Feed analyses for small ruminants

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Abstract

The objective of this presentation is to provide the veterinary practitioner working with small ruminant species a practical understanding of feed-testing procedures and their interpretation. Forage is the cornerstone of the small ruminant diet, and quality of forage will have tremendous impact on animal health and performance. Many small ruminant owners do not utilize feed-testing services for many reasons, but often due to their inability to interpret and apply the information to their feeding program. Veterinarians are well-suited to provide this service to small ruminant clients as critical assessment of the feeding program provides insight to diagnostics of animal or flock health concerns and productive performance. Although many current feed-testing procedures were developed for cattle, most measures can be directly applied to small ruminant nutrition, while others can be interpreted with some extrapolation. Determinations of dry matter, crude protein, neutral and acid detergent fiber, as well as the minerals, are all beneficial in evaluating forage quality and dietary appropriateness. Veterinarians well-versed in interpreting feed analysis testing reports can provide an essential service to their small ruminant clients.

Key words: sheep, goats, nutrition, feed analysis

Résumé

L'objectif de cette présentation est de fournir le vétérinaire travaillant avec de petits ruminants une compréhension pratique des procédures d'essais d'alimentation et leur interprétation. Le fourrage est la pierre angulaire de la diète des petits ruminants, et la qualité du brout aura des répercussions considérables sur la santé des animaux et la performance. De nombreux propriétaires de petits ruminants n'utilisent pas les services d'essais d'alimentation pour de nombreuses raisons, mais souvent en raison de leur incapacité à interpréter et appliquer l'information à leur programme d'alimentation. Les vétérinaires sont bien adaptées pour fournir ce service pour les clients des petits ruminants comme l'évaluation critique des le programme de l'alimentation fournit la perspicacité pour les diagnostics de l'animal ou de troupeau les préoccupations en matière de santé et de productivité. Bien que de nombreuses procédures d'évaluation des flux actuels ont été mis au point pour le bétail, la plupart des mesures peuvent être appliquées directement à petite nutrition ruminant, tandis que d'autres peuvent être interprétées avec une certaine extrapolation. Déterminations de la matière sèche, la teneur en protéines brutes, fibre au détergent acide et neutre, ainsi que les minéraux, sont toutes bénéfiques dans l'évaluation de la qualité du fourrage et dietary pertinence. Les vétérinaires connaissent bien interpréter les rapports d'essais d'analyse d'alimentation peut fournir un service essentiel à leurs clients des petits ruminants.

Introduction

Feed costs account for 50 to 80% of production costs for confinement-based small ruminant feeding systems.[2] Forage quality is the foundation of a productively efficient ration and meeting the nutrient needs of the rumen microbial population and host animal.[1] Most small ruminant producers assess forage quality qualitatively through organoleptic parameters of color, smell, and visual and tactile estimation of maturity (leaf-to-stem ratio; rigidity of stems).[1] Use of forage testing through time-tested chemical parameters is rarely used for a variety of reasons, including costs, frequent purchasing of hay, and a lack of interpretation abilities. Veterinary practitioners, even if they are not interested in performing nutritional formulations, should be familiar with interpretation of these parameters relative to feed quality and potential role in animal health and production problem situations. The objectives of this presentation are to describe key laboratory analysis parameters important to evaluating forage or feed quality issues and provide a diagnostic framework for their interpretation.

Analytical Methods

Standardized chemical methods of feed analysis were developed more than 150 years ago. The proximate analysis system that includes crude protein (CP), crude fiber (CF), ether extract (EE), and ash has been in use for more than 100 years.[1] However, this system is not adequate in characterizing feed composition relative to rumen fermentation and cow needs.[4,5,9] Newer chemical and biological methods of feed analysis that best relate to nutritional function have been developed over the past 40 years and continue to be developed. A primary difference between the proximate analysis procedures and currently used Van Soest detergent system is in the fractionation of feed carbohydrates (CHO).[9,13] This has greatly improved our ability to separate slowly fermented structural CHO from more readily digested or fermented nonstructural CHO, independent of their physical location in the plant. Newer methods are better at characterizing the digestible CHO content as detailed below. The gold standard for testing procedures utilizes wet chemistry methodologies. Use of near infrared spectroscopy (NIR) analytical techniques

has greatly improved and many laboratories provide this lower-cost service, which may be more amendable to small ruminant clients. Remember that NIR methods remain inappropriate for measuring mineral content of feeds.[3,10]

Although many analytical methods are standardized, there is still potential for laboratory differences and intra-laboratory variation. One should consider using a single laboratory and one that is certified by the National Forage Testing Association (NFTA). This organization has a searchable list of certified laboratories on their website (www.foragetesting.org) and other information on forage probes and sampling techniques.

A number of biologic tests have been added to our feed analysis repertoire; however, selection of a laboratory to perform these tests is even more critical. Most biologic tests use either *in vitro* or *in situ* methodologies, which results in tremendous variation in results across laboratories.[9] This does not mean 1 value is more correct than another; it just suggests you need to understand the methodology used and constraints on interpretation.[4,5] More importantly, values for many of these specialized tests cannot be compared across laboratories. Examples of such procedures include determinations of NDF fermentability (NDFD), starch fermentability, and protein degradability.[9] Each of these procedures is attempting to determine the extent to which a given feed nutrient (NDF, starch, protein) is available to the rumen system. Inherently the underlying premise for these tests is faulty, as there is no 1 value. Rumen degradability is a function of passage rate through the rumen and degradation rate of the compound.[9] Passage rate is highly influenced by environmental, nutritional, digestive and physiologic factors, resulting in a variable rate of rumen availability.[13] Test results are sensitive to incubation time, grinding size of sample, inoculant source, and methodology. Another issue is whether or not the parameters for performing these biologic tests is appropriately extrapolated to small ruminants. Most likely this would not be the case, given differences in mastication efficiency and rumen passage rate, but relative differences would be appropriate to interpret relative to animal performance. Other biologic testing becoming more routine includes fermentation analyses of silages, mold counts and identifications, as well as mycotoxin screening.

Moisture - The Elusive Value

Moisture content is a direct measure of feed water content, and surprisingly is the most variable measure of feed quality. Variable results occur with the different methods, but of concern are ensiled feeds where volatile fatty acids are lost, reducing true dry matter (DM) content during the drying process. How a given sample is collected, handled, and processed will impact the final moisture result. The reason moisture is such an important measure is that it determines the amount of dry matter (DM). The nutrient content of a feed must be compared or evaluated on a "dry matter basis" for appropriate interpretation. On a laboratory level, all wet chemistry analyses of nutrient content are completed on "as is" samples and converted to DM using the determined moisture content. If there is a 5 or 10 % error in this value, this will alter the DM basis content of feed components, especially NDF or other larger constituents. On the farm level, if silage moisture is wetter than you believe, you are feeding less DM If it is drier, then you are feeding more DM. These differences may account for intake problems as well as not meeting expected nutrient composition of the total diet.

Moisture content is of concern in dried feeds because as moisture increases above 15%, potential risk for mold growth increases dramatically. This greatly increases a risk for heat generation and spontaneous combustion of hay bales. Moisture content of feeds to be ensiled is critical to successful fermentation. Practitioners should have moisture-testing capabilities for use on the farm (microwave, Koster tester®) to monitor weekly changes in moisture, especially with wet feeds. Excessively wet (<40% moisture with ensiled feeds) diets may limit intake. Excessively wet (<30% DM) or dry silages (>50% DM) may result in inadequate fermentation and unstable products. Excessively wet silages are prone to clostridial fermentation, which generates ammonia from proteolysis resulting in buffering of silage pH. If silage pH exceeds 5.0, there is greater risk for listeria vegetative growth if the silage has soil contamination (nearly always).

Protein Analyses

Feed protein content (termed crude protein (CP)) is determined by the Kjeldahl procedure to determine total nitrogen content, then converted to a CP basis by multiplying by 6.25 (proteins are assumed to contain 16% nitrogen). Forage protein content is a reasonable marker of forage quality, with more immature plants having greater protein content compared to mature plants (Table 1). Excessively high-forage CP (>25% DM) may be determined in lush spring pastures. This higher CP value is most likely the result of significant nitrogen compounds in the growing plant that are not in true protein form. Sufficient dietary protein (>8% DM) is necessary to facilitate microbial fermentation in the rumen and if deficient, reduced dry matter intake will result. From a ruminant animal vantage, CP is a worthless value as it does not provide information relative to rumen availability. Partitioning CP into rumen-soluble, degradable, undegradable, and unavailable fractions is needed to further assess dietary protein sufficiency.

Acid Detergent Insoluble Nitrogen (Protein). The amount of nitrogen (or crude protein; N x 6.25) that is found in the acid detergent fiber residue is defined as ADIN (nitrogen) or ADIP (protein). This represents the nitrogen in a feed bound to the cell wall. This represents heat-damaged protein, which is unavailable to both microbes and the cow. The Maillard reaction causes heat damage by covalently linking nitrogen

from amino acids to sugar residues of the plant cell wall. Moisture and heat are needed to promote this reaction.

Any feed subjected to heating during processing can initiate the Maillard reaction. Heat-treated soybeans, distillers and brewers grains, corn gluten feed and meal among other products should be tested for ADIN if their color ranges from light to dark brown. Some of these products may contain as much as 30% bound protein. Silages are also of concern with bound protein, and all silage analyses should have ADIN determined. Excessive heating during initial fermentation can result in a wide range of ADIN values within silages. Typically, secondary fermentation does not induce further Maillard reaction products. The goal is to have less than 10 to 12% of total CP as bound protein. If ADIN is excessive, then additional protein will need to be added to the diet.

Neutral Detergent Insoluble Nitrogen (Protein) is a measure similar to ADIN, except the Kjeldahl procedure to determine nitrogen content is completed on the NDF fraction of a feed. Nitrogen found in NDF includes that in ADIN in addition to other feed proteins less soluble in neutral detergent or associated with cell wall fiber. These proteins are not all indigestible, similar to ADIN, but are considered more slowly degraded in the rumen. This protein fraction is used by rumen computer models (Cornell Net Carbohydrate and Protein System (CNCPS); Cornell-Penn-Miner (CPM) Program) to estimate rumen undegraded protein fraction. This system was developed in modeling feed digestion and end-product generation for cattle diets. However, this rumen model was adapted by altering rates of passage and rates of digestion to model sheep and goat feeding systems, and is provided in software packages using this modified CNCPS model (Small Ruminant Nutrition System, Texas A&M University or NDS Small Ruminant Program, Italy).

Soluble Protein measures the total nitrogen amount in feed (expressed on percent of CP basis) that is potentially soluble in rumen fluid. Soluble protein contains both non-protein nitrogen (NPN) and true protein compounds. These nitrogen sources are readily used by rumen microbes for microbial protein production and contribute to a rapid increase in the rumen ammonia pool. Fiber-fermenting bacteria are dependent upon the rumen ammonia pool as their sole source of nitrogen for protein synthesis. Utilization efficiency is dependent upon available fermentable carbohydrate in the rumen. Excess soluble protein will be absorbed and detoxified by the liver and excreted as urea, thus increasing blood or milk urea concentrations.

Silages experiencing excessive proteolysis (clostridial fermentations) or have been treated with ammonia or urea will have large amounts of soluble protein (>60%). These silages may be associated with reduced intake and poor bunk stability. A goal for ensiled feeds is to maintain protein solubility within a range of 40 to 55 % of total CP. Grass and legume hays typically will have <30 and <45% soluble protein, respectively.

Ammonia Nitrogen as a percent of total nitrogen measures the NPN component of the soluble protein fraction. This analysis is most often used as part of a fermentation profile to assess the amount of proteolytic activity within the silage. One goal of silage is to minimize proteolytic activity from plant respiratory enzymes or microbes, primarily *Clostridium* spp. The amount of NPN compounds increases greatly with proteolytic activity, which will buffer and increase silage pH, making it less stable. Also, some toxic NPN compounds such as amines can reduce feed intake. The goal is to have ammonia nitrogen less than 8%, and 10 to 12% of total nitrogen for corn silage and hay-crop silage, respectively. In wet clostridial fermentation silages this value may exceed 20%. Higher ammonia nitrogen in silage increases the rapidly degraded rumen nitrogen, and can contribute to high blood and milk urea nitrogen concentrations.

Carbohydrate Analyses

Carbohydrates are a tremendously diverse group of organic compounds, and usually comprise upwards of 70% or more of a small ruminant's total diet. Plant CHOs are primarily differentiated on the basis of their association to the cell wall. Due to the diversity and complexity in CHO structure, our ability to chemically characterize important nutritional fractions of CHO has been somewhat limited within constraints of practicality and economics.[9]

Neutral Detergent Fiber (NDF) is a good measure of feed quality, especially with forages where NDF content increases with maturity (Table 1).[1] Due to its slower fermentation rate and need for mastication, NDF is often associated with intake capacity in ruminants.[11] High NDF feeds have lower potential intake, although feed processing can modify intake potential. In formulating diets, a minimal amount of "effective" NDF is needed to be consumed to ensure proper rumen function, but excessive amounts will result in reduced intake capacity and potential limitations to production. Beyond total NDF amount, quality or fermentability of NDF needs to be considered in evaluating feeding situations. This can be directly measured or evaluated by lignin content. Grasses and legumes average 7.5% and 17.5% lignin as a percent of NDF. Values below or above these indicate greater or lesser, respectively, NDF digestibility. Current methods to determine NDF digestibility is directed to cattle diets, but relative differences in these values can be applied to small ruminant diets. Small ruminants will be similarly affected by changes in NDF digestibility and its impact on intake.

Acid Detergent Fiber (ADF) contains cellulose and lignin as well as heat-damaged protein and other resistant plant compounds (cutins, tannins, silicas). Although there is not a biologic association, ADF content of a given feed is statistically associated with feed digestibility and energy content, and thus is associated with feed quality. If ADF values on a report are greater than the NDF determination, ask the lab to rerun the sample using a sequential NDF-ADF procedure as ADF should always be a lesser value (Table 1). Given NDF measures hemicellulose, cellulose, and lignin and ADF col-

Table 1. Typical test value of alfalfa and grass hays harvested at various stages of plant maturity (all values on dry matter basis).

Hay type and maturity stage	CP % DM	ADF % DM	NDF % DM	ME Mcal/lb	TDN % DM
Alfalfa					
Pre-bloom	> 19	< 31	< 40	1.03 - 1.13	63 - 66
Early bloom	17-19	30-35	40-46	0.98 - 1.02	60 - 62
Mid bloom	13-16	36-41	46-51	0.92 - 0.97	56 - 59
Late bloom	< 13	> 41	> 51	< 0.90	< 55
Grass					
Pre-head	> 18	< 33	< 55	0.98 - 1.07	60 - 65
Early head	13-18	34-38	55-60	0.85 - 0.91	52 - 56
Head	8-12	39-41	61-65	0.75 - 0.84	46 - 51
Post-head	< 8	> 41	> 65	< 0.75	< 46

Abbreviations: CP = crude protein; ADF = acid detergent fiber; NDF = neutral detergent fiber; TDN = total digestible nutrients.

lects cellulose and lignin, their difference can be used as an estimate of hemicellulose content of a forage- or plant-based feed. Pure legumes generally have low hemicellulose content, typically between 5 and 8% of dry matter (ADF:NDF ratio of 0.82). Grasses have a greater amount of hemicellulose, usually 15 to 20% of dry matter or higher (ADF:NDF ratio of 0.62). Blended forages will average somewhere in between these values.

Nonfiber Carbohydrates (NFC). Historically, digestible CHO (sugars and starches) had not been directly measured but were estimated using a subtraction equation based on other proximate analysis component procedures. In using the Van Soest detergent system, NFC is determined by subtraction, with NDF used to determine total cell wall content. All errors within component testing methods will accumulate into the NFC estimate. Additionally, there is some double accounting that reduces the estimated NFC content.[5,9] Crude protein measures all nitrogen in a feed and is converted to a protein basis by multiplying by 6.25. However, NDF will also contain some nitrogen compounds bound to the cell wall, thus one needs to subtract the NDIN (see discussion above) amount from total NDF. The amount of NDIN in a feed is variable, but can be significant enough to alter the NFC estimate upwards by 3 to 5 percent units for various forages.

In high-grain diets fed to support lactation, dietary NFC content can range from 33 to 45 % of DM. Similar to NDF recommendations, the nutritionist must consider a number of factors to decide what will potentially be the optimum level of NFC in the diet. If the NFC are primarily coming from cereal grains (corn, barley, wheat) and are processed (steam-flaked, finely ground, ensiled), then one should formulate to the lower range of total NFC. The reason is to account for the greater degradability of these starch sources and the potentially negative impact on rumen pH. If one is using fiber byproducts and starch sources are low to moderate degradability, then one can formulate to higher levels of NFC in the diet. Nutritionists should also consider amount of physically effective NDF in the diet and feeding program (total mixed ration vs. meal feeding) to fine tune dietary NFC content.

Nonstructural Carbohydrates (NSC) - There is ongoing confusion over terminology currently in use relative to digestible carbohydrates. In the more recent NRC small ruminant report, a decision was made to use NFC as the collective term for all neutral detergent soluble carbohydrates (NDSC) and determination by subtraction.[12] The term NSC is now used to collectively characterize those carbohydrates that can be determined through enzymatic digestion, primarily sugars and starches. As defined by the NRC small ruminant committee, NFC and NSC are separate entities, but NSC is a subset of NFC. For example, pectins are included in NFC, but not NSC. In contrast, starch is accounted for in both NFC and NSC. Newer chemical fractionation methods are allowing for better determinations of various neutral detergent soluble carbohydrates in feedstuffs.[6-8]

Many laboratories are measuring sugar and starch as separate entities, though both methologies are based on measuring glucose content of the compound. With the interest in fructosan polysaccharides (sucrose polymers found in cool-season grasses), additional methods of measuring water soluble carbohydrates (WSC) and ethanol soluble carbohydrates (ESC) are being used to separate out the large molecular weight fructosan compounds from the smaller and more readily fermented smaller fructose oligomers. The large fructosan content of fresh cool- season grasses could be associated with incidents of ruminal acidosis, as they are readily fermented to lactic acid.

Minerals

One of the more important components of feed analysis for small ruminants is to determine mineral content. Both macrominerals (Ca, P, Mg, K, S) and microminerals (Fe, Cu, Mn, Zn) should be determined by wet chemistry methods. Use of NIR to determine forage/feed mineral content is not recom-

mended, as mineral values are not adequately quantified.[3,10] Additionally, molybdenum (Mo) should be requested due to its potential interaction with copper availability. Most labs will be able to measure all of these minerals, though sulfur and Mo may require an additional cost.

Interpretation of forage mineral content relates measured values not only to requirement, but relative to each other. Forage Ca:P ratio should be 1.5:1 at a minimum. Ratios close to 1:1 or lower are risks for bone and hypocalcemia problems. Ratio of K to the sum of Ca plus Mg (all converted to mEq/kg basis) greater than 2.2 increases risk for hypomagnesemia and possibly hypocalcemia. Forage copper is important in small ruminant diets relative to concerns of potential toxicity in sheep and deficiency in goats. Molybdenum and sulfur in the diet (or water) is converted by rumen microbes to thiomolybdate compounds, which chelate copper making it unavailable to the host animal. Forage or diet Cu:Mo ratios below 6:1 generally indicate potential for copper deficiency, whereas ratios above 12:1 are at increasing risk for toxicity. Desired Cu:Mo ratio is 6 to 8:1 for sheep and 6 to 10:1 for goats. High iron content (>1000 ppm DM) suggests soil contamination of the forage sample. Selenium can also be determined in feed ingredients, but it is also an additional cost and a more expensive analysis (>$38/sample). If one lives in a selenium-deficient area, then 1 forage test to confirm would be sufficient. If one lives in an area where selenium status may range from low to moderate, then more regular testing of forages for selenium content should be undertaken.

Summary and Conclusions

Routine feed testing is a critical component of monitoring the feeding program for dairy and beef cattle operations, and should be equally applied to small ruminant farms. Methods of feed analysis have become highly sophisticated, but routine measures of forage quality such as DM, CP, ADF, and NDF should be part of a minimal analysis to target appropriate feeding practices for sheep and goats. Mineral analysis of feeds is also essential for small ruminants to ensure proper feeding, but also to prevent or diagnose potential health issues of urolithiasis, hypocalcemia, and copper deficiency or toxicity. Veterinarians, if well-versed in the interpretation of feed analysis reports, can provide a valuable service to small ruminant clients by encouraging and utilizing the information from feed analysis reports.

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