for poor quality forages is not a feasible solution. How do we determine quality of forage? This can be accomplished primarily through chemical analysis of the forage and sensory inspection. Sensory inspection can be helpful in distinguishing between poor and high quality forages but, it can not predict nutrient content. Chemical or nutrient analysis is the best method to estimate forage quality.

Sensory Evaluation of Forages

1. Stage of Maturity refers to the growth stage of the plant at the time of harvesting. As with all living things, specific changes occur with aging. As a plant becomes more mature the cell wall portion increases (Table 3). All other nutrients will decrease with the increase in cell wall. Many nutrients can become unavailable as a result of being bound to the cell wall. More mature plants will have larger and thicker stems and either seed heads or blooms.

2. Leafiness is an important factor in evaluating hay since most of the digestible nutrients, especially protein, reside in the leaf. As the plant matures the leaf-to-stem ratio will decline. If the plant is not cured and handled properly many leaves will be lost due to leaf shatter. This is especially important in alfalfa hays.

3. Color of forage can indicate when the plant was cut and how well it was cured and stored. Bright green color indicates high vitamin A content and generally high quality. Yellowing color to the hay may indicate excessive sun curing, overly mature forage or both. Brown to black discoloration usually indicates heating from fermentation and moisture damage. These forages have the highest potential for molding and are unacceptable feeds. Silages may be a yellow color or funny greenish color as a result of abnormal fermentations.

Table 3. Typical test values of alfalfa and grass hays harvested at various stages.

Type of Hay	Crude Protein	ADF	NDF	Digestible Energy
	%	%	%	Mcal/lb
Alfalfa				
Pre-bloom	> 19	< 30	< 35	1.25
Early bloom	17-19	30-35	35-39	1.13

Mid bloom	13-16	36-41	41-47	1.03
Late bloom	< 13	> 41	> 48	0.98
Grass				
Prehead	>17	< 29	< 55	1.08
Early head	12-17	30-35	56-61	0.94
Head	8-12	36-44	60-65	0.88
Post-head	< 8	> 45	> 65	0.82

4. Odor of good quality hay should be similar to new-mown grass. Hay should not have a musty, mildew or rotten smell. Silages that smell like vinegar, ethanol, or rancid butter all have abnormal fermentations, which can result in depressed feed intake. Heat-damaged feeds will smell like tobacco, caramelized, or burned.

5. Foreign Material is anything which does not belong in hay. Harmless foreign material would include certain weeds, other plants, sticks or dirt. Other materials that could harm the goat can also be found in forages. These materials may include poisonous plants, awns, metal objects, insects and molds. Good quality forage should be free of foreign material.

Feed Nutrient Analysis

A forage or any other feed can be analyzed for it's nutrient content by two methods: wet chemistry or near infrared spectroscopy (NIR). A wide variety of tests can be completed by most forage testing service labs. The most common tests run are listed and detailed below:

1. Dry Matter Content is determined by heating a weighed sample of the feed in a drying oven until a constant weight and is expressed as a percentage of weight of the wet sample. Example: a forage which contains 10% water has a dry matter content of 90%. Hay and other dried feeds should contain less than 15% moisture, otherwise they are prone to molding. Silages will vary from 70% to 50% moisture. Pasture may contain anywhere from <15% to 25% moisture.

2. Crude protein is determined by measuring the nitrogen content of a sample of the feed and multiplying by 6.25 (assumes all nitrogen in the sample is protein nitrogen and that protein is approximately 16% nitrogen). Protein content of a forage will depend upon the plant species. Protein content from lowest to highest for common forages would be: corn silage (7-9%), grass (8-14%), and alfalfa (15-22%).

3. Fiber analysis is a measure of the plant cell wall and other less digestible or fermentable components of the plant. The original measure of fiber is Crude Fiber (CF). However, crude fiber does not define the total cell wall fraction (indigestible or slowly digestible material) of feedstuffs very well. This results in overestimation of the energy values for forages in comparison to concentrates. As a result, a newer procedure to determine cell wall content was developed.

    a. Neutral Detergent Fiber (NDF) contains hemicellulose, cellulose and lignin, which better represents the total cell wall portion of the plant. NDF content of a plant has been associated with intake. The higher the NDF the more mature and lower quality the plant (Table 3).

b. Acid Detergent Fiber (ADF) contains cellulose and lignin. The difference between CF and ADF is that the ADF fraction more closely estimates the poorly digestible carbohydrate fraction than does CF, which excludes some poorly digestible components. Low quality forages have higher ADF values (Table 3).

4. Minerals - both macromineral (e.g., calcium, phosphorus, magnesium, potassium, sodium and sulfur) and micromineral (e.g., iron, copper, zinc, manganese and molybdenum) content can be determined. Mineral analysis is not always done since it is the most expensive test. Mineral content of forages will depend upon plant species, soil conditions and fertilization practices and are very variable.

5. Energy is derived from carbohydrate, fat and protein. Energy content of a feed (i.e., digestible energy, total digestible nutrients [TDN]) is not directly measured like other nutrients but, derived through regression equations. ADF and CP values are used to predict energy value. Most labs report energy values based on cattle equations, which are reasonably close estimates for goats.

The cost of nutrient analysis is variable with a range from $12 for limited information up to $65 for a more extensive report. As with hay prices, a high cost does not necessarily mean a high quality report. NIR analyses are potentially more fraught with error, especially with minerals, compared to wet chemistry. However, wet chemistry is usually more expensive. One needs to contact a number of labs and ask questions concerning methods used, quality control validation, retesting procedures and costs. With an analysis of the feed, one can better address the nutritional needs of the rumen and goat to minimize health problems and maximize milk production.

Summary

Mother nature has developed an exquisitely orchestrated interrelationship between doe and rumen bacteria. This relationship allows the doe to utilize feed materials which she could not have used without the aid of the rumen bacteria. In our agricultural production systems we should be taking full advantage of this system rather than trying to work against it or attempt to ignore the rumen and its function. Our feeding programs should be formulated to address daily nutrient needs for both doe and rumen in order to maximize milk yield for minimal total feed costs and maintain animal health and longevity, thus making milk production more efficient. When evaluating your feeding program be thinking in terms of whether or not you are adequately addressing rumen function and fermentation rates of carbohydrate and protein sources. Are carbohydrate and protein sources appropriately balanced to maximize microbial protein production? Make the rumen bugs work for you and watch the milk flow!