Introduction

In previous Field Days of the E (Kika) de la Garza Institute for Goat Research, nutrition and feeding programs for dairy and meat goats have been discussed. However, for the maximum benefit to be realized from such information and to most effectively apply this knowledge to the broad array of nutritional scenarios encountered by goat producers, a background in general, practical nutritional concepts for goats is necessary. Likewise, many answers to common questions from goat producers regarding feeding programs involve the basics of nutrient utilization. Therefore, the purpose of this overview is to highlight most important general nutritional concepts for goats, so as to lay a strong foundation for future feeding management decisions.

Crude Protein (CP)

Crude protein refers to the total amount of nitrogen in a feedstuff rather than ‘protein’ per se. Crude protein concentration is typically estimated as total nitrogen level multiplied by 6.25, assuming an average nitrogen concentration in protein of 16%. Therefore, CP concentration does not provide information pertaining to feedstuff levels of nonprotein or true protein nitrogen or to quality of true protein. A number of dietary factors dictate how well CP concentration correlates with the quantity of actual protein or amino acids being absorbed by the animal, which will be addressed later. For this reason nutrient requirement systems for other ruminant species now entail usage of absorbed or metabolizable protein.

Ruminants have requirements for amino acids (building blocks of true protein), rather than for CP or even true protein. The rumen is a compartment of the stomach hosting a large population of bacteria, protozoa, and fungi. These microorganisms degrade ingested feedstuffs to form new cells, yielding volatile fatty acids as endproducts of digestion. The animal then absorbs volatile fatty acids, which are used for energy and other purposes such as glucose synthesis. Primary origins of amino acids absorbed in the small intestine are feed, microbial cells, and endogenous substances (of animal origin). On most diets, the majority of amino acids passing from the rumen are found in microbial cell protein, although passage of intact feed protein to the small intestine can be appreciable with some diets and feedstuffs. Thus, two common ways by which the intestinal protein or amino acid supply can be increased are through elevating ruminal outflow of protein in feed or in microbial cells.
Nitrogen in feedstuffs can be fractionated into components differing in their behavior in the rumen. One such fraction is soluble protein, rapidly solubilized after consumption and typically completely degraded by ruminal microorganisms. Final products of ruminal microbial degradation of protein are largely ammonia and volatile fatty acids, with lower levels of amino acids and peptides (short chains of amino acids) that change with time after consumption. A second important fraction is protein not soluble in ruminal fluid but degradable both by ruminal microbes and in the small intestine if passing from the rumen intact. The rate of microbial breakdown of this protein fraction in the rumen is quite variable among feedstuffs. The last common fraction of feed protein is not degraded in the rumen or in the small intestine, being particularly high in heat-damaged feedstuffs. Therefore, feedstuffs high in soluble protein tend to be extensively degraded in the rumen, and the opposite applies to heat-damaged feedstuffs high in indigestible protein. The extent of ruminal degradation of insoluble protein potentially degradable in the rumen, again, depends on the nature of the specific protein. An example of a feedstuff high in protein largely insoluble in ruminal fluid but rapidly degraded by ruminal microbes is soybean meal. Typically 70 to 75% of soybean meal protein is degraded in the rumen, with only 25 to 30% passing intact to the small intestine. Much of the protein in alfalfa is soluble in the rumen and, therefore, quickly broken down after consumption. Rates of ruminal degradation of protein in feedstuffs such as blood, feather, fish, and corn gluten meals are slow, with normal ruminal undegradable protein (RUP) concentrations of approximately 80 to 90% for blood and feather meals and 60 to 70% for fish and corn gluten meals.

**Cell Walls and Non-Cell Wall Plant Components**

The old analytical system for characterizing feedstuff carbohydrates has been largely replaced by the Van Soest or detergent analysis system. However, in some instances crude fiber levels are still listed. The crude fiber/nitrogen free extract system was replaced because of not consistently accurately fractionating feedstuff constituents into a highly or completely digestible component and a component only partially digestible. Thus, Van Soest fractions will be highlighted below.

Neutral detergent fiber is often referred to as “cell walls” or “fiber” and includes three general cell wall components differing in chemical properties: cellulose, hemicellulose, and lignin. Actually, lignin is not a carbohydrate and is generally indigestible. In fact, lignin limits the extent to which ruminal microbes can degrade hemicellulose, in part through bonding and physical associations. Effects on cell wall digestion of lignin vary among feedstuffs. For example, legumes are usually higher in lignin concentration than grasses, but adverse effects on hemicellulose and cellulose digestion per unit of lignin are less for legumes. The acid detergent fiber fraction includes cellulose and lignin, and one assay for lignin is called acid detergent lignin. The rate and potential extent of cell wall degradation are quite variable among feedstuffs. For example, as forages mature digestibility declines because of the increasing lignin concentration and changes in the structure of plant tissues that limit access of microbes to digestible cell wall components.
The neutral detergent soluble fraction usually is completely potentially digestible in the rumen, and includes substances like starch, sugars, and proteins. Feedstuffs low in fiber, such as corn, have high neutral detergent soluble concentrations. However, the nature of neutral detergent solubles varies considerably among feedstuffs. For instance, dependent on processing a considerable amount of corn starch reaches the small intestine intact without being degraded by ruminal microbes, whereas neutral detergent solubles of alfalfa consist largely of soluble proteins and sugars that are rapidly and completely broken down in the rumen by microbes. Nonetheless, the fractionation of plant material into neutral detergent fiber and solubles provides a great deal of information regarding nutritive value of plant material. But, as for CP fractions, components of each fraction can differ markedly in the rate they are broken down by ruminal microorganisms.

Energy

There are a number of different classifications of energy that need to be understood for proper livestock feeding programs. First, there is gross energy, which is the total amount of energy in a feedstuff, not accounting for energy losses upon consumption by the animal. Apparent digestible energy is that which is absorbed or enters the animal, and is calculated as total energy intake minus energy excreted in feces. The term “apparent” is used because feces also contains endogenous products, or substances such as epithelial cells and enzymes from the animal, that did not originate from the food being consumed at that time. Metabolizable energy considers or accounts for energy that is lost in urine and fermentation gases. These losses are subtracted from digestible energy because this energy did not become available for metabolism or was not completely metabolized by the animal. However, as for endogenous energy in feces, urinary energy includes energy in a small quantity of products of animal metabolism that theoretically would be present without feed consumption. Total digestible nutrients (TDN) is a very commonly used energy term, expressed in percentage units and based on concentrations and digestibilities of different chemical fractions of a feedstuff or diet. Although, TDN of feedstuffs typically is predicted based on levels of chemical fractions such as CP, neutral detergent fiber, acid detergent fiber, etc. Rankings of feedstuffs or diets by TDN concentration are similar to those by digestible and metabolizable energy, since TDN considers fecal energy losses and includes a partial correction for energy loss in urine. The next classification of energy is net energy, taking into account energy given off as heat in normal metabolism due to feed ingestion, since chemical events in the body are not 100% efficient. Thus, net energy refers to actual quantities of energy used for different functions, such as body weight maintenance, growth, and lactation. Very importantly, the efficiency of energy use, or energy loss in metabolism, varies with the purpose energy is being used for. For example, energy is metabolized for maintenance more efficiently than for growth, although the overall efficiency of energy metabolism for lactation is similar to that for maintenance. There are a number of reasons for these differences in estimates of efficiency of metabolism, which would require a great deal of time to thoroughly address.

The amount of energy required for body weight maintenance is typically estimated as a quantity of energy multiplied by body weight raised to the three-quarter power, commonly known as metabolic body weight. Previous experimentation over many years and around the world has determined that, in general, maintenance energy requirements increase linearly with increasing metabolic body weight.
This maintenance energy requirement can also be expressed as metabolizable energy, TDN, or digestible energy, with appropriate assumptions of the efficiencies of energy use for maintenance and other losses accounted for by each system. The same applies for growth or lactation, with requirements expressed per unit of live weight gain or milk production.

Efficiencies of energy metabolism have not been extensively studied in goats, but presumably are similar to those for other ruminant species. Besides the effect of functions for which energy is used, efficiencies of energy metabolism differ among feedstuffs. Efficiencies are greater for concentrates than for forages. That is, for each unit of feed consumed, more heat is lost with forage versus concentrate. Secondly, differences between concentrates and forages are less with low feed intake and when most or all energy is used for maintenance than with high feed intake and when an appreciable amount of energy is used for growth. This is one of the reasons why mature ruminants can be maintained on diets composed solely or primarily of moderate-quality forage, whereas rapidly growing animals require dietary inclusion of concentrate and(or) high-quality forage. Similar differences in efficiencies of metabolism exist among forages, with efficiencies increasing and energy losses decreasing as forage quality rises. Hence, increasing dietary concentrate level and increasing forage quality decrease energy losses in both feces (i.e., increasing digestibility) and in heat given off in metabolism (i.e., increasing efficiency of metabolism, or an increasing ratio of net:metabolizable energy). However, this is somewhat of a simplification, in that these factors influence level of free-choice or voluntary feed intake. For example, up to certain dietary levels of concentrate, free-choice level of feed intake increases as diet quality rises, which may lessen the magnitude of these differences among feedstuffs or diets in digestibility and efficiency of metabolism.

**Nutrient and Energy Demands**

Energy is actually a property of nutrients rather than a nutrient per se, since energy is derived from feedstuff components such as protein, starch, fiber or cell walls, fat, etc. However, in much of the following discussions “nutrients” will refer to energy as well as particular nutrients like protein and amino acids.

The various classes and production stages or states of goats are accompanied by requirements for different quantities of nutrients. Also, the types or array of nutrients needed can vary. These demands or potentials for nutrient use have critical effects on diet or supplementation decisions that a goat producer must make.

*Does*

Lowest nutrient requirements are probably for nonpregnant, mature does, although requirements in the first one-half to two-thirds of gestation are not much greater. For nonpregnant does, other than perhaps during the last 2 or 3 weeks preceding breeding and for the first 1 or 2 weeks of the breeding period, a nutritional plane only slightly greater than that adequate for body weight maintenance is necessary, depending of course on initial body condition.
But, severe undernutrition in early and mid-gestation can adversely affect the number of kids born, kid health, and in some instances productivity of kids when grown. With doelings or does in low body condition, the nutritional plane during early and mid-gestation should be increased to allow for growth or tissue replenishment, which is unlikely to be easily achieved in late gestation. In this regard and as has been presented in previous Field Day discussions, most kid growth occurs in the last one-third or 50 days of gestation. Thus, nutrient intake should be increased during this time to ensure healthy kids at birth and so that the dam is prepared for the nutrient demands of lactation. A high nutritional plane in the last few weeks of gestation is particularly important to the immune system of does, for formation of colostral antibodies, and for minimal doe health problems after parturition such as mastitis. As will be discussed later, these shifts in nutrient intake can be achieved through changes in the level or composition of concentrate supplements or in the quality of forage being offered. Another factor to be noted is the number of fetuses; obviously, does with twins or triplets require more nutrients in late gestation and during lactation for proper fetal development and postnatal growth, respectively, compared with does bearing a single fetus. Because of the ability of does to use tissue stores of nutrients for support of fetal growth, a slight limitation in nutrient intake during late gestation might not adversely affect kid or litter birth weight, but kid health may be impaired. Also, excessive tissue loss by the doe in late gestation is accompanied by decreased birth weight and a lessened ability to draw upon maternal tissue nutrient reserves in early lactation, when it is not possible for the level of feed intake to be great enough to achieve maximum milk production. Both energy and protein needs are very high during early lactation and decline as lactation advances after the peak in milk production. Again, in meat and fiber-producing goats milk production and associated requirements for nutrients are influenced by the number of kids. A limiting nutritional plane during this period restricts milk production and growth of kids from multiple births more than that with single kids. Likewise, the associated high degree of tissue mobilization by the doe would necessitate an increased nutritional plane later for tissue replenishment.

**Kids**

Bottle-feeding milk replacer or milk in the suckling period has been addressed in previous Field Day discussions. An important aspect is early adaptation to dry feed in preparation for weaning. As for other ruminant species, nutrient requirements relative to body weight of young animals are quite high, decreasing as animals age and approach maturity. In accordance, concentrations of nutrients required in diets decrease with time. However, much less is known about the rate of maturation of goats than of cattle or sheep, suggesting that change with age in nutrient requirements may not be exactly the same. Limited research suggests a slower rate of maturation of goats, implying less change with time in nutrient requirements. In this regard, compensatory growth should be mentioned. Compensatory growth is when the rate of growth while on a high nutritional plane is greater than expected, following a period of restricted growth with a low plane of nutrition. However, compensatory growth by goats has not been extensively studied, and it is not known how compensatory growth by goats compares with that by sheep and cattle.

Another factor to be recognized regarding differences among ruminant species is in fat deposition. Goat meat is generally viewed as being leaner than beef or lamb, although goats appear to
deposit more internal fat. First, little is known concerning dietary and management factors influencing internal fat deposition. Secondly, assuming the rate of internal fat deposition to be relatively steady as age and body weight increase, live weight gain of growing-finishing goats may decrease at a slower rate than cattle and sheep that deposit more carcass fat. Thus, because of the aforementioned factors that are not well understood, post-weaning growth will be referred to rather than use of separate growing and finishing phases, as is common when describing cattle and sheep production systems. Further research at the E (Kika) de la Garza Institute for Goat Research will allow a refined description of how goat nutrient requirements change with advancing age, body weight, and stage of maturity.

**Important Considerations**

**Protein**

The two primary factors influencing the quantity of microbial protein synthesized in the rumen are adequacy of compounds containing nitrogen that microbes need to reproduce and the quantity of organic matter that can be fermented to yield energy for microbial cell replication (i.e., reproduction). Other factors also have impact, such as the rate at which digesta passes from the rumen and the timing of the availability of nitrogen-containing compounds and energy, but these effects are less than, and depend upon, the two factors mentioned above.

The nitrogen-containing compound needed by most ruminal microbes in the greatest amount is ammonia, although some microbes require, and growth of others may be stimulated by, amino acids and peptides. As noted earlier, proteins degraded in the rumen largely end up as ammonia and volatile fatty acids. Nonprotein nitrogen sources such as urea are also degraded to ammonia in the rumen. An important source of ammonia for ruminal microbes with diets very low in CP is recycled nitrogen. Ruminants are able to add nitrogen to the rumen through urea contained in saliva and by transfer of urea from blood vessels lining the rumen wall, with most derived from the latter mode. However, even with nitrogen recycling, with diets very low in CP (e.g., less than 5 or 6%) ruminal microbes will not have adequate ammonia to efficiently grow or reproduce, which limits the amount of microbial protein passing to the small intestine and results in insufficient amino acids available to animal tissues. Another item worthy of mention here is sulfur. When ruminal microorganisms synthesize protein, in addition to nitrogen such as from ammonia, sulfur is needed to form some amino acids (e.g., methionine). The National Research Council currently lists a sulfur requirement of 10% of the nitrogen requirement or level in the diet, or 0.16% of dry matter intake for a 10% CP diet. However, higher sulfur requirements have been suggested for high fiber-producing goats. Furthermore, the amount of organic matter that is available for ruminal microbes to digest or ferment for energy sets the quantity of nitrogen-containing compounds such as ammonia that microbes can potentially use to form new cells. For example, the potential for use of ammonia by ruminal microbes to form new cells or microbial protein is greater with a diet that is 60% digestible than with a lower quality diet 50% in digestibility. This is a very important relationship to note, regarding various types of diets fed to animals with different requirements for protein or amino acids and energy. For instance, this relationship helps explain why the CP requirement for a moderate-quality (i.e., moderate digestibility) forage fed to nonpregnant goats is lower than that for a higher quality forage diet, perhaps with some concentrate, being consumed by weaned, growing-
finishing goats. Relatedly, an oversupply of ruminally degradable nitrogen eliciting a high concentration of ammonia in the rumen, results in considerable nitrogen wastage if the quantity of fermentable organic matter is not sufficient to allow use of this nitrogen in formation of protein in new microbial cells. This high ammonia concentration causes high ammonia absorption in the rumen and excretion of nitrogen as urea in urine.

The above information should hopefully highlight the existence and importance of interrelationships between dietary concentrations of digestible organic matter or energy and CP. Interrelationships of absorbed energy and amino acids or protein at the animal tissue level exist as well, which will be touched upon later. Besides the significance of a sufficient quantity of ammonia in the rumen to allow high synthesis and flow from the rumen of microbial protein, it is critical for maximal digestion of the forage or diet as well, which impacts energy that the animal will absorb. That is, a low ruminal ammonia level can limit not only microbial protein synthesis but also the ability of the microbes to digest. For example, the digestibility of a forage such as wheat straw or prairie hay, 5% or less in CP, is limited by low activity of ruminal microbes that is a consequence of the low quantity of ammonia in the rumen available. Thus, supplementation with a ruminally degradable nitrogen source will increase forage digestibility and also the amount of microbial protein being synthesized. In addition, free-choice feed intake will be elevated. This is one of the means by which ammoniation is effective. Ammoniation increases potential digestibility and rate of digestion of forage cell walls primarily through solubilization of bonds between the cell wall component hemicellulose and lignin. But, the increased CP concentration also contributes to the positive effect on animal performance through the increase in availability of nitrogen-containing compounds for microbes. This enhances microbial activity and increases digestion, resulting in greater formation of new microbial cells to elevate amino acids of microbial protein being absorbed in the small intestine of the animal.

As mentioned before, most amino acids absorbed in the small intestine typically are from microbes passing from the rumen. However, for animals with very high protein or amino acid requirements, the quantity of microbial protein and protein of normal feedstuffs passing from the rumen intact may be inadequate to achieve the potential level of productivity. In such instances, ruminal degradability of dietary feedstuffs should be viewed, and increased levels of feedstuffs high in RUP can be used. In general, forage proteins are thoroughly and rapidly degraded in the rumen. Because ruminal protein degradabilities for corn and sorghum grain are greater than for forages, ruminal undegradability of total dietary CP usually increases as the dietary concentrate level increases.

Probably the best example of a goat possibly requiring an increased dietary level of RUP is the high-producing lactating dairy goat. For example, in a recent experiment at the E (Kika) de la Garza Institute for Goat Research, lactating does and doelings were fed 17.5% CP diets with 40 or 80% forage and with or without addition of feedstuffs high in RUP. The added RUP was provided by a mixture of blood, fish, and feather meals, substituting for two-thirds of the CP in control diets being provided by soybean meal. Added RUP increased milk production in weeks 3 to 7 of lactation but did not have impact later when milk production had declined. Also, the effect of RUP tended to be greater with the diet higher in grain (40% forage) than with the high-forage diet (80% forage). These results bring out two important points. First, only when nutrient demand or potential for use is very high will
addition of RUP be beneficial. In accordance, in the first year of an experiment with Angora does and kids grazing different cool season grasses in the spring, fish meal added to a grain-based supplement did not affect doe or kid performance. Secondly, animals require a high quantity of absorbed energy to make efficient usage of the increased quantity of absorbed amino acids achieved by use of feedstuffs high in RUP.

Regardless of the potential for use of additional amino acids in the small intestine that may be achieved through use of RUP sources, the importance of an adequate supply of ruminally degradable protein or nitrogenous compounds should not be overlooked. There are numerous examples of experiments in which the level of substitution of RUP sources for feedstuffs providing needed ruminally degradable protein was too great, resulting in low availability of nitrogenous compounds for ruminal microbial growth and(or) digestion and decreased microbial protein synthesis and flow to the small intestine. For beef cattle, currently the ruminally degradable protein requirement is calculated as 13% of the TDN concentration, which when combined with a consideration for recycled nitrogen yields a ruminally degradable protein requirement of about 10% of the TDN level in the diet. Thus, the ruminally degradable protein requirement is 5% of dry matter for a 50% TDN forage or diet, and 6% for a diet or forage 60% in TDN concentration.

Another aspect of RUP sources that should be considered is protein quality, or the array of amino acids in relation to requirements of the animal. First, amino acid requirements of goats have not been well defined, as is also the case but to a lesser extent for other ruminant species. Secondly, many of the feedstuffs highest in RUP that are commonly used in ruminant diets are high in many essential amino acids but low in others. Thus, for cattle and sheep it is standard to add blends or mixtures of feedstuffs high in RUP rather than only one. Until further research is conducted, the same practice also seems advisable for meat and dairy goats. However, for fiber-producing goats, particularly Angoras, and for wool-producing sheep, amino acid requirements differ from animals reared for milk or meat production. The requirement for sulfur-containing amino acids, such as methionine, is particularly high for Angora goats. Thus, the optimal profile of amino acids in a supplement high in RUP for Angora goats may differ from that for lactating Alpines, Spanish, or Boer crossbreds.

Feed Intake

An obvious and important consideration in goat nutrition is feed intake, which has been or will be addressed for the other major nutritional concepts being dealt with in this overview. Feed intake by cattle can be empirically predicted reasonably well based on the chemical composition of feedstuffs and nutrient requirements or potential for use by the animal, although presently the underlying physiological processes in ruminants responsible for feed intake control have not been well defined. The state of knowledge regarding prediction of feed intake by goats is not advanced, which is in part due to the wide array of production conditions and types of goats used. Also, goats are more selective in grazing or foraging habits than other ruminant species. However, it is known that nutrient and energy demands by the animal and quality of the diet ingested are the two biggest factors influencing voluntary feed intake.
Diet “quality” is a vague and general term that typically refers to digestibility. Digestibility is directly related to the concentration of neutral detergent fiber, cell walls, or fiber, and to fiber digestibility. Normally, a low-quality forage does not necessitate a low CP concentration, although in many instances forages low in digestibility are also low in CP (e.g., wheat straw, prairie hay). Overall, there is a positive relationship between diet digestibility or quality and voluntary feed intake, but with very high grain levels this association may not exist.

There are many examples of factors influencing diet quality. Legumes are generally more digestible than grasses at a comparable relative stage of maturity, largely because of their lower level of cell walls. The same general differences exist for comparisons such as concentrates versus forages and leaves versus stems. The rate of cell wall digestion usually is more rapid for legume than for grass cell walls, but legume cell walls are more lignified, and so extent of cell wall digestion often is less for legumes. Other differences between legumes and grasses include a greater CP concentration in legumes and physical characteristics that influence particle breakdown with mastication. Such factors lead to greater potential voluntary intake of legumes than grasses.

At the same relative stage of maturity, cool-season grasses are usually more digestible and consumed at least in slightly greater amounts than warm-season grasses. However, forage management practices impact forage quality. For example, a mature cool-season grass can be of lower digestibility and have lower feed intake potential than a vegetative warm season grass. In accordance, digestibility and voluntary feed intake potential decrease with increasing plant maturity. But, there are other factors that influence differences among forages in selection and voluntary intake. One example is anti-nutritional factors. Condensed tannins will be addressed later. Ergot alkaloids are found in endophyte-infected fescue, which depress feed intake in cattle. Similar effects are presumed for goats. In support, in a recent experiment at the E (Kika) de la Garza Institute for Goat Research, live weight loss of Angora does was greater and gain by their suckling kids in the spring was less for endophyte-infected fescue than for orchardgrass, wheatgrass, or wheat pastures.

Overall, as animal nutrient needs increase, voluntary feed intake increases. For example, voluntary feed intake (relative to body weight) is greater for lactating versus dry does. Likewise, feed intake (relative to body weight) decreases as animals mature, since nutrients required for maintenance decrease slightly as animals mature and requirements for live weight gain obviously decline as well. However, diet composition affects such differences. For instance, feed intake (relative to body weight) of unsupplemented wheat straw or prairie hay will be no more and probably less for a growing meat goat than for a mature doe. But, with proper supplementation of such diets or use of any other high-quality diet, intake will be greater for the growing meat goat. Likewise, the strength or existence of the relationship between diet quality and voluntary feed intake generally increases as nutrient and energy needs of the animal increase, other than with diets very low in digestibility. The greater potential for nutrient use by growing or lactating (particularly the former) goats compared with nonpregnant or early gestation goats facilitates greater intake (relative to body weight) only if diet quality is moderate to high.

**Associative Effects**
When considering grain supplementation of forage-based diets, associative effects of feedstuffs need to be kept in mind. An associative effect exists when a response, typically in digestibility and(or) feed intake, to feeding two or more feedstuffs together is not as expected based on measures when the feedstuffs are fed alone. Associative effects can be positive or negative. An example of a positive effect is when a low level of supplemental soybean meal or cottonseed meal increases intake and(or) digestibility of a low-protein forage like prairie hay or wheat straw. As noted previously, this response is largely elicited through the increase in ruminal ammonia concentration that increases fiber digestibility and microbial protein synthesis, for increased volatile fatty acid absorption for energy and small intestinal absorption of amino acids from microbial protein. A good example of a negative associative effect is the depression in fiber digestibility elicited by a high level of supplemental grain given with a low- to moderate-quality forage. This response is brought about by two changes in the rumen environment, which involve the ability of many ruminal microbes to degrade both starch and fiber and the adverse effect of high acidity or low pH on production and activity of fibrolytic enzymes (ones degrading fiber) produced by microbes that are only capable of degrading fiber. Small depressions in fiber digestion elicited by low levels of grain inclusion in forage-based diets occur via preferential starch digestion by fibrolytic microbes than also can degrade starch. More severe depressions resulting from high levels of grain addition to diets are largely elicited by reductions in pH (when below 6.0) and concomitant decreases in the number of microbes degrading fiber (particularly those that only and are most capable of breaking down fiber) and increases in ones breaking down starch. However, it is important to note that these negative associative effects do not become appreciable until grain composes at least 25 to 30% of the total diet. Also, even though fiber digestibility may be depressed, the overall quantity of energy being absorbed by the animal is usually increased because of the greater digestibility of grain than forage, and this increased quantity of ruminally fermentable organic matter increases microbial protein synthesis. In relation, increased ruminally fermentable organic matter and microbial protein synthesis increase the need of ruminal microbes for ammonia. Thus, moderate to high levels of supplemental grain may necessitate simultaneous supplementation with a ruminally degradable protein source. In fact, if this is not done, high levels of supplemental grain will have a greater deleterious effect on fiber digestion, because the generally earlier microbial fermentation of grain starch than fiber can lessen the availability of ammonia for later degradation of fiber.

Besides the impact of the level of concentrate supplementation on forage digestibility and intake, the type of supplemental feedstuff also has impact. For example, feedstuffs high in fiber that is highly degradable in the rumen, such as soybean hulls, can increase energy absorption by the animal with little or no adverse effect on digestibility of the basal dietary forage. However, one of the most important factors determining the type of supplement used is cost per unit of nutrient or energy that a supplement is being provided for. Potential associative effects then should be used to adjust such cost comparisons.
High-Concentrate Diets

As for other ruminant species, switching from forage-based diets to diets high in concentrate for goats should be done slowly and gradually, allowing normal changes in types and activities of ruminal microbes to take place. Too rapid of change can cause digestive disturbances such as acidosis and diarrhea. In fact, any kind of dietary change should be slow and gradual, as digestive tract conditions in goats seem relatively more adversely affected by shifts in the nature of the diet compared with cattle and sheep.

There has not been a great deal of research conducted with very high concentrate diets for goats compared with cattle and sheep. From casual observations, goats appear more comparable to sheep than cattle in regard to minimum dietary levels of structural roughage or effective fiber. Saliva in ruminants contains buffers necessary to prevent ruminal fluid from becoming too acid or having too low of a pH. The amount of saliva flow relates directly to time spent in mastication during eating and rumination. Time of mastication is very short for grains compared with long-stemmed or chopped forages. Because grains generally are quickly and thoroughly digested in the rumen, with resultant high and fast volatile fatty acid production by ruminal microbes, inclusion of some forage in the diet is essential with high-grain diets to lengthen total mastication time and achieve adequate salivary buffer flow. It is also important to note that the cell wall or neutral detergent fiber concentration in a feedstuff does not necessarily indicate its effect on salivary buffer flow. For example, the particle size of soybean hulls is small, which results in short mastication time. Also, soybean hulls fiber is highly digestible in the rumen and, thus, not present in the rumen for very long to stimulate mastication. Hence, dietary inclusion of feedstuffs such as soybean hulls certainly cannot preclude use of feedstuffs that have a substantial effect on salivary buffer flow such as long-stemmed or chopped grass hay or cottonseed hulls.

Herbage Selection and Browse

Goats have very mobile mouthparts and necks, which allow them to select nutritious plant parts, including leaves, buds, and fruits and to avoid poor-quality stems, dead leaves, and spines. Therefore, most goats in the world are under raised under grazing, foraging, or browsing conditions rather than in confined settings. They are agile, frequently stand on hind legs, reach high, and easily feed from a wide range of plants, including trees, bushes, and leguminous and grass forages. Determining supplementation needs for grazing goats is difficult because of the often wide array of types of plants available for consumption and the ability of goats to select specific plants and plant parts. However, with experience and through observation, many goat producers can reasonably describe what his or her goats are consuming at particular times of the year while occupying particular areas of land.

It is well known that goats consume more tree and shrub plant parts than do sheep or cattle. Trees and shrubs are important food sources for goats, particularly in arid areas of the world. In the US there is great potential for goat production on rangelands. It has been estimated that approximately 60% of the ½ billion acres of US rangeland has been invaded by undesirable browse species, which could be utilized for raising goats. In Oklahoma and surrounding states, goats are being used to control
weeds (forbs) and brush. Many such plants are high in condensed tannins (CT). Condensed tannins are quite interesting, in that animal performance may benefit from their consumption at low levels but be severely impaired at high concentrations. Condensed tannins are compounds that can bind to proteins at normal pH in the rumen. However, at pH typical of the abomasum or “true stomach” and in the first part of the small intestine, these complexes come apart, allowing the proteins to be digested and amino acids to be absorbed by the animal. Furthermore, when the intake of ruminally degradable CP provides more ammonia than is needed by ruminal microbes to ferment the quantity of organic matter that is available, resulting in high ammonia absorption in the rumen and consequent loss of nitrogen in urine, low levels of CT have beneficial effects through the lessening this nutrient loss. Goats are able to tolerate higher dietary levels of CT than sheep or cattle, and all ruminants can adapt somewhat to high dietary CT concentrations, but, adverse effects of very high levels of CT still can occur with goats.

In recent years, considerable research has been conducted with CT in various areas of the world, and the E (Kika) de la Garza Institute for Goat Research has such a project underway as well. However, presently there is not a thorough understanding of how CT in plants being consumed impact supplementation considerations. Nonetheless, based on the current state of knowledge, such general concepts can be outlined. It is important to mention that effects of CT depend on their level in the diet, with effects gradually changing as the CT concentration varies. Nonetheless, supplementation considerations highlighted below are categorized for low (e.g., 2.5% of total dry matter intake or less) and high levels of CT (e.g., greater than 5% of total dry matter intake).

With low total dietary levels of CT, as long as the dietary CP concentration is at least slightly more than needed for ruminal microbial growth and digestion, CT should increase the quantity of amino acids being absorbed in the small intestine, without any appreciable negative effects. If the goats have high nutrient and energy demands, and if the overall digestibility of the herbage being consumed is low to moderate, then perhaps a low to moderate level of a cereal-grain based supplement would be beneficial to facilitate efficient use of the greater quantity of amino acids becoming available to animal tissues. However, because the CT will at least slightly depress the concentration of ammonia in the rumen, probably a supplement CP concentration of 15 to 25% would be advisable to make sure that ammonia in the rumen is ample for microbial needs. Otherwise, if cereal grain is supplemented alone, as mentioned before a ruminal ammonia deficiency might be caused, which could increase the potential depressing effect that the high-starch cereal grain might have on ruminal microbial digestion of fiber. If the particular goats being used do not have high nutrient and energy demands, then a low level of CT should not alter supplement needs.

A very common plant in this region with a low to moderate level of CT is Sericea lespedeza, although the CT level in lespedeza and other plants can vary markedly with plant variety, time of the year, and forage management practices. Legumes such as lespedeza are actually excellent plants for low to moderate levels of CT. As noted before, the rate at which CP in legumes is broken down in the rumen is normally quite rapid and degradation is thorough, resulting in considerable nitrogen loss through ruminal absorption of ammonia and urinary excretion of urea. However, the low to moderate level of CT lessens the extent of ruminal microbial breakdown of the protein in lespedeza, to increase ruminal outflow of intact feed protein for small intestinal digestion and amino acid absorption. The total
CP concentration in such legumes is moderate to high, so that even with these CT effects there is still ample nitrogenous compounds such as ammonia available to microbes in the rumen.

With high dietary levels of CT, fiber digestion is depressed, reducing the amount of energy the animal is absorbing. This limited ability to digest fiber appears to be caused by CT complexing of microbial enzymes in the rumen. Depending on the level of CP in the diet, binding of feed protein in the rumen that limits ammonia available to microbes may be important as well. Also, high CT levels can have adverse effects on epithelial cells of the rumen wall. Quite importantly, CT appear to bind enzymes in the small intestine that break down proteins to peptides and amino acids, and complexes with feed proteins that are not available for digestion can be reformed in the intestines. These factors ultimately limit small intestinal protein digestion and amino acids becoming available to the animal. However, typically when goats and other ruminants can select among plants, some of which have high CT levels and some that do not, the high-CT plants will be selected against. When forced to consume these plants high in CT, animal performance will be low. If no other grazing areas are available, one course of action is to substitute another feedstuff (e.g., grass or grass/legume hay) for the CT-rich plant. Recent research in Israel has shown that the efficiency of usage of concentrate supplements high in cereal grain or soybean meal is low with a basal diet very high in CT, due to the factors mentioned above. Although, very high levels of supplemental concentrates would have beneficial effects, but feed costs would be high as well.

The research project underway at the E (Kika) de la Garza Institute for Goat Research pertaining to CT involves use of polyethylene glycol (PEG) as a supplement. Research at other countries such as Israel has shown promise in use of PEG to enhance utilization of herbage high in CT. This potential lies in the ability of PEG to bind to or form complexes with CT, thereby preventing their complexing with feed proteins or enzymes of ruminal microbes or in the small intestine of the animal. Again, low levels of CT can be advantageous in some instances, but very high levels are not. Relatedly, work in Israel has indicated that with consumption of high-tannin oak leaves, very little benefit was achieved through supplementation with cereal grain- or soybean meal-based concentrates, whereas substantial improvements in digestibility, feed intake, and live weight gain occurred when PEG was also given. Supplementation with PEG alone had positive effects as well. Although goats do have the ability to tolerate higher levels of CT than other ruminant species, PEG supplementation someday might be a way of enhancing the use of goats to control and decrease levels of undesirable plants such as shinnery oak, through altering plant selection to increase quantities of oak consumed, broadening the growing season during which appreciable oak consumption occurs, and improving animal performance while consuming different levels of oak.

Example Diet or Supplementation Considerations

For a discussion of example diet or supplementation considerations, for simplicity three general types or categories of forages will be considered. The first is low-protein forages, harvested or grazed, which are also high in fiber of limited potential digestibility (i.e., less than 50%). Examples include wheat straw and mature prairie hay. The second general type is medium quality forages moderate in both CP concentration (e.g., 8 to 13%) and digestibility (e.g., 50 to 60%). Examples are harvested or
grazed vegetative bermudagrass, cool-season grasses such as orchardgrass in late vegetative or early reproductive stages of growth, and annual cool-season grasses such as wheat at or near maturity. The last type includes high-protein and highly digestible cool-season grasses such as vegetative wheat and orchardgrass, with CP concentrations 14% or greater and digestibilities higher than 60%.

Four types of goats, highlighted earlier, will be used to outline how animal and forage characteristics interact in the type of concentrate supplement warranted. These are goats that are nonpregnant or early gestation, in late gestation, in early lactation, or in a growing-finishing phase. The first questions that must be asked when making supplementation decisions are what is the most limiting factor and what level of animal performance is desired. Obvious other things to be contemplated include acceptability or palatability and costs.

For any class of goat, with forages very low in CP concentration and digestibility, the most limiting factor is the ruminal supply of nitrogen-containing compounds, primarily ammonia, which limits microbial fiber digestion and microbial protein production. For nonpregnant goats or ones in early gestation, perhaps only a limited amount (e.g., 0.15 to 0.25% of body weight of dry matter) of a protein source or commercial supplement with protein highly degradable in the rumen, such as soybean meal, will be required, bringing the total dietary CP level to at least 7 or 8%. For goats with higher protein and energy requirements, such as in late gestation, it will be necessary to supplement with a highly digestible feedstuff such as a cereal grain as well. As noted earlier, the level of supplemental CP may also need to be elevated when grain is supplemented. In such instances, often a commercial supplement perhaps 15 to 25% in CP can be used, given at least at twice the level of the higher CP supplement used before. For females in early lactation, particularly dairy goats, such low-quality forage will not permit acceptable performance to be realized, or would necessitate too high of a dietary level of concentrate. The same thing somewhat applies to growing-finishing goats, in that it is not possible to achieve a fast rate of growth with such forage composing a large portion of the diet. However, dependent on the nature of compensatory growth by goats, a relatively slow rate of growth for a limited period after weaning might be partially or perhaps totally compensated for by use of a higher quality diet later, depending on factors such as the length and severity of nutrient restriction in the early growth period.

With the medium-quality forage characterized earlier, goats that are not pregnant and ones in early gestation will not require concentrate supplementation. Although, one thing that should be pointed out is potential effects of stocking rate or grazing pressure on time spent grazing or harvesting herbage. Energy used for grazing relates closely to time spent grazing. With low available forage mass, grazing time can be long, and ruminants will therefore expend a great deal of energy foraging. In such instances a low level of a high-energy supplement composed solely or primarily of grain will decrease energy used in grazing, thereby improving energy status. The same sort of accountings should be made for topography of the land. For females in late gestation, depending on the specific herbage being consumed, only a low to moderate quantity of a concentrate supplement would be required, which should be primarily of a high-energy feedstuff such as a cereal grain with a lesser proportion of a high-protein feedstuff with protein highly degradable in the rumen. A supplemental CP level from 15 to 25% in this instance would be appropriate, perhaps with a feeding level of 0.5 to 1.0% of body weight of dry
matter. In early lactation the level of supplementation or dietary inclusion of this 15 to 25% CP supplement should be increased, depending on the level of milk production possible or desired, as influenced by breed and number of fetuses. The number of fetuses also impacts supplement needs in late gestation. As noted earlier, for lactating dairy goats at highest stages of production, other dietary considerations such as use of RUP sources should be made. The supplement CP level may be increased slightly for such high-producing animals, particularly with high levels of dietary concentrate (e.g., 50 to 65% of total dry matter), but there are limits above which no added benefits are derived. For high-producing dairy goats, once the dietary CP level is raised to somewhere around 15% via use of ruminally degradable protein sources such as soybean meal, further increases in soybean meal consumption will only increase ruminal ammonia absorption and loss of this added nitrogen in urine. Conversely, feedstuffs high in RUP increase amino acid absorption in the small intestine that can be used for milk synthesis or replenishment of animal tissues. As the lactation period advances, the dietary levels of concentrate, CP, and RUP can be gradually decreased. For grazing goats such shifts will, of course, be influenced by changes in the quality and quantity of herbage available for consumption. For growing-finishing goats, as noted before, supplementation will depend on the desired levels and patterns of growth desired. For relatively low growth early after weaning to be compensated for later with a higher plane of nutrition, with such moderate-quality forage no concentrate supplementation is required. For more rapid growth, a moderate level (e.g., 0.5 to 1.0% of body weight) of a supplement 15 to 25% in CP, with the supplemental CP source being high in ruminally degradable protein such as soybean meal, can be used. However, as noted for highly productive lactating dairy goats, with high levels of dietary concentrate, for most rapid growth total dietary levels of CP perhaps greater than about 15% CP should only be achieved through use of feedstuffs high in RUP. The total dietary CP concentration requirement does decrease as animals increase in stage of maturity, depositing proportionately more fat and less protein, but again, such changes have not been well characterized in goats and may be slower than with sheep and cattle.

High-quality forages are in most cases used for animals with high nutrient requirements, or for animals with moderate requirements with a high stocking rate and low available forage mass to limit feed intake. Most efficient supplements of high-quality forages have not been clearly delineated for goats, as is also true for cattle and sheep. Responses have been quite variable. Overall, most economical production for animals with moderate nutrient requirements has been without supplementation. Performance can in some instances be increased by concentrate supplementation, usually for animals with high potential performance, but in most instances the cost per unit of added performance is high. This may even be more true for meat goats than for sheep or cattle because of the apparent relatively slow rate of growth. Although, little research has been conducted with Boer goats consuming such forages. Supplementation is a valuable means, however, to extend forage supplies. For very high-producing dairy goats in the period of highest production, a moderate to high dietary level of concentrate or a grain-based supplemental concentrate typically increases performance, as occurs with lactating dairy cows. Because protein of such forages is rapidly and extensively degraded in the rumen, there is little or no need for added protein sources highly degradable in the rumen. Alternatively, protein sources high in RUP can increase the intestinal protein supply to increase milk production if the absorbed energy supply is adequate.
Conclusions

The ruminant digestive system is unique and complex. Consideration needs to be given to microbial growth and digestion in the rumen and to nutrients becoming available to animal tissues. Feedstuffs differ in composition, and nutrient and energy needs vary with properties of the animal. Only by understanding key nutritional concepts integrating feedstuffs characteristics and animal nutritional needs can most efficient goat management systems be achieved.

Suggested Readings


The proper citation for this article is: