Nutritional Overview: Forage, Feed, Minerals and Other Supplements

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Introduction

The practice of feeding animals is considered part science and part art. Unfortunately, when it comes to basic feeding practices for llamas and alpacas, we are short on science and long on art. Scientific reports documenting specific nutrient requirements for camelids are limited. A large portion of the available data comes from research in South America with very different forages from those available here in North America. In most cases, camelid feeding recommendations have been extrapolated from that of sheep and cattle. Available data relative to camelids does suggest a similarity of the digestive process with other domesticated ruminant animals. With a functional understanding of camelid digestive anatomy and physiology, one could make appropriate recommendations based on well-established databases for both cattle and sheep. A National Research Council (NRC) publication describing nutrient requirements for small ruminants includes suggested requirements for llamas and alpacas (NRC, 2007). This review will detail the new nutrient requirement models for llamas and alpacas, summarize current nutrient requirement recommendations, and provide some practical feeding recommendations.

Unique Nutritional Issues

New World camelids are ruminant animals ("chewers of the cud") in that they have an expanded foregut to facilitate microbial fermentation of ingested feedstuffs and they chew their cud. However, camelids are not considered "true ruminants" as a result of some very distinct anatomic and physiologic differences in their digestive tracts compared to the variety of species belonging to the Suborder Ruminantia.

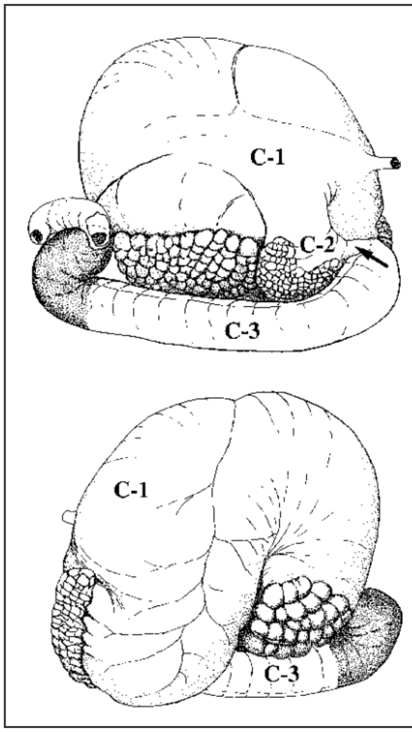

Figure 1. Pregastric fermentation chamber and stomach of camelids (drawing by Dr. Karen Timm).

Foregut Anatomy and Function

The most striking difference between camelid and ruminant digestive tracts is anatomic; camelids having only three distinct compartments associated with the foregut and stomach as compared to the four compartment ruminant organ (Figure 1) (Vallenas et al., 1971). Another unique feature of the camelid foregut is the presence of small saccules in both C-1 and C-2. These saccules are lined with a glandular (e.g., secretory function) epithelium as compared to the stratified squamous (e.g., protective function) epithelium of the remaining area (Vallenas et al., 1971; Rübsamen and von Engelhardt, 1979). A secretory function aiding fermentation buffering capacity has been suggested (Eckerlin and Stevens, 1973). However other investigators have suggested that these saccules aid in rapid absorption of fermentation end products (e.g., volatile fatty acids [VFA]) and solutes (Rübsamen and von Engelhardt, 1979).

Though anatomically different, studies of fermentation characteristics show the microbial fermentation process and end product VFA production for camelids is similar to true ruminants (Vallenas et al, 1971; Vallenas and Stevens, 1971). The microorganisms found in the camelid foregut are the same ones found in other anaerobic fermentation systems (e.g., ruminant foregut and equine hindgut) (Navarre et al., 1999). This observation is also supported by the clinical ability to transfaunate camelids with rumen contents from cattle, sheep or goats.

Motility of the forestomach is a critical function with regard to continual fermentation activity. Foregut motility ensures constant exposure of the ingested feedstuffs to microbial and subsequent degradation. Similar to the true ruminants, foregut motility in camelids occurs in two distinct phases. Beyond this, foregut motility is dramatically different. In camelids C-2 contracts strongly, followed by contraction of the distal aspect of C-1 (A phase). Phase B initiates when the cranial portion of C-1 contracts followed by contraction of C-2 and the caudal portion of C-1. This B phase may repeat itself 3 to 6 times during a cycle before a brief rest period and beginning of a new cycle (Heller et al., 1984). Eructation of gases may occur 3-4 times during each motility cycle. In comparison, camelids have greater forestomach activity compared to the single bi- or triphasic contraction per minute of true ruminants. This increased motility pattern found in camelids may also have some bearing on the observation that these animals are fairly resistant to foregut gas accumulation or bloat as opposed to true ruminants.

Metabolic Differences

Although ruminant animals, camelids show unique aspects to glucose and amino acid (protein) metabolism compared to ruminant animals.

Glucose metabolism in camelids is an enigma. Ruminant animals maintain low blood glucose concentration (<3.88 mmol/L) compared to nonruminant animals (>4.72 mmol/L). Low blood glucose is the result of microbial fermentation of dietary sugars and starches to the volatile fatty acid propionate, with minimal glucose being presented to the small intestine for absorption. Preweaned milk-fed calves are not functional ruminants and will maintain a higher blood glucose concentration similar to nonruminant animals. As the rumen becomes functional, blood glucose will decline to adult concentrations. In contrast to ruminants, llamas and alpacas maintain higher blood glucose concentrations more similar to that of nonruminant animals. Llamas and alpacas also display an extreme hyperglycemic response (blood glucose concentrations >11 mmol/L) in response to even minimal stress situations. Elevated blood glucose can be somewhat explained by recent studies showing a sluggish insulin response and moderate insulin resistance, somewhat similar to a diabetes condition, in llamas and alpacas (Cebra et al., 2001a,b). This diabetic-like situation in llamas and alpacas may account for their high susceptibility to hepatic lipidosis during periods of stress and reduced feed intake.

Urea metabolism. Another unresolved issue with camelids is the normally higher level of urea nitrogen (UN) in their blood compared to ruminant animals (Lassen et al., 1986; Simons et al., 1993). Blood UN concentration reflects protein level of the diet. Low protein diets result in low UN, while high UN is associated with high protein diets or excessive protein breakdown. Higher BUN concentrations in camelids suggest they are being overfed protein relative to requirements, metabolize urea differently from other ruminants, have an inherently high metabolic rate of protein turnover, or some combination (Van Saun, 2006). Results from a llama urea metabolism study would suggest llamas have a lower rate of urea turnover, and kidney urea excretion rate compared to other ruminants (Hinderer and von Engelhardt, 1975). These differences allow the llama to recycle more urea to the forestomach for use by bacteria to produce microbial protein. In addition to recycling more urea to bacteria, llamas have been shown to have greater urease activity, the enzyme needed to metabolize urea, than other ruminants (Hinderer and von Engelhardt, 1975). Greater urea recycling and utilization coupled with slower rate of passage in C-1 are critical physiologic adaptations of camelids allowing them to survive in their native environment under harsh conditions consuming low-quality forages for a significant portion of the year.

The observed elevations in blood glucose and UN concentrations may be linked and a unique metabolic adaptation of camelids. A perplexing issue here is the origin of the observed higher blood glucose concentration in camelids. Like other ruminants, camelids do not absorb much dietary glucose as it usually is fermented in the foregut. Predominantly blood glucose is derived from liver synthesis using precursors in the diet, namely propionate. However, typical diets do not contain significant amounts of starch precursors for propionate production. Amino acids are also a good precursor for glucose synthesis. Camelids may metabolize a fair amount of amino acids to support their blood glucose status, thus accounting for the higher BUN concentrations and suggesting a higher than perceived protein requirement. This metabolic approach requires a higher protein input and may explain why camelids attempt to ferment forage to a greater extent as they are growing bacterial protein that is a highly concentrated protein source, thus allowing them to survive under harsh conditions (San Martin and Van Saun, 2014).

Animal Requirements - Understanding Essential Nutrients

Summarized diets for differing life stages in feeding llamas and alpacas are provided in Table 1. This information provides general recommendations for dietary nutrient density, but actual performance will depend on level of feed intake.

Feed Intake

The foundation of any feeding program is knowing how much the animal eats so the required amount of nutrients can be packaged appropriately into the consumed diet. Although it would seem that camelids are easily compared to other ruminant animals, there is one glaring difference; dry matter intake capacity. Comparative studies between camelids and true ruminants show a slower rate of passage for particulate material through the camelid foregut (Clemens and Stevens, 1980; San Martin, 1987). This slower rate of passage results in feed materials being retained within the fermentation chamber for a prolonged period of time. As a result of the slowed rate of passage, total feed intake, measured as dry matter intake, will be reduced in camelids compared to other ruminant animals. At maintenance, most ruminant animals will consume between 15 and 20 g/kg of body weight as dry matter feed intake. In contrast camelids have been observed to consume between 10.5 and 15 g/kg of body weight as dry matter (San Martin, 1987; NRC, 2007). When intake for llamas and alpacas were adjusted for metabolic body weight (i.e., body surface area to mass ratio), there were no differences between llamas and alpacas, but intake was 26% lower for improved and 36% lower for unimproved pastures compared to sheep (San Martin, 1987). This lower intake capacity must be accounted for when extrapolating nutrient requirements from other species. A lower intake capacity in camelids with similar daily nutrient requirements will result in higher dietary nutrient concentration requirements compared to other ruminants.

Camelids are capable of a more extensive fermentation of ingested feed material compared to true ruminants as a result of prolonged feed retention time. This digestive approach would facilitate a diet composed mostly of highly mature, poorer quality forages. In their natural environment, camelids consume this type of diet. From another perspective, high quality forages like alfalfa may result in excessive fat accumulation when fed to camelids. Granted there is much individual variation, social behaviors as well as feed ingredient-based issues that control feed intake. Very little documentation of feed intake has occurred with camelids leaving a large hole in our ability to properly manage a feeding program. This situation requires that other monitors need to be used to evaluate the adequacy and appropriateness of a feeding program.

The NRC (2007) shows expected dry matter intake (DMI) for llamas and alpacas to range from 10 to 15 g/kg of body weight (BW). Summarized data from South America suggested higher intakes rates of 20 and 18 g/kg of BW for alpacas and llamas, respectively (San Martin and Bryant, 1989). Data from Chile suggested slightly lower DMI expectations for llamas (15 g/kg BW) and alpacas (17 g/kg BW) (Lopez and Raggi, 1992). If models to predict amounts of nutrients required are correct, then these differences in expected DMI will result in variable expectations for dietary nutrient density in providing these nutrients. This may explain differences in dietary energy and protein concentrations between North American and South American feeding guidelines.

To better address these differences studies directly measuring daily DMI in llamas and alpacas are needed. Unfortunately, estimating DMI for animals managed on pasture is extremely difficult. Nine recently published studies were identified that had sufficient individual intake data and adequately characterized feed composition to evaluate expected DMI and dietary factors that might control intake (Carmean et al., 1992; Lopez et al., 1998; Sponheimer et al., 2003; Robinson et al., 2005, 2006; Davies et al., 2007ab; Liu et al., 2009; Jalali et al., 2012). Across these studies with 25 different forage comparisons, averaged DMI was 15 ± 4 g/kg BW for both llamas and alpacas.

Intake potential in llamas and alpacas was suggested to be related to dietary crude protein content with depressed intake resulting from low protein diets. In ruminant animals, microbial fermentation of fiber is the rate limiting step of intake and dietary NDF content is highly associated with feed intake regulation. From these nine studies, relationships between intake and dietary NDF and crude protein content were investigated. Unfortunately, no clear predictive relationships among DMI and protein or NDF intake were identified. In ruminants, NDF intake is maximized at approximately 12 g/kg BW. In these data, NDF intake as a percent of BW was lower (8.7 ± 2.6 g/kg BW) compared with other ruminant animals. This observation would be consistent with fiber retention within C-1 and greater degree of NDF digestibility. Using these data we might set desired NDF intake to range between 8 and 10 g/kg BW as a guideline for predicting DMI potential or identifying amount of needed dietary fiber. It must also be remembered that late pregnant animals and young growing animals will have a lower NDF intake capacity. Based on other ruminant data, NDF intake of 5.5-7.5 g/kg BW might be appropriate for late pregnant and growing llamas and alpacas. Predicted intake potential (% of body weight) can then be determined from forage NDF content and estimated NDF intake capacity (Table 2) in evaluating whether a diet can be reasonably consumed.

Table 1. Suggested feeding groups based on physiologic state and nutrient requirements. More precise dietary needs will be determined by level of production (milk, rate of growth), environmental conditions and desired changes in body condition.

Group	Physiologic State	Feeding Plan	Dietary Guidelines*
Nursing Dams with crias	Lactation	Highest nutrient requirements, feed best-quality forages, with energy/protein supplements	9.1-10.6 MJ ME/kg, 120-140g/kg Crude protein, 8-9g/kg BW NDF, 4.5-6.2 g/kg Ca, 3.2-4.5g/kg P,**
Weanlings up to 1.5 years	Growth	Highest nutrient requirements, feed best-quality forages, with energy/protein supplements	8.3-9.8 MJ ME/kg, 140-160 g/kg Crude protein, 6-8 g/kg BW NDF, 5.3-7.3 g/kg Ca, 2.7-3.8 g/kg P, **
Males >1 year	Maintenance	Low requirements unless working, then adjust accordingly, low-to-moderate quality forage	8.3-9.1 MJ ME/kg, 80-100 g/kg Crude protein, 80-100 g/kg BW NDF, 3-4.8 g/kg Ca, 2.1-2.8 g/kg P,**
Pregnant females 1-8 months	Maintenance	Low requirements, but ensure no loss of body condition, adequate protein, minerals, and vitamins	7.5-8.3 MJ ME/kg, 80-100 g/kg Crude protein, 8-9 g/kg BW NDF, 2-2.4 g/kg Ca, 1.2-2 g/kg P
Pregnant females 9-11 months	Pregnancy	Moderate to high forage quality with supplement for additional mineral and vitamin needs	7.5-10.6 MJ ME/kg, 100-140 g/kg Crude protein, 6-8 g/kg BW NDF, 4.5-5.6 g/kg Ca, 2.8-3.3 g/kg P, **,†
Breeding females	Maintenance	Low to moderate; ensure do not become fat or lose condition	7.5-8.3 MJ ME/kg, 80-100 g/kg Crude protein, 8-10 g/kg BW NDF, 2-2.4 g/kg Ca, 1.2-2 g/kg P
Obese females	Sub-Maintenance	Low; low-quality forages with mineral/vitamin supplement unless pregnant	6.8-8 MJ ME/kg, 80-90 g/kg Crude protein, 8-10 g/kg BW NDF, 2-2.4 g/kg Ca, 1.2-2 g/kg P

*Ensure adequate available water and free choice salt. White salt should be used when trace minerals are included in a supplement. Otherwise trace mineral salt should be available.

**These feeding groups require higher amounts of trace minerals and vitamins preferably delivered by a supplement (refer to text for details).

†Dietary energy and crude protein content may need to be increased further in late pregnancy if dry matter intake drops below 1.5 percent of body weight.

Table 2. Predicted total dietary intake as a percent of body weight (BW) based on the relationship between NDF intake rate and forage NDF content.

Forage Quality	Forage NDF g/kg DM	NDF Intake (g/kg of BW)			
		10	9	8	6
Excellent	380	2.63	2.37	2.11	1.58
	420	2.38	2.14	1.90	1.43
	440	2.27	2.04	1.74	1.36
	460	2.17	1.96	1.82	1.30
	500	2.0	1.80	1.60	1.20
	540	1.85	1.67	1.48	1.11
	580	1.72	1.55	1.38	1.03
	620	1.61	1.45	1.29	0.97
Poor	660	1.52	1.36	1.21	0.91

Energy Requirements

Various simple and complex carbohydrates, including sugars, starches, hemicellulose, and cellulose, are the primary source of dietary energy for camelids. As with other pregastric fermenting animals, the primary source of energy for the host animal is volatile fatty acids, the end product of carbohydrate and protein fermentation. Metabolizable energy (ME) requirement has been determined to be 304.8 kJ/kg $BW^{.75}$ and is not different for llama and alpaca maintenance requirements (Van Saun, 2006; NRC, 2007). Energy requirement for maintenance will be influenced by environmental conditions, activity level, and animal insulation factors. Animal insulation factors include hide thickness, length of fleece, and condition of the coat (i.e., dry, wet, muddy, etc.). These factors lead to either increased to decreased conduction and convection heat losses and depending upon the prevailing environmental conditions (i.e., heat or cold stress) will result in increased energy expenditure to maintain normal body temperature. Though little data are available, ME requirements for other physiologic states (i.e., growth, lactation, gestation, activity) were extrapolated from sheep and goat requirement data (Van Saun, 2006; NRC, 2007).

Based on current NRC intake recommendations, dietary energy density between 7.5 and 12.1 MJ/kg metabolizable energy (ME) will adequately meet maintenance, late pregnancy, and lactational requirements. In contrast, dietary energy density recommendations from South America range from 7.3 to 9.8 MJ ME/kg and 6.2 to 8.9 MJ ME/kg for alpacas and llamas, respectively. The discrepancy between these recommendations is primarily a result of lower intake expectations and slightly higher predicted energy requirements with NRC compared to South American data. A 12.1 MJ ME/kg diet seems excessively high considering corn grain has 13.3 MJ ME/kg. To achieve such a high dietary energy density, one would need to blend 70% corn grain with 30% high quality forage (9.1 MJ ME/kg). The low dietary energy values for the South American recommendations seem too low for North American conditions. Clearly these differences emphasize the need for further investigation into energy metabolism and intake capacity of llamas and alpacas.

The lower dietary energy value for maintenance can easily be met with good to average quality forages with minimal additional grain supplements. Additional energy supplements will be needed in the diet to support late pregnancy and lactation, especially if lower quality forages are being fed. The feeding of poor quality forages, especially grasses, to late pregnant or early lactating animals will require more grain supplementation, potentially predisposing the animal to foregut acidosis (Cebra et al., 1996), or result in body weight loss and increased susceptibility to hepatic lipidosis (fatty liver disease) (Tornquist et al., 2001). More moderate feeding recommendation summaries for various feeding groups are presented (Table 1).

Protein Requirements

There is only a single study that determined maintenance crude protein requirement (3.5 g CP/$BW_{kg}^{0.75}$) of llamas, which is a lower than that estimated for sheep or cattle (San Martin and Van Saun, 2014). Some recent studies from the BYU group have used individual feeding trials to assess protein requirements (Sponheimer et al., 2003; Robinson et al., 2005, 2006; Davies et al., 2007ab). A more recent study has also provided some data for evaluating protein requirement in alpacas (Liu et al., 2009). Although one study (Davies et al., 2007a) suggested a much higher (5.2 g CP/ $BW_{kg}^{0.75}$) for llamas, regression analysis of retained nitrogen onto intake nitrogen per unit of metabolic BW is consistent with the previous protein requirement value. There was a suggestion that protein requirements may differ between high and low altitude, but there is not sufficient data to support this hypothesis.

There are large differences in recommended dietary protein content necessary to support llamas and alpacas in differing physiologic states. The recommendations in the NRC (2007) report suggest 90 g/kg crude protein in dietary dry matter for maintenance. This is in contrast to recommendations in South America that range from 65 to 88 g/kg CP in maintenance diets. Both systems are using the same requirement model, but the difference comes from the differing feed intake expectations.

A protein feeding study was undertaken in Australia, but insufficient information was provided to use this study to assess protein requirement. Of interest in this particular study are the objectives of determining the amount of undegradable protein (UDP) in the diet relative to fiber production and reproductive performance (Blache et al., 2011). Supplementation of UDP numerically increased fiber yield, but diameter was greater in supplemented groups compared with the unsupplemented group. There also was not documented improvement in fiber quality with specific supplementation of the amino acid methionine. Similarly, no beneficial effects of UDP supplementation were found on improvement of male fertility and reproductive development. Clearly more research needs to be undertaken to better clarify dietary protein fractions in llamas and alpacas. At this point in time we should continue to provide dietary protein at current NRC recommendations, adjusted for intake potential.

Mineral Requirements

The primary missing piece of describing nutrient requirements for camelids is the lack of published feeding studies defining requirements for minerals and vitamins. Initially models extrapolated from mineral requirements for beef cattle, sheep and goats in converting a requirement to an amount per unit body weight and adjusting for differences in intake (Van Saun, 2006). These models seemingly depicted current feeding practices but had not been truly validated through controlled feeding trials. As a result, the NRC (2007) did not use any suggested model and instead suggested using the models predicting mineral requirements for sheep. Unfortunately, the models generated by the NRC committee for sheep mineral requirements are based on a factorial approach rather than a dietary concentration. To use these models directly, one would have to assume the bioavailability of mineral sources was similar across species and the utilization of mineral in support of various bodily functions was similar in need and utilization efficiency.

Comparisons were made between the new NRC (2007) requirement models for sheep and goats in generating an appropriate model for llamas and alpacas. A summary of the adjusted recommendations for the microminerals are provided in Table 3. These suggested requirements are within typical feeding practices of llamas and alpacas in North America. These should be considered lower end of requirements and under certain circumstances may be adjusted upward to ensure the desired animal response. Inhibitory mineral interactions are not accounted for in these recommendations, so again dietary mineral content will need to be adjusted accordingly.

Table 3. Suggested dietary concentrations for the essential microminerals in llamas and alpacas for various physiologic states.

Nutrient	**Averaged Requirement[1]**	**Extrapolated Requirement**		
		Intake, mg/day[2]	**Diet, mg/kg[3]**	**Group[4]**
Cobalt	1.76 µg/kg BW	0.11–0.28	0.12–0.15	M, G, P, L
Copper	0.12 mg/kg BW	7.2–19.2	8–12	M, G
	0.15–0.18 mg/kg BW	9–27.2	9–12	P, L
Iodine	8.8 µg/kg BW	0.5–1.4	0.55–0.65	M, G, P
	15.7 µg/kg BW	0.9–2.5	0.65–0.75	L
Iron	0.6 mg/kg BW	36–96	35–40	M, G, P, L
Manganese	0.33 mg/kg	19.8–52.8	22–25	M, G, L
	0.52 mg/kg	31.2–83.2	28–30	P
Selenium	6.5–6.8 µg/kg BW	0.4–1.07	0.42–0.45	M, G
	7–7.5 µg/kg BW	0.44–1.2	0.46–0.5	P, L
Zinc	0.56 mg/kg BW	33.6–89.6	45	M, G
	0.8–1.3 mg/kg BW	60–160	55–60	P, L

[1]Extrapolated from nutrient requirements for beef cattle (National Research Council: *Nutrient requirements of beef cattle*, ed 7, Washington, DC, 1996, National Academy Press), sheep and goats (National Research Council: *Nutrient requirements of small ruminants: sheep, goats, cervids and New World camelids,* Washington, DC, 2007, National Academic Press).
[2]Estimated daily requirement based on a range of adult body weights from 60 to 160 kg.
[3]Dietary concentration (mg/kg) on dry matter (DM) basis. Nutrient density calculations based on an assumed range of DM intake between 12.5 and 15 g/kg of body weight.
[4]Physiologic states of maintenance (M), growth (G), lactation (L), and pregnancy (P) for which the requirement is defined.

Vitamin Requirements

As with other ruminants, it is hypothesized that all necessary B-vitamins are synthesized by bacteria in the fermentation vat and therefore are not required in the diet. However, under certain stress conditions or fermentation disorders, B-vitamin supplementation may be beneficial. Fat soluble vitamins, namely vitamins A, D, and E, are of greatest concern and should be supplemented in the diet. Vitamins A and E will be adequately ingested if the camelids are grazing on fresh pasture. Dietary vitamins A and E may be insufficient when feeding stored sun-cured forages, thus additional supplementation is required (Dart et al., 1996; Smith et al., 1998). Current NRC recommendations consider vitamins A and E requirements for llamas and alpacas to be consistent with other small ruminant species (NRC, 2007), suggesting 31.4, 45.5, 53.5, and 100 retinol equivalents (RE)/kg body weight daily for maintenance, pregnant, lactating, and growing camelids, respectively. Vitamin E recommendations are 5.3, 5.6, and 10 IU/kg body weight daily for maintenance, reproduction, and growing animals, respectively. Many mineral supplements may also contain vitamins A and E to meet this need. Fat-soluble vitamins do not significantly cross the placenta; thus the newborn animal is in a fairly deficient state. Most fat-soluble vitamins are important mediators of the immune response, and if deficient, can increase infectious disease susceptibility. Colostrum is a good source of fat-soluble vitamins is the late pregnant dam is adequately supplemented.

A greater documented problem in llamas and alpacas is a vitamin D-responsive rickets syndrome in neonatal (3-6 months) camelids, which is characterized by hypophosphatemia (Van Saun, et al., 1996). Further investigation has shown a seasonal incidence with this syndrome with highest incidence occurring during the winter months of December to March, coincident with lowest serum vitamin D and phosphorus concentrations occurring during these same months (Smith et al., 2001). These data might suggest a decreased ability of camelids to either absorb dietary vitamin D or synthesize endogenous vitamin D. Further research has shown an appropriate dose response curve to parenteral vitamin D supplementation in treating or preventing the disease (Judson and Feakes, 1999). Additional research on oral vitamin D supplementation has suggested a higher level of supplementation (30-40 IU/kg body weight) compared to other species is necessary to maintain preventive serum vitamin D concentrations (NRC, 2007; Van Saun, 2006).

Other Supplements

There is a wide range of dietary supplements above-and-beyond essential nutrients that are considered for providing in the diet with some perceived function. Most supplements are targeted to improve animal health or performance. Many of the supplements are extrapolated from similar supplements for humans or other species. There is little to no information on how or if these supplements may provide benefit or cause harm to camelids. Use of dietary supplements is totally experimental when it comes to camelids.

Marketed food additives for camelids includes products like antioxidant mixtures, direct fed microbials (probiotics and yeast extracts), sea kelp, herbs and botanicals, single-cell protein supplements, various joint supplements (glucosamine, yucca, chondroitin), fatty acid supplements and the list goes on. For the most part these are not products which are supplying some essential nutrient but are being marketed as products which may facilitate or improve animal performance, health or other facet. In this regard they would be considered a "drug" by the FDA and warrant research to validate efficacy and safety. However, most of these products do not undergo strict evaluation as they are being marketed as nutritional supplements. One of the primary concerns in the lack of regulation of nutritional supplements beyond safety is the tremendous variation in quality control and content of active ingredient. A number of studies have shown many nutritional supplements not to contain as much active ingredient as was listed on their label.

Of these additives the only one having undergone significant controlled research, but not specifically in camelids, is yeast products. There have been a large number (>70 studies) of research studies or research summaries indicating a strongly positive response in animal performance when fed yeast products. The effect seems to be to improve microbial growth and efficiency of fermentation in the rumen of cattle or other ruminants. One would consider a similar positive effect in the fermentation vat (C-1) of camelids. This brings up an important point to consider. Most feed additives or dietary supplements are targeted to non-ruminant animals or humans; thus one needs to consider what impact, positive or negative, the dietary supplement will have on the fermentation vat in camelids. In many cases the compound administered may be degraded or significantly altered by microbes of C-1 and not have the same impact as seen in other nonruminant species. We cannot directly extrapolate the use of dietary supplements between species.

Feeding Management - Role of Feeding Behavior

Feeding management is that part of the science of nutrition that enters the realm of art. In many instances one could feed the exact same ration to animals on two different farms and observe completely divergent responses. Feeding management is the integration process of providing an adequately formulated diet to the proper animals in a manner which results in sufficient consumption to meet daily nutrient needs. Factors to be considered in feeding management concerns include feed availability, environment, housing facilities, and animal grouping strategies.

Feeding system facilities means size, number, and placement of hay feeders or amount of pasture and expected stocking density. All these factors need to be considered in properly providing adequate nutrients to all animals. The environment in which the animals are housed should also be considered. How good is the ventilation when the animals are inside? Do the animals have to wade through knee-high mud to get to pasture or hay racks? What kind of feed storage facilities are needed to support the number of animals? What kind of animal segregation can be accomplished with the facilities?

Animal grouping is an important aspect of feeding management. After all we have just discussed how animals in different physiologic states have different nutrient needs. A proper feeding program should have the capability to segregate different animal groups in order to feed to meet their specific nutrient needs.

Most operations would not have the capability to separate out this many groups; however, a number of these groups could be combined as a result of similar requirements. When groups are combined, one needs to be aware of the possibility of overfeeding one or more individuals and make appropriate adjustments. Many llama and alpaca feeding systems are based on individual feeding, which allows one the greatest flexibility in more precisely meeting the daily animal needs.

One other consideration is the proper feeding of the newborn and growing animal. Of first concern is the ingestion of an adequate amount of good quality colostrum or a sufficient substitute (cow or goat colostrum). Neonatal camelids will begin to nibble at dry forage within the first week of life. It is extremely important to remember that the fermentation process in the foregut is not present at birth and needs to be developed over time. Weaning usually occurs between 4 and 6 months of age. Even though fermentation end product concentrations are similar to adult values at 12 weeks of age, this does not mean that the weanling can be placed on adult diets. The higher nutrient requirements to support growth and the less efficient fiber fermentation system of the young animal all support the need for a little special care diet wise to ensure continued good growth and performance. Nothing can set a recently weaned animal back more than a poor quality diet. One can monitor body weight of growing animals to assess adequacy of their postnatal feeding system.

Role of Feeding Behavior

One final piece to the feeding management puzzle is feeding behavior. If one is to have a successful feeding program, irrespective of facility planning, an understanding of the animal's feeding behavior and how it may be impacted by social behaviors is needed. Llamas and alpacas, like other domestic species, establish and reestablish a strong social hierarchy, which can derail a well-planned diet. Feeding behavior defines what forages are preferred by llamas and alpacas and how selective they may be in consuming other available forages in an environment. The more selective the feeding behavior, the more adaptable the animal is too harsh conditions. An animal's ability to select feeds is dependent upon two factors: anatomy and feed availability. Both the llama and alpaca have a narrow muzzle and prehensile lips that allows them to be extremely discriminatory in selecting feed to be consumed.

Llamas are considered more of an intermediate browser, preferring to consume some forbs (weeds) and browse (leafy plants) along with grasses. In contrast the alpaca is considered more of a grazer, not preferring to consume forbs and browse. However, forbs and browse have been observed to account for a significant proportion of the alpaca diet in Peru. What this says is that given the opportunity, llamas and alpacas will make good use of non-grass forage as part of their diets. Therefore, feeding management programs that minimize the camelid's nature ability to forage are more critically dependent upon forage quality concerns. These comments are not inferring that overrun weedy pastures are the preferred feeding management system for camelids. A comparison of nutrient requirements to different forages and blackberry leaves shows the potential nutritional value of allowing camelids to browse some forbs (Table 4).

Often the question of forage type is asked relative to feeding llamas. Is alfalfa better than grass or visa versa? There really is no simple answer. Alfalfa hay has received much negative press relative to feeding camelids in that it is often associated with causing obesity. Situations of malnutrition or deficient energy intake where alfalfa was fed have not been documented. In contrast, most cases of malnutrition, hepatic lipidosis, or other energy deficiency problem have been associated with grass hay feeding programs.

One needs only to understand the difference between alfalfa and grasses relative to the relationship of stems and leaves in each plant. Alfalfa has a very distinct leaf and stem. As the plant matures, the stem thickens but this does not significantly impact nutrient availability in the leaf. With the selective feeding ability of the llama, the alfalfa leaf could be preferentially consumed, thus potentially leading to obesity problems. In situations where mature alfalfa is being fed, the animal can compensate for the low forage quality by primarily consuming the leaves. The llama does not have this luxury with the grass plant. In grasses the leaf and stem are one in the same. As the grass matures and becomes more lignified, nutrient availability is greatly reduced and the animal cannot compensate for low forage quality with selective feeding behaviors if no other forage source is available. Thus, the association of more animal health problems with mature grass forages.

Table 4. Comparison of nutrient content of legume and grass hays, pasture and blackberry leaves to suggested nutrient requirements for camelids.[1]

Nutrient	Estimated Require-ment	Mean (Range) Nutrient Content			
		Mixed Mostly Legume Hay	Mixed Mostly Grass Hay	Mixed Grass Pasture	Blackberry Leaves
	- - - - - - g/kg of dry matter - - - - -				
Crude Protein	80 - 160	170 (136-204)	120 (83-157)	202 (140-263)	136 (125-152)
ME[2], MJ/kg	8.0 – 9.8	8.65 (8.15-9.14)	5.12 (7.96-8.99)	9.44 (8.59-10.3)	9.72 (9.53-9.83)
NDF[2]	> 300	497 (419-576)	608 (537-680)	519 (419-619)	349 (311-392)
ADF[2]	> 200	353 (304-402)	388 (342-435)	308 (247-369)	266 (244-306)
Calcium	2 – 7.5	12 (8.8-15.2)	7.1 (4.3-9.9)	6.6 (4.0-9.2)	12 (8.4 – 16.2)
Phosphorus	1.6 – 4.0	2.9 (2.3-3.5)	2.7 (1.9-3.4)	3.6 (2.5-4.7)	2.5 (1.6 – 3.6)

[1]Forage analysis data from Dairy One Forage Laboratory, Ithaca, NY (www.dairyone.com)
[2]ME = metabolizable energy; NDF = neutral detergent fiber (a measure of total fiber); ADF = acid detergent fiber (a measure of indigestible fiber).

Body Condition Scoring

There are a number of ways one can determine nutrient adequacy. By far, the single best method is body condition scoring. Body condition scoring is a method which subjectively grades animals by amount of subcutaneous fat stores over the loin, pelvis, and tailhead into five categories covering physical states of emaciated (1), thin (2), average (3), fat (4) and obese (5) (Figure 2). Alternative scales are also used grading animals from a 1 to 9 scale (Hilton et al., 1998; Johnson, 1994). As with sheep, to body condition score a camelid one needs to palpate through the fiber coat to feel the ribs, loin, and pelvis for thickness of fat cover. Important times to assess body condition score would be during early to mid-pregnancy; early to mid-lactation and periodically to other animals of the herd to assess energy status (Hilton et al., 1998). As a diagnostic tool, body condition scoring is the least expensive and yields excellent information relative to animal energy balance. However, body condition scoring is often overlooked as a herd management tool because it is viewed as being too time consuming.

Summary

Nutrition of llamas and alpacas is not necessarily complicated, though some unique differences provide some challenges. The intent of this review was to provide readers with a strong foundation on which to make sound decisions, based on functional knowledge, relative to their feeding management approaches. The current state of knowledge on llama and alpaca nutrition is limited, but growing with many essential components being available. Given the majority of financial resources needed to maintain a camelid herd goes to nutrition, owners also need to be informed in various aspects of agronomy. Understanding the fundamentals of forage growth and its impact on composition is absolutely essential to making a nutrition program work. Distributing available forages to match quality with animal requirements will provide the greatest return on investment through improved animal health and performance. The final phase is knowledge application-- integrating issues of animal numbers, forage resources, and handling and feeding facilities into an economically sound nutrition program designed to maintain good animal health and meet desired level of productivity.

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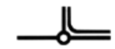
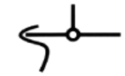
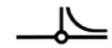
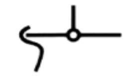
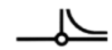
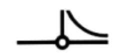
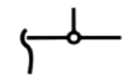
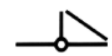
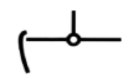
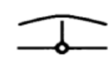
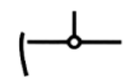
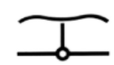
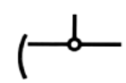
Figure 2. Body condition scoring chart for llamas and alpacas. Degree of fatness is assessed by hands-on palpation of four defined areas as shown. Transverse processes of the spine and the paralumbar fossa are located in the region behind the ribs and in front of the pelvis (on last page of notes).

Body Condition Scoring Sheet for Camelids

	Score	Animal Description	1 Frontal Profile	2 Rear Profile	3 Spinous to Transverse Process	4 Paralumbar Fossa
Emaciated	1.0	No visible or palpable fat or muscle between skin and bones. Ribs, dorsal spinous and transverse processes, and pelvic bones are individually prominent. Extreme loss of muscle mass.	Prominent "V" Keel	Acutely Inverted "V"	 Deep depression	Gaunt, tucked-in fossa 
Poor	1.5					
Thin	2.0	Slight cover over bony structure. Ribs, spinous processes still visible and easily palpated as sharp. Less muscle mass loss.	Gradual Flattening of Sternum	Gradual Filling of "V"	Obvious depression	Prominent shelf
Borderline	2.5					
Moderate	3.0	Overall smooth appearance. Slight fat cover over ribs and other bony processes. Ribs and spinous processes can be palpated with slight pressure. No muscle mass loss present.			 Smooth concave curve	 Slight shelf
High Moderate	3.5		Moderate fat	Moderate fat	 Smooth slope	
Excess	4.0	Fleshy appearance with visible coverage of fat. Moderate to firm pressure necessary to palpate bony structures under skin.				No shelf
Fat	4.5				Nearly flat	 Edge barely discernable
Grossly Obese	5.0	Excessive fat cover over entire body with smooth, rounded appearance. Bony prominences cannot be palpated, even with firm pressure. Bulging fat pads visible around tailhead.	Sternum Bulging in fat	Inguinal Area Bulging in fat	 Rounded	 Buried in fat

Adapted from Edmonson et al., JDS 1989;72:68 and Russel, A. Body condition scoring sheep, Sheep and Goat Practice 1991.