INTRODUCTION

The National Research Council (NRC) was established in 1916 by the National Academy of Science to increase the scientific and technical knowledge of the government, the public and the scientific communities. The Nutrient Requirements series has been one of the most widely utilized publications prepared by the National Research Council. Nutrient Requirements of Small Ruminants was published in 2007 and was designed to provide information about the nutrient requirements, dietary habits and management of sheep (*Ovis aries*), goats (*Capra hircus*), cervids (white-tailed deer [*Odocoileus virginianus*], red deer [*Cervus elaphus*], elk wapiti/American [*Cervus elaphus*], caribou/reindeer [*Rangifer tarandus*]), and New World camelids (alpacas [*Lama glama*] and llamas [*Vicugna pacos*]).

This publication provides 25 years of new research information since the last published reports for sheep (*Nutrient Requirements of Sheep, 6th edition, 1985*) and for goats (*Nutrient Requirement of Goats, 1st edition, 1981*). This is the first time that a report has been published by NRC regarding other small ruminants specifically, cervids or members of the deer family and though not true ruminants New World camelids (alpacas & llamas) have also been included in this publication.

BASIS

Small ruminants comprise a large number of animals throughout the world that produce a significant amount of food and fiber. These domesticated animals plus wild ruminants have a significant impact on both economic as well as environmental factors around the world. This report undoubtedly has the most diverse audience of any previous publication in the *Nutrient Requirement* series. *Nutrient Requirements of Small Ruminants* was designed for not only nutritionists and livestock managers but also biologists, ecologists and environmental scientists with different levels of understanding and technical expertise. Thus portions of this report may be too technical for some readers while others too simplistic.

This publication contains many of the basic topical chapters such as energy, protein, minerals, vitamins and water. There are chapters that discuss unique health and management issues with small ruminants, anatomical and physiological characteristics of the different ruminant types, and the physical and chemical nature of the plants and how that affects utilization and selection by the different classes of small ruminants. Another chapter discusses environmental impacts of small ruminants and how this can be managed. There is a chapter that focuses on the practical use of this information and how a reader can determine the nutrient requirements for ration formulation or evaluation without studying the previous chapters. Finally, there is a section that
contains nutrient requirement tables for sheep, goats, cervids and New World camelids plus feedstuff composition tables that contain typical as well as unusual feed ingredients.

NUTRIENTS AND NUTRIENT REQUIREMENTS

Energy, protein, lipids, minerals and vitamins are each discussed in individual chapters. The equations and methods used to determine requirements are described in detail and pertinent research is cited. In most cases, nutrient requirements were determined by the factorial method. Thus, separate estimates were determined for maintenance, daily tissue gain, fiber production, pregnancy and lactation to estimate an animal’s overall nutrient requirement. This method was used to construct the nutrient requirement tables in this publication. However; all the equations are available in this report so that the user can develop new requirements for unique or specific feeding situations.

In most cases there was sufficient data to develop sheep and goat nutrient requirement estimates but in some cases that data was extrapolated using data from other species. This occurred frequently when requirements for minerals and water for cervids and New World camelids were estimated and were extrapolated from sheep, goat or cattle data. Less frequently, requirements for goats were extrapolated from sheep or cattle data.

Throughout this report there is general discussion that pertains to all small ruminants and when there are unique differences between types of small ruminants they are noted. In other sections of this publication, as in the energy chapter, each species is discussed separately.

The nutrient requirement tables are much more descriptive than in earlier reports. The user will find more types or classifications of productivity descriptions based on body size, daily gain, age, gender, maturity pattern and milk production for sheep and goats. With significantly more data available and the increase in genetic potential, the ability to accurately estimate nutrient requirements is beneficial to the practicing nutritionist and animal manager.

The user will also find new and more detailed nutrient terminology. Energy requirements are now described in terms of total digestible nutrients (TDN), metabolizable energy (ME), or net energy of maintenance and gain (NEm & NEg). Previously protein requirements were listed as crude protein; the Nutrient Requirements of Small Ruminants 2007 report utilizes crude protein as affected by degradability (UIP), metabolizable protein (MP) and degradable intake protein (DIP). For the experienced ruminant nutritionist this is simply adoption of terminology used in the Beef (2000) and Dairy (2001) NRC reports.

Energy

A detailed discussion explains the effects that feed intake, genotype or biotype, mature body size, age, gender, body composition, activity level and environment have on energy requirements. Nutrient Requirements of Small Ruminants assumes that energy requirements are species specific and thus both discussion and methodology are presented separately for sheep, goats, cervids & camelids.
Sheep. The Cornell Net Carbohydrate and Protein System for Sheep (CNCPS-S) model developed by Cannas et al. (2004) has been used to predict energy requirements in the tables found in the Nutrient Requirements of Sheep tables. This decision was based on the fact that when compared to the 1985 NRC sheep method to determine energy requirements neither system was found superior - plus, the CNCPS-S method also estimated protein requirements and allows for body weight loss calculations. Both methods are described in the text and if the user wants, can calculate energy requirements using either methodology.

Goats. Energy requirements for goats are based primarily on research and report summaries conducted by Sahlu and coworkers. These studies were based on regression analyses of a goat research database gleaned from the literature. It was felt that this was preferable to other systems that were based on extrapolated data from other ruminant species. Equations for calculating the different energy components are found in the report allowing the user to calculate custom energy requirements for different biotypes.

Cervids. Energy requirements for cervids are based on published values for white-tailed deer, reindeer/caribou, red deer and elk/wapiti. Because data are limited, many of the estimates are based on extrapolation from other species and interpolation and were combined with published data to estimate energy requirements. More research is needed to improve confidence in cervids’ estimated energy requirements.

Camelids. Limited research is available to estimate the energy requirements of llamas and alpacas. Van Saun (2006) reviewed research of the nutrient requirements of alpacas and llamas and presented rationale to develop nutrient requirements similar to other ruminant animals to allow the use of the factorial approach to estimate energy requirements. Equations are provided to estimate energy requirements and are based primarily on sheep and goat data. There is a look-up table in the final section of the report that provides estimates of energy requirements of New World camelids.

Protein

*Nutrient Requirements of Small Ruminants* recommends metabolizable protein (MP) as the preferred method of estimating protein requirements. However, because of application problems with MP or preference of some users accustomed to crude protein, NRC (2007) suggests a simple conversion of MP to crude protein (CP) found in NRC (2000). \( CP = MP/((64 + (0.16 \times \% \text{ UIP}))/100) \). This is a useful method of estimating CP from MP needs except when microbial growth is restricted by factors such as low rumen nitrogen availability. Estimates for both crude protein and metabolizable protein requirements can be found in the look-up tables for all the small ruminant types mentioned above.

Factors that affect protein requirements are discussed. Parasitism, gender, previous plane of nutrition, heat and cold stress, all affect protein requirements of small ruminants. Growth, lactation, fiber growth, pregnancy, and antler growth and their impact on protein requirements are also outlined in this publication.
Amino acid requirements for small ruminants are discussed and in general are felt to be similar to beef and dairy except for greater sulfur-amino acids required for wool and mohair production. The publication suggests that the most limiting amino acids for small ruminants, in descending order, are methionine, lysine, arginine and histidine.

**Sheep.** The CNCPS-S model developed by Cannas et al. (2004) has been used to predict protein requirements found in the Nutrient Requirements of Sheep tables and, this system is recommended when developing custom protein requirements. There are several modifications or additional considerations suggested and explained in the report for pregnancy, lactation and growing/finishing lambs. The authors of this report state that the metabolizable protein requirements generated from CNCPS-S may be in the low to average ranges and that additional protein may be justified. Users of this report will find a significant increase in the amount of crude protein recommended when compared to the 1985 Sheep NRC publication.

**Goats.** Protein requirements for goats are based on reports summarized by Sahlu and co-workers. It was felt that the equations developed by these workers using only goat research were preferable to models that used data from other ruminant species. Equations and estimates for maintenance, tissue gain, lactation and pregnancy are presented in the report and can be used to develop specific metabolizable protein requirements for different biotypes of goats.

**Cervids.** Metabolizable protein requirements for cervids are based on published data from white-tailed deer, reindeer/caribou, red deer and wapiti/elk research. Equations for determining MP for maintenance, tissue gain, pregnancy and lactation are presented and methodology discussed. Future research is needed to improve the confidence of these estimated protein requirements.

**Camelids.** Little research is available to estimate the crude protein requirements of llamas and alpacas. Van Saun (2006) reviewed research of the nutrient requirements of alpacas and llamas. He presented two different approaches to develop crude protein requirements similar to other ruminant animals to allow the use of the factorial approach to estimate crude protein requirements. Equations are provided to estimate crude protein requirements and are based primarily on goat data.

**Minerals**

The *Nutrient Requirements of Small Ruminants* report has an excellent and detailed explanation of mineral nutrition. For each mineral there is general discussion of purpose followed by specific mineral requirements for each subgroup: sheep, goats, cervids and camelids and, the methodology used to determine each subgroups mineral requirement. When possible, mineral requirements were determined by the factorial method and estimates of mineral requirements are presented in the last section of the publication for each subgroup.

In most cases, homeostasis, deficiency and toxicity for each mineral are discussed for the 14 essential minerals. There is also information provided on the potentially essential or toxic minerals aluminum, boron, cadmium, chromium, fluorine, lead, lithium, mercury, nickel, rubidium, silicon, tin and vanadium.
Vitamins

The fat-soluble vitamins A, D, E and K and the water-soluble B-vitamins and Vitamin C are reviewed for small ruminants with classic discussions about metabolic function, requirements, sources, deficiencies and possible toxicities. In general, the committee on Nutrient Requirements of Small Ruminants recommends supplementation for only Vitamins A and E based on research available. Recommended levels of Vitamin A and E are found in the look-up tables in the back of the report for each subgroup of small ruminants.

The remaining vitamins are either found in sufficient amounts in feedstuffs or produced in sufficient quantities by exposure to sunlight (Vitamin D) or by microbial synthesis (B-Vitamins) to meet animal requirements. The report suggests that there are high-production or stress situations when supplementation of B-vitamins may result in improved rumen microbial metabolism, immune response and animal performance.

The user should note that Vitamin E requirements for sheep in this report are significantly higher than what was recommended in the 1985 Sheep NRC publication. The subcommittee is recommending 10 IU of Vitamin E/kg of body weight. This recommendation results in a Vitamin E requirement of 500 to 800 IU per day. Justification for this was based on possible low selenium status, immune response and increased storage case life of lamb meat.

Water

An excellent discussion on water distribution, water intake, water loss, water sources and how water intake affects dry matter intake is provided. The impact that physiological function, species and environmental stress have on water utilization and need is also covered. As with other nutrients, the factorial approach to estimate water requirements is used and equations are provided in the text.

OTHER CHAPTERS

The remaining chapters in Nutrient Requirements of Small Ruminants provide information on the physical and chemical makeup of plants and how these factors affect nutrient availability – both negatively and positively. Emphasis is placed on carbohydrate type, content and nutritive value and how best to relate nutritive value to animal response.

There is a chapter on nutrient source and feeding practices that discusses how feeds are evaluated and the use of the nutrient composition tables contained in this report. Feeding systems can be used that maximize nutrient composition and animal performance and minimize or reduce the impact that animal production has on the environment.

Another chapter provides a review of common diseases and metabolic problems that result from feeding small ruminants. There is also information provided on metabolic modifiers and their impact on nutrient utilization and effect on subsequent animal performance.
TAKE HOME MESSAGE

_Nutrient Requirements of Small Ruminants_ (2007) is a much needed update to outdated NRC reports for sheep (1985) and goats (1981). This report (it’s a book!) provides users with significantly more detailed and current nutrient information and requirements and allows the user to develop unique or custom requirements based on the factorial method. This report, for the first time, provides nutrient and management information on Cervids and camelids.

This publication is not without controversy, the user should be aware that levels of some nutrients are significantly different from previous recommendations and should appreciate that NRC _Nutrient Requirements_ publications are guidelines.

LITERATURE CITED


