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Goat nutrition in Australia - Literature review

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Executive summary

The foundations of profitable animal production systems include market demand, processing facilities, genetic potential for growth and production and a sound knowledge of the nutritional requirements of livestock which underpin cost-efficient productivity. The diversity of genotypes in the Australian goat population and the starkly contrasting environments where goats exist or are farmed increases the complexity of their nutrient requirements. Much of the research into goat nutrition has been undertaken in tropical environments and the relevance of this to Australian conditions and goat populations remains unclear.

The Australian rangeland goat appears well adapted to its environment whereas Boer goats, imported for their superior growth potential, appear less well suited to either rangeland or intensive production systems.

The purpose of this review was to thoroughly investigate the gaps in nutritional information to support future investment decisions by Meat & Livestock Australia to underpin the growth of the goat industry. The terms of reference were as follows:

- Clarify the nutritional requirements for goats
- Determine how and why publications vary widely in their recommendations
- Determine the variation in nutrient requirements between rangeland, Boer, Boer-cross, dairy and fleece-producing goats and their progeny
- Investigate the alignment between the recommendations and animals response to a range of feeding regimes and practises

This review has provided confirmation that the guidelines for the nutrient requirements of goats vary widely and that there remains a diversity of opinion as to which is the correct source of information. NRC (2007) has published the most comprehensive set of recommendations following an extensive review of published research from 1981 to 2006 however these guidelines require validation under a range of environmental conditions.

Satisfaction of daily nutrient demand is assumed to be reliant on dry matter intake however no allowance has been made for when intake is restricted for any reason; this is of particular importance for goats where the phenomenon of “winter stasis” has been identified as an important factor limiting productivity. Their unique oral structure and inherent ability of goats to select the most nutritious components of plant material ensures their survival in rangeland areas when sufficient feed is available however pastoralists may benefit from education programs directed at the identification of key indicator species to assist in early destocking decisions. Depot nutrition is becoming increasingly important and it is clear that producers would benefit from some education about nutritional management of goats under confined conditions.

The recommendations for daily energy requirements of goats in the literature vary predominantly in line with the key differences between NRC (1981) and NRC (2007) such that the former attributed an activity allowance for ME_m and the latter did not. It appears the main reason for this change is based on the presumption that goats will have access to grazing and hence nutrient intake while walking. NRC (2007) acknowledges that these recommendations require field evaluation. Once validation has been undertaken, producers will benefit from the development of a set of simple set of guidelines for their genotype and a concurrent education program of implementation.

It is well understood that the protein requirements of goats increases with an increasing level of productivity such that the protein requirements of lactating goats of any genotype are likely to be higher than that required for maintenance. As pasture species mature, protein concentration declines however the change in nutritive value of some perennial shrubs such as the saltbushes, appears more random. Of greater interest is the ability of goats to adapt to pasture species that provide excessively high protein concentrations in winter and spring; Boer and Boer-cross goats in medium to high rainfall environments exhibit severe symptoms of lameness and scouring under these conditions and appear to have low resistance to internal parasites. It should be noted that within these environments there are many animals that are not affected providing a positive outlook for genetic selection.

Although the majority of goats producers and their advisors are of the opinion that goats require a diet that is high in fibre there is a plethora of evidence demonstrating a similar preference for a highly digestible diet to sheep where it is available. It is the opinion of this author that the degree of environmental adaptation may determine a goat’s preference for fibre such that within a rangeland environment where selectivity is high, goats may be eating a more digestible diet than is immediately apparent. As for all ruminants, a minimum level of effective dietary fibre is required to maintain a neutral pH in the rumen to facilitate digestion.

The mineral nutrition of goats particularly under intensive farming regimes requires urgent attention; the requirements of goats for key nutrients such as copper appear significantly different to sheep and it may be that acute mineral deficiencies are partially responsible for the productivity constraints of intensively farmed goats.

As goats have prolific reproductive capacity, it is likely that the application of the current nutritional strategies for ewes may be of benefit to does; these include stimulation of ovulation rates with a sudden increase in the plane of nutrition pre joining and particular emphasis on late pregnancy nutrition to increase kid survival. These intensive strategies are unlikely to be of practical benefit in an extensive pastoral environment and there may be differences in the cost-effective responses between genotypes.

Although the optimum weight and age for weaning has yet to be determined, it is apparent that Boer and Boer cross kids have similar growth potential to lambs when fed a high quality diet and that their requirement for protein may be less than that of lambs. Where it is cost-efficient to do so, kids respond well to lot feeding providing they have prior introduction to the feedlot diet pre-weaning.

Optimisation of transitional feeding of goats in depots prior to transport is impeded by the lack of time to adapt to a change in feed such that the focus is one of weight loss minimisation rather than weight gain or productivity. As the pregnancy status of these goats is unknown and nutritional requirements increase significantly as pregnancy advances it is clear that a maintenance diet may not always be appropriate. The cost-efficiency of improved feeding strategies was outside the terms of reference of this review but needs to be determined; depot managers would benefit greatly from improved nutritional information.

At the end of each chapter of this review recommendations for further research have been suggested for consideration. Validation of the most relevant nutrient requirements for goats would provide the industry with a platform on which to expand with a higher degree of confidence than currently exists.

Recommendations for further research

1. **Dry matter intake**
    - Clarify the dry matter intake requirements of all classes and genotypes of goat
    - Determine the appropriateness or otherwise of the application of an activity rating for grazing goats
    - Ensure pastoralists are familiar with their key indicator species and how to monitor their decline
    - Ensure goat producers and managers of depots and intensive operations understand how to assess dry matter intake such that nutrient intake can be adjusted if dry matter intake is sub-optimal
    - Investigate the phenomenon of winter stasis as a priority such that remedial measures can be implemented

2. **Energy requirements**
    - Determine the energy requirements for mature goats under field conditions – validation of NRC, 2007 recommendations
    - Validations should include a range of genotypes, pastures, supplements and liveweights
    - Determine an appropriate activity rating for ME above maintenance for grazing goats of different genotypes where appropriate
    - Develop a user-friendly, practical set of ME guidelines for goat producers and their advisors
    - Develop education programs for goat producers to improve their understanding of goat nutrition and management

3. **Protein requirements**
    - Clarify the protein requirements of goats including variation across genotypes where appropriate
    - Determine the cause(s) of lameness in medium to high rainfall regions
    - Investigate the role of excessive dietary protein in the poor productivity of Boer goats and their crosses in medium to high rainfall areas
    - Develop education programs for goat producers in nutrition and health management
    - Investigate the cost-effectiveness of urea inclusion as a protein source in the supplementary feed rations of weaned kids and confined goats
    - Consider embryo transfer and artificial insemination programs to hasten the increase of well adapted Boer and Boer cross genetics in medium to high rainfall regions

4. **Fibre requirements**
    - Develop education programs for goat producers and their advisors to improve their understanding of the fibre requirements of goats and how to apply that knowledge to their enterprises

5. **Vitamin and mineral requirements**
    - Verify the daily mineral requirements of domesticated goats
    - Determine the links between copper deficiency, lameness and scouring in goats
    - Determine the daily requirement of copper supplementation for goats
    - Verify the length of activity of 3 year selenium capsules in goats
    - Determine the relationship between production losses and mineral deficiencies in medium to high rainfall areas

6. **Water requirements**
    - There does not appear to be any requirements for further research into the water requirements of goats

7. **Nutrient requirements of reproductive goats**
    - Validation of the nutrient requirements for reproductive does of all genotypes as considered appropriate
    - Investigation of an appropriate activity rating to be applied to all nutrient recommendations for pregnancy and lactation
    - Development of a set of comprehensive and practical set of nutrient guidelines for reproductive does for use by the goat industry
    - Application and validation of the current and well researched nutritional strategies for ewes as they may apply to goats

8. **Nutrition of weaned kids**
    - Determine the appropriate age and weight for weaning kids of each genotype to optimise productivity and survival
    - Provide education program for producers and their advisors in the nutritional management of the reproductive herd so as to optimise weaner potential
    - Consider identification and selection of more resilient genotypes within the Australian goat herd within environments – review the uptake, implementation and outcomes for producers of Kidplan® as a practical and cost-effective selection tool
    - Investigate the cost-efficiency of lot feeding weaners to reduce morbidity and mortality in all environments following similar principles as have recently been developed for lambs

9. **Depot nutrition**
    - Information sessions for depot managers and their staff about the management of ruminants in confinement and strategies for rapid adaptation to feed
    - Clarification of the current mortality rates and their causes
    - Clarification of the current weight differential during depot confinement
    - Determination of the rate of adaptation to a pelleted diet in depots
    - Development of a set of guidelines for depot management

10. **Parasitism and nutrition**

- Clarify the protein requirements of goats
- Determine if parasitism is associated with low protein intake in goats
- Investigate the potential for CT- containing, pasture species as an aid in worm control
- Consider the genetic selection of goats apparently more resistant to worms as a longer term management tool for goat breeders

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Introduction

The Australian goat population is highly diverse consisting predominantly of rangeland goats, previously known as bush or feral goats, and domesticated goats the breeds of which are detailed in Table 1 (Schuster 2011)

Table 1 Recognised breeds of domesticated goats (Schuster 2011)

Dairy	Meat	Fibre
Saanen	Boer	Angora
Toggenburg	Kalahari Red	Cashmere
British Alpine	Savannah	
Anglo Nubian		
Australian Melaan		
Australian Brown		

The nutritional aspects of goat production in tropical regions have been well researched over recent years (Morand-Fehr 2005) however differences in methodologies used by researchers, genotype and environmental differences make comparison between studies difficult; further the relevance of tropical goat nutrition to Mediterranean and temperate environments remains unclear.

One major constraint to assessing the nutritional recommendations for goats from online publications is where the genotype of the goats is unspecified. There are vast differences between the genotypes of goats such that dairy, meat, rangeland, desert and fibre producing goats are unlikely to have similar mature weights or to grow at similar rates from birth to maturity; hence their nutritive requirements are likely to be different. Accurate and reliable determination of nutrient requirements of goats is a challenging task as significant variation exists between authors and publications as well as across genotypes and between classes of goat.

From a nutritional perspective, the composite bush goat appears well adapted to the Australian rangeland environment in terms of superior digestive physiology. Goats have demonstrated prolonged retention time of digestive material, enhanced ability to digest cellulose which may be attributed to their efficient recycling of urea from the bloodstream to the rumen (Devendra 1989). Middle Eastern goats have a rumen with a larger surface area per unit of body weight than sheep (Bhattacharya 1980) for efficient absorption of volatile fatty acids and enhanced buffering capacity. Goats secrete greater volumes of saliva per unit of feed intake than sheep (Domingue *et al.* 1991a) favouring more efficient recycling of urea when grazing low quality forages.

However the optimum time required for adaptation of the digestive system of the goat to a highly digestible, low fibre diet under high rainfall pastoral conditions where Boer, rangeland goats and their crosses struggle to perform, remains unclear. There is evidence from the field situation that individual goats adapt well, but as a herd they appear constrained by severe lameness and poor resistance to parasites; however in many herds it is encouraging to see that there are individuals from which more resistant genotypes offer the potential for selection. Sheep breeds such as the Dorper which have been bred under range conditions in South Africa and imported into Australia demonstrate similar adaptive difficulties in high rainfall environments as their Boer goat counterparts.

Kid mortality is reportedly high at around 40%; mothering ability of does is generally poor, with chronic lameness and parasite infestation being major impediments to productivity and welfare.

Producers cite animal health and nutrition as their greatest challenges to the successful production of goats in southern Australia.

Factors that influence daily nutrient requirements include level of activity (confined vs open range), environment (adaptation; heat and cold stress), season, gender, stage of pregnancy and lactation, quality and quantity of milk production, growth potential and diet quality such that no simple rules of thumb will be likely to result in optimal levels of productivity.

There is an increasing amount of evidence both anecdotal and within the published literature that all ruminant species have their individual characteristics, such that knowledge derived from work with one species may not necessarily be applicable or transferable to another (Zhao *et al.* 2011), however many of the published nutrient requirements for goats have been derived from those recommended for sheep and/or cattle (NRC 1981).

Lu *et al.* (1988) observed that goats differed from other ruminants in their feed intake, diet selection and feeding behaviour and in their intake rate. In an extensive review of feedstuff digestibility of goats in comparison with other ruminants, Louca *et al.* (1982) found the digestive systems to be quite similar. Comparative capacity of the stomach with the reticulorumen was larger (85%) in goats than sheep (73%) and cattle (64%). Goats demonstrated superior ability to digest low protein, high fibre forages, maize and lucerne. Goats had increased populations of cellulolytic bacteria for fibre digestion with increased urea cycling.

Silanikove (1996) observed that desert goats had increased ability to digest lignified fibrous material than non-desert goats and other ruminant animals. Goats appear more efficient at chewing and rumination, have increased concentrations of microbial protein production and are able to select high quality plant components from a broader range of vegetation types.

The nutrient requirement per unit of dry matter of goats exceeds that of most ruminants due to their small body size (Poore and Luginbuhl 2002). Their ability to graze, browse and climb enables them to select a wider range of nutritious plant material together with the structural components of their jaw which facilitates the selection process.

The most recent international publications of nutrient requirements for goats include the "Nutrient Requirements of Small Ruminants; Sheep, goats, cervids and new world camelids" National Research Council (NRC 2007) and the Nutrient Requirements of Domesticated Ruminants (CSIRO 2007). Although both publications offer a significant increase in recommendations and detail, CSIRO offers little information specific to goats and many of the NRC (2007) recommendations for goats have largely been generated from pen studies and questions remain as to their applicability under pastoral conditions.

Determination of the nutrient requirement for goats is complicated by the vastly different environments in which goats exist, the lack of practical application of recommendations in the literature and the extremes of genotypes (dairy, rangeland and Boer) used in feeding studies.

Norton (1984) in reviewing the nutrition of goats following the release of the Nutrient Requirements of Goats (NRC 1981) stated that although there are similarities between sheep, cattle and goats that the differences were possibly of greater consequence. These included differences in feed selection and water requirements, milk and carcase composition, physical activity and grazing habits, metabolic disorders and parasite infestation.

The aim of this review is to clarify the nutritional requirements for goats; to determine to what extent and why publications vary in their recommendations; to investigate if requirements differ between breeds of goat and to correlate recommendations with current industry practices. It is not intended to be a comprehensive feeding guide for goat producers, but to highlight key areas of deficiency in nutritional knowledge that may benefit from future industry investment.

The topics to be reviewed include the requirements of rangeland, intensive, dairy and fibre producing goats in terms of:

- Dry matter intake
- Metabolisable energy
- Crude protein
- Fibre
- Mineral and trace element nutrition
- Water quality and intake
- Pregnancy and lactation
- Weaner growth
- Depot nutrition
- Feedlot nutrition
- Nutritive value of rangeland plant species

Dry matter intake

Dry matter intake is the major determinant of productivity of ruminants including goats across all environments however there are a range of factors that affect the provision and utilisation of nutrients for metabolic purposes; these include the digestibility of the plant material and the concentration of neutral detergent fibre (NDF), nutrient content of the feed on offer, the presence of anti-nutrient factors or secondary compounds such as tannins, the application of nitrogenous fertilisers, sensory factors including palatability, the water content of the forage (Black *et al.* 1987), the height and density of pasture, intake capacity such as stage of production or liveweight, digesta flow rates and efficiency of fermentation and digestion (Black 1990).

Goetsch *et al.* (2010) highlighted differences in breed, grazing management, type of vegetation and time of year; dietary components, group dynamics such as competition for feed or feeding space (Table 2) and stage of production as affecting the intake of goats. Mineral deficiencies and excesses have been found to reduce dry matter intake (Beede *et al.* 1984; Ternouth and Sevilla 1990).

Table 2 Effects of the number of Boer cross goats per pen or feeding station on feed intake, growth performance and feeding behaviour (Gipson et al. 2006)

Goats per pen	***6***	***8***	***10***	***12***
Number of feeder visits	17.5	17.1	17.9	18.7
Number of meals	8.9	9	9.3	8.9
Feeder occupancy (min): per animal & per day	97.8	73.2	83	71.7
Feeder occupancy (min): per animal & per visit	5.8	4.4	5	3.8
Feeder occupancy (min): per animal & per meal	11.2	8.2	9.2	8.1
DMI (g/min)	14.6	24.9	21.5	23.1
Daily DMI (kg/d)	1.45	1.51	1.6	1.37
Growth rate (g/d)	156	167	181	136

The purpose of feed intake is to ensure animal requirements for energy, protein, fibre, vitamins and minerals are met however it should be noted that most animals are able to maintain condition on dry matter intakes less than they voluntarily consume (Harvey and Tobin 1982). However animals should not be relied upon to restrict intake according to nutrient need – an important consideration when setting stocking rates according to demand.

Where feed quality is high, stocking rates can be adjusted to reduce dry matter intake although it is unlikely that any restriction of voluntary intake will be observed until a feed shortage occurs. It is an important consideration for livestock managers, as when feed quality is low, dry matter intake will not necessarily increase to ensure daily nutrient requirements are satisfied. In the goat's favour is their inherent efficiency of NDF digestion compared with sheep and cattle (Norton 1984) as depicted in Table 3.

Table 3 Measurements of digestion in sheep and goats fed high (12.2% CP) and low (5.1% CP) Pangola grass hay (Adapted from Norton 1984)

	Sheep		Goats		
Measurement	*High*	*Low*	*High*	*Low*	*SEM*
Dry matter intake (g/kg $^{0.75}$ /d)	47.8	31.9	49.5	32.6	*2.8*
NDF digestibility (%)	73.4	63.5	75.3	71.3	*1.2*
Rumen ammonia (mg N/l)	141	43	145	106	*11*

When feeding sheep and goats prairie grass straw at (8.45% crude protein) Domingue *et al.* (1991b) observed that goats had the ability to maintain higher rumen ammonia concentrations than sheep (115 vs. 80gN/l); goats demonstrated higher apparent digestibility of lignin and increased fractional degradation rates of cellulose and lignin. These factors in combination with a higher proportion of smaller particulate matter in the rumen contents contributed to higher levels of voluntary intake of low quality straw.

Coleman *et al.* (2003), found that wether goats offered a range of hays had the highest intake (25g/kg LW) of lucerne hay and the lowest wheaten hay at 13.6g/kg LW; they observed that intake and digestibility were better related to rumination and retention time than to nutritive value and concluded that forage retention time and acid detergent fibre (ADF) were the best predictors of intake in goats. Currently no equation exists to easily predict intake based on these factors.

Intake and digestion – differences between goats, sheep and cattle

Although all ruminants, it is clear that the digestibility of organic matter differs between sheep, cattle and goats. Silanikove (2000) attributed the "superior digestion capacity" of goats to their rumen capacity and absorptive area, large salivary gland and their inherent ability to alter the volume of their foregut as required by environmental conditions. Digestibility of organic matter ADF and NDF was better in goats than sheep.

Digestibility of dry matter and NDF was found to be higher in mature cattle and goats than sheep (Reid *et al.* 1990) when fed a range of C3 and C4 grass and legume hays. Intake was highest for legumes with no difference between C3 and C4 grasses:

Dry matter intake:

- Cattle – 92.6 g/kg $LW^{0.75}$ ($P<0.01$)
- Goats – 68.6 g/kg $LW^{0.75}$
- Sheep – 65.8 g/kg $LW^{0.75}$

NDF intake:

- Cattle – 58.7 g/kg $LW^{0.75}$
- Goats – 42.6 g/kg $LW^{0.75}$
- Sheep – 39.6 g/kg $LW^{0.75}$

The organic matter intake of Angora goats fed high quality sub clover hay was 68 g/kg $LW^{0.75}$ whereas the intake of Merino sheep was lower at 61g/ kg $LW^{0.75}$ (Doyle *et al.* 1984). When making assessments of intake due consideration should be given to the component of plant material being grazed such as leaf versus stems and the differences between feed types (Lachica and Aguilera 2003).

Larbi *et al.* (1991) reported West African Dwarf goats fed Napier grass consumed 32 and 54 g/kg $LW^{0.75}$ whole plant and leaves respectively.

Doyle *et al.* (1984) concluded that differences in organic matter digestibility were less likely when sheep and goats consumed high quality forages, but noted that on lower quality diets, goats appeared to digest more plant cell wall material than sheep. Kids at 14 weeks were observed by Van *et al.* (2007) to have similar intakes of a high quality tropical diet (jackfruit / sugarcane/ concentrate) at 50 g/kg LW compared with lambs at 47 g/kg LW.

Goats have a higher relative intake of low quality fibrous feeds than sheep (56 vs 36 g/kg $LW^{0.75}$) with an increased apparent digestibility (36.8 vs 32.6%). Although goats appear to be similar to sheep in time spent eating and ruminating, intake rate appears to be lower for goats in that they demonstrate a higher level of digestive efficiency (Van *et al.* 2002).

In comparative intake studies with goats and sheep fed lucerne chaff, (Domingue *et al.* 1991c) determined that goats demonstrated significantly higher levels of mastication efficiency (85 cf. 48%) and hence particle size reduction, than sheep respectively. Goats had significantly higher rates of saliva production and salivary secretion of nitrogen than sheep and higher levels of rumen ammonia production than sheep (Domingue *et al.* 1990). The superior digestibility of low quality roughages by goats may be attributable in part to their apparent high levels of rumen ammonia production expressed in Table 4 as irreversible loss rate (IRL).

Table 4 Kinetics of ammonia (NH_3-N) production in the rumen of deer, goats and sheep fed on lucerne hay ad-libitum in winter together with the rumen NH3-N concentration, rumen NH3-N pool size and NH3-N outflow from the rumen in summer and winter (Domingue et al. 1991c)

	Season	*Deer*	*Goats*	*Sheep*	*SEM*
Total N intake (NI) (g/kg $LW^{0.75}$ per day)	S	1.90	1.95	1.43	0.08
	W	1.63	1.63	1.61	0.087
Rumen NH_3-N kinetics					
NH_3-N concentration (mg N/litre)	S	172	158	181	5.5
	W	110	165	172	6.3
NH_3-N pool size (mg N/g NI)	S	22.7	24.0	29.9	1.61
	W	10.4	22.2	29.1	1.38
NH_3-N outflow in winter (mg N/g NI)	S	86.4	56.5	69.4	4.64
		40.9	53.2	70.5	2.58
Irreversible loss rate (IRL) of NH_3-N (mg N/g NI)	***W***	***535***	***692***	***607***	***35.9***
IRL - NH_3-N outflow in water (mg N/g NI)	W	494	639	536	35.7
Bacterial N from NH_3-N (%)	W	36.6	48.0	40.0	1.99
Bacterial N (% digesta NAN)	W	63.4	52.0	60.0	1.99
Total N in rumen digesta (% DM)	W	2.39	2.69	2.44	0.03
Total N in isolated rumen bacterial cells (% DM)	W	6.62	6.25	6.17	0.14
Rumen pH	S	6.57	6.54	6.42	0.05
	W	6.61	6.59	6.45	0.04

S = summer; W = winter

Estimations of daily dry matter intake

Measurement or prediction of dry matter intake (DMI) is not an exact science which is a significantly limiting factor in nutritional management of grazing animals. Computer programs such as Grazfeed® base their predictions of intake around feed on offer and digestibility whereas NRC (2007) assumes intake as a proportion of liveweight. In both situations, minimal accounting is taken of the many factors that can and do influence intake. Luo *et al.* (2004a) developed voluntary feed intake predictions for goats however they are of limited value as they apply only to thermoneutral conditions where the goats were fed individually in pens or stalls. When evaluating feeding studies the effect of goat behavioural characteristics on research outcomes needs to be considered.

The majority of Australia's current goat population is located in the rangelands where goats are harvested mainly on an opportunistic basis and where nutritional management is largely controlled by the goat rather than the manager. Estimations of intake are largely based on the ability of the goat to select the most highly nutritious components of available plant material and on the rate of decline of key indicator species.

Dry matter intake - extensive environments

Predictions of intake of goats grazing Australia's rangelands (Figure 1) is largely impractical due to the diversity of plant species available across seasons, the ability of the goat to selectively graze, the concentration of secondary compounds in most species and the variation in nutritive value of plant material.

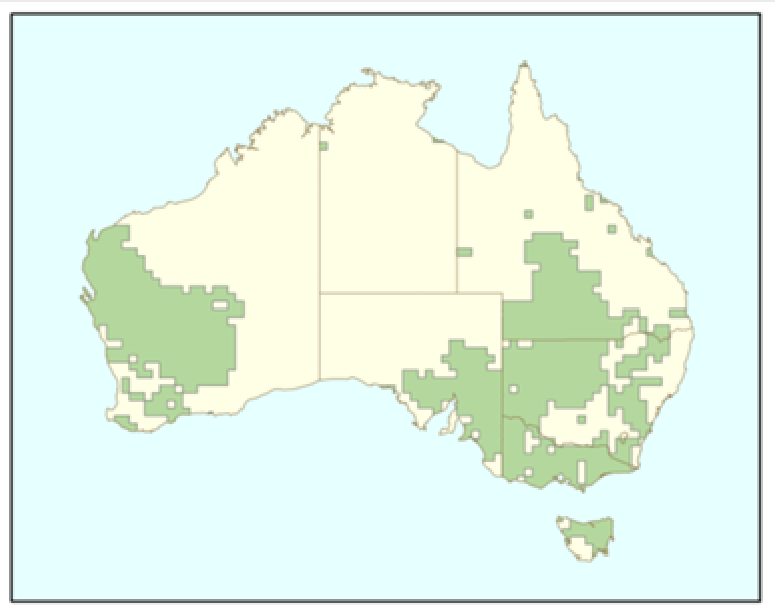

Figure 1 Distribution of rangeland goats in Australia (Source: http://www.environment.gov.au, 2008)

Woody plants (Papachristou *et al.* 2005) and shrubs contain a number of physical and chemical properties referred to as anti-nutritive factors or secondary compounds that significantly influence intake. In addition, many shrub species contain high concentrations of salts such as sodium and potassium which have been shown to significantly reduce dry matter intake, growth rate and wool production of Merino wethers (Masters *et al.* 2005) as highlighted in Table 5.

Table 5 Effect of increasing sodium (Na) and potassium (K) concentrations on voluntary intake of Merino wether lambs (34kg LW) fed a diet of oats, lupins and oaten hay (adapted from Masters et al. 2005)

Na %	K %	Weaner Intake kg/day (as fed)	LW gain g/day	Clean wool growth g/day
0.16	1.60	1.35	144	13.5
2.27	1.60	1.31	162	13.8
4.74	2.30	0.93	77	9.76
7.60	2.50	0.55	-12	8.6

Tannin-complexing agents such as polyethylene glycol (PEG) have been observed to increase the daily intake of goats browsing on tannin rich plant species (Narvaez *et al.* 2011), however Moujahed *et al.* (2005) found that when supplementing *Acacia cyanophylla* based diet with PEG that although N retention was significantly improved, there was no increase in dry matter intake. Rogosic *et al.* (2008) observed that intake of Mediterranean shrub species was more related to the amount of feed on offer rather than the concentration of secondary compounds.

Retrospective measures of intake can be estimated in a pastoral environment via faecal NIRS, body condition scoring and disappearance of preferentially grazed or "indicator" species known to the grazier. It is useful for pastoralists to be familiar with the range in nutritive value (NV) of key indicator species such that as they decline in numbers, stocking rate strategies can be reviewed in line with productivity expectations and the avoidance of environmental degradation. Where it is profitable to do so, controlled grazing within fenced blocks can produce increased quantities of higher quality pasture; however this type of grazing management is not commonly found in rangeland systems.

Dry matter intake - intensive environments

The remaining goat population is found in the medium to high rainfall regions consisting of Boer-based meat goats, dairy and Angora goats. Many variations of cross breeds such as Boer x rangeland breeds also exist, primarily harvested for meat production. There are apparent differences in the daily dry matter intake recommendations for all these classes of goat *(NRC 2007)* which predominantly relate to liveweight and level of productivity. The application of these recommendations in this review will be largely limited to non-rangeland goats as management of intake across a pastoral landscape is an unrealistic and impractical task.

Dry matter intake of sheep is generally predicted on a dry sheep equivalent (dse) basis to facilitate the setting of stocking rates in high rainfall areas and in the wheat-sheep zone. This can be done by assessment of the amount of dry matter on offer plus the daily pasture growth rate minus the daily intake requirements of the class of animal grazing, although most producers choose to use a simplified dse rating system. Published dse ratings assume that goats consume the same amount of feed per unit of liveweight as sheep (Vincent 2005) however the evidence for this assumption does not appear to exist.

Account also needs to be taken of other factors that restrict intake such as the water and protein content and the neutral detergent fibre (NDF) concentration of the feed on offer. Van Saun published a guide to the intake potential of small ruminants based on NDF intake capacities (http://vbs.psu.edu/extension/resources-repository/publications/SRTransition.pdf) which is described in Table 6. As the fibre content of the feed increases and rate of passage slows accordingly it follows that intake rate will subsequently decrease.

Table 6 Predicted dry matter intake (DMI) as a percentage of live weight related to neutral detergent fibre (NDF) intake capacity (Saun no date, no date)

Forage NDF	DMI	NDF Capacity (% of LW)			
		1.2	***1***	***0.8***	***0.6***
38	Intake as a % of LW	3.16	2.63	2.11	1.58
42		2.86	2.38	1.90	1.43
44		2.61	2.27	1.74	1.36
46		2.73	2.17	1.82	1.30
50		2.40	2.00	1.6	1.20
54		2.22	1.85	1.48	1.11
58		2.07	1.72	1.38	1.03
62		1.94	1.61	1.29	0.97
66		1.82	1.52	1.21	0.91

Dry matter intake – dairy goats

Studies with dairy goat breeds provide a different picture of dry matter intake where they have higher levels of productivity per unit of liveweight than meat or fibre producing goats, and where adaptation to concentrate diets is well advanced. As for dairy cows the main objective of a daily goat production system is to maximise intake and hence milk production.

Figure 2 Maltese dairy goats (Source: http://eng.agraria.org/goat/maltese.htm)

Dairy goats are more likely to be offered a highly concentrated diet with a choice of feedstuffs such as grain, hay plus or minus pasture to ensure intake potential is reached. Their intake is more akin to that of rangeland goats when good seasonal conditions prevail where they are able to select a balanced ration; this is in stark contrast to goats run in more intensive grazing systems where their diet is limited to one or two pasture species.

Maltese goats, depicted in (Fedele *et al.* 2002) given a free choice diet (barley, chick peas, beet pulp, broad beans, lucerne and pasture hay) under confined conditions, increased their intake by 14% above that of goats offered *ad-libitum* lucerne hay and barley (Fedele *et al.* 2002).

Further Goetsch *et al.* (2003) reported that Alpine weaner goats (Figure 3) also demonstrated a significant increase in intake and growth rate when offered free choice concentrate and forage compared with a total mixed ration of fixed proportions (Table 7).

Table 7 Effects of separate offering of forage and concentrate on feed intake and growth of Alpine doeling weaners at 3.5 months of age at 15.8kg LW for 112d (adapted from Goetsch et al. 2003)

	Treatment				
	25%C	50%C	75%C	FC	R
Concentrate intake (g/d)	165	341	497	588	395
Forage intake (g/d)	461	300	126	115	258
Total intake (g/d)	626	641	623	704	653
DMI as % of LW (% DM)	4.0%	4.1%	3.9%	4.5%	4.1%
CP intake (g/d)	88	105	116	133	111
ME intake (MJ/d)	6.7	7.5	7.8	8.96	7.78
CP:ME intake (g/MJ)	13.1	14.0	14.9	14.8	14.3
Daily growth rate (g/d)	53	71	81	105	73
Feed conversion ratio (g gain/g DMI)	11.8	9.0	7.7	6.7	8.9

25%C – 25% concentrate, 75% forage; 50%C – 50% concentrate, 50% forage; 75%C – 75% concentrate, 25% forage; FC – free choice concentrate and forage; R – ad-libitum forage, restricted concentrate

Figure 3 British Alpine dairy goat (Source: http://www.nzdgba.co.nz/)

Dry matter intake – goat depots

As depots are predominantly used as containment areas for goats prior to ongoing transport and as a short stay facility, the focus of nutritional management is to minimise weight loss. Nutritional management should ideally be focused on rapid adaptation to a change in feed such that high quality, palatable, legume-dominant hay should be provided. Hay of high quality would minimise electrolyte loss from transport stress and ensure that the requirements of pregnant does were met; however legume hays or straws are not likely to be readily available within reasonable distance of the locations of many depots and will tend to be expensive. The cost-efficiency of improved nutritional depot management requires further investigation.

In most situations rumen bacterial populations require at least 10 days to fully adapt to a change in diet and as the time contained in depots is often limited to 7 days (P. Lynn pers comm. October 2011), it is likely that just as much of this time would have been spent adjusting to the environment as the diet (Figure 4). The belief that goats prefer a "high fibre diet" may lead to a diet of too low a quality being provided to depot goats which may be limiting dry matter intake. The assumption that oaten hay or straw is of high quality needs to be revised as the crude protein and energy concentrations of oaten hay, in particular, in most years, will be below the maintenance requirements of mature goats.

Figure 4 Goat depot, Cobar, NSW (Source: Ausgoat, 2011)

Dry matter intake - feedlots

To some extent feed intake can be estimated within a feedlot situation, but as a group rather than on an individual basis. Where feed is available on an *ad-libitum* basis, assessment of daily DMI is more difficult however where goats are allocated a specified amount of feed at regular intervals estimations of intake may be more reliable.

It should be noted that the nutritional recommendations in NRC (2007) rely heavily on daily intake requirements being achieved in order to provide adequate concentrations of crude protein and metabolisable energy (ME), and the assumption that underlies these requirements is that intake will not be constrained, or that where feed quality is poor, that intake will increase to compensate; this is rarely the case. This is of particular importance in relation to small ruminants such as fibre producing goats or young kids. Their intake potential is limited by their rumen capacity such that they require a diet consisting of highly concentrated nutrients.

At small body weights the perceived preference of goats for a diet high in fibre will effectively limit their ability to increase intake and hence become more productive. This may be one of the limiting factors to their survival and current growth potential, which requires further investigation.

Daily dry matter intake can vary according to the diet formulation as demonstrated by Gipson *et al.* (2007); Table 8 highlights the substantial differences in daily dry matter intake of Boer cross wethers between different feeds.

Table 8 Effect of diet (pelleted vs loose mix; concentrate vs lucerne) on feeding time, DMI, growth rate and feed conversion of meat goats (F1 and F2 Boer cross) (Gipson et al. 2007)

Diet	***Pelleted conc.***	***Loose conc.***	***Pelleted lucerne***	***Lucerne chaff***
Feeder occupancy (min): per animal & per day	74	130	105	132
DMI (g/min)	24.6	12.9	22	13.7
Daily DMI (kg/d)	**1.79**	**1.67**	**2.04**	**1.7**
Growth rate (g/d)	212	205	190	157
Feed conversion ratio (FCR)	8.44	8.15	10.74	10.83

Although the pelleted concentrate may have been more costly to feed, the ability to turn off kids earlier and potentially increase profit margins is an important consideration.

Differences in dry matter intake between sheep and goats

Interestingly sheep have often been used as the nutritional model for goats however there is sufficient evidence in the literature that there are significant differences between them. Goats are more aggressive and competitive feeders compared with sheep and this behaviour appears to increase as group size and competition for feed increases (Devendra 1989; Van *et al.* 2007).

Goats appear to adjust more readily than sheep or cattle to seasonal and geographic variation (Lu 1988) whereas sheep reportedly eat more white clover than goats (Devendra 1989). Goats in fact may be more similar to deer than sheep and cattle as their browsing and foraging behaviour appear similar (Gasparotto 2010).

According to NRC (2007) grazing ruminants, where possible, will select feed of higher digestibility, protein content and fewer secondary compounds however this is in contrast with Clark *et al.* (1982) who noted that where goats were able to select either white clover or gorse bush they ate more gorse.

Differences in shrub consumption have been reported by Rogosic et al (2006) who found that goats consumed more than twice as much foliage as sheep. Goats are thought to prefer trees and shrubs whereas sheep prefer herbs and grass (Field 1979 cited in Devendra 1989; Devendra 1989) however prior knowledge and adaptation to feed resources will influence preference. In contrast (Silanikove 1996) reported that goats and sheep grazing in Mediterranean environments exhibited a preference for browse species over more nutritious grasses in spring.

Simiane *et al.* (1981 cited in Van 2006) found that the mean intake of goats was 17% higher than sheep at 65.3 and 55.8 g DM/kg $LW^{0.75}$ respectively; similarly Wahed, (1987 cited in Van 2006) reported a difference of 59.6 and 76.8 g DM/kg $LW^{0.75}$ between sheep and goats where intake for goats exceeded that of sheep by 29%. In contrast the differences cited above may be more a factor of dietary constituents as Santra *et al.* (1998), Hadjipanayiotou (1995) and Moujahed *et al.* (2005) found no differences in intake between sheep and goats.

It is likely that any differences between sheep and goats may be related to prior experience and adaptation rather than any inherent species differences per se.

Seasonal patterns of voluntary feed intake

Ruminants appear to have a distinctive pattern of circadian feed intake in response to photoperiod, or changes in day length, throughout the year.

Rhind *et al.* (2002) reported the seasonality of voluntary intake in a range of ruminant species where intake increased with day length however this effect appeared to be more pronounced in temperate and Mediterranean environments and in entire males than females. As feed intake is a major driver of productivity, intake depression at any time of the year may have a negative effect on productivity.

The same authors noted the complexity of the many interactive factors influencing voluntary intake including the effect of neuropeptides, hormones and the hypothalamus, and their extensive review highlighted areas to consider for future research. These included meal patterns and intake rate; metabolic signals; seasonality of gastrointestinal structure and function; hormonal signals, their effect and regulation. Further they suggest more information should be sought on melatonin target sites, leptin and leptin receptors.

Deer reportedly exhibit a similar pattern of seasonality of feed intake to goats which is depressed in winter (Domingue *et al.* 1990) and which peaks in spring (Webster *et al.* 1999). The winter decline in feed intake appears to be associated with a decrease in prolactin activity and an increase in testosterone production. Simpson *et al.* (1984) noted a cycle of intake, gonadal activity and growth that corresponded with the cycle of day length in sheep and red deer.
Iason *et al.* (1994) investigated the effect of season on voluntary intake in three breeds of sheep and reported a significantly higher intake of all breeds in summer compared with winter; however of particular interest was their finding that the Scottish Blackface and Shetland breeds of sheep that are more seasonal in their reproductive characteristics, exhibited a greater seasonal variation in voluntary feed intake.

Male and female Cashmere goats were found to exhibit significant reproductive seasonality (Walkden-Brown *et al.* 1994b) however in contrast to the previously cited studies, these researchers noted a seasonal variation in feed intake that peaked rather than declined in winter and spring.

In a subsequent study Walkden-Brown *et al.* (1994a) housed domesticated rangeland bucks, three years of age, and fed them on either a high or low plane of nutrition. Both groups demonstrated a significant decline in voluntary feed intake in opposition to the photoperiodic reproductive cycle as depicted in Figure 6 and a subsequent loss of liveweight of between 7.6% (low quality diet) and 7.8% (high quality diet).

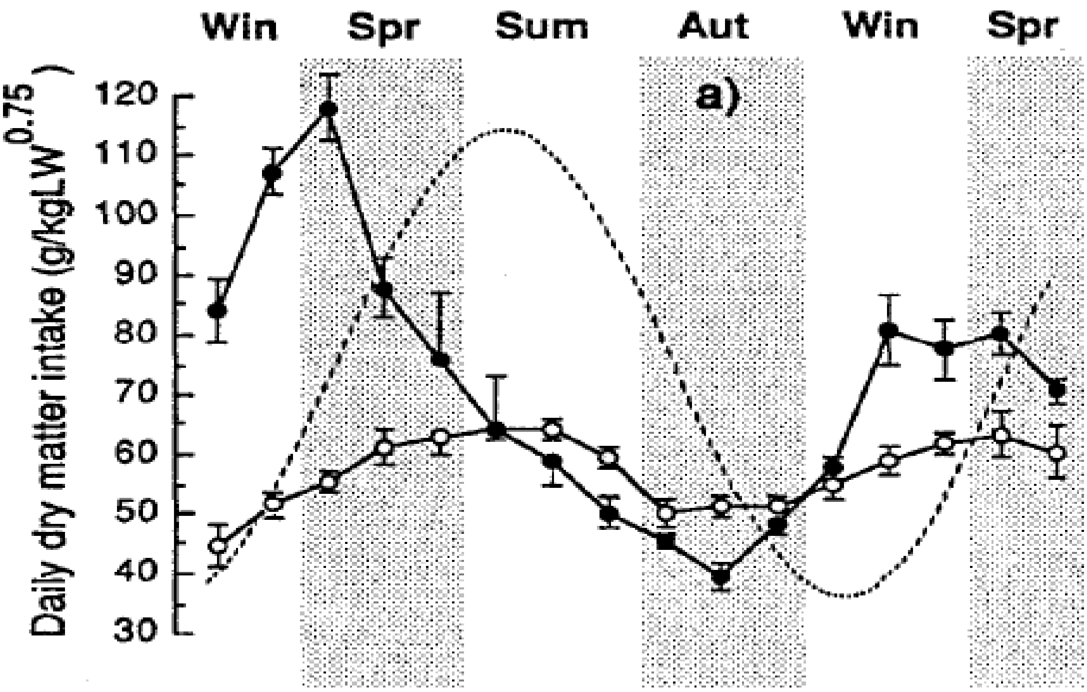

Figure 5 Monthly average voluntary feed intake of 3 year old Cashmere bucks fed pangola grass hay (o) or pelleted lucerne (•) The dashed curve was representative of photoperiod (–) (Walkden-Brown et al. 1994a)

Domingue *et al.* (1991c) found a small but insignificant reduction in DMI in winter for both deer and goats provided with *ad-libitum* access to lucerne hay (Table 9) whereas sheep increased DMI in winter compared with summer.

Table 9 Nitrogen (N) intake, excretion and balance in deer, goats and sheep fed on lucerne hay ad-libitum in summer and winter (adapted from Domingue et al. 1991c)

	Season	*Deer*	*Goats*	*Sheep*	*SEM*
Intake (mg/kg LW $^{0.75}$ per day)	S	1715	1883	1556	84
	W	1450	1749	1710	92
Apparent digestibility (%)	S	67.90	70.00	69.20	0.35
	W	63.00	72.30	67.00	0.72

S = summer; W = winter

Kawas and Andrade-Montemayer (2010) attributed reduced feed intake of Spanish wether goats during winter to characteristics of feed quality and availability which appears similar to the condition of winter stasis described by Australian producers intensively managing goats in high rainfall areas.

Winter weight stasis

Cessation or significant slowing of liveweight gain during winter has been identified as an area of concern by Australian goat producers and was investigated by Flint and Murray (2002); unfortunately the researchers used rats as the model for goats in their approach such that the relevance of their findings to goats remains unclear.

Lightweight Cashmere doe hoggets in New Zealand on high and low planes of nutrition (McCall *et al.* 1989) were observed to enter a period of winter live weight stasis from May 2nd in 1986 and from May 29th 1987. Although the cause of this period of stasis remains unknown it may be a photoperiodic response in doe hoggets as Norton (1984) reported similar findings.

Australian goat producers (Ramsay, Martin & Ryan pers comm. May 2011; P. Schuster pers comm. June 2011) have identified “winter stasis” as a significant issue affecting the productivity of their goat production systems. They described the syndrome as a combination of endoparasite load, infection, nutritional deficiencies and low dry matter intake during cold wet weather. These producers were confident that the condition could be alleviated to some extent by feeding out cereal hay *ad-libitum*. Ramsay also stated that his goats “did badly” when grazing cereal crops during winter however this could be attributed to nitrate toxicity or mineral deficiencies and may not be related to the syndrome of “winter stasis”. In the absence of pasture analyses it is difficult to draw any conclusions at this stage.

It may be that what producers describe as winter stasis is a combination of factors that limit the productivity of all grazing ruminants during winter which include the high water content of the pasture which limits dry matter intake; protein intake in excess of requirements, up to 40% in some leguminous pasture and low intake of effective fibre particularly when grazing short pasture. It may also be a factor of limited feed on offer during winter when energy requirements of small ruminants are high and in the case of goats where they have limited insulation against cold conditions. In sheep and cattle production systems these effects as described above appear to be worse for sheep than cattle.

The syndrome of excessive N intake increasing demand for energy (ME) which cannot be met due to difficulty in meeting intake requirements due to the high water content of the pasture is becoming more accepted as a realistic hypothesis to explain the poor productivity of small ruminants grazing “improved” pastures, however scientific evidence is lacking and research is clearly warranted.

For example:

A twin-bearing Boer doe at 60kg in late pregnancy requires 1.68kg DM per day, 13.43 MJ ME per day and 178grams of crude protein (NRC 2007).

Average nutritive value of high quality winter clover/perennial grass pasture:

- *Dry matter content - 14%*
- *Crude protein 28%*
- *ME 10.5*

The doe must eat 1.27kg DM pasture to meet energy requirements; however at 14% DM she will need to consume 9 kg of wet pasture to achieve a dry matter intake of 1.27kg. Due to the space occupied by twin foetus' it is unlikely she will eat this amount.

Every kilogram of pasture consumed will provide 280g of crude protein so to meet daily protein demand she only requires 635 g DM.

Therefore if she reaches her daily DM target she will consume 470g crude protein, 292g in excess of requirements and if she falls short of 1.27 kg DMI per day she will be deficient of energy.

Influence of preference, selection and grazing behaviour on dry matter intake

Goats have been described by Sidahmed *et al.* (1983) as adaptive mixed feeders or mixed foragers (NRC 2007) that demonstrate seasonal differences in diet selection. There is general agreement among researchers that they are more selective than sheep (McGregor 2000) and appear more ecologically adapted to browse species with their split and mobile upper lip (Lu 1988), narrow pointed muzzle (Gordon and Illius 1988) and ability to stand on their hind legs.

These characteristics also enable goats to select the highest quality material from the pasture mix available (Poore and Luginbuhl 2002). Goats have evolved to consume a wide range of plant species both thorny and bitter and as such can effectively be employed to assist in weed management programs. Holst *et al.* (2004) observed that goats effectively grazed Scotch broom (Figure 6) at a plant density of 4% of ground cover but were less effective at 10% cover. Reliance on goats alone for weed control may not be effective with all plant species as 8% of broom seeds remained viable following ingestion.

Figure 6 Cytisus scoparius - Scotch broom (Source: www.google.com; PA Graham)

Many weeds are high in NV particularly during the vegetative stage however weeds such as Scotch broom, artichoke and nodding thistles appear to increase in palatability more toward flowering (Holst *et al.* 2004).

Preference for forages appears to be driven predominantly by familiarity, smell and taste such that positive feedback from ingestion and subsequent digestion enhances ongoing consumption of particular forages.

Dumont *et al.* (1995) observed that goats were more selective in their grazing habits early in the day with a preference for browse over grass with the peak grazing activity period of Boer goats noted by Gipson (in Goetsch *et al.* 2010) to be at 0900 and 1400 hours. Van *et al.* (2005) reported that goats offered foliage hanging from a wall had increased dry matter intakes than those offered leaves fed via troughing; this finding was supported by Dziba *et al.* (2003b) who noted that although intake was similar between breeds (Boer vs Nguni), the height of the feed on offer had a significant effect on intake. In feeding trials with Boer cross wether goat kids Patterson *et al.* (2009) reported an increase in selectivity and refusals as the crude protein of the feed on offer declined; kids demonstrated preferential selection in favour of crude protein and NDF but against ADF.

Observations of the Outback Lakes SA in assessment of preference of grazing animals for arid plant species observed that preference changed with stage of growth (Jolly 2009). Similar observations were also made by Belovsky *et al.* (1999) who reported a positive relationship between DMI rate and preference for browse species. Pastoralists in the Lake Eyre region of South Australia reported that Buckbush (*Salsola kali*) was eaten readily from seedling through to reproductive stages of growth, but during seedset and dormancy, the species was not preferred by cattle or horses (Figure 7).

Figure 7 Buckbush with vegetative growth - Dulkaninna Station, Birdsville Track, SA

Swamp canegrass (*Eragrostis australasica*) was sought out readily by cattle and horses at all stages of growth (Figure 8) through to senescence however once dormant it was no longer preferentially grazed (Jolly 2009).

Figure 8 Swamp canegrass at various stages of growth– Dulkaninna Station, Birdsville Track, SA

Further observations of preferential selection of plant species by sheep and cattle were made in northern South Australia during an extended period of drought which revealed that most species were eaten readily (Figure 9) with the exception of some species of wattle which were only eaten as a last resort. The chemical diversity of plants may be influencing diet selection (Rogosic *et al.* 2008) such that animals are better able to avoid toxins and meet nutritional requirements.

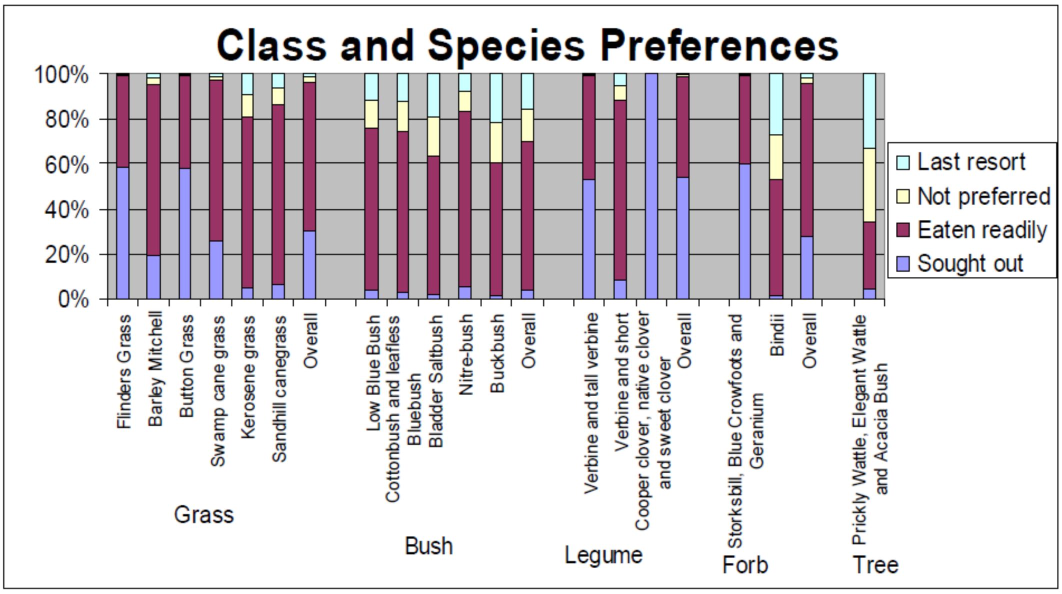

Figure 9 Class of plant and species preferentially grazed in the Outback lakes region of SA (Helby, 2009)

Goats grazing in high rainfall intensive pasture systems have less opportunity to differentiate between species than in a range environment however McGregor (2000) noted that goats, although flexible and selective grazers, have a preference for green grass when it is available.

Goats run in pasture-based systems prefer grazing clover in the morning and grasses in the afternoon whereas bush goats have been observed to prefer grasses in the morning and bushes and shrubs in the afternoon (Solanki 1994).

Daily dry matter intake of Cashmere goats and Scottish Blackface sheep (Hadjigeorgiou *et al.* 2003) was positively correlated with preference for both ryegrass hay and barley straw; preference was negatively correlated with ADF and NDF. Fedele *et al.* (2002) noted that Maltese dairy goats offered free choice hay and concentrate diets demonstrated a preference for the concentrate portion of the ration over lucerne and wheaten hay.

Dry matter intake may be a factor of time spent grazing where breed differences have been reported (Fedele V 1993; Aharon H 2007; Beker *et al.* 2009); Forbes and Provenza (2000) attributed this difference to unfamiliarity with browse species. Aharon *et al.* (2007) observed that Boer goats grazed a greater diversity of plant species than indigenous goats and appeared to have a difference in preference across browse species. Indigenous goats spent 44% of observed daylight time grazing herbaceous species whereas Boer goats selected the same species for only 22% of the time.

Dietary choice and dry matter intake

Maltese dairy goats offered a free choice ration in late pregnancy (Fedele *et al.* 2002) were observed to increase intake of crude protein (12.6->16.4%CP), decrease their intake of starch (33.3->31%) as pregnancy advanced, and maintain the NDF concentration of their diet at 40%. However once lactation commenced, the chemical composition of the diet selected was reversed such that the crude protein decreased by up to four percentage units, starch intake increased by 2-3 percentage units and the NDF remained unchanged.

Manteca *et al.* (2008) proposed the theory that although diets presented to grazing animals are in most situations abundant and nutritious, that monocultures often contain toxins (phalaris; brassicas) and excesses of certain nutrients (clover; lucerne), they do not necessarily promote animal welfare.

As interactions occur between nutrients and toxins the various components of a diet can influence the intake of the total diet. Rangelands rich in diversity provide goats with the opportunity to select a diet that not only meets requirements but also minimises the amount of toxins ingested. As goats select the most highly digestible nutrients as a priority it follows that in prolonged dry seasons the presence and persistence of the most nutritious species is likely to be the most limiting factor to intake, productivity and hence welfare.

It is likely that rangeland goats have adapted well to their diverse diet and have also developed a level of “immunity” to many of the toxins present in the most persistent plant species and it is therefore suggested that successful adaptation of goats to a more intensive management system and monocultural diet may take many generations to achieve.

It is apparent that ruminants seek diet diversity even when nutrient requirements are met (Provenza 1996) and that aversions by animals are observed whether the feed contains toxins or is highly digestible. Provenza *et al.* (2003) noted that selective grazing allowed animals to better meet their nutrient requirements and regulate their intake of toxins.

Continuous grazing at low stocking densities, a common practice in Australia’s rangelands, leads to a reduction in diet diversity due to the most highly nutritious species being preferentially grazed, allowing the less preferred species to become dominant. An increase in stocking density and grazing for short periods with long periods of rest encourages species diversity (Provenza *et al.* 2003).

Influence of secondary compounds on dry matter intake

Shrubs containing secondary compounds can have an adverse impact on animal health and productivity and a negative effect on organic matter intake (Rogosic *et al.* 2008). These plants are the dominant species across the arid lands of the world and have evolved with protective mechanisms against grazing pressure in order to survive.

Plant secondary compounds (PSC) include chemicals such as alkaloids, oxalates, glycosides and tannins. Effects of ingestion of PSC can negatively affect animal productivity and range from reduced weight gain to death and include reduction in intake, poisoning and bloat, abortion and interference with reproductive function. Flavonoid phenolic compounds directly interact with phytoestrogens and induce infertility similar to that seen with oestrogenic clovers (McDonald 1981).

Legume forages high in carbohydrates and protein may contain cyanogenic glycosides which will reduce intake (Provenza *et al.* 2003); white clover contains cyanogenic compounds and endophyte-infected tall fescue produces alkaloids (Thompson and Stuedemann 1993) which reduce the palatability of these species to grazing animals.

Fedele *et al.* (2005) investigated the presence of secondary metabolites in commonly grazed pasture species including ryegrass, medics and vetch and found that alcohols and ketones were the most prevalent compounds found in leaves during winter and spring. Concentration of volatile compounds increased as the plant developed with the monoterpenes being more abundant in winter and the sesquiterpenes in spring foliage.

Tannins, terpenes and saponins include the most common secondary compounds found in Mediterranean shrublands (Rogosic *et al.* 2008) where much of the goat nutrition research has been undertaken. Terpene compounds present in some browse species cause a reduction in palatability and appear to inhibit growth of rumen bacteria (Oh *et al.* 1968) and hence decrease the efficiency of protein digestion (Barbehenn and Constabel 2011).

Condensed tannins reduce carbohydrate fermentation and decrease fatty acid and ammonia production (Martinez *et al.* 2006); the nature of protein complexes changes the rate of starch digestion (Muir 2011). Tannins reduce the availability of minerals (Faithful 1984) such as iron and copper. When grazing salt tolerant plants such as some of the Atriplex spp., secondary compounds such as tannins and oxalates, betaine and proline appear to be absorbed but do not contribute to ME intake (Masters *et al.* 2001).

Secondary compounds serve to protect plants from overgrazing in many instances however some compounds ingested at low concentrations such as condensed tannins may potentially provide grazing animals with nutritional benefits. Condensed tannins are found in higher concentrations in herbaceous plants with long lived leaves (Muir 2011) and the lowest concentrations in rain-responsive desert annuals (Muir *et al.* 2009).

Condensed tannins (CT) are large molecules that bind to and precipitate proteins (Silanikove 1996; Muir 2011) and as such increase protein-use efficiency; condensed tannins also bind carbohydrates by inactivation of enzymatic activity in the digestive tract and have a negative effect on palatability, due to astringency and digestibility (Silanikove 1996). In contrast Austin *et al.* (1989) observed that the palatability of plants for goats appeared to be independent of CT concentration and suggested the proline-rich saliva of goats may negate the effects of CT.

It appears that goats can reasonably ingest 1.1-2.7 g/kg LW per day condensed tannins and 0.4-0.9 g/kg LW per day of soluble phenolics with no ill effects; goats fed tannin-rich browse (10-23g/head/day) did not exhibit any difference in metabolite concentrations which are sensitive indicators of damage to liver and kidneys, compared with those fed a cereal based diet. (Silanikove *et al.* 1996). CT concentrations in excess of 6% can depress DMI however levels between 2-4% can stimulate intake (Wang *et al.* 1996). Tannin concentrations above 5% have been reported as reducing dry matter intake (Rogosic *et al.* 2008) and inhibiting enzymatic function (McLeod 1974).

As tannin concentrations in feeds are rarely reported, the practical application of this information may be limited, however it may provide an indication as to why some species are preferentially grazed and promote positive welfare benefits such as protection against parasite infestation, and why others are avoided.

Adaptation to a diet rich in tannins is reportedly an evolutionary process however Silanikove (1996) hypothesises that the rangeland goats' ability to detoxify tannins is linked to their capacity to efficiently digest lignin with both being phenolic compounds.

Muir (2011) questions if goats have adapted to CT or have plants developed CT as a protective mechanism from grazing animals however it may be a more likely hypothesis that plants developed CT to protect against insect invasion.

When lambs select feeds containing nitrates and or oxalates, they consume greater amounts of the feeds containing one of the compounds and less of feed containing both (Burritt and Provenza 1998). Villalba *et al.* (2011) reported that lambs appear to reduce their intake of plant secondary compounds by altering their foraging behaviour to avoid over ingestion of single compounds. Laycock (1974) hypothesised that adaptations of herbivores included a diversity of diet such that high levels of one toxin were avoided. Additional adaptive behaviour included the detection and avoidance of toxic plant species and an inherent ability to detoxify secondary compounds. Interestingly Laycock also noted that the ability of herbivores to effectively co-exist with poisonous plants varied across species, and appeared to be more apparent in species that were born into the environment.

It has been reported that goats appear to be able to more effectively detoxify secondary plant compounds than either sheep or cattle however the process of transformation and excretion of plant toxins may result in a depletion of amino acids and glucose (Foley *et al.* 1995).

It is apparent that certain toxins have complementary requirements for detoxification; for example sheep eat more sagebrush when supplemented with a protein source rather than a high energy supplement (Villalba *et al*. 2002). However supplements high in soluble carbohydrates appear to lower rumen pH which may subsequently inhibit detoxification (Provenza *et al.* 2003). Plant secondary compounds reduce energy availability and hence increase ME requirements (Kawas *et al*. 2010) of grazing ruminants, such that where appropriate, it is likely that productivity will increase in response to supplementation with molasses or cereal grains. It should be noted however that there have been anecdotal reports of thiamine (Vitamin B1) deficiency in sheep supplemented with molasses when grazing saltbushes.

Some positive effects of secondary plant compounds include the potential to increase intake due to detoxification of one compound by the other (Rogosic *et al.* 2008). Martinez *et al.* (2006) found that condensed tannins reduced the fermentation rate of wheat starch compared with corn starch and concluded CT could potentially play a role in the prevention of acidosis under feedlot conditions (Muir 2011). This proposal may have merit and is worthy of further investigation.

Polyethylene glycol (PEG), charcoal and calcium hydroxide have been added to the diet of ruminants grazing tanniferous diets with some success as PEG binds with tannins and diminishes their negative effects (Provenza 2006). Henkin *et al.* (2009) supplemented beef cattle with PEG and observed an increase in their utilisation of shrub species known to contain high concentrations of tannins.

Inclusion of PEG in drinking water supplied to goats at 0.15% of liveweight was sufficient to inactivate the effects of tannins associated with Arctostaphylos spp. at 23% condensed tannins (Narvaez *et al*. 2011); however different concentrations of PEG that may be required according to the tannin level of browse species remain unclear. As recently published research (Belenguer *et al*. 2011) raises questions about the innocence of PEG to the rumen bacterial populations, it may be that PEG does not move beyond an academic consideration in terms of goat nutrition research. In addition, PEG is an expensive commodity and despite the above research outcomes it is unlikely to be cost-effectively implemented on a commercial scale.

Activated charcoal has been shown to reduce absorption of plant secondary compounds (Estell 2010) and to increase intake of shrubs as species diversity declined (Rogosic *et al.* 2006). Further calcium hydroxide can alleviate the effects of plant toxins (Rogosic *et al.* 2008) however as for PEG, it is unlikely that these products would be commercially viable options to increase dry matter intake of shrubs in a rangeland environment. Should the establishment of shrub species in more intensively grazed environments, as is currently being investigated by the Future Farm Industries CRC, be increasingly adopted, these supplementation strategies may become a more realistic option to improve dry matter intake.

Figure 10 Boer goat carcases (Courtesy: G. Reimers 2011)

Nutritive value of rangeland plant species

Although it has been suggested that goats are highly adapted to the often hostile pastoral environment, they tend to respond in much the same way as any grazing animal to adverse seasonal conditions. The number of goats harvested from the rangelands varies according to seasonal conditions such that it must be assumed that the fertility of the breeding doe declines, and kid mortality increases in line with a decline in feed quality. However it is clear that goats have a unique ability to harvest the most highly nutritious components of plant material which in combination with their suggested capacity to modify and absorb lignin and detoxify plant secondary compounds, makes them ideally suited to the rangeland environment.

The nutritive value (NV) of all pastoral plant species varies widely across regions, between and within species and on a seasonal basis and the analytical methods currently in use for determination of digestibility and hence ME remain the subject of research and are far from settled.

Caution should be exercised in relation to the interpretation of published NV's as conversion equations from dry matter digestibility (DMD) and dry organic matter digestibility to ME have changed in recent years and is unlikely to be consistent between laboratories. Further the publication of single values for any nutrient should be disregarded due to the variation of NV's over time and location as previously described.

Shrub species in particular require an associated description with the NV such as leaf or stem or leaf plus 2mm stem to facilitate a quantifiable evaluation of the accuracy of the result, but importantly it is imperative that the part of the plant that is preferentially eaten is the one that is analysed for NV. A guide to the NV of a range of pastoral plant species can be found in Appendix 6.

Nutritive value data was collected of commonly grazed rangeland species between 2003 and 2008 by groups of pastoralists in the South Australian arid lands (CNEFAP, 2004; Outback Lakes Group, 2008). Dry organic matter digestibility (DOMD) ranged from 32.8%-73.2% with a median value across 200 samples of 61.1%. This contrasted with previously published data (McDonald and Ternouth 1979) where DOMD results for a range of browse species ranged from 29.7% - 67% . DOMD of 9 samples of Salsoli kali (Buckbush) analysed from the South Australian rangelands (range: 53.6-75.7%; median 60%) compared well with the average DOMD across 9 samples from Western Queensland (McDonald and Ternouth 1979).

Far greater differences were apparent between DOMD analyses of Acacia aneura (Mulga) from the Oodnadatta region of South Australia (range 50.5-53.2%; median 50.8%) compared with Western Queensland at an average value of 27.9% (McDonald and Ternouth 1979).

Nutritional management strategies

The nutritional management of rangeland goats appears limited to the implementation of grazing management strategies that maintain the biodiversity of plant species available as a feed resource for goat production. Identification by pastoralists and land managers of key indicator species, that is, species that goats preferentially graze, and their patterns of nutritive value will enable pastoralists to develop destocking policies which preserve biodiversity and optimise their goat production systems. It is important also that pastoralists are familiar with the botanical names of indicator species as many people refer to the same species by a different name; confusion can result when assessing the NV of indicator species if pastoralists and advisers are using different terminology.

This is likely to be the most practical and realistic management tool however additional retrospective tools such as monitoring the nutritive value of trapped goats' diet using faecal sampling (FNIRS) can also be implemented as a method of detecting a decline in diet quality. Measurement of forage yield across seasons and estimations of intake have been suggested by Norton (1984) as useful guidelines to assist in setting stocking rates.

Monitoring of body condition of harvested and released goats during yarding will provide an additional indication of nutritional status of rangeland goats.

Management of goat nutrition in a rangeland environment can only extend to:

- familiarisation of the seasonal change in nutritive value of key plant species
- identification of indicator species for early destocking and biodiversity and animal welfare purposes
- monitoring of body condition of drafts of goats when trapping or mustering
- analysis of faecal NIRS to determine current plane of nutrition (Landau *et al.* 2006)

Dry matter intake requirements of goats

The daily dry matter intake requirement of goats varies with breed, sex, class, stage of productivity, level of milk production, required level of weight gain, prospective birth weight of kids and growth potential. Dry matter intake where feeding is controlled can be adjusted according to the nutrient density of the diet to meet daily requirements for ME, crude protein, fibre, vitamins and minerals; however in an *ad-libitum* feeding situation goats cannot be relied upon to limit their intake where feed quality is high nor to increase intake to compensate for low quality feed on offer.

Recommendations for daily intake requirements of goats abound – from many internet sources (Appendix 1), university and goat websites to scientific, peer reviewed publications.

Where recommendations refer specifically to tropical goat production, they have not been incorporated into this review except in consideration of the NRC (1981) "Nutrient Requirements of Goats: Angora, Dairy and Meat Goats in Temperate and Tropical Countries". This publication has underpinned many of the published requirements and formed the basis of feeding experiments from 1981 until a significant review of goat nutrition resulted in the publication of NRC (2007).

Whilst there are alternative publications such as CSIRO (2007) and the Agriculture and Food Research Council (AFRC 1993), NRC is the most widely used set of nutrient requirements internationally due to their clarity and ease of implementation. Prior to publication of NRC (2007), international nutrition scientists reviewed the recent literature in order to compile a set of recommendations. An Australian member of the editorial committee for CSIRO (2007) was also a contributing author to NRC (2007) such that it might be assumed that there were some synergies between both publications.

Recommendations for dry matter intake requirements are largely based on intake as a percentage of body weight or live weight which varies significantly between genotypes of the same age (Table 10).

NRC (1981), while acknowledging that very little nutritional research specific to goats was available at the time of publication, placed a high level of importance on the effect of level of activity on intake requirements of goats, whereas NRC (2007) has largely refuted these recommendations due to a lack of supporting data. Comparison of the two data sets is quite difficult as NRC (1981) includes an activity rating and bases DMI requirements on two different dietary ME concentrations. These concentrations allow for differences in pasture or dietary ME density.

Table 10 Mature liveweights of goat breeds in the literature

Breed	Genotype	Mature Wt (kgs)	Author
Alpine (France)	Dairy	80-90	Fehr *et al*. (1976) cited by McGregor (1985)
Anglo-Nubian	Dual purpose	80-90	Going Into Goats (2006)
Angora	Fibre	60-80	Going Into Goats (2006)
Angora (Texas/Australia)	Fibre	50-60	Shelton & Huston (1966) cited by McGregor (1985)
Barbari (India)	Meat	35-45	Singh *et al.* (1980) cited by McGregor (1985)
Boer	Meat	100-110	Going Into Goats (2006)
Boer doe	Meat	60	Blackburn (1995)
Boer - Improved (Sth Africa)	Meat	100-110	Campbell cited by Naude & Hofmeyr (1981) cited by McGregor (1985)
Condoblin	Rangeland	80-100	Going Into Goats (2006)
Damascus (Cyprus)	Dairy	80-90	Louca *et al*. (1977) cited by McGregor (1985)
Kalahari	Desert	100-110	Going Into Goats (2006)
Kambing/Katjang (Malaysia & Indonesia)	Meat	25-30	Devendra (1967) cited by McGregor (1985)
Rangeland	Rangeland	45-80	Going Into Goats (2006)
Rangeland (Australia)	Rangeland	45-55	McGregor *et al.* (1982) cited by McGregor (1985)
Spanish doe	Meat	45	Blackburn (1995)
Saanan	Dairy	90-100	Going Into Goats (2006)
Saanen (Britain, Australia)	Dairy	90-100	McGregor (1980) cited by McGregor (1985)

Intake requirements as recommended by NRC (1981) for goats at maintenance plus activity at a range of liveweights where the ME density of the diet is 8.37 MJ ME per kg DM are summarised in Table 11.

Similarly daily DMI based on a dietary ME density of 10.04MJ.kg DM with increasing allowances for activity above maintenance is presented in Table 12. Three activity ratings are equally applied to both sets of requirements. Where feed intake is controlled, such as in a feedlot or dairy, it may be reasonable to formulate rations to an ME concentration and control intake, however, under paddock conditions where the ME of the diet is likely to be closer to 10, the recommendations in Table *12* may be a more appropriate guide to requirements.

Table 11 Dry matter intake (kg/d) recommended for goats at maintenance and three levels of activity (low, medium and high) at a dietary ME concentration of 8.37 MJ/kg DM (adapted from NRC 1981)

	Activity level											
LW	***Maintenance***			***Low 25%***			***Medium 50%***			High ***75%***		
Kg	***Kg***	% LW	MJ/d	Kg	%LW	MJ/d	Kg	%LW	MJ/d	Kg	%LW	MJ/d
10	0.28	2.8%	2.34	0.36	3.6%	3.01	0.43	4.3%	3.60	0.50	5.0%	4.19
20	0.48	2.4%	4.02	0.60	3.0%	5.02	0.72	3.6%	6.03	0.84	4.2%	7.03
30	0.65	2.2%	5.44	0.81	2.7%	6.78	0.98	3.3%	8.20	1.14	3.8%	9.54
40	0.81	2.0%	6.78	1.01	2.5%	8.45	1.21	3.0%	10.13	1.41	3.5%	11.80
50	**0.95**	1.9%	7.95	1.19	2.4%	9.96	1.43	2.9%	11.97	1.67	3.3%	13.98
60	**1.09**	1.8%	9.12	1.36	2.3%	11.38	1.64	2.7%	13.73	1.92	3.2%	16.07
70	**1.23**	1.8%	10.30	1.54	2.2%	12.89	1.84	2.6%	15.40	2.14	3.1%	17.91
80	**1.36**	1.7%	11.38	1.70	2.1%	14.23	2.03	2.5%	16.99	2.37	3.0%	19.84
90	1.48	1.6%	12.39	1.85	2.1%	15.48	2.22	2.5%	18.58	2.59	2.9%	21.68
100	1.60	1.6%	13.39	2.00	2.0%	16.74	2.41	2.4%	20.17	2.81	2.8%	23.52

Table 12 Dry matter intake (kg/d) recommended for goats at maintenance and three levels of activity (low, medium and high) at a dietary ME concentration of 10.04 MJ/kg DM (adapted from NRC 1981)

	Activity level											
LW	***Maintenance***			***Low 25%***			***Medium 50%***			High ***75%***		
Kg	***Kg***	% LW	MJ/d	Kg	%LW	MJ/d	Kg	%LW	MJ/d	Kg	%LW	MJ/d
10	0.24	2.4%	2.41	0.30	3.0%	3.01	0.36	3.6%	3.61	0.42	4%	4.22
20	0.40	2.0%	4.02	0.50	2.5%	5.02	0.60	3.0%	6.02	0.70	4%	7.03
30	0.54	1.8%	5.42	0.67	2.2%	6.73	0.81	2.7%	8.13	0.95	3%	9.54
40	0.67	1.7%	6.73	0.84	2.1%	8.43	1.01	2.5%	10.14	1.18	3%	11.85
50	**0.79**	1.6%	7.93	0.99	2.0%	9.94	1.19	2.4%	11.95	1.39	3%	13.96
60	**0.91**	1.5%	9.14	1.14	1.9%	11.45	1.37	2.3%	13.75	1.60	3%	16.06
70	**1.02**	1.5%	10.24	1.28	1.8%	12.85	1.53	2.2%	15.36	1.79	3%	17.97
80	**1.13**	1.4%	11.35	1.41	1.8%	14.16	1.69	2.1%	16.97	1.98	2%	19.88
90	1.23	1.4%	12.35	1.54	1.7%	15.46	1.85	2.1%	18.57	2.16	2%	21.69
100	1.34	1.3%	13.45	1.67	1.7%	16.77	2.01	2.0%	20.18	2.34	2%	23.49

Providing the ME density of the feed on offer is equivalent to a total of 8 ME, either in the paddock or as a formulated ration, the total daily DMI and energy requirement per NRC, 2007 for mature, non-dairy does have not changed significantly from NRC, 1981 for maintenance alone (Table 13); however there is no additional ME allowance for activity in these recommendations which is likely to be unrealistic for grazing goats.

Table 13 Dry matter intake requirements (% of LW & kg/d) for three goat genotypes at maintenance, with an ME density of 7.6-8.0 ME (adapted from NRC 2007)

Class – age	Breed	Class – production	LW	Fibre growth g/d	DMI % of LW	DMI kg/d	ME MJ/kg
Mature doe	Dairy	Maintenance	50		2.36	1.18	8.0
			60		2.25	1.35	8.0
			70		2.17	1.52	8.0
	Non-dairy	Maintenance	50		1.99	**1.00**	8.0
			60		1.90	**1.14**	8.0
			70		1.83	**1.28**	8.0
			80		1.77	**1.42**	8.0
	Angora	Maintenance	40	10	2.99	1.20	7.6
			50	10	2.76	1.38	7.6
			60	10	2.58	1.55	7.6

The NRC (1981) nutrient requirements for goats were largely based on treadmill studies according to Lachica *et al.* (1997) and on distances travelled by sheep across a slope (ARC 1980). Sahlu *et al.* (2004) suggests that access to grazing while walking may confound the increase in energy requirements attributed to walking long distances which is the basis for the lack of accounting for activity. There appears to be merit in the application of an activity factor to the maintenance requirements of goats in particular when grazing pastures under conditions of sparse vegetative cover. This will be discussed in more detail in the following section.

The reportedly suboptimal productivity of domesticated meat goats, particularly in high rainfall environments, would indicate that urgent validation of these recommendations is required to underpin the potential growth of the intensive meat goat industry.

Conclusion

There are many recommendations for the nutrient requirements of goats however most of these publications have been reviewed as a component of NRC (2007); AFRC (1998) acknowledges that there was little research available on goats at the time of publication and CSIRO (2007) contains few references specific to goats.

Prediction or assessment of dry matter intake is a critically important component of ensuring the nutrient requirements of goats are met on a daily basis. The most comprehensive set of nutritional guidelines for goats was published by NRC in 2007 where the supply of nutrients such as protein and ME to the goat, are predominantly driven by an assumed level of dry matter intake. Thus the factors influencing intake require consideration when formulating diets for confined goats or when assessing the provision of nutrients from grazed pastures.

Predictions of intake within a rangeland environment are more difficult and seldom considered; however new technology such as faecal NIRS offers a method of estimation of the diet grazed by ruminants in range country for those who might want to avail themselves of this technology.

Retrospective measures of intake such as body condition score can be monitored at each mustering; this is usually done on a visual basis. The intake of rangeland goats is more likely to be significantly influenced by selection, preference and the presence of secondary compounds in plant material. As the more palatable or indicator plant species decline so productivity diminishes accordingly. Supplementary measures to alleviate the effects of secondary compounds are unlikely to be practical or cost-effective in pastoral areas. It is the responsibility of pastoralists, as well as in their best interests, to reduce goat populations and/or grazing pressure as key indicator species decline.

Assessment of feed on offer in pasture-based intensive environments is a simpler task and where stocking rates are high, prediction of daily dry matter intake is an important component of grazing management. Intake of goats confined within depots and feedlots requires monitoring, and consideration of NDF as a key to intake must be accounted for by producers and managers and their advisors.

Winter weight stasis has been raised by industry personnel as a significant factor limiting the productivity of goats however there is scant and variable supporting evidence of this phenomenon in the published literature. This issue requires investigation and quantification.

Offering goats a choice of feeds to increase intake has, as for sheep and lambs, produced a positive response in intake however the practicality and cost-effectiveness of such a measure other than in a goat dairy have not been clarified.

The intake requirements for goats have been extensively reviewed; the majority of published recommendations prior to 2007 have been based on NRC (1981). Comparison of more recent publications with NRC (1981) is difficult as all recommendations in that publication were assigned an “activity” rating where requirements were increased with an increasing level of unspecified activity. NRC (2007) requirements have largely been based on the recommendations of Sahlu *et al.* (2004) where all reference to activity has been removed on the basis that goats are likely to have access to feed while grazing and hence walking, unlike dairy cows that might be walking on laneways.

Before the nutrient requirements of NRC (2007) for dry matter intake can be implemented, these recommendations require validation.

Recommendations

- Clarify the dry matter intake requirements of all classes and genotypes of goat
- Determine the appropriateness or otherwise of the application of an activity rating for grazing goats
- Ensure pastoralists are familiar with their key indicator species and how to monitor their decline
- Ensure goat producers and managers of depots and intensive operations understand how to assess dry matter intake such that nutrient intake can be adjusted if dry matter intake is sub-optimal
- Investigate the phenomenon of winter stasis as a priority such that remedial measures can be implemented

Energy requirements of goats

The energy content of the diet can be best described as the amount of energy released as a result of fermentation of dietary components by rumen microbes. Metabolisable energy (ME) is the energy available for maintenance, activity, milk production, pregnancy and weight gain. Energy is expressed as megajoules per day (MJ/d) or as megajoules per kilogram of dry matter (MJ/kg DM) referred to as energy density such that energy availability is determined by the amount of kilograms of feed ingested.

Daily energy demand increases with increased levels of productivity, however factors such as heat and cold stress, transport stress, shearing, disease and high salt intakes are certain to increase demand, but the degree of increase required for goats or differences among genotypes, has yet to be quantified. Estell (2010) hypothesised that ME requirements of rangeland goats may increase to facilitate detoxification of plant secondary metabolites and to allow for increased distances travelled in search of nutritious species. Under favourable seasonal conditions it is likely that rangeland goats select the most nutritious components of the plant species on offer in an effort to meet energy requirements; however where the range country is reduced to predominantly halophytic shrubs, energy requirements to sustain multiple pregnancies are unlikely to be met.

Small ruminants balance their relatively high energy requirements with an ability to increase voluntary intake of feeds higher in nutritive value as feeds high in cellulolytic fibre are bioenergetically inefficient. This creates a conundrum as both sheep and goats prefer a dietary NDF concentration of 40% which, unless the fibre source is highly digestible, will potentially limit total ME intake particularly of small ruminants. Caution should be exercised when assuming that ME intake from ingestion of low quality feeds can be overcome by an increase in dry matter intake, as this is often not the case.

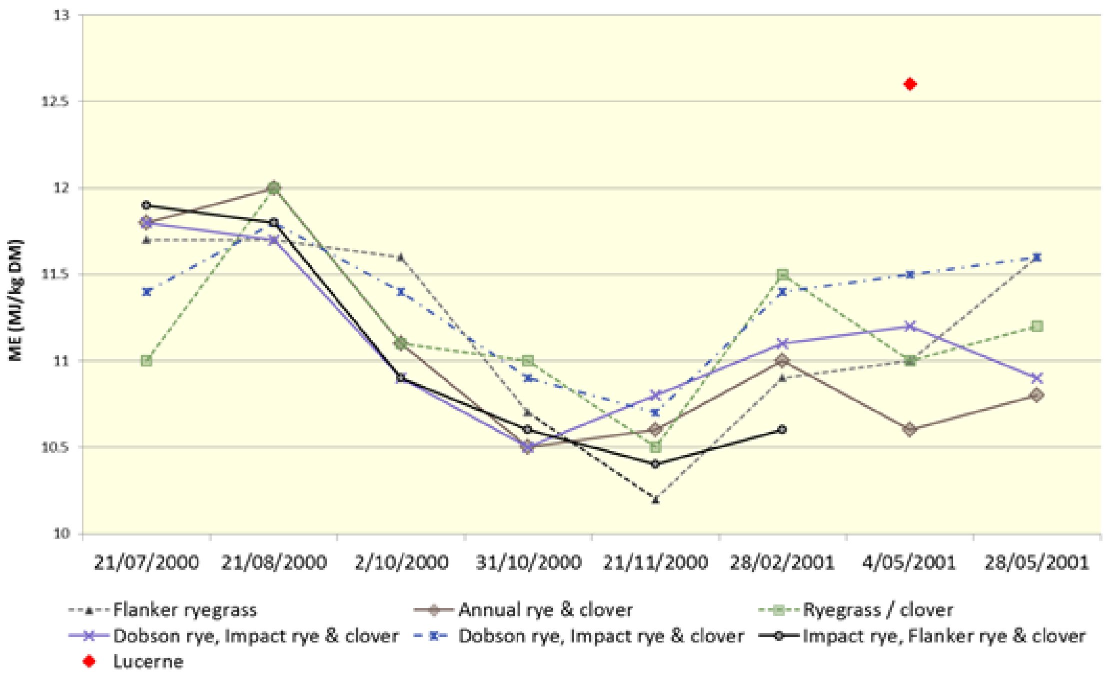

Figure 11 Seasonal change in metabolisable energy (ME) of a range of pasture species under irrigation and rotationally grazed by dairy cows at Meningie, SA (Jolly, unpublished data)

When formulating diets for confined goats the aim is to meet daily nutrient requirements for ME; if the dietary intake is controlled or restricted it is important to ensure ME requirements are met and that intake rate is able to be achieved to that end. However where rations are made available to goats on an *ad-libitum* basis it is necessary to monitor daily intake of ration components to ensure that ME requirements are being met but not exceeded in order to constrain costs. There is general acceptance that maintenance of body condition and herd productivity is dependent on the amount of energy available from intake and digestion of the dry matter (Sachdeva *et al.* 1973) however the growth and milk production responses to ME intake alone appear less well defined.

Domesticated goats have high levels of productivity relative to their body weight and therefore require a diet high in ME density (Poore and Luginbuhl 2002). In southern Australia pasture quality remains high for a limited period despite the pasture appearing to be “green”. ME concentration begins to decline from the onset of spring in most areas (Figure 11) as plants move toward their reproductive phase.

Figure 12 Oldman saltbush (Atriplex nummularia) Carrieton, SA

Salt intakes reportedly decrease energy use efficiency which Arieli *et al.* (1989) attributed to mineral metabolism in the rumen. ME values based on dry matter digestibility may not be indicative of the digestible plant material as up to 30% of the dry matter can be minerals which do not contribute to the energy value (Masters *et al.* 2007). Grazing animals absorb secondary compounds such as tannins, oxalates, betaine and proline from halophytic saltbushes; these compounds also do not contribute to ME intake (Masters *et al.* 2001) but require energy for the metabolic process of digestion and hence increase total ME requirement.

The degree to which the provision of shade and shelter alleviates an increase in ME demand for all classes of goat requires clarification. It has been suggested that an increase in ME_m requirement of between 7-25% may be required under conditions of heat stress (NRC 2007). Although the effects of heat and cold stress can be modulated by body condition, fibre length and time of shearing (NRC 2007), Boer producers report winter mortality rates of pre-weaned kids of up to 40% as being the norm. This would imply that despite access to high quality pastures, energy available for late pregnancy and lactation may have been suboptimal.

Ruminants tend to reduce feed intake under conditions of heat stress and to reduce metabolic heat production, however feed digestibility and hence the availability of ME is reduced under conditions of cold stress due to an increased rate of passage of feed through the digestive system (NRC 2007). Both of these metabolic responses are likely to result in ME intakes below requirements unless the feed on offer is of high quality.

Inclusion of an activity allowance in nutrient requirements

Maintenance energy requirements when practically applied should account for "normal" activity of the grazing ruminant. These requirements are likely to increase significantly for domesticated goats grazing in hilly terrain or in the rangelands under prolonged dry conditions. Sahlu *et al.* (2004) suggested the energy cost per hour spent grazing plus walking was 5% per hour. CSIRO (1990) recommended an increase in daily ME intake for activity of 10-20% above that required for confined ruminants, and up to a 50% increase under extensive grazing conditions. Lachica and Aguilera (2003) proposed that "free-ranging" goats' energy requirements exceeded those of confined goats, however NRC (2007) and Sahlu *et al.* (2004) have suggested that further validation is required prior to adoption of these recommendations.

NRC (1981) published nutrient requirement tables for goats under conditions of minimal, low, medium and high activity where the following definitions apply:

- Minimal – 25% above maintenance
    - Intensive management
    - Tropical range
    - Early pregnancy

- Medium – 50% above maintenance
    - Semi-arid rangeland
    - Slightly hilly pastures
    - Early pregnancy

- High – 75% above maintenance
    - Arid rangeland
    - Sparse vegetation
    - Mountainous pastures
    - Early pregnancy

Where energy expenditure has been reported it has varied widely. Lachica *et al.* (1999) found that goats travelling between 8.1-12.8 km, had expenditure 32-47% of an assumed ME_m of 401kJ/kg LW $^{0.75}$; however under similar conditions in a previous study, Lachica *et al.* (1997) had determined energy expenditure at 9-14% above an assumed maintenance requirement of 443kJ/kg LW $^{0.75}$

In further work, Lachica and Aguilera (2003) reported the energy expenditure of pasture-based, yearling crossbred Boer goats with limited movement during summer was 43% of ME_m.

Energy expenditure is influenced by pasture availability and increases with stocking rate. Investigation by Lachica and Aguilera (2003) of pasture-based yearling crossbred goats at low and high stocking rates, observed that at high stocking rates energy expenditure was 50% of maintenance and with high pasture availability 24% of ME_m.

CSIRO (2007) have provided recommended allowances for the energy expenditure of grazing ruminants based on calorimetric studies (CSIRO 2007) which are tabulated in Table 14 below.

The earlier work of Lachica and Aguilera (2003) highlights the marked effect that the physical form of the diet has on the energy cost of eating as detailed in Table 15. The longer the fibre the higher the energy cost of eating.

Table 14 Energy cost of various physical activities by ruminant animals per kg liveweight (CSIRO 2007)

Activity	Energy cost per kg LW
Standing (compared with lying)	10 kj/d
Changing body position	0.26 kj
Walking - horizontal	2.6 kj/km
Walking - vertical	28 kj/km
Eating - prehension & chewing	2.5 kj/h
Ruminating	2 kj/h

Table 15 Rate of ingestion and energy cost of eating in goats offered seven different feeds (Lachica and Aguilera 2003)

	Feed and physical form						
	Barley	Beans	Lucerne	Lucerne	Lucerne	Vetch	Olive
	Grain		*Pelleted hay*	*Chopped hay*	*Fresh cut*	*Straw*	*Leaves & twigs*
Mean LW(kg)	37.50	37.90	38.00	38.30	41.20	38.40	35.10
Dry matter intake (DMI) g	363.70	362.50	367.50	178.30	76.40	125.10	112.20
Time spent eating (min)	3.70	9.50	6.60	12.50	12.60	16.70	13.90
Rate of ingestion (g DM/kg LW/min)	2.64	1.21	1.59	0.38	0.15	0.20	0.24
Energy cost of eating:							
J/kg/g DM	1.45	1.65	2.24	4.75	7.08	8.20	11.78
J/kg/min	143.80	75.80	135.90	69.80	44.60	63.90	97.80
J/g DOM	63.60	78.00	179.60	348.80	492.20	606.20	735.20
%ME	0.40	0.50	1.20	2.20	3.20	3.90	4.70

Sutton and Alderman (2000) in a review of the energy requirements of pregnant and lactating dairy goats for AFRC concluded that the recommendations for ME remained uncertain; this factor is highlighted by the variation in estimates of the cost of activity from three sources which is summarised in Table 16.

Table 16 Estimates of the cost of activity as % above maintenance (Sutton and Alderman 2000)

	NRC (1981)	*Morand-Fehr (1987)*	*AFRC (1998)*
Pasture	25	10-20	19
Good range		30-50	25
Poor range	50	50-80	93
Mountainous	75		108

Recommended daily ME requirements of goats

McGregor (2005) proposed a range of 267-485 kJ ME/kg LW $^{0.75}$ for maintenance of goat liveweight under drought conditions should be considered and that the most appropriate value of 404.7 kJ ME/kg LW $^{0.75}$ should be applied; but for what class of goat under what conditions was not clear and the range in itself is vast. These recommendations were made on the basis of indoor studies of rangeland goats (Ash and Norton 1987; Dunshea 1987); (a derivation from Norton 1982; cited in McGregor 2005). It is assumed many of the ME maintenance recommendations of McGregor (2005) were derived from CSIRO (1990) however this publication contains few references for goats and is clear in the assumption that the maintenance metabolism of goats are similar to sheep; this conclusion is far from agreed.

A factor of 0.422 -0.7 MJME/kg LW$^{0.75}$ for maintenance was recommended in NRC (1981) however in the 2007 edition and based on the work of Sahlu *et al.* (2004) this recommendation had been significantly increased to $ME_{m:}$ 0.423 - 0.624MJME/kg LW$^{0.75}$.

NRC (2007) provides the most detailed basis for the nutrient requirements of goats based on the work of Sahlu *et al.* (2004) and co-workers which include consideration of genotype differences. A downward adjustment factor for maintenance ME requirements of 20% has been suggested for goats on a low plane of nutrition for a prolonged period. This adjustment can be factored in to an online goat nutrient requirement system (http://www2.luresext.edu/GOATS/research/nutreqgoats.html) which was developed in support of the recommendations of Sahlu *et al.* (2004). This web tool may be useful for field use when conducting validation studies of goat nutritive requirements.

Goats may have lower daily requirements for ME than other ruminants as evidenced by Schmidt *et al.* (1935) who reported the conversion of dietary energy into weight gain in goats was less than for other ruminants (cited in Morand-Fehr *et al.* 1982); Silanikove (1996) commented that desert breeds of goat such as the Bedouin were able to respond to a reduction in feed availability by reducing their energy requirements by up to 65%, a finding which may have some relevance to Australian rangeland goats under prolonged dry conditions that are also well adapted to their environment.

The energy requirements recommended in NRC, 2007 are largely based on studies by (Sahlu *et al.* 2004) with goats in confinement and hence may require some uncertain degree of refinement for range conditions. It is likely that these refinements will vary according to the amount of feed on offer while grazing for example, rangeland vs high rainfall pasture systems.

NRC (1981) recommendations were based on few studies with predominantly tropical goats and a range of breeds not commonly found in Australia. The applicability of this data to Australian range and pastoral conditions remains unclear. This section of the report will review the energy requirements of mature does of three genotypes whereas the requirements of kids will be reviewed as a component of growth potential and requirements specific to stages of pregnancy will be reviewed later in this report.

Nutrition of the doe in late pregnancy is likely to be of equal significance to kid survival as the nutrition of ewes during the same period is to lamb survival. During the last 60 days of pregnancy foetal growth in the lamb accelerates and nutrient requirements increase accordingly. The nutrient density of the diet needs to increase during this time as there may be limitations on the doe’s capacity to increase forage intake due to the increased space occupied by the gravid uterus.

Daily energy requirements in the *Going Into Goats Guide* (2006) closely reflect those in NRC (1981) as outlined in Table 17 however NRC (1981) included a fixed increase in ME of 5.48 MJ/day in late pregnancy above maintenance requirements to account for 6% fat corrected milk (fcm) during late pregnancy; a correction factor of 5.94 MJ/d above maintenance was applied in the *Going Into Goats Guide*. The origins of the latter correction appear to be based on recommendations by Stubbs and Abud (2002) however the reasons for the discrepancy with NRC (1981) remain unclear. There was no increase in ME requirements to account for multiple pregnancies until NRC (2007). As multiple pregnancies are common in goats, particularly domesticated meat and dairy goats, NRC (2007) recommendations may be a more appropriate guide.

Table 17 Differences in daily ME requirements recommended for goats during late pregnancy; Going into Goats Guide (GIG) (2006); NRC (1981) and adapted from NRC (2007)

	GIG Guide, 2006		NRC 1981		NRC, 2007 (*errata*)					
	Late pregnancy				Late pregnancy					
	Maintenance		*Maintenance*		*Non-dairy*			*Dairy*		
	6% fcm	*5.94*		*5.48*	single	twins	triplets	single	twins	triplets
LW (kg)										
10	2.27		2.38							
20	3.82		4.01					7.19	8.20	
30	5.18	11.12	5.44	10.92	8.45	9.66	10.30	9.45	10.67	11.30
40	6.43	12.37	6.73	12.21	10.25	11.59	12.47	11.15	12.85	13.73
50	7.60	13.54	7.99	13.47	11.89	13.43	14.31	13.35	14.94	15.82
60	8.71	14.65	9.16	14.64	13.43	15.23	16.15	15.15	16.95	17.83
70	9.78	15.72	10.25	15.73	14.98	16.82	17.91	16.87	18.75	19.80
80	10.81	16.75	11.34	16.82	16.36	18.54	19.63	18.46	20.63	21.72
90	11.80	17.74	12.38	17.86	17.70	20.04	21.30	20.00	22.35	23.60
100	12.78	18.72	13.43	18.91						

Additional 5.48 MJ per 6% fat (NRC 1981) and 5.94 (Going Into Goats Guide) above ME_m

Although the liveweight of Angora goats is more likely to be closer to 50kg, the reference weight of 60kg was chosen in the example in Table 18 for the purpose of comparing the nutrient requirements (NRC 2007) of three genotypes, non-dairy, dairy and Angora, in late pregnancy.

Table 18 Daily dry matter intake (DMI) and energy requirements according to pregnancy status of three goat genotypes weighing 60 kg in late pregnancy (Adapted from NRC 2007)

Genotype	Pregnancy status	Stage of pregnancy	LW	LW change g/d	Fibre growth g/d	DMI % of LW	DMI kg/d	ME MJ/d	ME MJ/kg
Non-dairy	Single	Late	60	86		2.80	1.68	13.43	8.0
	Twin	Late	60	143		2.54	1.52	15.23	10.0
	Triplet	Late	60	186		2.69	1.61	16.15	10.0
Dairy	Single	Late	60	86		3.15	1.89	15.15	8.0
	Twin	Late	60	143		2.82	1.69	16.95	10.0
	Triplet	Late	60	163		2.97	1.78	17.83	10.0
Angora	Single	Late	60	86	10	3.52	2.11	16.11	7.6
	Twin	Late	60	143	10	3.90	2.34	17.91	7.7

As the energy demand of late pregnancy increase from singles to multiples, so the daily ME requirement increases, which appears a logical assumption. In the case of a twin pregnancy recommendations for intake have been decreased presumably to allow for increased space occupied by the pregnancy, and as such ME density of the available feed must increase. This recommendation appears logical however an increase in DMI in late pregnancy to meet the increased ME demand of triplets appears nonsensical. The recommendations for Angora does in late pregnancy require validation as it appears to be assumed that intake will increase with increased demand of multiple pregnancy in order to meet ME demand; this is not likely to be the case in practise.

Differences in recommendations across genotypes of goat are highlighted in Table 18. These should be accounted for when formulating rations or when assessing the suitability of pasture for late pregnancy. Many book values of pasture quality quote ME values of 11-12 ME for green pasture however in reality these concentrations are more often closer to 10 ME.

Nutrient requirements sourced from websites seldom cite the origins of their information and differ from the published literature; this can be a source of confusion for industry personnel seeking facts about nutrition. Table 19 is indicative of the type of information where intake or pregnancy status is not provided such that the value of the data is limited. The recommended energy requirement of 9.82 MJ/kg DM for a high producing doe aligns with NRC (2007) but is significantly lower than the ME concentration recommended by Coffey (Table 20).

Table 19 Energy requirements of meat goats during late pregnancy and lactation (adapted from www.sheepandgoat.com/articles/meatgoat.htm)

	ME (MJ ME/kg DM)
Late Gestation	9.06
Lactating Doe	9.06
High Producing Doe	9.82

Coffey (2006) suggests that lactating dairy does require an ME density in their diet of 10.7 and mature does of unstated genotype, 10.4 ME the details of which are summarised in Table 20. At the recommended DMI of 3.04 kg this would provide a daily ME intake of 32.5 MJ ME which is a 35% increase above the recommendations of NRC (2007) summarised in Table 21 and which appears excessive.

Table 20 Feed intake and energy requirements of goats during lactation (adapted from Coffey 2006)

CLASS OF GOAT	Liveweight *kg*	Feed intake *kg DM/d*	ME *MJ ME/kg DM*
Dairy doe - lactation	60.7	3.04	10.7
3yr old doe	44.5	2.03	10.4

Beverley & Moore (2008) recommended increased ME requirements for lactating Boer goats per level of daily milk production as follows:

- 2 litres per day – 19 MJ/d
- 3 litres per day – 24 MJ/d
- 4 litres per day – 30 MJ/d

These recommendations at high levels of milk production appear more closely aligned to those of Coffey than to NRC (2007).

The NRC (2007) recommendations for does in early lactation consisting of a range of genotypes detailed in Table 21 are curious; dairy does most commonly have access to concentrate feeds such as grains that are highly concentrated sources of ME such that it is unlikely that the ME density of their diet would ever approximate 8 ME during lactation.

Again the assumption is made that dairy does will compensate for the low ME by consuming 4.61% of their liveweight in dry matter in order to meet energy requirements. At an ME density of 8 MJ/kg DM it is unlikely that dairy goats would consume 4.6% of liveweight as to do so would require the NDF of the diet to be lower than 30%; this is not a likely scenario. Smaller ruminants require access to a diet that is higher in ME such as recommended in Table 21 for Angora does at 30kg with kids at foot. This is a more realistic recommendation.

Table 21 Energy requirements of a mature doe with twin kids at foot in early lactation (adapted from NRC 2007)

Twins: *early lactation*	LW	LW change g/d	Fibre growth g/d	DMI % of LW	DMI kg/d	ME MJ/d	ME MJ/kg
Dairy	50	-45		4.61	2.31	18.46	8.0
Non-dairy	50	-50		3.08	1.54	12.93	8.0
Angora	30	-38	10	3.22	0.96	11.59	12.07
Angora	50	-50	10	2.96	1.48	14.77	10.0

Poore and Luginbuhl (2002) reviewed the nutrient requirements of Angora goats and NRC (1981) and produced a table of recommendations for lactating meat does which are summarised in Table 22. The liveweights would indicate that these requirements are for Angora or rangeland does rather than meat does however they do not compare well with NRC (2007). A 30kg Angora doe with twins at foot in early lactation according to NRC (2007) has a daily energy requirement of 13.9 MJ at an intake of 1.25 kg DM.

Table 22 Daily nutrient requirements for meat producing goats (adapted from Poore and Luginbuhl 2002)

	Live weight	Dry matter intake	ME	ME
CLASS OF GOAT	*kg*	*DMI kg/d*	*MJ/d*	*MJ ME/kg DM*
Doe - lactating low production	32.4	1.82	16.4	9.06
Doe - lactating high production	32.4	2	19.6	9.8

Although NRC (2007) has published the most recent and comprehensive set of nutrient guidelines for goats, they appear to be significantly lower in their recommendations than the previous edition of 1981. The lack of accounting for activity, particularly under Australian conditions, as goats are a highly active animal is cause for concern as previously discussed.

NRC (2007) has also significantly lowered the nutrient recommendations for growing lambs from the previous publication in 1985 however there has been a large amount of research published over that 25 year period. Field experience has determined that in the case of light lambs the NRC (2007) requirements are suboptimal and weight loss has been observed where Merino lambs were expected to gain 100 g/day (Dickson & Jolly, unpublished) according to the recommendations. The statement in NRC (2007) *"in some cases diets having greater or lesser concentrations of energy would be more appropriate"* provides an indication as to the degree of confidence in their recommendations.

Goat producers appear keen to receive accurate and applicable nutritional information and guidance to increase the productivity of their operations and to reduce mortality rates, particularly during winter and post weaning. The producers interviewed as a component of this review did not appear to have a high level of understanding about nutrition, the value of feed analyses or ration formulation; these issues were approached on an ad-hoc basis compared with beef and lamb producers.

Conclusion

As ME intake is entirely dependent upon daily dry matter intakes being achieved, ensuring this is the case is an imperative in the nutritional management of goats.

Energy requirements of goats are complex due to the variation between genotypes and the lack of knowledge about the productivity potential of each genotype under a broad range of Australian conditions. In addition ME requirements vary with activity level and the protein content of the diet. As goats are managed in the rangelands, in high rainfall and low rainfall farming country and in depots; kids are weaned onto range and intensive pastoral systems as well as feedlots, the differences in their energy requirements may be significant.

It is likely that the high kid mortality rates and sub-optimal reproductive rates of intensively managed does are in part due to a lack of available ME; this requires further investigation.

It may be logical to conclude that the energy requirement of mature does varies between genotypes and stage of production, however the reasons for the variation in recommendations between publications remains unclear. There remains sufficient doubt about the accuracy of published energy requirements and their relevance to Australian domesticated and bush goats to warrant further research.

The information to be found on the internet is conflicting, confusing and of little benefit to anyone that does not have a good understanding of nutrition. The published nutrient requirements for goats require nutritional expertise for interpretation and implementation despite being a well set out and comprehensive set of guidelines.

There appears to be general agreeance that to base energy requirements of goats of a range of genotypes on those derivations for sheep and/or cattle may not be sound practise and the inclusion or otherwise of an activity allowance in ME recommendations requires review and resolution.

Recommendations

- Determine the energy requirements for mature goats under field conditions – validation of NRC, 2007 recommendations
- Validations should include a range of genotypes, pastures, supplements and liveweights
- Determine an appropriate activity rating for ME above maintenance for grazing goats of different genotypes where appropriate
- Develop a user-friendly, practical set of ME guidelines for goat producers and their advisors
- Develop education programs for goat producers to improve their understanding of goat nutrition and management

Protein requirements of goats

Protein is ingested in the feed of goats as nitrogen, approximately 80% of which under intensive grazing situations is utilised by the rumen microbes during fermentation and results in the production of microbial protein. The remainder (20%) escapes fermentation and is absorbed as amino acids via the small intestine and is referred to as undegradable protein (UDP), by-pass or escape protein.

In addressing the nutrient requirements of goats under individual sections it is important to note that goats require a balance of protein, energy, fibre and minerals to optimise their level of productivity and that nutrients should not be considered independent of each other. Daily requirement for protein is dependent on the energy density of the diet and the weight, age and stage of productivity of the animal (Oddy pers comm. September 2006). Animals maintain a balance of energy and protein that meet their nutritional requirements where the feed on offer permits them to do so (Provenza *et al.* 2003).

Oddy, (2006 unpublished) proposed the relationships depicted in Table 23 between energy density and crude protein (CP) be considered to ensure rumen microbial protein production is not limited by N availability. These relationships have yet to be tested for goats.

Table 23 Recommended energy density (M/D = MJ ME/kg DM) and crude protein (%) levels in the diet to ensure rumen microbial protein production is not limited by N availability (Oddy 2006 unpub.)

M/D	Degradability of protein in rumen			
	0.6	0.7	0.8	0.9
9	13.5%	11.6%	10.1%	9.0%
10	15.0%	12.9%	11.3%	10.0%
11	16.5%	14.1%	12.4%	11.0%
12	18.0%	15.4%	13.5%	12.0%
13	19.5%	16.7%	14.6%	13.0%

It is considered to be more accurate to determine dietary protein requirements on a metabolisable protein basis rather than by crude protein however it is unlikely that the target audience of this review or the subsequent edition of the *Going into Goats Guide* would be able to make practical use of that information. For that reason, this section will address protein requirements on a crude protein (N x 6.25) basis. When formulating rations or considering the nutritive value of pasture and its likelihood of meeting animal requirements, account should be taken of total daily protein requirements (grams per head per day). Consideration of protein provision on a percentage basis assumes a level of dry matter intake that may or may not be realistic. For example if a doe required a DMI of 950grams per day of pasture at 7.9% crude protein, this would provide her with 75 grams of CP for the day; however if other factors such as salt or fibre limited her intake to 500 grams DMI per day she would only receive 39.5 grams of CP per day.

Minimum crude protein levels in the diets of goats of 6-8.5% will vary with age (Patterson *et al.* 2009) however the critical level for microbial activity has been identified as being 6% (Van Niekerk and Casey 1988). Lu (2011) observed that animals on protein-deficient diets produce less antibody immunoglobulin IgA which is thought to supress worm growth and reproductive capacity and may act as a mechanism of resistance (Strain and Stear 2001).

Adequate dietary protein increases resilience of goats to endoparasites and disease such that the synthesis of antibodies may be limited by the availability of amino acids; The maintenance of an enhanced state of immunity has been largely attributed to intake of protein with a protein deficiency being described as increasing susceptibility to endoparasites (Lu 2011). Although an increase in dietary protein intake has been reported to result in a reduction in faecal worm egg count (Max *et al.* 2007; T. Young pers comm. November 2006) it is evident from the goat producers currently running goats in high rainfall country that the availability of high protein pastures is not a panacea for worm control alone.

Excessive ammonia production following microbial fermentation of high protein feeds causes a reduction in dry matter intake (Cooper *et al.* 1995; Francis 2002). Intake of N in excess of requirements appears to be as detrimental to goats as it is to sheep and cattle as evidenced by severe laminitis (J. Gilbert pers. comm. October 2011), urinary calculi (Gasparotto 2010), ruminal acidosis and red gut (Figure 13).

Figure 13 Red gut – inflamed intestine of sheep (Source: Victorian DPI, 2004)

The maximum tolerable level of rumen degradable protein needs to be established for goats. Severe lameness is a commonplace observation in sheep in the Western Districts of Victoria during winter where pasture crude protein levels can be excessively high (>30%); 25% of pasture-based Boer and Boer cross does at Dorrigo, NSW and up to 60% of bucks become acutely lame when given access to high protein pasture. The addition of cottonseed to a feedlot ration at Dorrigo, NSW resulted in the acute onset of lameness and laminitis (J. Gilbert pers. comm. October 2011) in Boer kids.

Although it is important to eliminate alternative causes of lameness such as foot angle, mineral deficiencies and footrot, currently lameness appears to be a major constraint to the productivity of goats in medium to high rainfall environments, the causes of which require determination and remediation.

Producers in these regions have expressed increasing frustration at the significant economic losses they are experiencing due to scouring and lameness and indicated that the ongoing management costs are not sustainable.

Nutritional management such as that employed in the sheep industry including the provision of straw and low protein cereal grain supplements may alleviate the symptoms however it is important that these remedial measures are cost-efficient. This has yet to be determined.

It appears likely that there is an opportunity for selection of genotypes within the Boer population resistant to the detrimental effects of high performance pastures such that in one herd there were significant numbers of does and kids observed that were healthy and apparently unaffected (S. Jolly pers. comm. October 2011) where others were severely lame.

Condensed tannins (CT) found in many leguminous plant species effectively bind protein in the rumen under conditions of neutral pH; the inclusion of tanniferous plants within high rainfall farming systems may increase N-use efficiency by increasing the percentage of forage protein that passes through to the large intestine as UDP or bypass protein (Muir 2011). However CT:protein complexes are fractured under conditions of low pH (McAllister *et al.* 2005) which are often found in the rumen of animals grazing lush pasture (Wales *et al.* 2004) therefore animals grazing tanniferous plants within intensive pasture systems may not realise similar benefits.

Intake of salt tolerant species such as saltbushes decreases forage digestibility as a result of an increase in the rate of digesta flow; this allows a greater proportion of dietary protein to be digested in the small intestine (Franklin-McEvoy 2002).

Recommended daily protein requirements for goats

Differences between the protein requirements for goats published by NRC (1981, 2007) may be explained by differences in accounting for activity. As well, the protein requirements of goats published in NRC (1981) did not account for the differences in protein degradability in the rumen and small intestine however NRC (2007) accounts for protein intake and digestibility as well as microbial and feed protein available at the small intestine.

Table 24 Comparison of daily crude protein requirements (g/d) for goats as recommended by the Going Into Goats guide (2006), NRC (1981, 2007) for maintenance and early pregnancy

	Going Into Goats 2006	NRC 1981	NRC 2007
	Maintenance	***Maintenance & early pregnancy at low activity***	***Non-dairy, maintenance***
Liveweight (kg)	Crude protein (g/d)		
10	33	22	
20	55	38	36
30	74	51	49
40	93	63	61
50	110	75	71
60	126	86	82
70	141	96	92
80	156	106	101
90	170	116	111
100	184	126	

As for energy the reasons for differences in requirements for protein between publications is not always clear. The maintenance protein requirements published in the *Going Into Goats Guide* reflect NRC (1981) recommendations for maintenance plus medium activity. NRC (1981) did not account for increased requirements above maintenance during early pregnancy and the recommendations outlined in Table 24 are reflective of those required at low levels of activity. Although NRC (2007) removed all accounting for activity, their recommendations for early pregnancy were above the 1981 recommendations for maintenance for all classes of goat (Table 25). The reason for this adjustment remains unclear.

Interestingly NRC (2007) recommends an increase in protein required as pregnancy advances to a peak in early lactation however for single pregnancies protein requirements are higher in late pregnancy than in early lactation (Table 25). Further, ME requirements recommended in NRC (2007) markedly decline from late pregnancy to lactation. Although fat reserves are mobilised to assist in the provision of additional energy during early lactation it seems unusual not to recommend dietary requirements that might minimise that effect. Particularly as the condition that does are in at the point of kidding is not specified and in practice may not be accounted.

The dietary protein concentration of sheep is limited during late pregnancy in an attempt to reduce the incidence of dystocia which is perceived to be a foetal growth response to high protein intake. The protein requirement of both dairy cows and ewes (NRC 2007) increases with advancing stage of pregnancy and peaks during early lactation, therefore the reason for a decline in protein and ME requirements recommended for goats from late pregnancy to early lactation is difficult to explain.

Table 25 Dry matter intake (DMI), crude protein and energy (ME) requirements for mature, non-dairy does for maintenance, joining and at all stages of pregnancy and lactation (adapted from NRC 2007)

Class	LW	LW change	DMI		ME		Crude Protein	
	kg	*g/d*	*% of LW*	*kg/d*	*MJ/d*	*MJ/kg*	*g/d*	*%*
Maintenance	60		1.9	1.14	9.12	8	82	7.20%
Joining	60		2.09	1.25	10	8	90	7.20%
Early pregnancy - single	60	21	2.24	1.57	12.6	8	137	8.70%
Early pregnancy - twins	60	36	2.38	1.43	11.4	8	140	9.80%
Early pregnancy - triplets	60	47	2.47	1.48	11.9	8	150	10.10%
Late pregnancy - single	60	86	3.15	1.89	15.2	8	187	9.90%
Late pregnancy - twins	60	143	2.54	1.52	15.2	10	206	13.50%
Late pregnancy - triplets	60	186	2.69	1.61	16.2	10	228	14.10%
Early lactation - single	60	-28	2.58	1.55	12.4	8	172	11.10%
Early lactation - twins	60	-55	2.91	1.75	14	8	207	11.90%
Early lactation - triplets	60	-83	3.04	1.82	14.6	8	261	14.30%
Late lactation - single	60	22	2.4	1.44	11.6	8	130	9.00%
Late lactation - twins	60	44	2.79	1.67	13.4	8	166	9.90%
Late lactation - triplets	60	66	3.11	1.89	14.9	8	196	10.50%

It is not possible to compare NRC (2007) protein requirements for goats with those published in 1981 as the scales used were different. The current recommendations provide significantly more detail for all classes of doe at a constant level of fat concentration (4% fcm), whereas in 1981 requirements were adjusted for fat corrected milk concentrations between 2.5 and 6% (NRC 1981). CSIRO (2007) suggest that goats' milk is more similar to the milk of Holstein-Friesian cows rather than sheep and as such a fcm factor of 3.2% may be more appropriate.

Daily dry matter intake, protein and energy requirements of goats from various authors are summarised in Table 26. Poore and Luginbuhl (2002) from the University of Kentucky, USA and www.sheepandgoat.com where, with the exception of does in late pregnancy, protein requirements are substantially higher than NRC (2007) recommendations.

Table 26 highlights the variation in recommendations between authors in dietary protein concentration for lactating goats of 12-14.5% crude protein where the derivations of their recommendations are not always clear. Similarly, the daily protein recommendations of Nsahlai *et al.* (2004) and Greyling *et al.* (2004) in Table 26 for lactating Boer does are significantly different with no apparent basis for these differences.

Table 26 Liveweight, dry matter intake (DMI), Crude Protein and ME requirements of pregnant and lactating does from various sources

		LW	**DMI**	**Protein (CP)**		**ME**		**Authors**
Genotype	**Class of goat**	*kg*	*DMI kg/d*	*% of DM*	*g/d*	*MJ ME/kg DM*	*MJ/d*	
Dairy doe		61	3.04	12	353	10.72		Adapted from Coffey, 2006
Dairy doe				15-18			24	McGregor, 2005
Doe	early pregnancy	32	1.82	10	182	9.06		Poore & Luginbuhl, 2002
Doe	late pregnancy			11		9.06		adapted from www.sheepandgoat.com
Doe	lactation			11		9.06		adapted from www.sheepandgoat.com
Doe	lactating - low production	32	1.82	11	200	9.06		Poore & Luginbuhl, 2002
Doe	lactating - high production			14		9.82		adapted from www.sheepandgoat.com
Doe	lactating - high production	32	2	14	280	9.8		Poore & Luginbuhl, 2002
Angora doe	early lactation - twins	30	0.96	14.5	140	11.59		Adapted from NRC, 2007
Boer	lactating	45			107		18.2	Nsahlai *et al.* 2004
Boer	lactating	45	1.6	14	*224**	8.9		Greyling *et al.* 2004
Indigenous	lactating	32	1	14	*140**	8.9		Greyling *et al.* 2004
Indigenous	lactating	32			84.3		14.6	Nsahlai *et al.* 2004
Unspecified	lactating					4.9-5.2		Nsahlai *et al.* 2004

**values calculated from DMI and protein percent*

As the protein content of any diet, be it grazing pasture or supplementary feed, is the most expensive consideration, it is important to determine with some degree of accuracy the protein requirements of goats.

This may not be a simple task as Sahlu *et al.* (1993) reported no difference between Nubian, Alpine or Angora goats in N utilisation when fed pellets containing 9-21% crude protein.

Seasonal change in protein availability

Seasonal decline in pasture nitrogen concentrations presents challenges for goat producers in southern Australia. In most grazing systems, matching supply with demand for lactation means that by the time kids are weaned pasture quality has declined below daily requirements. Weaner kids have high requirements for protein for growth and development, often in excess of protein supply, such that the risk of light weight weaner mortality is high and in the absence of high quality feed post weaning, supplementation is required. Legume crops and pastures retain their protein value for longer periods than cereals and grasses; specialist summer crops such as brassicas and pastures such as lucerne and chicory can alleviate the gap in feed quality over summer and autumn.

Cereals are more frequently being utilised as a source of pasture feed for sheep, cattle and goats during winter and spring however analysis of plant tissue shows a typical decline in protein concentration as the plants approach reproduction (Figure 14).

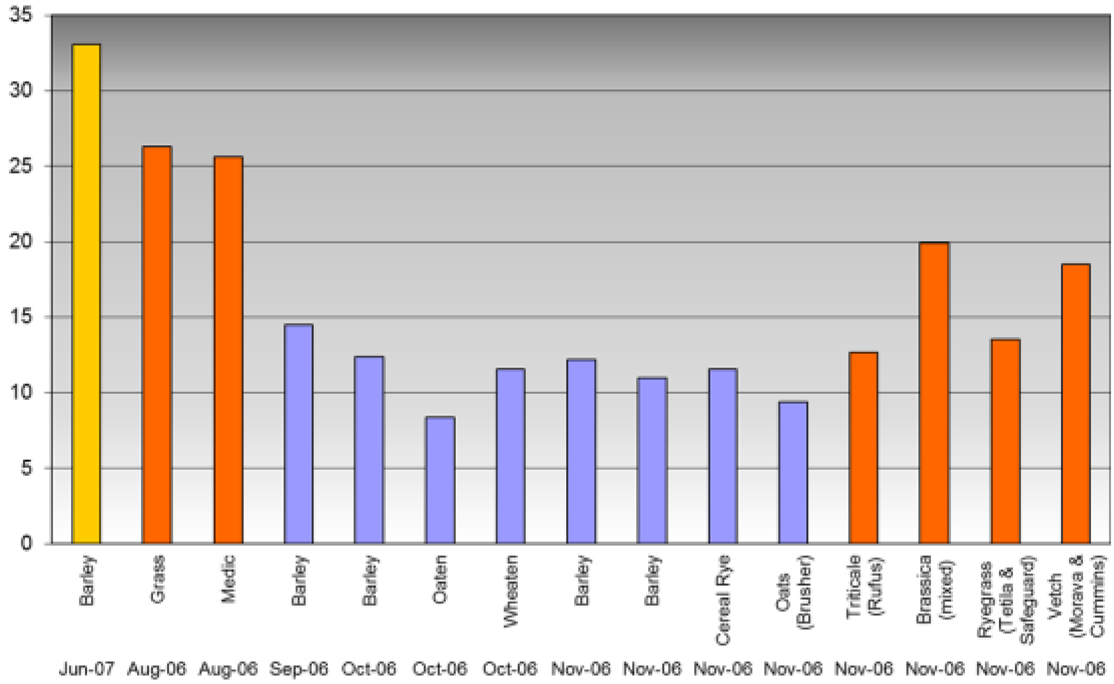

Figure 14 Seasonal changes in crude protein values of selected crop and pasture species tested at Minnipa, SA (Jolly, unpublished)

Perennial pastures decline more slowly in crude protein toward flowering and seed set (***Figure 15***) however annual pastures show similar rates of declines to cereals as depicted in Figure 16. Although perennial pastures have a slower rate of decline in NV, they have lower dry matter production during winter than the annual grasses such as hybrid ryegrasses. The annual hybrids are more likely to have excessive concentrations of protein available in winter.

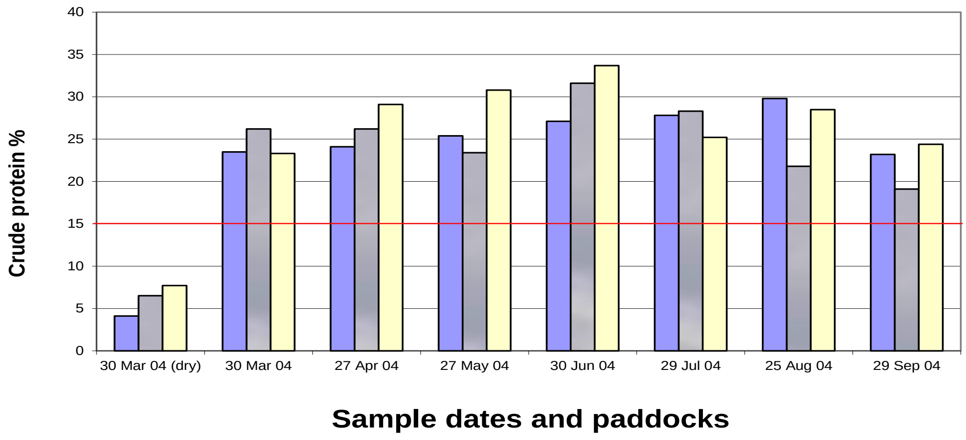

Figure 15 Variation in crude protein concentration in clover-based pastures in south west Victoria in 2004

Although the trends are similar, there are differences between annual grass species in their seasonal rate of decline in protein concentration and in their response to rotational grazing which is highlighted in Figure 16. Despite rotational grazing and irrigation the seasonal variation in protein concentration is evident.

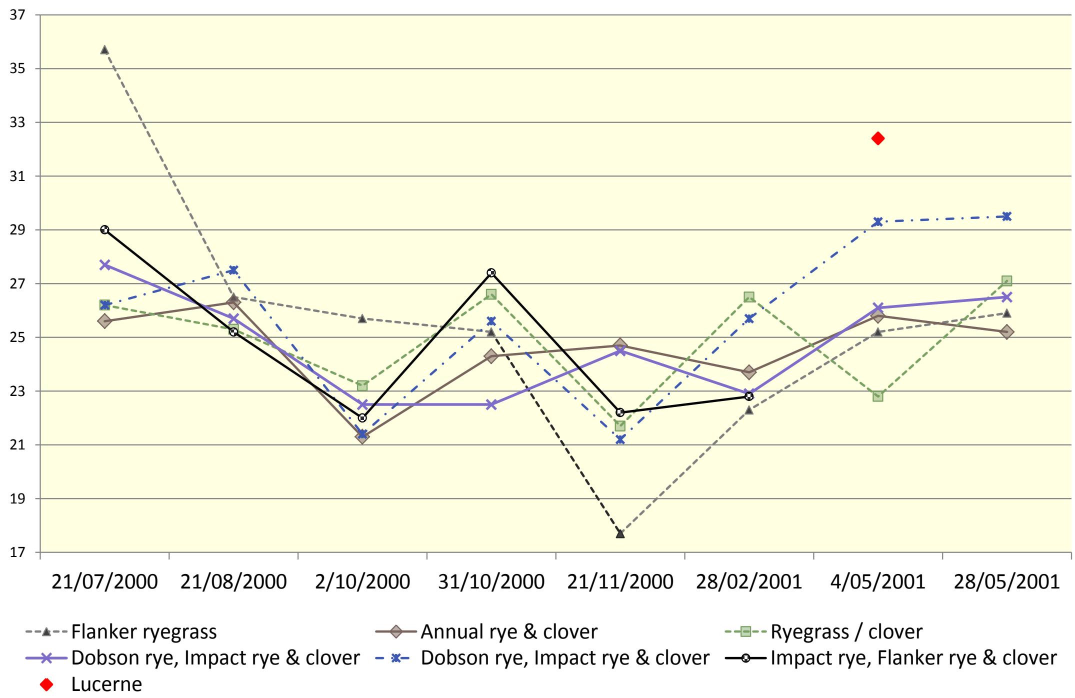

Figure 16 Seasonal changes in crude protein concentration of a range of pasture species rotationally grazed under irrigation at Meningie, SA in 2000/2001 (Jolly, unpublished)

For the realisation of genetic potential it is important for producers to ensure that pasture quality aligns with nutrient demand of grazing goats where it is practical to do so. Analysis of the nutritive value of pasture at critical times of demand such as during late pregnancy, lactation and pre-weaning will facilitate decision-making about appropriate and cost-effective levels of supplementation and/or allocation of pasture to meet requirements.

Crude protein provided by rangeland plant species

Historically, pastoral shrub species have been thought to be non-limiting in protein supply for range goats however this may not be the case. Although goats are highly selective grazers, the high salt load of halophytic shrubs such as saltbushes are likely to disrupt microbial protein supply to the small intestine due to the highly saline rumen environment. Research into this topic is ongoing at CSIRO, WA. Recent and incomplete unpublished work by Costin & Dickson (Productive Nutrition) has demonstrated a 20% increase in the weaning rates of ewes grazing saltbush supplemented with lupins when compared with oats. The implication may be that although the saltbush supply was unlimited it failed to fully meet protein requirements of the ewes. What is clear to date however, is that supplementation with a high protein source such as lupins while grazing saltbush did not appear to induce any symptoms of excessive protein intake in the ewes or their progeny.

It should be noted that supply of microbial protein to the intestine is dependent on the amount of energy available for microbial protein synthesis (AFRC 1998) and hence where ME is limiting as it is from many halophytic plants, the availability of digestible protein is likely to be limited.

Table 27 Seasonal change in crude protein (CP %) concentration and metabolisable energy (ME) of saltbush at 3 sites in South Australia (Costin & Dickson, unpublished)

Location	*Feed type*	*Site*	*Date*	*CP %*	*ME*
Booderoo	Saltbush (RSB)	Plot 10	8/03/2011	13.90	9.9
Booderoo	Saltbush (OMSB)	Plot 10	8/03/2011	17.70	11.4
Booderoo	Saltbush (OMSB)	Plot 6	8/03/2011	16.80	11.4
Booderoo	Saltbush (OMSB)	Plot 14	8/03/2011	14.00	11.4
Booderoo	Saltbush (OMSB)	Plot 14	8/03/2011	13.70	9.6
Carrieton	Saltbush	Flat	7/04/2010	18.20	10.7
Carrieton	Saltbush	Flat	8/03/2011	23.10	11.2
Carrieton	Saltbush	Flat	15/04/2011	21.60	11.5
Carrieton	Saltbush	Hills	10/03/2010	20.80	11.8
Carrieton	Saltbush	Hills	8/03/2011	23.90	11.2
Carrieton	Saltbush	Hills	15/04/2011	22.20	11.7
Point Pass	Saltbush	Site 1	16/04/2010	10.60	11.1
Point Pass	Saltbush	Site 1	14/04/2011	16.70	11.7
Point Pass	Saltbush	Site 2	14/04/2011	18.10	11.5
Point Pass	Saltbush	Site 2	16/04/2010	13.90	11.2
Carrieton	Saltbush	Flat	9/09/2010	19.90	11.5
Point Pass	Saltbush	Site 1	9/09/2010	18.30	11.9
Point Pass	Saltbush	Site 2	9/09/2010	17.40	11.7
Carrieton	Saltbush	Flat	16/11/2010	20.00	10.9

RSB River Saltbush; OMSB Oldman Saltbush

Serial analysis of saltbush at three sites in South Australia in 2010 / 2011, depicted in Table 27 demonstrates the variation in NV of saltbush leaves within and between seasons. Although a useful source of crude protein for goats, saltbush cannot be relied upon to consistently meet the protein requirements of productive goats.

Urea as a protein source for goats

There have been anecdotal reports of poor responses to urea in rations fed to sheep and goats compared with cattle however there is little supporting evidence to be found in the published literature. Following rapid introduction of urea to goats, ammonia toxicity may limit a productive response. The maximum level of urea in the diet of sheep and goats should not exceed 1% of the total diet.

A reduction in weight gain of young goats was reported when the proportion of urea in the concentrate component of the diet exceeded 2.3% (Haryu *et al.* 1975); where 40% of the nitrogen concentration of a diet was supplied by urea, Staub (1974) noted that male kids had lower protein efficiency and live weight gain.

The addition of urea to grain rations may reduce the palatability of the feed (Staub 1974) which may not be desirable in the case of early weaned kids at low liveweight. Urea should not be included in the diet of pre-ruminants as the rumen needs to be fully developed and fermentation processes functional for effective utilisation of urea.

In contrast however Hungerford (1990) and Harmeyer and Martens (1980) suggest that urea is used just as efficiently by goats as it is by sheep and cattle. McGregor *et al.* (1982) found that Angora and rangeland goats fed 68.6% oats and 30% Lucerne chaff (CP 11.1%) performed better than those fed oats with 1.4% urea (CP 12.4%); kid ADG 175g/d^{-1} vs 118g/d^{-1}.

Conclusion

Protein requirements increase with increasing level of productivity such that the requirements for goats in early lactation and weaner kids are higher than for goats at maintenance. Pastures tend to provide high concentrations of crude protein to grazing goats during vegetative growth however it is apparent that with some exceptions, Boer goats in medium to high rainfall regions are not well adapted to these conditions.

If the goat industry is to expand in higher rainfall areas, the significant health impediment to productivity in these regions, part of which may be attributable to high protein intake, requires urgent investigation and resolution. Introduction of halophytic species such as saltbush into these environments may be worthy of further investigation to potentially alleviate the effects of excessive rumen degradable protein. Further, producers may benefit in the short term from education programs in goat nutrition so as to better manage these health issues. Conversely rangeland goats are unlikely to experience excesses of dietary crude protein and have a wider range of feed options from which to select.

Urea may be a useful protein source for addition to kid feedlot rations or for use in supplementary rations for goat depots however its efficacy and cost-efficiency is yet to be determined.

The recommendations for protein requirements for various goat genotypes in the literature vary significantly however NRC (2007) has published the most comprehensive guide which requires validation under Australian conditions. In addition, the application of an activity allowance for protein requirements requires determination.

Recommendations

- Clarify the protein requirements of goats including variation across genotypes where appropriate
- Determine the cause(s) of lameness in medium to high rainfall regions
- Investigate the role of excessive dietary protein in the poor productivity of Boer goats and their crosses in medium to high rainfall areas
- Develop education programs for goat producers in nutrition and health management
- Investigate the cost-effectiveness of urea inclusion as a protein source in the supplementary feed rations of weaned kids and confined goats
- Consider embryo transfer and artificial insemination programs to hasten the increase of well adapted Boer and Boer cross genetics in medium to high rainfall regions

Fibre requirements of goats

Ruminants require fibre in their diet to stimulate the growth and development of the rumen during the pre-weaning phase, and once weaned, to stimulate rumen motility (CSIRO 1990). Fibrous feeds stimulate saliva production which provide natural buffering (maintenance of rumen pH) of the rumen environment. Chewing is stimulated by particle length and particle size, the aim being to reduce the particle size to facilitate digestive processes. At a laboratory level, structural and non-structural carbohydrates (Figure 17) is measured and reported as acid detergent fibre (ADF) for cereal grains or neutral detergent fibre (NDF) for roughages such as hay, straw, almond hulls or silage. Physically effective NDF (peNDF) increases with particle length and in a study by Zhao *et al.* (2011) goats appeared to prefer a particle length of >8mm.

NDF consists of the slowly digested fibrous portion of the plant; the cellulose, hemicellulose and lignin which is most of the cell wall material. As dietary NDF and peNDF increase, dry matter intake declines (Robinson *et al.* 1998; Zhao *et al.* 2011); both NDF and peNDF can be used as a guide to dry matter intake in ration formulation where the nutritive values of dietary components are known.

As total dietary NDF increases with plant maturity, voluntary intake tends to decline (Robinson *et al.* 1998) irrespective of whether or not the plant material is still green in colour.

ADF is a sub-fraction of NDF and consists primarily of lignin and cellulose and is negatively correlated with digestibility (Dalton 2005).

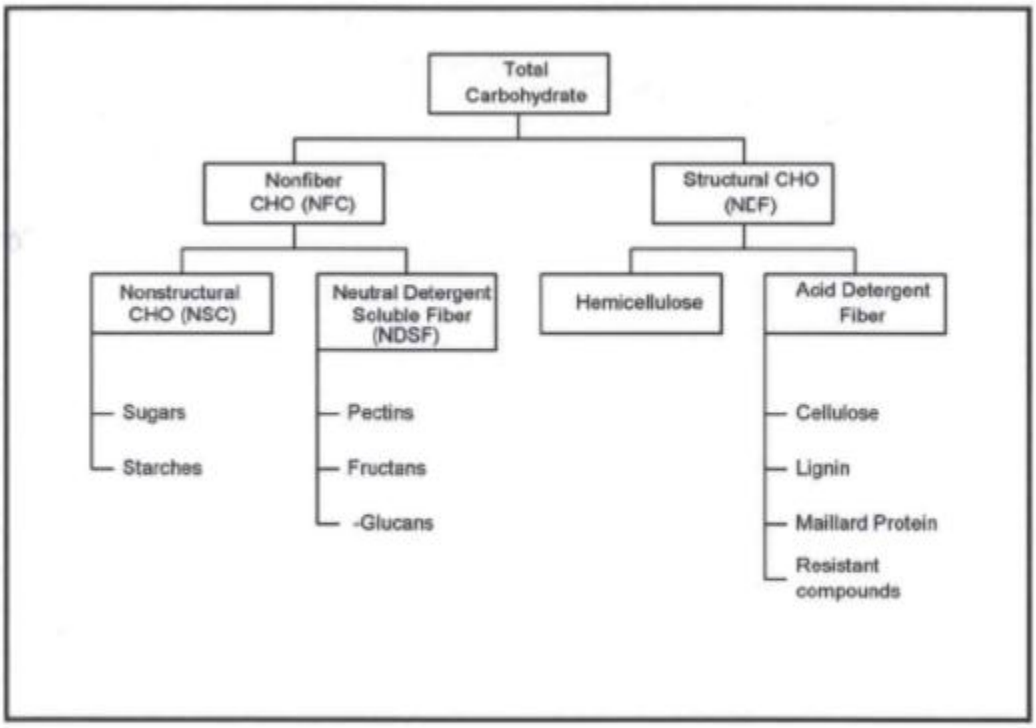

Figure 17 Structural and non-structural carbohydrate components of plants (van Saun, vbs.psu.edu/extension/focus.../goats/nutrition)

Neither ADF nor NDF provide an accurate measure of the effectiveness of the fibre in the diet, and although NDF of long fibre can provide an indication, once that fibre is processed into pellet form, the usefulness of NDF as a predictive measure of intake is negated. The minimum NDF intake required to maintain rumen health varies according to the starch concentration of the total diet (Harmison *et al.* 1997) but is generally considered to be 30% of the dry matter. The preferred dietary concentration of NDF selected by sheep is 40% of the dietary DM (Francis 2002). Following studies that compared the intake differences of C3 and C4 grass and legume hays between cattle, sheep and goats, Reid *et al.* (1990) concluded that goats more effectively digested NDF than sheep.

There appear to be two opposing schools of thought about the ability of goats to efficiently digest fibrous material. Van Soest (1982) attributes their success in harsh environments to their inherent ability to select leaves and stems of higher quality in conjunction with a higher rate of digesta flow and a smaller gut than goats run in “softer” environments. Devendra (1989) attributes their resilience in range environments to their greater efficiency of digestion with a longer mean retention time of ruminal digesta.

There is little doubt that in most environments where goats thrive the available feed is predominantly fibrous, lignified, often low in protein and contains secondary compounds (Silanikove 1996). Bedouin goats (Figure 18) have been shown to extensively modify, degrade and absorb lignin from low quality roughage to facilitate fermentation of structural carbohydrates (Silanikove 1986) however no such studies have been conducted on Boer or rangeland goats under Australian conditions.

Figure 18 Bedouin goats (Source: http://www.nationalgeographicstock.com)

The rumen volume of Bedouin goats at 20% of body mass greatly exceeds that of sheep which may account for their longer mean retention time of rumen digesta (Watson and Norton 1982), higher fermentation rate and hence increased feed intake and digestibility. It is likely that the Australian rangeland goat has undergone similar adaptation even if not to the same extent as its desert-adapted Bedouin counterpart.

However Boer goats appear to select a diet more akin to sheep. Solaiman *et al.* (2001) investigated feed intake of forage and concentrate and growth performance of Boer and Kiko (New Zealand dairy/feral cross) kids (Figure 19).

Figure 19 Kiko goat (Source: http://www.ansi.okstate.edu)

They found that Boer kids preferred a diet of less hay (23.1%) and more grain (76.9%) than their Kiko counterparts. This proportion is very similar to that found in weaned or feedlot lambs.

Goats' superior digestive ability appears limited to forage with an organic matter digestibility of less than 60% as no differences have been reported with high quality feed (Devendra 1989). The ratio of DOMD: NDF may be a useful guide to the prediction of intake for goats (

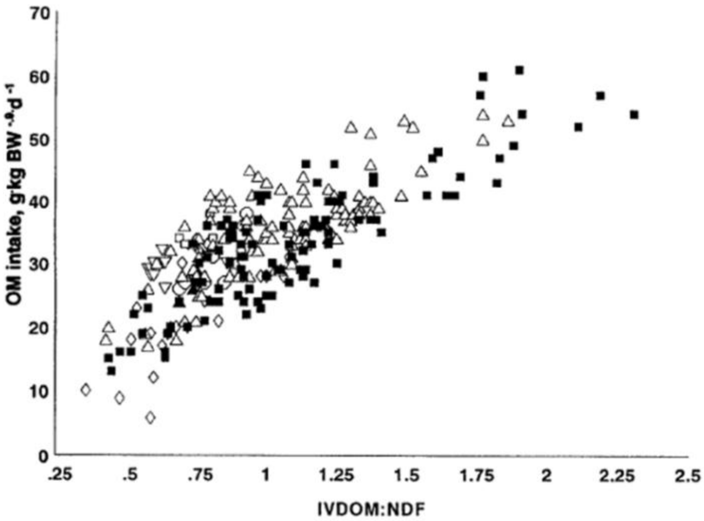

Figure 20) such that Meissner and Paulsmeier (1995) reported that the ratio correlated highly with organic matter intake.

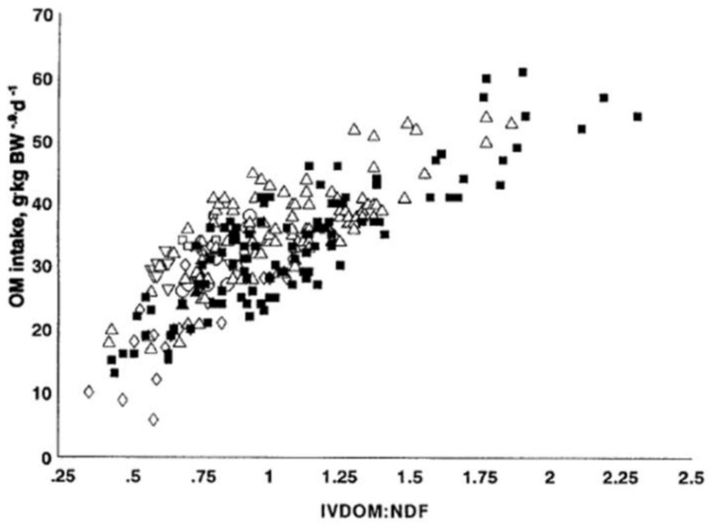

Figure 20 The relationship between intake and the ratio of DOMD:NDF for sheep ▪ (R^2=0.97), cattle Δ (R2=0.98), & goats ◊ (R2=0.97), (Meissner and Paulsmeier 1995)

High carbohydrate diets where intake of effective fibre is limited will potentially induce acidosis in all ruminants; this includes highly digestible pastures as well as high grain feedlot or containment diets.

Acidosis has been studied more in dairy goats within intensive production systems where grain supplementation is commonplace and where goats are at higher risk of acidosis. On high grain diets the risk of acidosis can be assessed by measuring the ratio of non-fibre carbohydrates (NFC) to NDF; in dairy cows the preferred ratio is < 1.63 (Han *et al.* 2011) however Zhao *et al*. (2011) investigated an acidosis risk ratio of peNDF to rumen degradable starch and determined that a ratio in excess of 0.88 did not induce acidosis in crossbred and dairy goats.

All these factors are assessable by Australian feed laboratories such that some degree of prediction of risk can be assessed.

McGregor (2000) in “Goat Notes” states that research has demonstrated that the roughage requirements of young sheep on wheat based diets was no more than 2% and that goats maximised intake at between 13-34% roughage in the diet. However the comparative diets, the conditions under which these observations were made or the productive responses achieved were not provided.

McGregor (2000) also reported that goats will preferentially select the most highly digestible components of plant material as their mobile upper lip allows them to access these between thistles and sharp twigs, unlike sheep and cattle. However he concluded that given a choice, goats tend to select high quality pasture ahead of browse. This is in contrast with Correa (2009) who reported that goats preferred to eat bushy plants and “effectively digested coarse, fibrous feeds”.

It should be noted that is often not clear to what genotype of goat the author is referring such that inherent differences may be present and comparisons irrelevant; the observations of McGregor (2000) appear more likely to relate to Angora goats whereas Correa (2009) was referring to “meat goats” of unspecified genotype.

Further challenging the assumption that goats must have a relatively high proportion of roughage or long fibre in their diet was a study by Patterson *et al.* (2009) which demonstrated growth rates in Boer cross wethers of 245.6 g/day when fed a complete pellet at 18% crude protein and 31% neutral detergent fibre (NDF).

More recently Silva *et al.* (2011) fed Boer x Saanen and Saanen goats and reported that a progressive increase in NDF from 49-69% resulted in a decrease in feeding, chewing and rumination efficiency and an increase in chewing time.

Branco *et al.* (2010b) observed when feeding dairy goats that NDF intake was maintained at 1.2% of liveweight and that optimum efficiency of utilisation of ME for milk production was measured at a dietary NDF concentration of 35%. Further research demonstrated optimum efficiency of microbial protein synthesis was recorded at 29.57% NDF (Branco *et al.* 2010a).

There is evidence that sheep, cattle and goats born in lush pastured environments struggle to adapt to a rangeland environment however animals native to that environment thrive. Successful adaptation of rangeland goats to the pastoral areas of Australia is clearly evident such that they have a demonstrated ability to select feed of high nutritive value when seasonal conditions are favourable and adjust to a highly fibrous diet during drought.

The adaptation of goats to high rainfall environments has provided more of a challenge, some of which may be attributable to a lack of effective fibre in their diet however the NDF concentration in perennial and annual pastures, cereals and fodder crops seldom falls below 30% and is often closer to 40%; the preferred level for goats and sheep. Samples of nutritive values of vegetative pastures including NDF are listed in

Table *28* below. It is difficult therefore to conclude that the health challenges faced by goats including high worm burdens, lameness and scouring are attributable to a deficiency of fibre in the diet.

Goats held in depots prior to transport to markets are provided with hay or straw on an *ad-libitum* basis in order to minimise weight loss. Conserved forage is rarely tested for nutritive value nor assessed for intake potential prior to feeding which could make the difference between weight gain and loss. It would be preferable to offer high quality hay to encourage intake however it may not always be cost-effective to do so; this requires further investigation and determination.

Small ruminants require high quality roughage in order to maximise nutrient intake whereas larger ruminants such as cattle can more readily compensate for low quality fibre by increasing intake.

Weaned kids have high nutrient requirements therefore the provision of straw or low quality hay in their diets as a fibre source is unlikely to optimise growth potential. Fibre sources for productive goats should include legume hays that contain highly digestible nutrients.

Table 28 Nutritive value of vegetative pasture samples highlighting the variation in NDF concentration (Productive Nutrition database)

Sample description	DM %	CP % of DM	ADF	***NDF % of DM***	DMD %	DOMD %	Est ME MJ/kg DM
Clover/Ryegrass	9.7	29.3		***45.2***	75.6		11.1
Fescue/ cocksfoot/ Phalaris/clover	12.4	19.2	30.5	***46.4***	64.6	61.6	9.5
Clover/ryegrass	14.3	21.0	27.0	***41.8***	69.6	65.7	10.5
Clover/ryegrass	14.7	29.7	26.0	***35.8***	70.3		10.5
Clover/ryegrass	14.9	22.7	42.4	***63.1***	57.5	55.6	8.3
Clover/ryegrass	14.9	26.9	39.2	***65.4***	60.0	57.7	8.7
Clover/ryegrass	15.1	21.8	40.0	***54.4***	58.6	56.5	8.5
Clover/ryegrass	15.3	33.1	18.2	***27.4***	75.1		11.3
Clover/ryegrass	15.4	25.9	26.0	***38.0***	68.9	65.2	10.2
Clover/cocksfoot/ryegrass	15.4	30.7	19.7	***34.1***	72.4	68.2	10.8
Clover/ryegrass	16.2	24.7		***49.6***	68.5		9.9
Clover/ryegrass	16.2	30.5	18.8	***30.6***	73.9		11.1
Clover/ryegrass	17.2	30.9	20.2	***32.0***	72.9		10.9
Fescue/ cocksfoot/ Phalaris/clover	17.7	27.0	34.1	***69.7***	64.1	61.1	9.4
Clover/ryegrass	18.0	21.2	27.1	***42.4***	67.1	63.7	9.9
Clover/ryegrass	19.2	24.6	24.9	***41.2***	68.3	64.7	10.4
Clover/ryegrass	19.4	19.2	23.4	***38.7***	69.6	65.8	10.4
Clover/ryegrass	19.7	25.3	30.7	***44.5***	66.7		9.9
Medic / grass	20.0	22.6	29.6	***46.3***	65.0	61.9	9.6
Cocksfoot/Clover	25.0	9.4		***65.0***			9.4
Cocksfoot/phalaris	26.1	13.7	34.5	***74.4***	54.5	53.0	7.8

Pelleted diets

Pelleted diets provide significant challenges for goats particularly in terms of adaptation (Gherardi and Johnson 1995). Ruminants are particularly sensitive to smell and what appeals to humans such as molasses may not readily appeal to goats; a period of adaptation is always required to a change in feed. Although hay-based pellets reduce the risk of acidosis, the NDF concentration cannot be relied upon to provide a source of “effective” dietary fibre to stimulate rumination. Hay or straw is finely ground prior to pelleting which reduces the effectiveness of the roughage in stimulation of saliva production on which goats are highly dependent for the maintenance of rumen pH and effective digestion of nutrients.

The palatability of pellets varies widely according to pelleting processes and ingredient selection and subsequent difficulties encountered by producers feeding pelleted diets in containment have included an increase in shy feeders (McGregor 2005).

Consistency of feeding value of hay-based pellets is difficult to control as every bale of hay is not analysed for nutritive value prior to pelleting. Stockfeed manufacturers that produce a formulated pellet which is more likely to be grain rather than hay-based, and use a wide range of feedstuffs to achieve the same formulation; some of these feedstuffs can change the taste and smell of each batch of pellets.

The physiology of the current Australian bush and Boer goat would suggest that palatable, effective fibre is an essential dietary component and where this is denied, a high percentage of “shy feeders” suffering inanition will continue to be a challenge for the industry.

The formulation of pelleted diets is a complex science; pellets should be formulated to meet the requirements of the animal to be fed and to complement alternative sources of feed where the pellets do not make up the total diet. Unfortunately this is rarely the case. Assessment of the efficacy of a pellet formulated to a particular ME or protein level is not possible if the nutritive value of alternative feeds on offer remain unknown. Where it is practical to do so feeds should be analysed for nutritive value to ensure the ration is meeting requirements.

Pellets have been well recognised as a cause of nutritional disorders such as urolithiasis or calculi (Shahrom and Zamri-Saad 2011) and refusals due to low palatability or neophobia are relatively common. In young or light goats with limited body weight reserves, it is important to encourage intake by the provision of palatable, quality roughage, high enough in essential nutrients to encourage intake during the adaptation process to pellets; legume hays and occasionally high quality straws provide a reliable starting point. It should be noted that in dry years the nutritive value of straws can equal that of hay.

Gherardi and Johnson (1995) and McGregor (2005) reported significant weight loss following the provision of good quality hay during the introductory period to pellets however the nutritive value of the hay was not provided and how the assessment of quality was made was not clear.

Conclusion

Many goat industry personnel believe that all goats require access to a source of fibre at all times however the quality of the fibre source will in many cases determine productivity outcomes. Goats apparently efficiently digest most forms of roughage in comparison to sheep and cattle however if the roughage source is the only feed available as in hay, straw or silage, and the nutritive value of that feed fails to meet the requirements, it is likely that productivity will decline accordingly.

Low quality fibre sources will limit intake potential which is critically important in terms of goats being able to meet protein and energy requirements. In order to optimise voluntary feed intake the smaller the ruminant the higher quality the roughage source should be.

Pelleted diets provide a safer feeding option if the pellets are hay-based, which should not be assumed, however pelleted diets cannot be relied upon as a source of *effective* fibre. Where rapid adaptation to a change in feed is required, such as post weaning or in depots for short term confinement, the palatability of the roughage source is the most important characteristic to be considered. Assumptions about the NDF concentration or quality of fibre sources such as hay, silage or pasture will inevitability result in sub-optimal productivity, and feed testing should be encouraged in the goat industry.

Rangeland goats will selectively graze available plant material in order to meet their roughage requirements and unless access to feed is limited by prolonged drought or overstocking it is unlikely that access to roughage will limit their productivity.

Recommendations

- Develop education programs for goat producers and their advisors to improve their understanding of the fibre requirements of goats and how to apply that knowledge to their enterprises

Courtesy: G Reimers 2011

Mineral and Vitamin nutrition of goats

The mineral requirement of goats has been reviewed extensively Devendra (1971), Kessler (1991), Haenlein (1980, 1987, 1991, 1992) and NRC (1981, 2007). Recommended daily requirements have been determined experimentally using predominantly dairy breeds including Saanan and Alpine goats (Haenlein and Anke 2011). Previous requirements were mostly extrapolated from sheep and cattle (NRC 1981; AFRC 1991) however major advances have been made over the last five years in the determination of requirements specific to goats. It appears that the mineral requirements of goats may be higher than for sheep (NRC 2007) of equivalent body weight (Table 29) although it is not entirely clear if their requirements are higher due to a higher tolerance, lower rate of absorption, storage capacity or an increased need. NRC (2007) differentiates between meat and milk goats and Angora goats in their mineral requirements.

Table 29 Macro and micro mineral requirements of growing lambs and meat and milk kids (NRC 2007)

			Liveweight			
			20 kg @ 100g/d		***30 kg @ 200g/d***	
Element	*Symbol*		*Lambs*	*Kids*	*Lambs*	*Kids*
Sodium	Na	g/d	0.4	0.58	0.6	0.96
Chloride	Cl	g/d	0.3	0.68	0.5	1.08
Potassium	K	g/d	2.9	3.3	4.8	5.2
Magnesium	Mg	g/d	0.6	0.55	1	0.93
Sulphur	S	g/d	1.1	1.8	2	2.7
Cobalt	Co	mg/d	0.13	0.07	0.22	0.12
Copper	Cu	mg/d	3.1	17	5.5	26
Iodine	I	mg/d	0.3	0.34	0.5	0.52
Iron	Fe	mg/d	32	34	62	67
Manganese	Mn	mg/d	12	12	21	21
Selenium [f]	Se	mg/d	0.09	0.48	0.18	0.66
Zinc	Zn	mg/d	13	11	24	21

[f] selenium absorption coefficient 0.3 applicable to forage diets

The main source of minerals for goats is from either grazed pastures, shrubs or crops, in both rangeland and intensive production systems however sodium, chlorine, magnesium, sulphur, iron, manganese and iodine can also be provided by the water supply to varying degrees. The pH of the soil and water supply will affect the availability of minerals as will the type and stage of growth of the pasture. Cereals tend to be deficient in calcium and sodium whereas leguminous plants contain higher concentrations of minerals than grasses, even when dry (Underwood and Suttle 1999).

Goats grazing cereal stubbles or foraging for medic seed over summer and autumn or during drought ingest significant amounts of minerals from soil however high concentrations of iron in many soils may reduce absorption of these minerals.

Assessment of the mineral status of goats requires determination of the mineral status of their feed, (with appropriate consideration of selective grazing) and water, knowledge of the interactions between minerals and the daily requirements of each class of goat. The mineral content of improved pastures within a district should no longer be taken as the norm for individual properties as changing fertiliser practices in combination with intensification of livestock production has produced mineral deficiencies not previously suspected in those areas. An application of lime to increase soil pH alters the availability of selected minerals which in turn may reduce the availability of others.

Daily requirements vary with age, species, genotype, sex, level of productivity and activity and significant differences between species have now been reported (Haenlein and Anke 2011).

The mineral status of rangeland goats has not been widely investigated nor reported however a three year study by the Outback Lakes SA (www.productivenutrition.com.au) demonstrated a wide variation in the concentration of minerals between species and properties. No correlations were found between plant mineral status, seasons and mineral concentration however where cattle were found to have high serum concentrations of GSHPx, an indicator of selenium status, there was a higher proportion of preferentially grazed plants that were high in selenium. Phosphorus, zinc and copper deficiencies in plant tissue were widespread as were high concentrations of iron, cobalt and manganese. The concentrations of phosphorus, potassium, magnesium and sulphur decreased with increasing plant maturity whereas iron and cobalt concentrations increased.

Plants with salt tolerance that thrive in arid and semi-arid environments reportedly accumulate sulphur and selenium (Masters *et al.* 2007) and field studies http://www.productivenutrition.com.au/facts.html#bestpracticenutritionalmanagement) of the nutritive value and mineral concentration in such plants support these findings.

Table 30 Relative nutritional strengths and weaknesses of pastoral plant species analysed across northern South Australia (Franklin-McEvoy and Jolly 2005)

n	*Species*	*Common name*	*Strengths*	*Weaknesses*
4	*Atriplex nummularia*	Old man saltbush	High CP, ME	xs Cl, K, Mg, Na. Low NDF
7	*Atriplex* sp.	Annual saltbush	High CP	xs Cl, K, Mg, Na
12	*Atriplex vesicaria*	Bladder saltbush	High ME	xs Cl, Fe, K, Mg, Na. Low P, Zn
10	*Carrichtera annua*	Ward's weed	High CP, Ca	xs Fe
3	*Maireana georgii*	Sanity bluebush	High CP	xs Cl, Na. Low P, Zn
8	*Maireana pyramidata*	Black bluebush	High CP, Ca	xs Cl, Fe, Mg, Na. Low P, Zn
12	*Maireana sedifolia*	Pearl bluebush	High CP	xs Cl, Na. Low P, Zn
9	*Medicago sp.*	Medic	High CP, Ca	xs Al, Cu, Fe
3	*Myoporum platyoarpum*	Sugar wood	High ME	xs Cu. Low NDF, P, Zn
7	*Rhagodia sp.*	Rhagodia	High CP, Ca	xs Cl, K, Mg, Na. Low P, Zn
4	*Sclerolaena ch., dia., eria.*	Copperburr	High CP, ME, Ca	xs Cl, Fe, Na. Low P, Zn
3	*Sclerolaena obliquicuspis*	Limestone copperburr	High Ca	xs Na, Fe, NDF. Low P, Zn
4	*Sisymbrium erysimoides*	Mustard weed	High CP, ME, Ca	xs Fe, K, Na. Low NDF, P
6	*Soliva pterosperma*	Bindii	Low ME	xs NDF, Al, Cu, Fe, Na. Low P
6	*Stipa sp.*	Speargrass	Low ME	xs NDF. Low P, S, Zn
1	*Tetragonia tetragonoides*	Spinach	High CP, ME, Ca	xs Al, Cu, Fe, K, Na. Low NDF

In an earlier field study, Franklin-McEvoy (2005) analysed the nutritive value of pastoral plant species across northern South Australia which are summarised in Table 30; this work highlighted some of the factors about the mineral status of selected plant species that pastoralists identified as being key indicator species. Phosphorus and zinc deficiencies were prevalent whereas sodium, potassium and iron were generally present in amounts above animal requirements.

Daily requirements for copper and zinc differ between species and breeds of animal (Haenlein and Anke 2011) and as a further complication, plant tissues accumulate different concentrations of some trace elements as detailed in Table 31. These values will be representative of the soils in which the plants have been grown and should not be taken as absolutes.

Table 31 Average contents (mg/kg DM) of copper and zinc in typical feeds for goats (Anke and Szentmihalyi 1986; Anke et al. 1993; cited in Haenlein and Anke 2011)

	Copper	Zinc
Red clover	10	38
Lucerne	9	33
Mixed grasses	9	88
Maize green chop	8	63
Beet leaf silage	19	173
Maize silage	8	
Fodder beets	8	54
Rye	5	48
Barley	5	30
Wheat	4	39
Oats	3	45
Corn	2	
Brewer's grain	21	
Wheat bran	15	82
Rye bran	13	
Beet pulp	10	
Straw	3	

Determination of mineral deficiencies in grazed plants

There is a plethora of information about the *average* nutritive value of various plant species however these values have limited relevance to individual situations. Producers should be encouraged to determine the mineral profile of their pastures at critical times of the year such as joining, pre kidding and weaning to ensure that the pasture or feed on offer is meeting the requirements of the particular class of goat.

It is apparent in high rainfall areas that mineral nutrition is of critical importance to goat survival and productivity however few producers appear to have a complete understanding of the deficiencies that exist, the correct method of detection or how to manage them.

Deficiencies can be induced from an interaction between minerals which may not be immediately obvious, for example; plant concentrations of copper may be within the normal range for a particular class of goat however if the concentration of sulphur, iron and molybdenum are high, it is likely that a copper deficiency will ensue. Similarly, where plant concentrations of potassium are high, magnesium and calcium can be rendered unavailable to the grazing animal despite being present in normal concentrations.

Detection of mineral deficiencies in goats

It is important to analyse the appropriate animal tissue to accurately detect a deficiency. Heinlein and Anke (2011) have determined the indicator tissues most likely to accumulate minerals and therefore to provide a reliable source of information. Tissue analysis is an expensive process, therefore it is important to ensure the correct tissue is sampled when a deficiency is suspected.

Different indicator tissues are required for analysis depending on the mineral of interest for example; ribs, for detection of zinc deficiency; blood or hair to detect deficiencies of molybdenum, selenium and iodine; liver analysis for detection of copper, manganese, cadmium and lead deficiencies. The appropriate indicator tissues for analysis are highlighted in Table 32.

Table 32 Indicator tissues for the detection of deficiency status in ruminants (Adapted from Anke et al. 1988 cited in; Haenlein and Anke 2011)

Tissue	Cu	Mn	Zn	Mo	Se	I
Liver	***	***	0	***	**	***
Kidneys	0	*	0	**	*	***
Brain	***	0	0	*	0	0
Ribs	0	0	***	*	0	0
Blood serum	*	0	0	***	***	***
Hair	*	*	*	***	**	***

Indicator tissues with*** (best), ** (medium), *(low) or 0 no reliability for detection of deficiency

A Boer goat producer on the east coast of Australia has kindly provided the results of a 4 year study of mineral deficiencies carried out on his property; these results and comparative reference ranges are summarised in Table 33.

Table 33 Recommended reference ranges for blood calcium, phosphorus, potassium, copper and selenium for goats and results from Boer and Boer cross goats averaged over a 4 year period at Dorrigo NSW (Courtesy: J. Gilbert October 2011)

	Recommended		Results		
	Underwood & Suttle (1999) & Puls(1989)	Goat average (source unknown)	Home bred (av.)	Grain diet (av.)	Bought in goats (av.)
	Blood µmol/l				
Calcium	1.5-2.25(s)	2.2-3.1	2.1	2.3	2.3
Phosphorus	1.3-1.9 (s)	1.2-4.4	2.2	2.6	2.5
Potassium	3-6(s)	3.5-6.7	8	n/a	n/a
Copper	6-10	9-25	12	16	12
Selenium	150-250	40-300	18	400	240

Values for sheep (s)

Unfortunately some of the analyses are not appropriate detection mechanisms for particular trace minerals. For example, copper deficiency is rarely detected with any degree of accuracy in blood samples – liver sampling is far more accurate as copper is stored in the liver. However recent work by Zervas *et al.* (1990) has raised questions about the ability of the goat to store copper in the liver; this requires further investigation. There is evidence of chronic and severe copper deficiency in goats on this property despite the recent introduction of routine mineral drenching; if the recommendations of NRC (2007) are accurate and the copper requirements for goats are significantly higher than for sheep, an increase in the rate of copper supplementation may be warranted.

In contrast, the selenium results are quite interesting where blood tests are generally highly accurate. The bought in and grain fed goats had normal selenium status which may indicate the purchased goats had been treated for selenium deficiency previously or came from a selenium-rich environment.

Cereal grains are known to be concentrated sources of selenium (Ensminger *et al.* 1990) which would account for the higher status of the grain fed goats. No comparative pasture samples were taken to determine selenium availability from the pasture-based diet for the home bred goats but one could assume a deficiency of selenium or an excess of sulphur may have been evident in the pasture.

Unless a severe deficiency of calcium and phosphorus was present blood tests are not reliable indicators of their status as normal homeostatic mechanisms attempt to continually mobilise these elements in order to maintain normal serum levels. The high serum level of potassium would be expected from animals grazing pastures inherently high in the mineral.

The cooperating goat producer has observed significant improvement in productivity of the goat herd following administration of the mineral drench detailed in Table 34 to his herd.

Table 34 Mineral-Plus drench (TNN Industries) administered to does in late pregnancy (Courtesy: J. Gilbert 2011)

Concentration	Grams per litre mg/ml	Dose rate per head per 6 weeks Does mg/ 10mls	Kids mg/5mls
Magnesium	4.5	45	22.5
Cobalt	2	20	10
Selenium	2.1	21	10.5
Sulphur	26.7	267	133.5
Copper	3.6	36	18
Zinc	7.5	75	37.5
Manganese	5.1	51	25.5
Iodine	0.12	1.2	0.6
Sugars	42	420	210
Crude Protein	305	3050	1525
Kelp	110	1100	550
PEG	100	1000	500
Vit A	1.125	11.25	5.625
Vit D	7.5	75	37.5
Vit E	10	100	50

The retention rate of copper sulphate in sheep and cattle as administered as an oral drench is approximately 2 weeks (Judson 2002).

Further blood testing was carried out to determine physiological responses to the mineral drench; these are detailed in Table 35. Selenium status had significantly improved however despite seemingly high doses of copper serum, copper status did not markedly increase. Liver tests may have revealed a clearer picture.

Table 35 Recommended reference ranges for blood calcium, phosphorus, copper and selenium for goats and results from Boer and Boer cross goats 4 weeks after drenching with TNN Mineral-Plus at Dorrigo NSW (Courtesy: J. Gilbert October 2011)

	Reference ranges		Results (29/9/2010)			
	Underwood & Suttle (1999) & Puls(1989)	Goat average (TNN)	Kids	Does - mid pregnancy	Does - late pregnancy	Bucks
	Blood (mmol/l)		*Blood (mmol/l)*			
Calcium	1.5-2.25(s)	2.2-3.1	2.19	2.34	2.23	2.42
Phosphorus	1.3-1.9 (s)	1.2-4.4	1.57	2.1	1.4	1.5
Copper	6-10	9-25	18.5	18.83	15.15	13.6
Selenium	150-250	40-300	347	239	165.8	137

Accurate determination of mineral deficiencies, taking account of deficiencies induced secondary to interactions is not a simple task and as well it can be an expensive process. Many producers opt instead to take a “shotgun” approach to mineral supplementation which unfortunately is actively encouraged by product salespeople.

As the effects of mineral deficiencies can be severe and in some cases have a significantly negative effect on productivity and hence profitability, and excesses of certain trace elements may be cumulative and fatal, producers should be encouraged to identify specific deficiencies within their own properties and to treat them accordingly.

***Figure 21 Severe selenium deficiency is common in lambs and kids** (Source: http://www.infobarrel.com/Selenium_Deficiency_in_Livestock)*

The signs and symptoms of mineral deficiencies in young goats are summarised in Table 36 as a guide. In addition, the function, manifestation and likelihood of mineral deficiencies occurring in sheep (Masters and White 1996) are summarised in Appendix 1 for interest.

Treatment of mineral deficiencies

Once a deficiency has been identified there may be a range of prophylactic or treatment options available; independent advice should be sought and the most cost-effective option implemented.

There are a vast range of mineral preparations available on the market, many of which do not contain sufficient mineral concentrations to adequately alleviate a severe deficiency. The reason for this is to avoid toxicity in animals that are not deficient as many products are sold by people with little knowledge of mineral nutrition or the mineral status of the property of the purchaser. Conversely, mineral drenches contain very high levels of trace minerals such that they require administration once every 6 weeks; the risk of toxicity when using these preparations has been evident in some sheep populations.

Producers and marketers alike appear to believe in the case of mineral nutrition that “more is better” or that “it can’t hurt” however this is not always the case. Minerals such as iodine and cobalt have a wide margin for error but copper and selenium are highly toxic elements when administered in excess. Goats have a significantly higher tolerance to copper than sheep (Zervas *et al.* 1990) such that sheep store 6-9 times the amount of copper in the liver than goats. The toxic level of copper for goats has not been established.

Mineral deficiencies such as cobalt, copper or selenium can be treated with intra-ruminal capsules, mineral drenches, loose licks and blocks or by injection however care should be taken when feeding supplements designed for cattle as these may contain levels of minerals at toxic levels for goats. Rumen boluses or “bullets” have been shown to be highly effective in the prevention of copper, cobalt and selenium deficiency in sheep (Zervas *et al.* 1988), however there is some anecdotal suggestion that slow release selenium capsules failed to maintain adequate serum levels in treated goats for the recommended period of time (J. Gilbert pers. comm. October 2011).

Water medication is a popular method of supplementation in some areas, however with the exception of selenium, most mineral deficiencies peak in spring when foraging ruminants are inclined to drink less water.

Calcium deficiency is commonly found when stock have been grazing rangeland plants high in oxalates, or following long periods of stubble grazing or cereal grain supplementation. Calcium supplementation can be provided cost-effectively in the form of a loose lick of finely ground limestone with 10% salt added as an attractant. Unfortunately the use of salt as an appetiser has less effect in range country where goats have access to salty species.

Kawas and Andrade-Montemayer (2010) recommend the provision of lick blocks for supplementation of urea and molasses for goats browsing low quality feed, however although this type of supplementation is likely to assist in the maintenance of body condition in non-lactating animals, blocks are unlikely to provide sufficient protein or energy to support productive activity or to adequately address severe mineral deficiencies.

	Ca	P	Mg	Se	K	S	Fe	Cu	Mo	Co	Zn	Mn	I	NaCl
Reduced growth rate	x	x	x	-	x	-	X	x	x	x	x	x	x	x
Inappetance	x	x	x	-	x	x	X	x	x	x	x	-	x	x
Low reproductive rates	x	x	-	x	-	x	x	x	-	x	-	x	x	-
Weak offspring	x	x	-	x	-	-	x	-	-	-	-	x	x	x
Low milk production	x	x	-	-	x	-	-	x	-	x	x	-	x	x
<u>*Other effects:*</u>														
Alopecia											x		x	
Anaemia							x	x		x				
Ataxia				x				x		x		x		
Cachexie								x		x	x			
Cardiac problems				x										
Dermatitis											x			
Diarrhoea				x						x				
Dyspnoea				x										
Oestrus irregular												x		
Goitre													x	
Heat stress					x									
Hoof deformation											x			
Milk fever	x		x											
Osteophagia		x												
Pica								x		x				
Rough hair														x
Skeletal deformation								x			x	x		
Spontaneous fracture								x						
Staring								x			x	x	x	
Stillbirth								x						
Tetany			x											
Weak, dull						x								
White muscle disease.				x										

Table 36 Symptoms of mineral deficiencies in young goats (Haenlein, 2011); positive (x); negative (-)

Mineral requirements of goats

Macro minerals

Calcium and Phosphorus

Calcium is required in the diet of kids for bone growth and development, muscle function and to reduce the incidence of urinary calculi. Calcium and phosphorus are required in the diet at a ratio of 2:1 to prevent calculi formation in bucks and male kids particularly if being supplemented with grain. Grain rations are inherently deficient in calcium and high in phosphorus such that calcium supplementation is essential unless legume hay or silage is a major component of the diet. Leguminous pastures are rich in calcium in contrast to grass dominant pastures which can be deficient.

Phosphorus deficiency is not a common finding in intensive grazing systems however it is inherent in native pasture systems such as found in the rangelands. Phosphorus deficiency has been reported to reduce intake in goats by between 10 and 50% (Ternouth 1991).

Sources of calcium include finely ground limestone (35-38% calcium), which is typically the most cost-effective source, gypsum (23% calcium; 18% sulphur) and dicalcium phosphate (22% calcium; 18% phosphorus). Dicalcium phosphate is seldom required in the diet as phosphorus is rarely a limiting factor unless by-products are being fed. Care needs to be taken if providing gypsum on an *ad-libitum* basis as excessive intake of sulphur can induce a selenium deficiency.

Sodium

As cereal grains, particularly wheat, tend to be inherently low in sodium, grain based finishing rations require additional sodium. Sodium can be provided as sodium chloride (salt), sodium bicarbonate or sodium bentonite at an addition rate of 1% of the total diet. A deficiency of salt in the diet can result in a reduction in dry matter intake and hence, growth rate (Underwood and Suttle 1999). The inclusion of sodium in the diet of kids on high grain diets, also provides a buffering effect against ruminal acidosis by increasing rumen outflow rate and hence the pH of rumen fluid. The addition of salt to the diet stimulates water intake which assists in the prevention of urinary calculi.

Potassium

Diets containing urea may require supplementation with potassium. Sources of potassium include potassium chloride or potassium iodide, which is frequently used by stockfeed manufacturers in prepared feeds as a supplemental source of iodine and potassium.

A deficiency of potassium may depress growth rates of kids secondary to reduced dry matter intake although care should be taken with supplementation as dietary potassium in excess can reduce the absorption of magnesium. The strength of a potassium: magnesium antagonism study in goats suggested that the requirements for goats may be more aligned to that of sheep, than cattle (Schonewille *et al.* 1997 cited in; Suttle 2010).

Magnesium

Supplemental magnesium is seldom required other than where goats are grazing improved pastures during autumn around the ‘break of the season’, where on individual properties, magnesium deficiency can occur. Magnesium deficiency can also occur in response to high levels of rumen ammonia on high protein diets, which is more likely to occur on pasture-based finishing systems than in feedlots. Sources of magnesium include magnesium oxide (54% magnesium), calcium magnesium carbonate (dolomite – 8-12.5% magnesium) or magnesium sulphate (10% magnesium).

Signs of magnesium deficiency include excessive salivation, rigidity of the limbs, inappetance and death (NRC 1985).

Sulphur

Additional sulphur is required to complement urea where it is used as a source of non-protein nitrogen. The recommended ratio of urea to sulphur for cattle lies between 10:1 and 13:1; this ratio is required to facilitate synthesis of microbial protein (O'Reagain and McMeniman 2002), however it is unclear if the ratio for goats is the same. High levels of dietary sulphur may reduce the availability of selenium.

Micro minerals or trace elements or trace minerals

The most economically important trace minerals (also commonly referred to as trace elements) for small ruminants include selenium, cobalt, copper and zinc. Deficiencies of any or all of these, has been shown to result in a depression in growth rate and dry matter intake of lambs (Lee *et al.* 2002).

Goats grazing spring pastures in southern Australia may be deficient in one or all of the above trace elements and require supplementation. However, care should be exercised, particularly in terms of copper supplementation as the potential risk of toxicity is high, and the margin for error low. Goats grazing in the cereal zones over the summer period may have ingested *Heliotropium europaeum* (potato weed) containing hepatotoxic alkaloids that can cause copper accumulation in the liver.

Cereal grains are generally low in selenium, therefore supplementation is recommended for goats on long term, high grain rations, although care should be exercised if supplementing from additional sources such as inclusions in drenches and vaccinations. Many commonly grazed plant species in the pastoral areas of South Australia are known to be high in selenium and lambs grazing those species have been found to have high serum activity of glutathione peroxidase, an indicator of selenium status (Jolly 2003 unpub.). Suttle (2010) suggests that the selenium requirement for goats may be halfway between that of sheep and cattle however NRC (2007) recommends five times the daily selenium requirements for kids than lambs.

Copper deficiency presents in neonatal kids as “swayback” or congenital ataxia due to inefficient synthesis of the myelin sheath during foetal development. Copper deficiency may also cause chronic scouring and infertility and is prevalent in many areas of Australia from the rangelands to high rainfall areas. Copper deficiency in pastoral shrub species in north east Mexico is also prevalent (Haenlein and Fahmy 1999). Despite reporting that goats require between 14 and 28 mg copper per head per day, Poore and Luginbuhl (2002) suggest that the copper requirements for goats have not been clearly defined. Dairy goats and Boer crosses appear less susceptible to copper toxicity than sheep (Zervas *et al.* 1990; Solaiman *et al.* 2001; Poore and Luginbuhl 2002) such that NRC (2007) suggests the toxic level for goats may be similar to cattle at 40 mg/kg. Haenlein and Anke (2011) report that although toxicity symptoms have been noted in sheep at 10-20 mg Cu/kg DM, goats retain 6-9 times less copper in their livers than lambs implying differences in utilisation and tolerance of toxicity than lambs (Zervas *et al.* 1990).

Copper absorption is influenced by the sulphur, iron and molybdenum concentration in the diet and the absorption levels where sulphur and molybdenum concentrations are within normal limits are detailed in Table 37. Deficiencies are increasingly found in regions where acid soils have been extensively limed which as soil pH increases, increases the availability of molybdenum. Interactions with, and antagonism from these minerals will determine the daily copper requirements of goats which Kessler (1991 cited in NRC 2007) determined to be 8-10 mg/kg DM.

Table 37 Copper absorption in ruminants based on normal concentrations of molybdenum and sulphur in the diet (Suttle and McLauchlin 1976)

Dietary sulphur	Dietary molybdenum	Copper absorption
g/kg	mg/kg	%
1.5	1	5.15
2	1	4.65
2.5	1	4.2
1.5	1.5	5.03
2	1.5	4.51
2.5	1.5	4.04
1.5	2	4.91
2	2	4.36
2.5	2	3.88
Mean copper absorption, %		4.53
Standard deviation		*0.5*

Cobalt deficiency is relatively common in weaned spring drop lambs in high rainfall areas, and in young ruminants fed grain-based finishing rations. Cobalt is required by rumen micro-organisms for the synthesis of Vitamin B_{12} (CSIRO 1990). Symptoms include suboptimal growth rates in young stock and watery eyes. Supplementation can be provided in the form of slow release cobalt capsules or as injectable Vitamin B_{12}. It is important to determine the need for supplementation with Vitamin B_{12} as it is widely promoted as being beneficial to livestock however when purchased as a component of vaccinations, it will double the cost.

Goats grazing either the pastoral areas of southern Australia or in the wheat-sheep zone may be at risk of zinc deficiency and may require additional zinc in their diet. Extensive analysis of improved pastures and shrubs from the South Australian pastoral zone (Jolly 2003 unpub) has revealed widespread zinc deficiency. Extensive areas of the cropping zone now is zinc deficient (P. March pers. comm. September 2006), which has been attributed to the long term use of chlorsulphuron herbicides in wheat crops (Osborne and Robson 1992).

Symptoms of zinc deficiency may include reduced dry matter intake, skeletal and reproductive disorders and abnormalities of the skin. The recommended daily intake of zinc for goats varies from between 37 and 52 mg/kg DM (Suttle 2010) and 50 mg/kg DM (AFRC 1997). Zinc can be applied to pastures as a component of a fertiliser blend or directly supplemented as zinc sulphate via water medication.

Of lesser importance are the trace elements manganese, iron and iodine however iodine deficiency is more commonly seen in the higher rainfall, mountainous areas of Victoria and Tasmania. According to The Department of Primary Industries, Parks, Water and Environment in Tasmania, goat kids are highly susceptible to iodine deficiency and attribute their high mortality rate to cold stress secondary to the deficiency.

Pregnant does deficient in iodine are more prone to producing weak and/or stillborn kids or in less severe cases, kids with evidence of goitre. As iodine deficiency reduces an animal's capacity to withstand cold stress, it may be a more important factor involved in the high mortality rates of kids in high rainfall areas than has previously been considered.

Under seasonal conditions that promote rapid pasture growth, iodine deficiency is more likely to occur. Iodine deficiency has been shown to significantly reduce fertility and body weight gain (Table 38), increase abortion rates and mortality of newborn dairy goat kids (Haenlein and Anke 2011). Goats grazing brassica crops or *Leucaena* species (Pattanaik *et al.* 2011) have increased susceptibility to an induced deficiency (Underwood and Suttle 1999) due to the presence of goitrogens that reduce the availability of iodine.

The commercial cost of testing pasture for iodine concentration is currently in excess of $100 per sample however if supplementation can significantly reduce kid mortality, testing is likely to be a worthy investment.

Drenching with 20 g potassium iodide in 1 litre water given at 10 mls per 20 kg liveweight 4 weeks pre mating, 6-8 weeks pre kidding and again 2 weeks before kidding commences has been suggested as a reliable prophylactic in known iodine deficient regions (http://boergoat.une.edu.au/technical%20articles/issue15_cobalt_selenium_iodine.pdf).

Table 38 Effects of I-deficient ration (mg I/kg DM) on reproduction and tissue contents of goats (adapted from Groppel et al. 1990 cited in Haenlein and Anke 2011)

	I-deficient goats (n=19)			Control goats (n=18)	
	(0.04 mg I)	*(0.06 mg I)*	*(0.11 mg I)*	*(0.40 mg I)*	*(0.63 mg I)*
Success of 1st insemination %	27***	40*	36	73	80
Conception rate, %	79 ns	77	85	83	83
Abortion rate, %	47**	20	18	0	0
Length of pregnancy, days	158**	156	152	152	151
Mortality of born kids, %	83*	-	42	5	-
BW gain, g/day					
1-84 days	90*	-	-	123	-
85-262 days	71*	-	-	105	-
I content					
Milk, 14th day, nmol/L	39***	-	-	1823	-
Hair, 50th day, μg/kg DM	165**	-	-	540	-
Uterus, μg/kg DM	75**	80	100	300	350
Lungs, μg/kg DM	40**	50	100	375	410
Liver, μg/kg DM	40**	50	90	175	200
Pancreas, μg/kg DM	62**	62	73	297	297
Brain μg/kg DM	30**	40	50	75	102
Kidneys, μg/kg DM	50**	75	100	250	301
Heart, μg/kg DM	30**	50	90	120	162

Ns = P > 0.05; - = no data
** P < 0.05*
*** P < 0.01*
**** P < 0.001*

Manganese deficiency is not commonly seen in ruminants in Australia but there are small known pockets of prevalence where calves and lambs have been born with skeletal deformities. Suttle (2010) states that "data on manganese deficiency in goats are meagre and their minimum requirements ill-defined".

Vitamin deficiencies

Free ranging goats with access to green feed are unlikely to experience severe vitamin deficiencies.

Vitamin A is essential for effective vision and immune cell function and deficiency symptoms include night blindness, depression in growth rate and an increase in susceptibility to disease. Goats can be at risk of a deficiency of Vitamin A resulting in reduced feed intake and growth rate or body weight gain, once liver stores are depleted. Liver stores will provide adequate amounts of Vitamin A for approximately three to six months after the disappearance of green feed. Vitamin A metabolism and tolerance of a deficiency is thought to be the same for sheep as goats (Donoghue *et al.* 1983) however there is no definitive proof of this. Vitamin A requirements increase when kids are fed high grain diets, grazing toxic plants or recovering from severe parasite infestation.

Vitamin B1 or thiamine deficiency (polioencephalomalacia) has been reported in Victoria in pasture-based goats following a sudden change in feed (Thomas *et al.* 1987); feeding mouldy hay or silage can also precipitate the disease. A change in diet may stimulate production of thiaminases in the rumen which effectively "tie up" thiamine. Vitamin B1 deficiency is not uncommon in grain supplemented goats in Western Australia over summer and autumn or in Queensland goats grazing bracken fern (Hungerford 1990).

Goats are generally found lying on their side with legs rigidly extended with nystagmus (rotating eyeballs) and aimlessly gazing about (Hungerford 1990). The condition can be avoided by a gradual change in feed, or by the addition of a prophylactic dose of thiamine added to a mineral concentrate. Alternatively 750-1000 mgs of thiamine hydrochloride powder may be administered as an oral drench (Hungerford 1990).

Vitamin B_{12} deficiency is caused by a lack of cobalt in the diet. Vitamin B_{12} plays an essential role in the conversion of sugars and starches into glucose (Hungerford 1990) and signs of a deficiency include poor growth, listlessness, scaly ears, inappetance, weight loss and anaemia. The vitamin B_{12} requirements of sheep are not well defined in the literature, however recent evidence suggests that goats requirements for Vitamin B_{12} is comparable with that of sheep (NRC 2007) and that the minimum requirements for sheep are adequate for goats.

The Vitamin D requirements for goats have not been reviewed since the publication of NRC (1981) where the recommendations were extrapolated from the requirements for sheep and cattle. Lambs backgrounded on pasture reportedly have sufficient stores of Vitamin D to last for 6-15 weeks (CSIRO 1990). Vitamin D deficiency is unlikely to be found in free ranging goats however goats grazing forage cereals for extended periods may have young kids that are at risk of developing rickets.

Vitamin E acts as an antioxidant removing free radicals and protecting the integrity of cell membranes in a complementary activity with selenium (CSIRO 1990). Signs of Vitamin E deficiency include stiffness of gait, although bright and alert (Hungerford 1990), and myopathy or muscle wasting (CSIRO 1990).

Vitamin E deficiency has been frequently reported in sheep in Queensland grazing bracken fern and in Western Australian lambs grazing wheat stubbles for prolonged periods over summer and autumn; however there is some disagreement as to the accuracy of the diagnosis.

The mineral requirements of goats has largely been determined from a few studies of dairy goats and extrapolated from dairy cattle and sheep such that accurate information remains elusive. NRC (2007) provides the most detailed set of recommendations for all classes of goat that they suggest require validation.

There is evidence that goat producers in medium to high rainfall areas are incurring serious productivity losses (Table 39) which may or may not be attributable to mineral or trace element deficiencies; this requires urgent attention if the domesticated goat industry is to prosper.

Table 39 Production losses of Boer goats through the breeding cycle (Courtesy: C. Ramsay October 2011)

Season	2009	2010
	% of herd - 500 does	
Joining to scanning	5	3
Does dry at scanning	23	24
Does dry at marking	19	17
Dead at birth	14	12
Deaths: birth to weaning	24	29

Although these productivity losses are similar to anecdotal reports for sheep, the gross margins from intensive sheep production systems are reportedly higher than for goats and are therefore more able to overcome the financial losses.

Conclusion

Mineral deficiencies have the potential to result in significant production losses either due to morbidity or mortality and it is clear that the requirements for goats require further clarification. However in the meantime producers would benefit from establishing the extent of deficiencies on their own properties, such that remedial programs can be implemented and assessed; avoidance of the “shotgun” approach should be encouraged such that any supplementation strategies are soundly based and implemented cost-effectively.

Soil, plant and animal investigations to determine the extent of deficiencies appear justified in productive environments however monitoring of faecal material via FNIRS technology where calibrations exist for the detection of any deficiencies in rangeland systems may be more appropriate.

There is little doubt that following season 2010-2011 during which time many areas of southern Australia experienced above average rainfall, mineral deficiencies have been more evident. However goat producers appear likely to benefit from research programs directed toward the effects and remediation of copper, cobalt, selenium and iodine deficiencies on goat production across a range of genotypes in high rainfall environments.

Recommended further research

- Verify the daily mineral requirements of domesticated goats
- Determine the links between copper deficiency, lameness and scouring in goats
- Determine the daily requirement of copper supplementation for goats
- Verify the length of activity of 3 year selenium capsules in goats
- Determine the relationship between production losses and mineral deficiencies in medium to high rainfall areas

Water requirements of goats

Water requirements of goats vary with breed, genotype (Olsson *et al.* no date no date), and stage of productivity; environmental conditions and dietary factors such as dry matter intake, feed composition and secondary metabolites present in plant species affect water requirements (Estell 2010). Daily water intake of goats is reportedly approximately 3 times dry matter intake (Giger-Reverdin and Gihad 1991) and can be as high as 4 litres per kg dry matter intake (INRA 1978).

Water intake as a proportion of milk yield varies from 1.28 litres/kg milk (Giger-Reverdin and Gihad 1991) to 1.43 litres/kg milk (Morand-Fehr and Sauvant 1978 cited in NRC 1981) however McGregor (2005) asserts that NRC (1981) recommendations for water requirements are outdated. McGregor (2005) recommends between 4-9 litres of water per goat per day and 1 litre per kg milk produced for lactating does.

Goats grazing in arid environments tend to have lower water requirements due to adaptive mechanisms for water regulation; Silanikove (1989) attributed this reduced requirement to a lower energy demand as an increase in energy demand is strongly associated with an increase in water use (Macfarlane and Howard 1966). Khan *et al.* (1978) observed after 4 days of water deprivation goats were better adapted than sheep or cattle in the central arid zone of India where Barmer goats (Figure 22) lost weight at the rate of 1.5% per day, Merino sheep at 4-5% and cattle at 8% of liveweight per day.

Figure 22 A Barmer goat (Khan et al. 1978)

McGregor (1986) observed that Angora wether goats grazing dry pastures during summer had a 50% higher water intake than fine wool Merino wethers however in 2004 McGregor reported that goats drank less water than sheep when shade was provided.

Goats appear to prefer saline water up to 12,500 mg/l TDS and Boer goats (Casey and Niekerk 1988) have higher water use than Angora goats (McGregor 2003). Water intake per unit of dry matter intake is lower in goats than sheep (Devendra 1989) and the water economy or turnover rate is more efficient in goats.

In contrast Alamer (2011) reported that Aardi goats in Saudi Arabia had lower water intakes than Awassi sheep during winter but higher intakes in summer however goats that have evolved in dry environments appear to have lower water requirements than their temperate counterparts (NRC 2007). (Silanikove 1989) attributed this characteristic to their lower ME requirements.
(NRC 2007) concluded that under similar environmental conditions, water intake of goats exceeded that of sheep; it therefore appears that the variation in requirements across breeds, genotypes and environments might create difficulties in transposition of recommendations across all goats.

Highly mineralised water affects the voluntary intake of all livestock and any depression in water intake is usually accompanied with a decrease in dry matter intake (NRC 2007). In addition it has been reported that water consumption of sheep and goats increases threefold when fed a high salt diet (Arieli *et al.* 1989; Giger-Reverdin and Gihad 1991; Masters *et al.* 2005).

Water intake may be influenced by feeding methods such that Devendra (1989) reported the daily water intake of goats fed *ad-libitum* averaged 3.5litres/kg DM. This reflected a consumption of 6% of body weight in winter which increased to 9% in summer.

Water quality

The water requirements of goats, predominantly Angora goats, has been extensively reviewed by McGregor (2004, 2005) where the emphasis of the research was clearly focused on the management of goats under drought conditions and their intake of saline water. Table 38 summarises the recommendations of total dissolved solids (TDS) tolerance levels for sheep and goats from three sources however the origins of these recommendations remain unclear. Scarlett (2002 cited in McGregor 2005) suggests that where stock have access to halophytic plants that the salinity levels in the water supply should be reduced by 30%; although where goats have access to bore water of low quality it is often not feasible to dilute the salinity to any degree. It should not be assumed however that water quality in the rangelands is of low quality as in many areas the water is potable.

Growth rate of lambs is supressed when the salinity of drinking water exceeds 3500ppm (CSIRO 1990) and as goat kids tend to be significantly smaller than lambs, the recommendations in Table 40 may need to be treated with caution. A publication from DPI Victoria (2010) states that water with an EC of <5800 (3700 TDS) is suitable for all classes of livestock however the origins of this recommendation remain unclear.

The tolerance of goats to saline water is likely to be dependent on whether they were born into the environment or introduced, with the former more likely to show greater levels of tolerance.

Table 40 Suggested maximum desirable level of total dissolved solids (TDS) in water available to sheep and goats (adapted from McGregor 2005; NRC 2007)

	Sheep (Court 2002)	*Goat (Scarlett, 2002)*	*NRC, (2007)*
		TDS, mg/l	
Class of animal			
Young	5000	7000	2000 - 4900
Dry adult	10000	14000	
Lactating female	5000	10000	

Results from a survey of 31 goat producers conducted by McGregor (2004) suggested that goats generally survived well on saline water up to 11,000 mg/l TDS and at higher levels some dilution factor was required such as access to lush pasture or blending with higher quality water.

Conclusion

The tolerance of goats to saline water without a detrimental effect on productivity will depend on their level of adaptation, age, diet and stage of productivity or class. Saline water will initially increase DM intake however when the tolerance level is reached intake depression will follow. Where possible and if appropriate, dilution of saline water to a tolerable or productive level is recommended.

Where optimal levels of productivity are required it is important to ensure that an adequate supply of clean, high quality water is available at all times.

Recommendations for further research

There does not appear to be any requirements for further research into the water requirements of goats.

Nutrient requirements of reproductive goats

Nutrition and ovulation

There are a range of factors that influence reproductive behaviour of small ruminants which include day length, socio-sexual cues and energy balance (Blache *et al.* 2008); hence nutrition is a potent driver of reproductive capacity.

Goats are dependent on their energy balance being positive or slightly negative during the reproductive cycle in order to meet the energetic demand of reproduction. Increasing energy intake increases the reproductive capacity of goats (Sachdeva *et al.* 1973) however it appears as if both the timing and level of energy increase are equally important (Blache *et al.* 2008). Key times along the reproductive axis where nutritional supplements may have a positive effect on reproduction are highlighted in Figure 23.

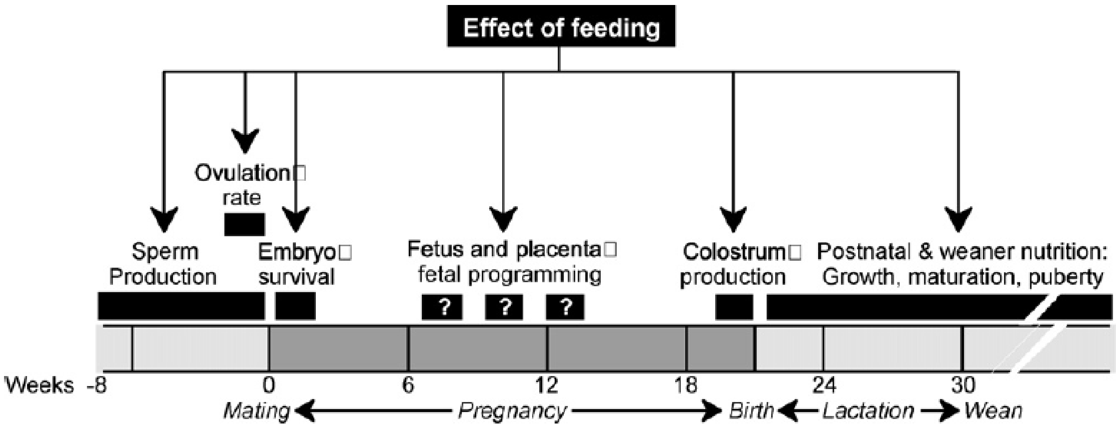

Figure 23 Strategic feeding periods during the reproductive cycle that may affect reproductive success of the herd (Blache et al. 2008 modified after Martin 2004)

Between 5-8 days of feeding energy and protein supplements such as lupin grain (Oldham and Lindsay 1984) has been shown to increase ovulation rates of ewes as has more recent work investigating the effect of different pasture types on ovulatory responses (Figure 24).

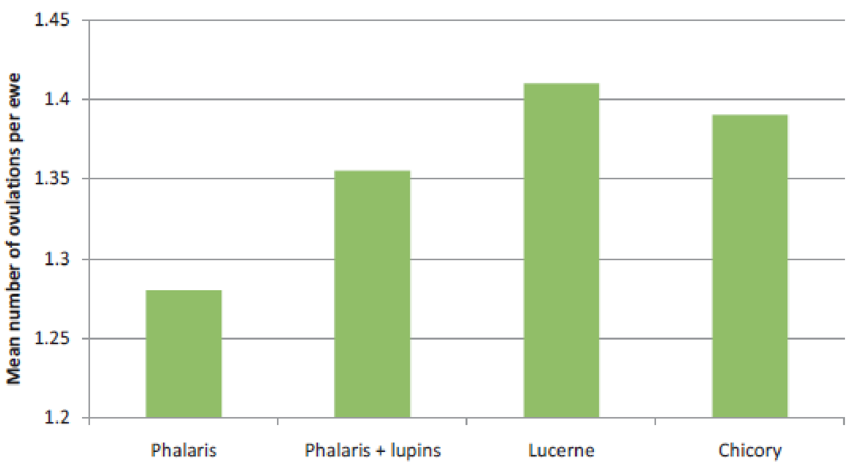

Figure 24 Mean ovulation rate per ewe grazing a range of pastures 2006-2008 (Robertson and Friend 2010)

However in contrast Acero-Camelo *et al.* (2008) noted no reproductive responses to flushing meat goats with concentrates prior to mating. As with any form of supplementation it is important that it complements the nutritive value of the base diet such that the nutrient requirements of the animal are met and not exceeded. Where this is not the case responses to supplementation may differ.

Damascan goats have reportedly responded to glucose injections with a significant increase (P> 0.05) in oestrus activity (Salem *et al.* 2011) which implies that the provision of an energy source such as cereal grain pre joining may produce similar ovulatory responses in goats as ewes. Pakistani Kosta does demonstrated significant responses to an increase in dietary ME to 9.2 MJ/kg DM (Aritonang 2009) in terms of feed efficiency, liveweight gain, birth weight and weaning weight; in addition, reproductive performance improved with earlier onset of puberty, shorter pregnancy and increased litter size.

Dairy goats fed low to medium energy levels during the dry period have improved reproductive rates and milk production (Lee *et al.* 2003) and increased fecundity and twinning rates (Kusina *et al.* 2001). Focus feeding strategies are currently under investigation by Blache and Martin (2009) in sheep and goats in Mediterranean regions.

It is well accepted that ovulation increases concurrently with body weight in sheep and a similar relationship has been reported in Saanen goats during the breeding season in Turkey (Serin *et al.* 2010) such that these authors recommend feeding high energy supplements to goats in lower condition pre joining. Mellado *et al.* (2005) observed that litter size and birth weight of crossbred goats were influenced by liveweight of does at mating and that lactation concurrent with pregnancy resulted in a significant depressive effect on reproductive success.

In earlier work Mellado *et al.* (2004) reported significant effects of low body condition, age, polledness and low magnesium and calcium intakes at joining on reproductive rate of cross bred does under range conditions.

Although the focus of reproductive success is more likely to be on the female the contribution of the male should not be ignored however it is often given less attention; Martin *et al.* (2010) in a review of the interactions between nutrition and reproduction in the male ruminant, commented that a reduction in feed intake profoundly affected sperm production, and that energy intake was likely to be more important than protein intake in remediation. In contrast, Abi-Saab *et al.* (1997) observed male kids fed a high protein diet (18%) from 28 days of age had significantly higher semen volume, sperm viability and concentration which remained significant at 7 months of age, than those on a 12% protein diet.

Nutrition during gestation

The relationship between nutrition and embryo survival may differ between sheep and goats as progesterone is produced by the corpus luteum in goats and by the uterus in pregnant sheep, and it is progesterone that maintains the pregnancy. Excessively high nutritional inputs post joining have reduced progesterone production (Parr *et al.* 1987; Landau and Molle 1997) and increased embryo loss (Gunn 1983) in sheep however it is not known if the effects are similar in goats (Blache *et al.* 2008). A restriction in dry matter intake to 25% of maintenance requirements can have a detrimental effect on embryonic development (Parr and Williams 1982) in sheep and should be avoided for the first 30 days after breeding when most embryonic losses occur (Schoenian 2011).

The abortion rate in goats can be affected by feeding low quality roughage such that Hussain *et al.* (1996) reported a significant increase in the abortion rate of does fed a low quality diet between days 90-120 of pregnancy. Diseases such as toxoplasmosis and campylobacter should also be considered as potential causes of abortion however their effects are more commonly seen in late pregnancy.

There is a plethora of evidence in sheep that poor nutrition during pregnancy negatively affects the reproductive potential of the progeny (Blache *et al.* 2008) however although Squires (1981) observed that ewes appeared more sensitive to under-nutrition than does under rangeland conditions, there is little similar work published for goats.

Nutrition in late pregnancy and early lactation

Foetal growth accelerates significantly in sheep during the last 60 days of gestation (Figure 25) and as such, nutrient requirements also increase. It is unlikely that increased demand will be met by an increase in intake alone as in the case of multiple pregnancies, the gravid uterus occupies an increasing amount of space within the peritoneal cavity, reducing the capacity of the rumen to expand.

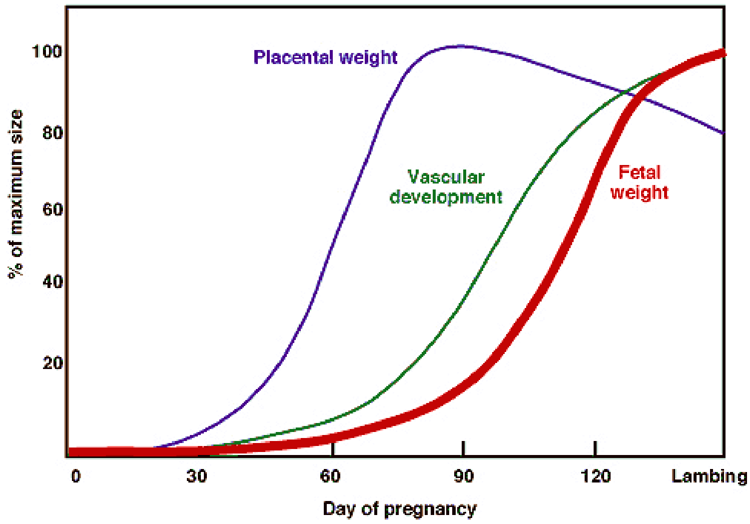

Figure 25 Foetal weight, placental growth and vascular development patterns in Merino ewes (Source: http://www.agric.wa.gov.au/PC_91913.htm)

It is important for the nutrient density of the feed on offer to increase during late pregnancy to align with demand and alleviate the imperative to increase intake as previously described.

Theoretical application of intake recommendations in a grazing situation can be misleading as goats will not necessarily increase or limit their daily dry matter intake to meet energy demand. The NDF concentration of the pasture will significantly influence intake regardless of demand and there are no guarantees that goats will limit their intake of a high quality pasture to align with daily requirements. Application of dry sheep equivalent (dse) ratings to set stocking rates are based on an assumption of dry matter intake increasing with demand however this is often not the case in practise.

As pregnancy advances feed quality has a far greater effect on litter weight, milk yield and lactation length than the quantity of feed on offer (Frileux *et al.* 2003) however differences between genotypes have been reported; Sibanda *et al.* (1999) noted that Matabele does appeared to be resistant to nutritional stress in late pregnancy as an important characteristic of their adaptation to range conditions.

The changing nutrient requirements during pregnancy and into early lactation are reflected in the recommendations by NRC (2007) summarised for a twin-bearing, non-dairy doe at 60 kg liveweight in Table 41. As previously discussed the reason for the decline in nutrient density recommendations during lactation compared with late pregnancy are difficult to explain. Increasing ME and protein intake in early lactation will limit the mobilisation of body fat and protein, minimise body weight loss and enhance the doe's reproductive capacity after kidding. Hamel and Cote (2009) reported the intake of does increased by up to 40% during lactation above that of non-lactating goats whereas NRC (2007) suggest an increase closer to 15 percent.

Table 41 Recommended daily intake (DMI) and energy requirement for a 60kg non-dairy, twin-bearing doe in early and late pregnancy and early lactation (adapted from NRC 2007)

		DMI			ME		Crude protein	
		LW (kg)	*% LW*	*kg DM/d*	*MJ/kg/d*	*MJ/kg DM*	*g/d*	*% of DM*
Twin pregnancy								
Gestation	Early	60	2.38%	1.43	11.42	8	140	9.3%
	Late	60	2.54%	1.52	15.23	10	206	13.6%
	Early lactation	60	2.91%	1.75	13.97	8	207	11.8%

As pregnancy advances, increasing the nutrient density of the diet (MJ/kg DM) assists in overcoming the potential limit in dry matter intake that occurs due to the increasing size of the gravid uterus. However these recommendations fail to account for does grazing high quality pasture where the ME density of the feed on offer may be as high as 12 MJ ME/kg DM and, as such, intake is not required to increase for nutrient requirements to be met. Similarly daily protein recommendations assume a given level of intake, but also fail to account for a pasture that may be as high as 30% crude protein. It is the responsibility of the person using these guidelines to properly account for these variations.

The nutrient requirements of goats appear to vary between genotypes according to NRC (2007) and summarised in Table 42.

Table 42 Variation in dry matter intake (DMI), crude protein and energy (ME) requirements for three different genotypes of goat at 50 kg liveweight in early lactation with twin kids at foot (adapted from NRC 2007)

	LW	DMI	Crude protein	Crude protein	ME
Genotype	*kg*	*DMI kg/d*	*gms/d*	*%DM*	*MJ/d*
Dairy doe	50	2.30	305	13.2	18.46
Non-dairy doe	50	1.54	202	13.1	12.30
Angora doe	50	1.48	205	13.9	14.77

As dairy does are likely to have significantly higher output of milk production than meat or fibre-producing does, their intake, protein and energy requirements are likely to be similarly increased.

The differences between the requirements of a meat doe and a fleece producing doe, although insignificant, remain unclear. Again, the assumption behind these recommendations is that these does will be grazing low quality pasture with an ME density of 8 MJ.kg DM and a crude protein concentration of 13-14% which may occur more frequently under range conditions. In more intensive grazing situations does with kids at foot would be more likely to be grazing pastures of significantly higher quality.

It is also important to be reminded at this point that these recommendations should be treated with caution as they do not include any allowance for activity. The recommendations may be applicable to dairy does however it is not likely that rangeland or domesticated meat or fibre producing does will be managed in confinement for long periods and may require an adjustment for activity.

Conclusion

Although recent publications and reviews refer to sheep and goats in their recommendations for nutrition in pregnancy much of the work contained in this section has been developed from experimental sheep. It appears that some variation in recommendations may be required for different genotypes of goats however the evidence is not convincing nor is the premise on which they are based.

It would appear logical that requirements would increase with advancing pregnancy as for all other ruminants; however the degree of increase remains largely untested. It would seem reasonable in the meantime to apply the same nutritional strategies for reproduction to intensively managed goats as for sheep to stimulate ovulation and account for increasing nutritional demand of the growing foetus(s).

The exclusion of an activity account in all NRC (2007) recommendations remains a concern which requires addressing if productivity of the Australian domesticated goat is to increase in the near future.

Recommended further research

- Validation of the nutrient requirements for reproductive does of all genotypes as considered appropriate
- Investigation of an appropriate activity rating to be applied to all nutrient recommendations for pregnancy and lactation
- Development of a set of comprehensive and practical set of nutrient guidelines for reproductive does for use by the goat industry
- Application and validation of the current and well researched nutritional strategies for ewes as they may apply to goats

Nutrition of weaned kids

Nutrition of the doe during pregnancy has a significant effect on the birth weight, survival rate and early vigour of kids (Aregheore and Lungu 1997); similarly, lambs that have been subjected to a period of nutritional restriction during foetal life exhibit suboptimal development of the small and large intestine (Trahair *et al.* 1997), deposit less bone, less muscle and more fat to weaning (Greenwood *et al.* 1998; Greenwood and Bell 2003) and have reduced reproductive performance over their lifetime (Rhind *et al.* 1998). These effects should be similarly considered for goats.

Early weaning

Kids can be weaned as young as 5 weeks of age or at a minimum live weight of 8.5 kg provided they have access to concentrate feed (grain) pre weaning and are consuming a minimum of 30 grams of concentrate per head per day (Morand-Fehr 1981; Lu and Potchoiba 1988). Male kids appear to be more susceptible to 'weaning shock", defined as weight loss post-weaning, than their female counterparts, therefore it is recommended that male kids are not weaned before 7 weeks of age. The greater the degree of weaning shock, the lower the compensatory growth response at 5-7 months (Morand-Fehr *et al.* 1982).

Lu and Potchoiba (1988) reported that liveweight at 16 weeks of age was significantly higher in dairy goats kids weaned at 8-10 weeks of age (Table 43) as opposed to those weaned between 4-6 weeks however weaning shock is likely to be significantly reduced by weaning according to weight rather than age.

Table 43 Effect of weaning weight on milk intake, weight gain and dry matter intake of dairy goat kids (from Teh et al. 1984 citied in Lu and Potchoiba 1988)

	Weaning weight, kg			
	8	***9***	***10***	***11***
n	6	6	7	8
Days on milk	31	35	42	49
Total milk intake, kg	38.5	48.9	55.0	68.1
Dry matter intake, kg	35.9	42.6	33.9	35.7
Weight gain, g/d	123	150	136	150

Palma and Galina (1995) investigated the effect of early (10 kg LW) and partial weaning to 15 kg LW of dairy kids and found the early weaned group grew at 98 g/d and the partially weaned (provided with an extra 30 days of milk) grew at 120 g/d, but at a 33% cost disadvantage. Both groups had achieved mating weight (60% of mature weight) by 8 months of age.

Rumen development

Rumen development from birth to weaning determines dry matter intake potential and the ability of the weaned kid to absorb nutrients. Post weaning productivity and survival is more likely to be optimised if weaning is delayed until the completion of rumen development and the post weaning diet is sufficiently concentrated to meet the requirements of kids of relatively low body weights.

The development of the rumen is characterised by weight and hence capacity in terms of future dry matter intake potential and internal papillae growth which influences absorption of volatile fatty acids (VFA) from carbohydrate fermentation (Tamate *et al.* 1962). Amaral *et al.* (2005) investigated the morphological characteristics of rumen development in response to pre weaning supplementation of Saanan goat kids fed different diets and found that kids fed a pelleted total ration compared with a ground or extruded total ration had significantly higher dry matter intakes pre and post weaning, higher weight gain and significantly advanced rumen development by 60 days of age.

Although the development of rumen papillae increased with increasing age, those kids fed the pelleted diet (PGR) had significantly increased papillae development (Figure 26). More advanced rumen development and hence increased DMI potential resulted in a 46.7% increase in live weight gain.

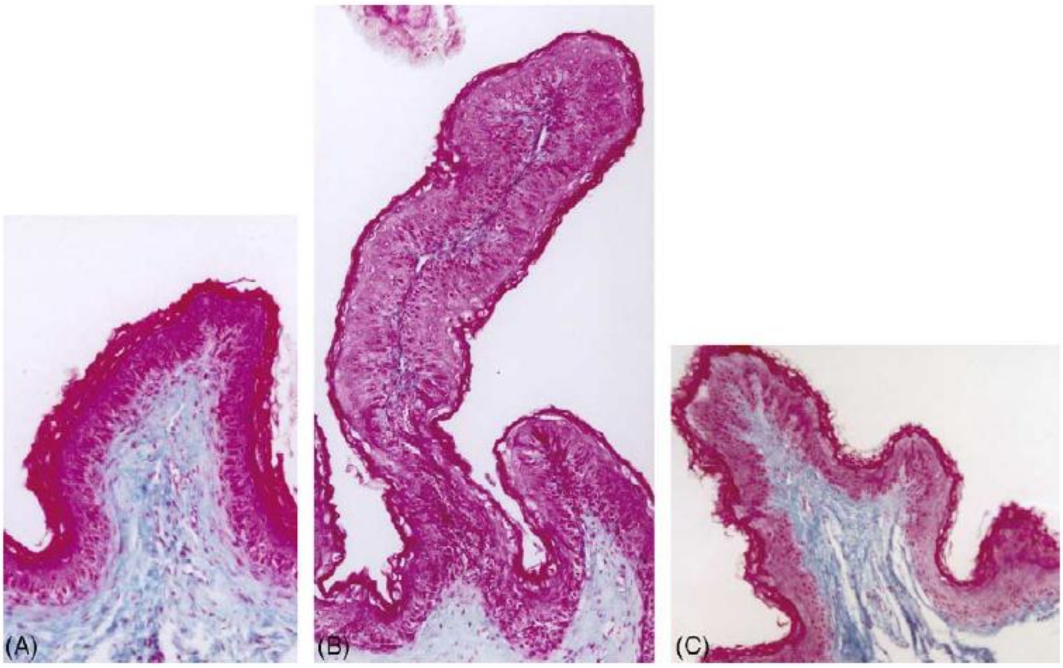

Figure 26 Photomicrography of the ruminal dorsal sac of Saanan kids at 60 days of age fed a ground total ration (GTR-A), pelleted total ration (PTR-B) or extruded total ration (ETR-C) (Amaral et al. 2005)

Kratochvil *et al.* (1996) investigated the weights of various organs of male Korean goat kids between 24 – 75 days of age and reported maximal rumen growth between 24 and 42 days with an increasing weight trend between 61 and 75 days of age. During the same period abomasal weight decreased concurrently.

Mgasa *et al.* (1994) reported enhanced development of the rumen papillae in male goat kids fed concentrated lucerne pellets in comparison with green forage pellets and concluded that the structural development of the reticulorumen is significantly influenced by the diet.

Ruminal VFA concentration may be indicative of the completion of rumen development. Muhsen (2009) reported that butyrate, propionate and acetate concentrations in week old kids increased steadily to 15 weeks of age whereupon they stabilised.

Weaning rates of goat kids
Young ruminants of low body weight face significant challenges to survival in intensive pasture-based systems. Lambing, calving and kidding are generally timed to match the time of highest feed production and quality; such that by the time weaning occurs, pasture quality has passed its peak nutritive value (Figure 27).

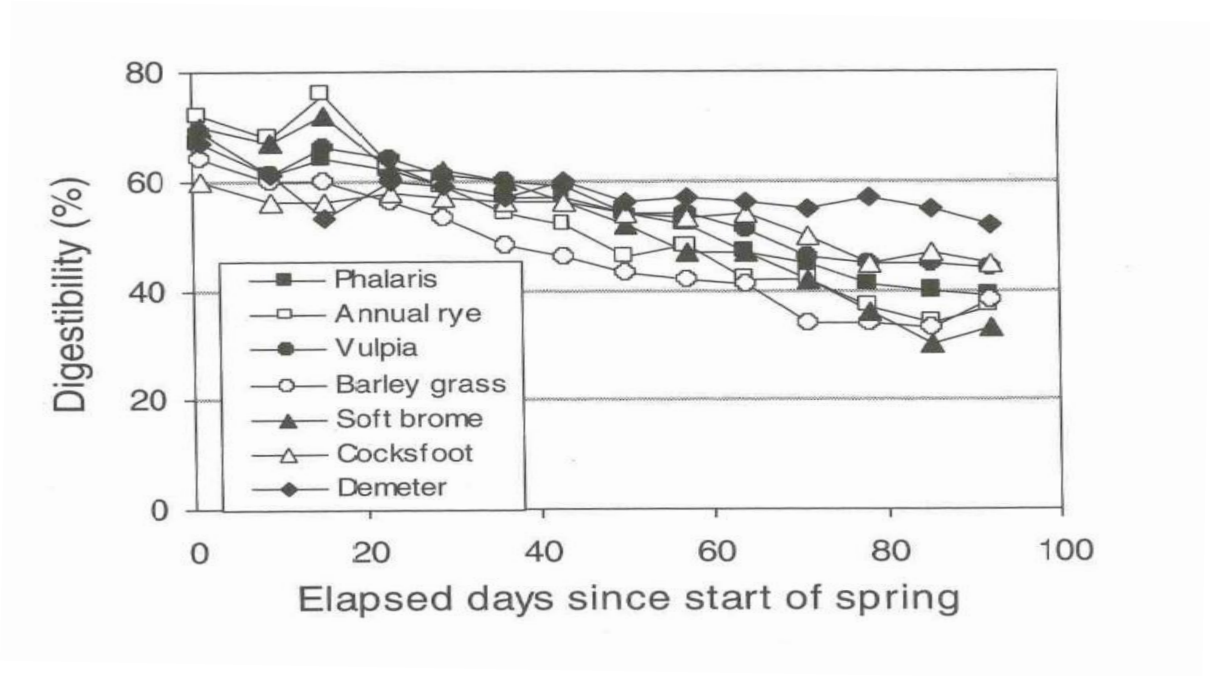

Figure 27 Changes in dry matter digestibility of a range of pasture grasses (NRC 2007 adapted from Radcliffe & Cochrane, 1970)

Use of brassica species, legume crops and ripened cereals can alleviate the decline in quality feed for weaners however determination of the cost-effectiveness of these systems for goat production requires investigation.

Weaners of all species with low body weights and hence low intake potential require a supply of highly concentrated nutrients to overcome these constraints; however it is evident that even where supplementation is provided weaning rates of goat kids remain suboptimal relative to birth rates (Table 44).

Table 44 Number of kids born and weaned among sire breed x dam breed combinations (adapted from Browning and Leite-Browning 2011)

	Breed of Sire								
	Boer			Kiko			Spanish		
Breed of Dam	*Born*	*Weaned*	*Wean%*	*Born*	*Weaned*	*Wean%*	*Born*	*Weaned*	*Wean%*
Boer	152	98	64%	160	100	63%	141	96	68%
Kiko	169	128	76%	217	166	76%	187	149	80%
Spanish	176	151	86%	176	149	85%	169	136	80%

In Australia (C. Ramsay pers comm. October 2011) and in the US (Browning and Leite-Browning 2011) there is a limited gene pool from which to select goats with enhanced survival characteristics. Browning and Leite-Browning (2011) conducted a long term study of three goat genotypes and 1547 kids over a six year period where they evaluated the genetic effects on pre weaning kid performance.

Their investigation concentrated on three goat breeds common to the US which included:

- Boer – breed from semi-arid South Africa and selected for improved growth characteristics
- Kiko – New Zealand composite (dairy x "feral") selected for tolerance to humid environments
- Spanish – meat goat naturally selected within semi-arid Texas

The goats had access to cool season tall fescue and warm season bermudagrass pastures and were supplemented with orchardgrass hay. Does were supplemented with a 16% protein, 10.8 ME pellet from kidding to weaning and average annual rainfall was 1200mm. Does were kidded at pasture and provided with access to shelter and kids were weaned at 3 months of age.

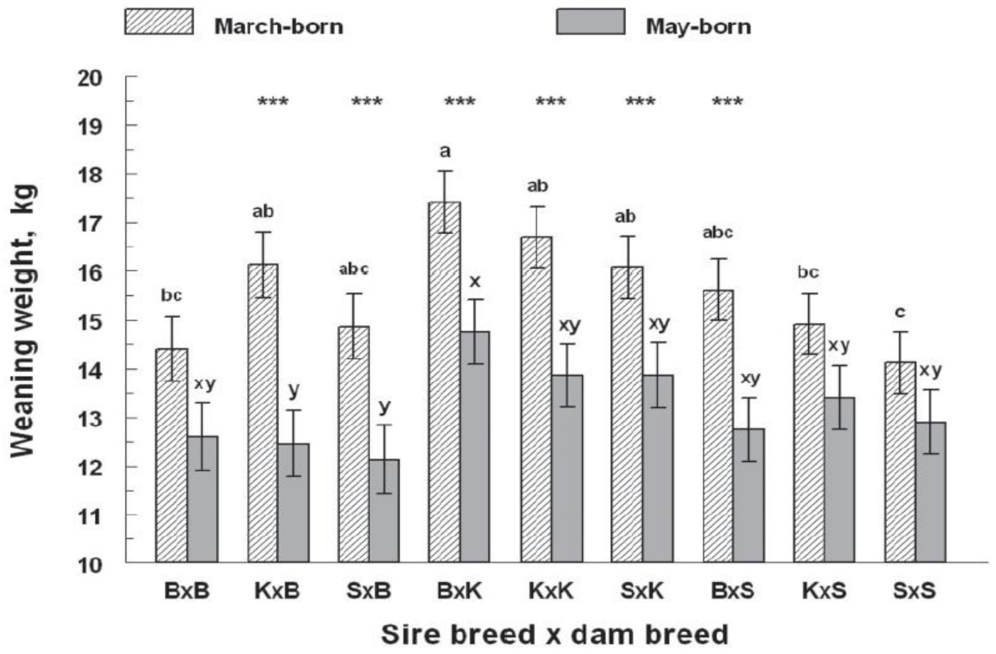

*Figure 28 Weaning weights (90-day adjusted) for kids within significant 3 way interaction of sire breed x dam breed x birth month. B = Boer; K = Kiko; S = Spanish. [a-c] Least squares means (+/- SE) for kid (sire breed x dam breed) genotypes within March-born group not sharing common letter differ (P<0.01). [x,y]Least squares means (+/- SE) for kid (sire breed x dam breed) genotypes within May-born group not sharing common letter differ (P<0.05). ***Least squares means (+/- SE) for month within kid genotype differ (P<0.001). (Browning and Leite-Browning 2011)*

Sire breed effect for weaning weight was not significant however maternal breed effect was highly significant (P<0.0001) with the Kiko effect strongly positive (P< 0.0001) and the Boer effect negative (P<0.0003).

Table 45 Pre-weaning kid survival rates within dam breed x birth litter size interaction (Browning and Leite-Browning 2011)

	Breed of Dam					
Litter size	*Boer*		*Kiko*		*Spanish*	
Single	85.7	+/-5.1 [ab]	96.1	+/-1.8 [a]	92.5	+/-3.7 [ab]
Twin	56.1	+/-7.1 [c]	81.0	+/-4.4 [b]	85.9	+/-3.6 [ab]
Triplet	58.1	+/-9.1 [c]	58.6	+/-9.1 [c]	81.0	+/-6.6 [bc]

[a-c] least squares means (+/- SE) within column or row not sharing a common superscript differ (P<0.05)

There was no sire effect on pre weaning kid survival rate however the maternal breed effect was highly significant (P<0.0005) with Kiko and Spanish dams having higher kid survival rates than Boers. The inferior ability of Boer does to raise kids to weaning is not an unusual finding across a range of comparative studies conducted in South Africa (Browning and Leite-Browning 2011). It has been suggested that Boer goat selection under optimal nutritional conditions for increased growth rates may result in suboptimal performance under more challenging conditions (James 2009; Wilson 2009). The current gross margins for goat enterprises may preclude cost-effective supplementation to improve Boer goat progeny survival and it may be that introduction and/or selection of more environmentally resilient genetics are required to underpin the growth of Australian intensive goat meat production.

Although kids have similar birth weights to lambs (2.5-4kg) they have less insulation than lambs (Jordan 2011) and a lower metabolic rate per unit of liveweight (Müller and McCutcheon 1991). Faurie *et al.* (2004) concluded thermoregulatory mechanisms support rectal temperature recovery immediately post-partum in lambs and it is these mechanisms that activate brown fat tissue for thermogenesis. Behavioural mechanisms such as suckling stimulate metabolic and digestive processes which have a significant effect on recovery of neonatal body temperature (Mercer and Jessen 1979).

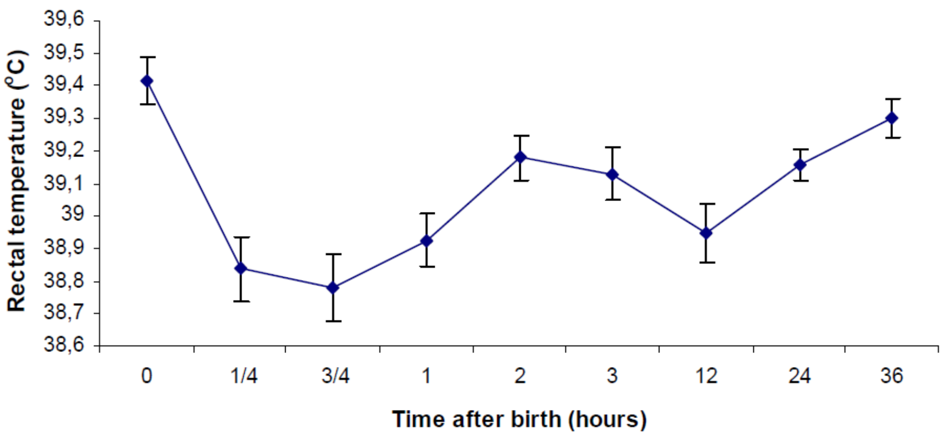

Figure 29 Rectal temperature dynamic in Toggenburg kids during the first 36h of neonatal life (Aleksiev 2009)

Aleksiev (2009) recorded rectal temperature of Toggenburg kids during the first 36 hours of life under controlled conditions where ambient temperatures were between 1.7˚ to 6.4˚C (Figure 29). These authors concluded that kids had well expressed thermoregulatory ability with rapid activation of heat generation and retention mechanisms.

In more recent work (Ninan *et al.* 2011) determined some baseline parameters for lambs and kids and reported significantly low rectal temperatures for both species at birth; these were 39.1˚C and 38.87˚C respectively which concurs with the findings of Aleksiev (2009). It appears that kids have similar temperature behaviour to lambs immediately after birth and are therefore not more likely to die of cold stress.

Post weaning growth potential of kids

It appears that goats have similar growth potential to lambs from birth to weaning (Van Niekerk and Casey 1988; Poore and Luginbuhl 2002; Solaiman *et al.* 2011) however there are many reports of sub-optimal growth rates (Haas 1978; Singh *et al.* 1980; Louca *et al.* 1982; Morand-Fehr *et al.* 1986; Barry and Godke 1997; Luo *et al.* 2004c). There appears to be a general consensus across the published literature that kids grow slower than lambs however it is difficult to assess these claims when details of comparative diets are not provided.

Although Louca *et al.* (1982) commented that growth rates of lambs (300-450 g/d) exceed that of kids (150-270 g/d), sustained growth rates of lambs of 300-450 g/d are not commonly seen in Australian sheep flocks post weaning and where such growth rates are achieved, they are usually short term (Jolly and Wallace 2007). Van Niekerk and Casey (1988) reported that Boer goats under optimal conditions average 200 g/day and under extensive subtropical conditions, 176g/day. Post weaning growth potential appears to be higher for Boer kids (150-250 g/d) and their crosses than for dairy kids at 160-220 g/d (Morand-Fehr *et al.* 1986). Growth rate of weaned lambs under pasture based conditions in southern Australia average 250 g/d (Jolly and Wallace 2007).

Heritability estimates for growth rate to weaning of 0.68 (Restall *et al.* 1984) for rangeland goats; for mature weight of Anglo-Nubian goats at 18 months of 0.28 (Sousa *et al.* 2011) and live weight of goats at 7 months of age at 0.69 (McDowell and Bove 1977) indicates that improvement is possible from genetic selection.

There is evidence of highly selected and supplemented Boer goats achieving growth rates in excess of 250 g/d and up to 400 g/d (Gilbert, and Ramsay, unpublished data) indicating the potential to grow as well as lambs and Australian producers have recorded post weaning growth rates as high as 400 g/d under feedlot conditions. Much of the gross margin from lamb and cattle feedlots arises from compensatory gain; the animals are purchased at a relatively low liveweight after having experienced a period of slow growth which is significantly accelerated in response to a high plane of nutrition; it has been suggested that kids do not express compensatory rates of gain comparable with cattle (Louca *et al.* 1982) or sheep (McDowell and Bove 1977).

It is important when assessing the growth potential of kids that it is done in context of the quality of the available feed such that (McGregor 1996) found when Cashmere kids grazing winter pasture were supplemented barley straw there was no improvement in weight gain. Cashmere kids at 24 kg liveweight require a diet that is energy dense whereas the NDF of barley straw would effectively reduce the energy density of the kids' total daily intake. This example highlights the need to ensure that any supplements provided complement the available feed so as to meet nutrient requirements.

In more recent work McGregor *et al.* (2010) fed 260 g/d lupin/barley grain mix to weaned Angora kids grazing pasture and reported a growth response of 59 g/head per day; unless mortality rates were significantly improved such a small response is unlikely to be cost-efficient.

Patterson *et al.* (2009) offered Boer goat kids a range of hays *ad-libitum* and measured the nutritive value of the hay residues; hay not eaten was significantly lower in crude protein and ME than hay selected (Table 46).

Table 46 Hay selected and refused by Boer goat kids on a dry matter basis (adapted from Patterson et al. 2009)

Constituent - hay	CP	NDF	ADF
Tifton-85 Bermuda grass	6.8	78.2	45.1
Tifton-85 refusals (83.3% +/- 9.9)	1.9	47.5	47.4
Sorghum-Sudan	8.3	73.7	47.9
Sorghum-Sudan refusals (77.3% +/- 5.2)	2.7	43.9	53.5
Coastal Bermuda grass	12.2	65.3	37.5
Coastal refusals (69.5% +/- 12.1)	5.9	40.4	42.2

When Boer kids were offered a concentrate pellet at 1% of body weight in addition to the hay described in Table 46, growth rates significantly improved (Figure 30). Kids fed the concentrate pellet alone clearly demonstrated their growth potential, apparently limited only by nutrition.

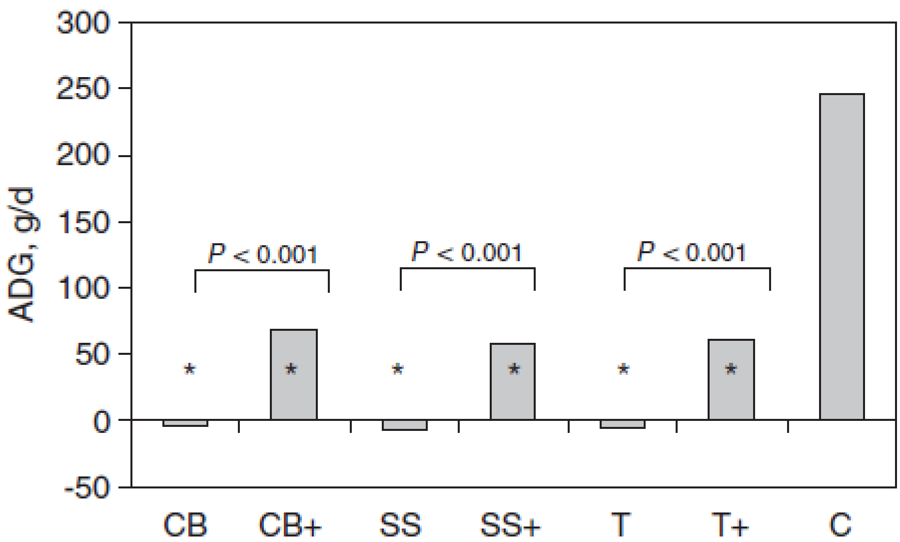

Figure 30 Average daily gain (g/d) of goats consuming coastal Bermuda grass (CB), Tifton-85 (T), or sorghum-Sudan grass (SS) alone or supplemented at 1% of BW (+) with a commercially available 18% CP goat ration (C). Bars with asterisk are different (P<0.05) from C. (Patterson et al. 2009)

The ability of weaner kids to efficiently convert feed to liveweight gain is the most important factor in determining profitability however producers do not yet have a selection index available to use as a selection tool. There is little published data on feed conversion ratios of weaned kids with the exception of work by Ueckermann (1969) who fed two groups of Boer goat kids (slaughter weight 31.8kg; slaughter weight 45.4kg) three different rations and found that feed conversion ratio (FCR) was more efficient at higher levels of dietary concentrate inclusion (Table 47).

Table 47 Feed conversion ratios of Boer goat kids fed different levels of forage and concentrates at two slaughter weights (Ueckermann 1969)

Slaughter weight (kg)	Ration	Ratio	FCR
31.8	Roughage:concentrate	60:40	8.6:1
	Roughage:concentrate	40:60	8.1:1
	Roughage: total	100:0	10.3:1
45.4	Roughage:concentrate	60:40	9.5:1
	Roughage:concentrate	40:60	9.5:1
	Roughage: total	100:0	13.2:1

Machen *et al*. (no date) suggest that the expected range of feed efficiency for goats should be between 6-8:1 however the origins of this recommendation remain unclear.

The growth potential of goat kids appears to be equal to that of lambs in response to the provision of high quality forage and concentrates, however the response needs to be cost effective and will vary according to market signals for milk, meat and fibre.

The growth rate of kids pre and post weaning is influenced by many factors including breed, sex, maternal nutrition and the physical and chemical characteristics of the diet (Lu and Potchoiba 1988). However the relationship between dietary protein, energy and growth rate appear similar to lambs (Jolly and Wallace 2007) in that those relationships are difficult to determine. Comparison of many published studies is constrained by a lack of information about the concentration of nutrients in the diet, the age or weight of the kids, inherent differences between individual animals, breed differences and differences in the physical form of the ration. Growth rate data reviewed as a component of this review is summarised in Appendix 2: Summary of feeding trials reviewed, listed by author.

It would seem logical that for any breed of weaned kid that where maternal nutrition has been adequate and weaner feed is well balanced for NDF to facilitate maximal dry matter intake and optimise rumen function that genetic potential for growth should be realised. Where goats have been selected for milk production potential, growth potential post weaning may be slower than in breeds such as Boers selected for high growth rate potential; and where feed quality is limiting growth would be expected to be slower, regardless of genetic potential than where weaner kids were given access to high quality pasture and/or supplements. Whether there are differences between kids and lambs in terms of their efficiency of digestion is questionable as there are conflicting opinions between authors; McGregor (2000) states that goats are more efficient than sheep however Jordan (2011) disagrees.

Nutrient requirements of weaned kids

NRC (2007) provides a detailed summary of the nutrient requirements for kids and differentiates between dairy, Boer, indigenous local (assumed to be equivalent to Australian rangeland, but may not be) and Angora. Daily requirements vary according to current or target liveweight, rate of daily gain, gender and are too extensive to list within this review; however Table 48 provides an extract to highlight the differences.

Table 48 Daily dry matter intakes (DMI), dietary NDF tolerance, crude protein, protein (CP) and energy (ME) of four goat genotypes at 20 and 30kg LW growing at 200g/d (adapted from NRC 2007)

Genotype	Liveweight	Growth rate	Fibre growth rate	DMI	DMI	NDF limit	CP	ME
	kg	*g/d*	*g/d*	*kg/d*	*% LW*	*%*	*g/d*	*MJ/d*
Dairy	*20*	200		0.73	3.7%	33%	130	9.66
Boer	*20*	200		0.66	3.3%	36%	163	8.91
Indigenous local	*20*	200		0.62	3.1%	39%	130	8.24
Angora	*20*	40	8	0.74	3.7%	32%	84	7.45
Dairy	*30*	200		1.14	3.8%	32%	145	11.47
Boer	*30*	200		1.04	3.5%	35%	179	10.42
Indigenous local	*30*	200		0.97	3.2%	37%	145	9.75
Angora	*30*	40	8	0.91	3.0%	40%	100	9.12

This author would urge caution in the application of these recommendations without prior validation as NRC (2007) states quite clearly that no validation of their requirements has been undertaken. There may be significant risk in the application of these recommendations where weaned kids are of low body weight as evidenced by the application of the NRC (2007) requirements to Merino wethers at 20 kg LW growing at 100 g/d. These lambs were lot fed according to NRC (2007) and proceeded to lose weight over a period of 30 days after which time the ration was significantly adjusted.

In order to meet daily nutrient requirements all these classes of kids require a daily intake of 3-3.8% of body weight; to achieve this level of intake dietary NDF would need to be restricted to 32-40% of dry matter. Where the pasture NDF exceeds the recommended limit, supplementation with a low fibre concentrate would be required for growth potential to be realised.

Prieto *et al.* (2000) reported that for crossbred and Spanish kids between 17.6 and 19.4 kg initial body weight, fed in confinement for 30 weeks *ad-libitum* (Table 49); there appeared to be no significant advantage in increasing the crude protein level of the diet above 14% and no benefit in feeding additional bypass protein (UDP). Interestingly growth rates of kids within this study ranged between 79 and 115 g/d with no significant increase in growth rate above 14% crude protein however it was apparent that as the protein level of the experimental diets increased, the corresponding ME was reduced which may have accounted for the lack of growth response to the higher protein diets. Morand-Fehr *et al.* (1986) reported that weaned dairy kids fed a high fat concentrate diet, which would have provided a high level of ME, had a higher weight gain than those on a low fat diet.

Table 49 Effects of dietary protein concentration on average daily gain of crossbred Boer and Spanish goat wethers from 4 months of age with a staring weight of 17.6 kg for the Boer cross and 19.4 kg for the Spanish kids (adapted from Prieto et al. 2000)

	Boer x Spanish				Spanish				
Crude protein concentration (% DM)	***10.20%***	***14.20%***	***18.30%***	***23.50%***	***10.20%***	***14.20%***	***18.30%***	***23.50%***	
ME concentration (MJ ME/kg DM)	***10.80***	***10.79***	***10.75***	***10.60***	***10.80***	***10.79***	***10.75***	***10.60***	*SE*
Weeks									
1-6	47	91	45	122	59	68	63	77	*18.7*
7-12	113	124	118	109	78	59	103	80	*12.9*
13-18	20	63	38	61	44	45	63	55	*12.4*
19-24	106	101	87	132	40	67	69	57	*22.5*
24-30	106	151	156	150	145	132	108	156	*23.3*
1-30	**79**	**106**	**89**	**115**	**73**	**74**	**81**	**85**	***7.5***

Tanabe *et al.* (1975 cited in Morand-Fehr 1982) demonstrated that kids at 8 weeks (11.5 kg LW) required a dietary crude protein concentration of at least 16 percent, and from 180 – 210 days of age (30 kg LW) that a protein concentration of 17.5% resulted in a 25% increase in weight gain over a diet of 8.3% crude protein (Beede *et al.* 1979).

The experience of goat producers in New South Wales of growth rates of Boer kids post weaning is summarised below (Table 50). Clearly this data provides an indication of the growth potential of weaned Boer kids which should not be surprising as Boer genetics have predominantly been selected for their growth potential.

Table 50 Growth rates of weaned Boer goat kids in NSW, 2009 (Courtesy: C Ramsay & J. Gilbert October 2011)

	Paddock	Feedlot
Annual rainfall, mm	560*	1375**
	Location	
Growth rate, g/d	Bethungra, NSW	Dorrigo, NSW
	2009	2010
>300	12%	10%
250-300	21%	5%
200-250	47%	29%
150-200	15%	23%
<150	5%	34%

**Winter dominant rainfall; **summer & autumn rainfall*

The post weaning growth rate of Angora kids is more focused on survival and growth to joining where the minimum joining weight is recommended to be 25 kg LW (Snyman 2007). Growth rates of Angora kids post weaning in many environments are well below potential (Nicoll *et al.* 1989) however these can be significantly improved with supplementation (Snyman 2007). Snyman (2007) investigated the performance of South African Angora goat kids from birth to 8 months of age between 2000 and 2004 across 12 production systems; the results are depicted in Table 51.

Table 51 Body weights and growth rates of South African Angora kids studied over 4 years grazing veld, supplemented and unsupplemented (Snyman 2007)

Trait	*Number of records*	*Average*	*CV%*
Birth weight (kg)	16644	3.2	16
Weaning weight (kg)	15510	17.6	20.3
ADG - birth to weaning (g/d)	15510	113	24.4
Weight at 8 months (kg)	7721	22.9	16.6
ADG - weaning to 8 months (g/d)	7721	40	56.7
12 month weight (kg)	3140	20.7	16.1
ADG - 8 - 12 months (g/d)	3140	9	231
16 month weight (kg)	2914	24.6	16.4
ADG - 12 - 16 months	2135	30	55
Body weight pre joining (kg)	1914	26.9	12.5
Body weight at scanning (kg)	1914	30.6	12.5
Number of kids scanned	1914	0.78	59.5
Number of kids born	1914	0.73	69.7
Number of kids weaned	1914	0.58	98.1
Weight of kids weaned / ewe mated (kg)	1914	9.4	89.5

The pastures of the South African veld are typically low in phosphorus, sodium and crude protein for 8 months of the year (van Pletzan 2009) which is similar to grass dominant, unimproved pastures in Australia. Kids raised on improved pastures without supplementation were found to be the heaviest at weaning and at 8 months of age compared with the lightest kids unsupplemented and reared on veld. Growth rates were reflective of environment and supplementary feeding practices. Although the growth potential of Angora kids may be significantly higher than those reported in this study it may not always be cost-efficient to supplement to increase growth rates pre joining.

Amaral *et al.* (2005) fed Saanen male kids from birth to 60 days of age three rations detailed in Table 52. Kids were weaned at 45 days of age and those fed the pelleted total ration had a 45.7% higher weight gain than those fed the ground and extruded rations.

Table 52 Dry matter intake (DMI) and weight gain of Saanen kids fed a ground total ration (GTR), pelleted total ration (PTR) or extruded total ration (ETR) (adapted from Amaral et al. 2005)

	Total ration		
	GTR	*PTR*	*ETR*
Birth weight (kg)	3.4 a	3.4 a	3.6 a
Weight at 60 days of age (kg)	9.0 b	13.2 a	10.4 b
Total DMI weaning (kg)	7.5 b	10.0 a	8.0 b
Total DMI post weaning (kg)	8.7 b	10.5a	8.08 b
Weight gain to weaning	3.6 b	6.0 a	4.4 b
Growth rate: birth to weaning @ 45d (g/d)	80	133	98
Post weaning weight gain (kg)	2.0 b	3.8 a	2.4 b
Post weaning growth rate: 45-60d (g/d)	133	253	160

Means in the same row with different letters differ by Tukey's HSD ($P<0.05$)

Lot feeding kids

The most important consideration when lot feeding kids is the gross margin budget or potential profitability. Genetic potential for rapid growth to minimise time spent in the feedlot, high sale value of the finished kids and minimisation of disease will ensure gross margins are optimised, however profitability will vary with each situation and is not guaranteed.

Feedlotting weaned kids should not be any more difficult than lot feeding lambs providing the 5 freedoms that apply to the welfare of lambs are considered. These include freedom from:

- hunger and thirst
- discomfort
- pain, injury or disease
- fear and distress, and
- freedom to express normal behaviour

Provision of high quality feed once weaned, and introduction to the feedlot ration prior to weaning, generally facilitates a smooth transition to the feedlot environment. The principles of lot feeding are similar to those recommended for lambs and a comprehensive guide can be found at www.productivenutrition.com.au .

Machen *et al.* (no date) lot fed Boer x Spanish goats of unspecified age for 63 days (Table 53) and recorded weight gains of between 126-146 g/day.

Table 53 Performance of Boer x Spanish wether goats' lot fed for 63 days (Machen et al. no date)

Feed Group	Initial Wt.,	Final Wt.,	ADG,	Feed Intake,	Feed Intake,	Feed: Gain (FCR)
	kg	*kg*	*kg/d*	*kg/hd/d*	*% BW*	
1	18.75	28.07	0.146	1.13	4.89	7.74
2	18.71	27.46	0.138	1.09	4.66	7.23
3	19.12	27.14	0.126	0.85	3.62	6.63
4	18.79	27.38	0.138	0.81	4.33	7.49

Feed intake varied across groups from 3.21% to 4.89% of liveweight. Group 1 with the highest weight gain were fed a lucerne based pellet (14% crude protein) with the lowest weight gain being recorded in Group 3; this group were fed a corn and premix pellet at 16% protein. The most efficient conversion of feed to gain was reported in Group 3. Groups 2 and 4 were offered 16% crude protein pellets with the latter having access to *ad-libitum* hay.

Boer and Boer-cross kids were weaned into the feedlot at Dorrigo, NSW in spring 2011, where growth rates were monitored after the first 14 days and thereafter weekly for a total period of 28 days. The kids were introduced to the feedlot ration prior to weaning to reduce the risk of weight loss post weaning. Their feed ration consisted of hammer-milled lucerne hay and rolled barley provided in open troughs in an open feedlot environment on an *ad-libitum* basis. Dry matter intake to 30 days post weaning averaged 4.2% of liveweight of a ration formulated to 12.2% crude protein, 13.5 ME, 22% NDF with a ratio of calcium: phosphorus of 0.7:1.

Initial growth was slow to day 14 post weaning (Table 54) after which time there was significant improvement to a median growth of 243g /day and an average of 251 g/day. Between days 23-30, 20% of the kids failed to gain weight however the reasons for this were not clear. The possibility of subclinical acidosis secondary to low NDF, the low concentration of crude protein and the lack of calcium in the diet were posed as potential impediments to productivity.

Table 54 Post weaning growth rate of weaned lot-fed Boer and Boer cross kids at Dorrigo NSW (Courtesy: J. Gilbert October 2011); average weaning weight 17.5 kg

	Days post weaning			
	0-14	*15-22*	*23-30*	*0-28*
Range (g/d)	0.14-271	25-675	25-500	13-300
Average (g/d)	77	251	177	138
Median (g/d)	64	243	171	136
Kids that failed to gain weight (%)	14.90%	5%	20%	4.20%

The feedlot site was well drained with shade and shelter provided in the form of shedding; the environment was enriched with randomly positioned piles of rock and logs which has been shown to double liveweight gain in Boer feral cross goats at 6 months of age (Flint and Murray 2001). The kids all appeared well adapted and settled on inspection however the ration was not well formulated and there was competition for feeding space.

Although there were periods of rapid growth during the feedlot period, average growth rates were similar to those reported by Machen *et al.* (no date). Similar observations have been reported for lambs with relatively short periods of high growth under feedlot conditions however these rates do not commonly persist under conditions of sustained confinement.

Flint and Murray (2001) fed Boer and Boer x feral goats to investigate the effects of pen enrichment and stocking density on growth rate, feed intake and inanition or failure to feed. They reported a doubling of growth rate at albeit low levels of gain from 34-63g/day, under conditions of pen enrichment (Table 55). The pens were enriched with railway sleepers and tyres with pipes and containers suspended from overhead wires.

Table 55 Feed intake, liveweight gain and inanition of Boer x feral goats lot-fed within an enriched or typical feedlot environment and at high and low pen densities (Adapted from Flint and Murray 2001)

	Pen density		Pen structure	
Variable	*High*	*Low*	*Enriched*	*Typical*
Feed intake (g/d)	850	891	870	871
Liveweight gain (g/d)	49.8	48.8	63.8	34.8
Occurrence of inanition (% of total)	11/99	7/55	7/75	11/79

The ration was a combination of lucerne chaff, cottonseed meal, maize, molasses and minerals and formulated to 14.6% crude protein at 32.8% NDF, however no indication was provided as to the ME of the ration and growth rates measured were clearly suboptimal. Although stocking density did not have an effect on growth rate, feed intake or inanition, the authors commented that aggressive behaviour increased at higher pen density.

Nutrient requirements of weaned kids for optimal growth rates

Following an extensive review of the published literature, NRC (2007) has published nutrient requirements for growing kids of four genotypes. It is assumed for the purposes of this review that recommendations for the indigenous goat refer to rangeland goats, however this may not be the case. NRC provides recommendations for a maximum growth potential of 250g/day for dairy, Boer and indigenous kids (Table 56) and 40 grams per day for Angora kids (Table 57). It is clear from the previous studies that individual Boer and Boer cross kids under Australian conditions have the potential to grow at rates exceeding 400g/day, albeit for short periods. The practical application of such requirements is challenging.

Table 56 Daily dry matter intake (DMI), crude protein and energy (ME) requirements for dairy, Boer and indigenous kids growing at 250 g/day, weaned at either 20 or 25 kg liveweight (NRC 2007)

	LW at weaning	DMI		Crude protein		ME	
	kg	*% LW*	*kg/d*	*%*	*g/d*	*MJ/kg*	*MJ/d*
Dairy kids	20	4.03	0.81	18.6%	151	13.38	10.84
	25	3.53	0.88	18.1%	159	13.36	11.76
Boer kids	20	3.70	0.74	26.2%	194	13.57	10.04
	25	3.22	0.80	25.1%	201	13.55	10.84
Indigenous kids	20	3.42	0.68	22.2%	151	13.53	9.20
	25	3.98	1.00	15.9%	159	10.00	10.00

What is not clear when reviewing tables of nutrient requirements is whether the daily requirements are aimed at restricting growth rate to that level? Angora kids may have the genetic potential to grow at rates in excess of 100 grams per day however the published nutrient requirements cover growth rates to a limit of 40grams per day (Table 57).

Table 57 Daily dry matter intake (DMI), crude protein and energy (ME) requirements of female and male Angora kids growing at 40 g/day weaned at either 20 or 30 kg liveweight; daily fleece growth rate – 8 gms per day (NRC 2007)

	LW at weaning	DMI		Crude protein		ME	
	kg	*% LW*	*kg/d*	*%*	*g/d*	*MJ/kg*	*MJ/d*
Female kids	20	3.72	0.74	11.4%	84	10.07	7.45
	30	3.04	0.91	11.0%	100	10.02	9.12
Male kids	20	4.08	0.82	10.2%	84	9.95	8.16
	30	3.36	1.01	9.9%	100	9.98	10.08

The low concentration of protein and ME recommended by NRC (2007) for Angora goats at 20 kg should be treated with caution until validation studies are undertaken. It is apparent that the nutrient requirements for Angora goats have been restricted in line with the aim of restricting fibre diameter and producing a fleece of high quality. The cost-efficiency of these recommendations requires further investigation.

NRC (2007) states quite clearly that “in some cases diets having greater or lesser concentrations of energy would be more appropriate” which emphasises the need for further investigation into the nutrient requirements of kids or at least validation studies of the existing recommendations.

Conclusion

It is apparent that the optimum weight and age for weaning kids has yet to be clearly defined, although it is likely that there will be variation between genotypes, and across different pasture systems in a range of environments. Small ruminants are particularly susceptible to weaning shock, and with minimal weight reserves it is important to ensure high quality feed or a saleable product is available at weaning. The aim post weaning is to minimise weaner mortality, optimise health and productivity and facilitate economically viable rates of growth.

There is limited evidence to suggest that the optimal age for weaning in terms of rumen development may be 10-15 weeks of age and the optimum dietary crude protein concentration to optimise the growth potential of weaned kids is approximately 14%. The requirements for ME remain unclear.

Attention to the nutrition of the pregnant and lactating doe is an imperative to conditioning the kid for successful weaning and post weaning performance. The pre weaning survival rates of kids requires urgent attention if the industry is to expand its commercial base in medium to high rainfall areas in Australia, such that producers enhance their profitability in comparison to sheep and beef production.

It appears that the current Australian genetic base of Boer and Boer cross goats have the potential for rapid post weaning growth and efficient conversion of feed to gain equivalent to that of lambs; however producers require some investment in their understanding of nutrition and encouragement to improve the nutritional management of their herds. The severe lameness of all age groups of goats including kids experienced in some herds in high rainfall areas needs to be properly investigated and eliminated. Boer goats do not appear well adapted to intensive grazing systems however there is clear evidence that not all animals within herds are equally affected; this would suggest that there is an opportunity for selection of more resistant genotypes within each herd.

Where appropriate and cost-effective to do so, there is no reason why lot feeding of kids would not be equally successful as lambs providing the basic principles of management of confined animals of that age and weight are followed.

Recommendations for further research

- Determine the appropriate age and weight for weaning kids of each genotype to optimise productivity and survival
- Provide education program for producers and their advisors in the nutritional management of the reproductive herd so as to optimise weaner potential
- Consider identification and selection of more resilient genotypes within the Australian goat herd within environments – review the uptake, implementation and outcomes for producers of Kidplan® as a practical and cost-effective selection tool
- Investigate the cost-efficiency of lot feeding weaners to reduce morbidity and mortality in all environments following similar principles as have recently been developed for lambs

Figure 31 Lot fed goats Source (Source: http://www.abc.net.au/landline/content/2006/s1712810.htm)

Depot nutrition

Rangeland goats are mustered from a wide range of pastoral properties and accumulated in transition depots (Figure 32) prior to transport to market; the aim of depot operators during this time is to minimise weight loss and mortality (P. Lynn pers comm. October 2011). Most goats that are held in depots remain there for an average of 7 days which limits the time for adaptation to a change in feed however all ruminants require at least 10 days for the populations of rumen flora to adjust in response to a change in feed. For this reason it is important to provide a diet that is fibrous, highly concentrated in mineral and vitamins and meets the energy and protein requirements of rangeland goats.

Due to the stress effects of mustering and transport, unfamiliar surroundings, the potential loss of social groupings and a period of curfew, appropriate management of depot nutrition diet is of critical importance.

Figure 32 Rangeland goats in a depot at Cobar, NSW (Courtesy: P Lynn October 2011)

Kannan *et al.* (2002) suggested that the change in environment and social isolation were likely to be greater pre slaughter stressors for goats within lairage than the period of curfew. As goats are considered to have a preference for a diet that is high in fibrous material, the feed of choice for depot transition is most likely to be cereal or pasture hay.

Table 58 Range of nutritive analyses of cereal hay and straw (Source: Productive Nutrition database)

	DM %	CP % of DM	ADF	NDF % of DM	DMD %	DOMD %	Est ME MJ/kg DM
Cereal straw	87.7	4.4		67.3	60.3	57.9	8.8
	87.2	4.2	49.1	81.3	52.3	51.1	7.4
	85.0	6.2		70.8	48.7	48.1	6.8
	84.2	2.3		74.5	46.1		6.4
Cereal hay	88.7	9.4	32.3	55.7	85.4		9.6
	89.4	5.3	31.8	55.9	61.2	58.7	8.9
	87.2	6.2	33.3	56.8	57.0		8.5
	88.2	4.8	38.4	61.0	57.2	55.3	8.1
	90.1	7.5	40.3	65.0	55.3	53.6	7.9
	87.6	6.0	39.8	65.1	55.4	53.7	7.9
	91.9	6.8	35.9	72.2	54.7	53.1	7.8

Oaten hay is the most readily available however a diet based on cereal hay or straw is unlikely to be adequate for maintenance of body condition as in most years the nutritive value of the hay will be below maintenance requirements of goats.

The range of nutritive values provided by random samples of oaten hay are summarised in Table 58 and clearly demonstrate that although ME concentrations will in the most part meet maintenance requirements crude protein will be deficient more often than not.

An added difficulty is that the pregnancy status of the does delivered to depots may not be known; as the requirements of pregnant or maiden does are significantly higher than for maintenance, it is unlikely that cereal hay will meet the requirements of all classes of goat likely to be mustered into a depot. The nutritive value of cereal will vary according to season as evidenced by the season 2010/2011 results of 507 samples published by the Feedtest laboratory (http://www.feedtest.com.au/) and summarised in Table 59. These results highlight the need for testing hay prior to purchase as the range in feeding value between samples is substantial and cannot be detected visually.

Table 59 Average and range in crude protein, metabolisable energy (ME) and neutral detergent fibre (NDF) concentrations of 507 oaten hay samples analyses by the Feedtest laboratory for season 2010/2011 (Source: http://www.feedtest.com.au/)

	Crude protein	ME	NDF
	%	*MJ ME/kg DM*	%
Average	5.8	8.2	60.5
Range	1.9-17.6	3.1-11.5	30.8-84.5

Provision of high quality roughage will enable the goats to increase intake to compensate to some degree for the lack of quality; however it would not be feasible or cost-efficient to feed all classes of goat to their requirements for a 7 day period. Therefore the provision of high quality hay to ensure rapid adaptation and nutrient replacement following transport may be worthy of consideration.

Pasture hay is more likely to include a percentage of leguminous material such as clover which will enhance its feeding value during the adaptation period; once again the quality can only be determined from an assessment of nutritive value by a feed laboratory.

Goats that arrive at the depot following long haul transport under hot and humid conditions will benefit from the provision of legume based hay or straw to help alleviate acute shortages of calcium, magnesium and potassium which may occur as a result of transport stress.

Pea hay and straw or a similar legume straw will be more likely to provide a fibrous and nutritious source of feed for confined goats and may be a better option than cereal hay in terms of palatability and maintenance of liveweight. Some average nutritive values for pea hay and straw are summarised in Table 60 below.

If the depot is sited in a rangeland environment then consideration, where appropriate, may be given to rotational management of the pens such that access to familiar feed is available for the goats on arrival.

Table 60 Range of nutritive analyses of pea hay and straw (Source: Productive Nutrition database)

	DM %	CP % of DM	ADF	NDF % of DM	DMD %	DOMD %	Est ME MJ/kg DM
Pea straw	83.2	15.4		53.6	58.6	56.4	8.5
	88.9	13.2		54.9	55.9	54.2	8.0
	85.9	8.0	53.2	67.1	49.2	48.5	6.8
	88.5	4.7	57.2	75.9	46.1	45.9	6.3
	94.1	11.3	57.2	76.8	45.3	45.2	6.2
	93.2	9.5	64.6	71.9	40.3	65.9	5.3
Pea hay	87.8	19.7		35.3	76.0	71.2	11.5
	90.1	13.6		34.9	75.9	71.1	11.4
	87.5	19.1		36.3	73.3	68.9	11.0
	90.3	12.1		39.2	70.6	66.7	10.5
	18.6	26.6			72.7		10.4
	82.1	16.6	34.4	42.9	63.8	60.9	9.4

From the variation in nutritive value of cereal and pea hay and straw it is evident that depot managers should be testing all types of hay prior to purchase. As large volumes of hay are commonly traded on their feeding value to livestock, it is not difficult or expensive to obtain a feed test and to ensure it meets the requirements relevant to the age and liveweight of the confined goats.

The management of goats in a confined environment is likely to be similar in principle to that of confined dry ewes in containment areas; a recently published set of detailed guidelines and recommendations can be sourced from www.productivenutrition.com.au for reference.

Transition of rangeland goats to a pelleted diet

Significant neophobia is commonly encountered in lambs during the transition from a pasture-based diet to a feedlot (Provenza *et al.* 2003; Jolly and Wallace 2007) due to a range of reasons similar in character to that experienced by rangeland goats adjusting to a pelleted diet within depots; these may include:

- unpalatable or unfamiliar feed
- feed formulation
- acidosis
- familiarity with personnel, feeding equipment, other animals
- social hierarchy and or dominance
- trough space - access
- nutritional history - rumen development and ability to digest nutrients
- "past experiences play a crucial role in an animal's propensity to learn to eat different foods" (Provenza *et al.* 2003)

It should be noted that these lambs will have had contact with dogs, yards and people prior to feedlot entry, and in many cases will be confined on the property of origin. Rangeland goats however may have been trapped or mustered, trucked potentially long distances and then exposed to unfamiliar surroundings and an unfamiliar diet, compounded by noise. The stress imposed by the above scenario is likely to induce transport stress characterised by acute calcium magnesium, and in humid areas potassium, deficiency; the provision of cereal hay or straw will exacerbate this problem whereas legume hay or straw is more likely to alleviate it.

If transition to a pelleted diet is required within a limited period of time within a goat depot, rapid adaptation will be facilitated by the introduction of pellets to goats prior to arrival. In many situations this will not be feasible but where possible this practice will rapidly overcome feed aversions and weight loss in transition depots.

Conclusion

Analysis of rations to be fed to goats during rapid transition through depots will improve maintenance of liveweight and minimise mortality. The use of legume -based hay or straw will alleviate health problems such as calcium and magnesium deficiency due to either transport stress or undiagnosed pregnancy. Prior introduction to feed, although unlikely to be a practical consideration in many instances, will alleviate neophobia or inanition induced by unfamiliarity with the feed provided at the depot.

Producers and depot managers should be directed towards the recently published National Procedures and Guidelines for Intensive Sheep and Lamb Feeding Systems (Dickson and Jolly 2011) which may serve as a useful source of information in the absence of a similar publication for goats.

Recommended further research

- Information sessions for depot managers and their staff about the management of ruminants in confinement and strategies for rapid adaptation to feed
- Clarification of the current mortality rates and their causes
- Clarification of the current weight differential during depot confinement
- Determination of the rate of adaptation to a pelleted diet in depots
- Development of a set of guidelines for depot management

Parasitism and nutrition

Gastrointestinal nematodes remain one of the most significant challenges for the expansion of goat production in both temperate and tropical environments (Hoste *et al.* 2005); Australian producers have expressed ongoing frustration at the lack of investment into the development and/or registration of effective anthelmintics for goats. However given the current size of the goat industry it is unlikely there will be any significant investment by animal health pharmaceutical companies in this area in the near future.

There is little doubt that animals on a falling plane of nutrition are likely to experience some loss of natural immunity to parasites and disease; Coop and Kyriazakis (1999, 2001) have identified protein as the most important nutrient. Min and Hart (2003) reported that protein supplementation improved resistance to diseases, however it should be noted that little is to be gained by supplementing crude protein significantly above daily requirements.

Protein supplementation in the form of urea did not reduce the effects of parasite infestation until a cottonseed supplement was added implying that there may be an important role for by-pass protein in the control of GI nematodes (Hoste *et al.* 2005). Important as it may be, it is unlikely that supplementation of goats with bypass protein sources would be cost-effective in the current marketing environment.

It is unlikely that protein deficiency would be a major contributing factor to parasitism in high rainfall areas where in winter and spring goats of all ages have access to pastures inherently high in nitrogen and hence crude protein. Kids weaned onto pastures in summer and autumn are more likely to incur a deficiency, and hence lowered immunity. It would be interesting to monitor worm loads in a range of environments in goats to determine the timing of the rise in parasitism to clinical levels and the associated protein concentration of the pasture.

Mineral deficiencies may be as important a contributing factor to parasitism as protein deficiency as worm loads have not been identified as a major production issue in the Australian rangelands where many plant species accumulate high concentrations of essential minerals, particularly in dry years (Franklin-McEvoy and Jolly 2005). Key trace elements including zinc, copper and iron have been identified as an essential base for a functional immune system (McClure 2008).

Lu (2011) cites an experiment by Max *et al.* (2007) who observed that in an organic goat farming system, acacia leaf meal fed to goats reduced worm egg counts (WEC) by 27% which Lu attributed to an increase in protein intake; however Max *et al.* (2007) concluded that the tanniferous effect of the acacia meal was the contributing factor. The establishment of perennial legumes in high rainfall areas containing tanniferous secondary compounds may be of benefit as a component of an integrated worm control program, however palatability and selection of these species when required cannot always be guaranteed.

A degree of suppression of *Haemonchus contortus* control has been observed in goats in response to forage containing condensed tannins (Min and Hart 2003) and of *Trichostrongylus columbriformis* (Butter *et al.* 2000) however their mode of action remains unclear (Muir 2011). Trials with commercial sources of condensed tannins (CT) have been successful in the suppression of parasite infestations however it is not yet clear if parasitic nematodes will develop similar resistance to CT as they have to commercial anthelmintics (Muir 2011). It should be noted that condensed tannins can also have negative effects on productivity as discussed earlier in this review; furthermore, combined EU/New Zealand research (Fernandez no date) has shown that the suppression of parasite activity in lambs varied with the location of the parasite and the plant species such that more detailed research appears to be required.

Selection for worm resistance in goats may be assisted by the development of an assay for serum IgA (Lu 2011) however this is yet to be fully investigated and to date Australian laboratories are not able to conduct this analysis (R. Paynter, Regional Laboratory Services, Benalla pers comm. September 2011). In addition, selection of goats with higher worm resistance can be made with simple faecal monitoring of individual sires on an annual basis; it is not clear if producers are aware of or have any inclination to adopt this as a future management strategy.

Conclusion

It is important to prioritise the validation of nutrient requirements for meat producing goats in high rainfall areas such that "high protein" strategies can be implemented and ultimately put to the test, as parasitism is a major constraint to the growth and development of the goat industry in medium to high rainfall areas in Australia. Pasture legume species such as Sulla may offer some short term benefits in terms of worm control due to the presence of condensed tannins, but differences in responses of parasites to plant species and the depressant effects on productivity of high intakes of condensed tannins suggest the need for further research in this area. Ultimately, the longer term approach to worm resistance may be the development of genetic selection tools for producers.

Recommended further research

- Clarify the protein requirements of goats
- Determine if parasitism is associated with low protein intake in goats
- Investigate the potential for CT- containing, pasture species as an aid in worm control
- Consider the genetic selection of goats apparently more resistant to worms as a longer term management tool for goat breeders

How and why do publications vary in their recommendations?

The guidelines for the nutritional requirements for goats referenced in most publications are derived from the NRC (1981) however the authors of that document acknowledge the lack of scientific experimentation and practical validation underpinning their recommendations at that time. Where there are guidelines, although relatively non-specific to individual classes of goat, many are based on sheep.

In 2007 the National Research Council published an updated set of nutrient requirements for goats; these recommendations provide for Boer, indigenous (assumed to mean feral/rangeland/ desert goats), dairy and Angora goats and their kids. It is a comprehensive set of requirements compiled by a team of international researchers including Hugh Dove from Australia, who is also a co-author of CSIRO (2007). The majority of the data for does at all stages of pregnancy and lactation accounting for single and multiple pregnancies is based on the work of Sahlu *et al.* (2004).

The introduction to the goat tables (NRC 2007) however includes a precautionary statement about intake being assumed as a percentage of liveweight and noting that in some situations, assumed to be when intake is less than expected, appropriate adjustment will need to be made to recommended energy densities. This is not unusual in any feeding situation however it raises the importance of producers and their advisers having access to a degree of expertise when formulating rations for confined goats such that these variables are properly accounted.

NRC (1981) included emphasis of an “activity rating” as does CSIRO (1990) however NRC (2007) has removed this consideration from the updated nutrient requirements due to a stated insufficiency of scientific evidence being available. It should therefore be noted that the recommendations for energy requirements in NRC (2007) are likely to be suboptimal for goats grazing in hilly terrain under conditions of limited pasture availability and may also underestimate the ME requirements of Australian rangeland goats. However as control of the nutrition of rangeland animals is likely to be limited to grazing management and stocking rates, it is the energy requirements of goats in high rainfall environments that is more likely to be of prime consideration. As it is apparent that goat production in these regions has significant constraints in terms of kid mortality, intensive production systems should be the focus of further research in an effort to increase industry productivity.

CSIRO (2007) has published a new edition of the Feeding Standards for Australian Livestock now called Nutrient Requirements of Domesticated Ruminants; while a comprehensive publication, it does not provide tables of nutrient requirements and relies on a high level of scientific knowledge or computer literacy for understanding and application. CSIRO (2007) also contains scant information relating specifically to goat nutrition. For this reason, more emphasis has been placed on NRC outputs in this review as that is where the majority of researchers, advisers and nutritionists are appear to have sourced their information, possibly for ease of use and application.

Martinez Marin *et al.* (2010) investigated the difference between the NRC (2007) and INRA (2007) nutrient recommendations for twelve month old dairy goats and found no difference in calculated intake of forage, protein and concentrate between either feed evaluation system whereas there were differences between systems in terms of energy intake.

Sutton and Alderman (2000) reviewed the energy and protein requirements for pregnant and lactating dairy goats and concluded that the INRA system was the most applicable set of guidelines for prediction of feed intake.

In conclusion, there are some similarities but many more differences in the nutrient requirements for goats between publications and between genotypes; the reasons for genotype differences are more easily understood than many of the differences between authors and publications. However what is not clear is to what degree productivity would respond if all genotypes were fed the same level of nutrients per unit of liveweight and potential output; clearly clinical trials are justified.

This review has emphasised the need to clearly establish the additional $ME_{maintenance}$ required for various levels of activity and it may be more cost-effective to do this via validation trials with a range of genotypes rather than to revisit in-depth metabolic research.

Validation of the nutrient requirements of particular classes of goat has not been undertaken extensively as a component of this review; this has been mainly due to time constraints, the lack of data held by producers and the variability between the limited data sets that were made available.

Appendix 1: Summary of function and signs of severe and marginal mineral deficiencies and likely incidence of deficiencies in sheep (Masters and White 1996)

Element	Function	Manifestation of deficiency		Likely occurrence of deficiency
		Severe	Marginal[a]	
Calcium	Mineralisation of bones and teeth Nerve conduction Muscle contraction Blood clotting Hormone secretion Message transmission	Lameness and stiffness of gait Enlarges painful joints Malformed teeth and jaws Milk fever, including muscle tremors, general inertia, inappetance and death[b]	Reduced growth Reduced milk production	High grain diet especially during drought Increased requirements in lactation Low calcium, acid soils in the tropics Low vitamin D
Phosphorus	Bone formation Energy metabolism Component of DNA, RNA Acid-base balance	Softening of bones, lameness Depressed appetite Abnormal appetite causing botulism	Reduced growth Reduced reproductive rates	Low soil phosphorus Prolonged dry period with dead pasture
Sodium	Maintenance of osmotic pressure Acid-base balance Water metabolism Rumen microbial growth	Abnormal appetite, licking of soil Depressed appetite Loss of weight Decreased milk production	Abnormal appetite (pica) Reduced growth Decreased milk production	Tropical or dry arid climates Rapidly growing or lactating sheep High grain diets
Sulfur	Component of amino acids methionine and cysteine Component of biotin and thiamine Sulphated polysaccharides in cartilage and joint lubrication Removal and/or storage of toxic elements & compounds	Reduced feed intake Reduced dry matter digestibility Reduced production of sulfur amino acids by rumen microbes Possible accumulation of copper in animal tissues and copper toxicity	Reduced feed intake Reduced wool growth	Low sulfur soils Dry pastures
Cobalt	Essential for the production of vitamin B_{12} by rumen microbes Use of volatile fatty acids for energy (as vitamin B_{12}) Recycling of methionine (as vitamin B_{12})	Loss of appetite Loss of weight, reduced wool growth Watery discharge from eyes Anaemia Poor reproductive performance White (fatty) liver disease	Reduced growth/unthriftiness Reduced wool reproduction	Occurs under range of soils and climatic conditions Sandy of volcanic soils Green lush pasture Young growing or reproducing sheep
Magnesium	Cofactor in many enzymes Nerve conduction Muscle contraction	Tetany as indicated by muscle twitching, staggers and convulsions High mortality Depressed appetite	Possible loss of condition Possible reduced milk production	Green pasture Often but not always associated with lactation High potassium, low sodium

Element	Function	Manifestation of deficiency		Likely occurrence of deficiency
		Severe	Marginal[a]	
Copper	Mobilisation and transport of iron in the body Collagen cross-linking in bone and elastic tissue Pigmentation of hair and wool Maintenance of myelin sheath around nervous tissue Crimp formation in wool Antioxidant	Enzootic ataxia (swayback) as paralysis or staggering gait in newborn lambs Bone fragility Anaemia Depigmentation of wool Loss of crimp and tensile strength of wool Reproductive disorders		Leached low copper soils Peat soils high in molybdenum Use of molybdenum
Iodine	Component of thyroid hormones that are essential for energy and protein metabolism and for foetal growth and development	Enlarged thyroid gland (goitre) Inability to withstand cold stress Reduced foetal size and retarded brain development A range of developmental disorders, wool loss	Increased lamb mortality and thyroid size relative to body size Small depression in wool and milk production	Low soil iodine Recent glaciation Mountainous areas Long distance from the sea Low rainfall Goitrogens in herbage
Selenium	Detoxification of peroxides Activation of thyroid hormone	Lesions in heart and skeletal muscle (nutritional myopathy or white muscle disease) Increased mortality Infertility in ewes Induced thyroid hormone deficiency	Reduced growth/illthrift Reduced wool growth	Green pasture Low selenium in soil High rainfall Young growing or reproducing sheep Low vitamin E
Zinc	Cofactor in a large number of enzymes DNA and protein synthesis	Reduced feed intake Reduced growth rates Reduced wool growth and loss of crimp Alopecia, parakeratosis	Reduced growth rate Reduced reproductive performance	Low zinc soils Dry pasture

[a] Marginal signs may also be seen during severe deficiency

[b] Acute deficiency resulting from a rapid loss of calcium during milk letdown

Appendix 2: Summary of feeding trials reviewed, listed by author

Breed	Age/ class	Sex / Birth Type	LW (kgs)	DMI (Kg)	ME		Protein		Growth rate g/d	FCE	Deaths (%)	Comment	Author
					/kg DM	MJ/ day	%	g/day					
Boer	GR to 100 days	Singles	23.5						239.5 - 257			Boer goats in Namibia compared to Germany	Barry and Godke (1997)
Boer	GR to 100 days	Twins	23.5						236.7 - 193			2.5l milk/d to drive GR>300g/d	Barry and Godke (1997)
Boer	GR to 100 days	Triplets	23.5						217.7 - 182				Barry and Godke (1997)
Boer	100 days	Male	23.5						213				Barry and Godke (1997)
Boer	100 days	Female	23.5						184				Barry and Godke (1997)
Boer	Young								13 - 118	17.7 -154.7		1986	Barry and Godke (1997)
Boer	Young								22 - 163	13.6 -88		1989	Barry and Godke (1997)
Improved Boer (Sth Africa)		Male	3-30						291			Concentrate and excellent grazing - highly selected meat goats	Campbell cited by Naude and Hofmeyr (1981) cited by McGregor (1985)
Improved Boer (Sth Africa)		Male	3-70						250			Concentrate and excellent grazing - highly selected meat goats	Campbell cited by Naude and Hofmeyr (1981) cited by McGregor (1985)
Improved Boer (Sth Africa)		Female	3-29						272			Concentrate and excellent grazing - highly selected meat goats	Campbell cited by Naude and Hofmeyr (1981) cited by McGregor (1985)
Improved Boer (Sth Africa)		Female	3-52						186			Concentrate and excellent grazing - highly selected meat goats	Campbell cited by Naude and Hofmeyr (1981) cited by McGregor (1985)
Kambing/ Katjang (Malaysia & Indonesia)		Mixed	2-22						57			Various feeds	Devendra (1967) cited by McGregor (1985)
Alpine (France)		Male	3-22						219			Milk replacer	Fehr *et al*. (1976) cited by McGregor (1985)
Alpine (France)		Male	3-22						241			Milk replacer & concentrates	Fehr *et al*. (1976) cited by McGregor (1985)
Rangeland		Bucks	26	0.708	8.8		11.88		-6.3		11.7	Pellet A high cereal grain content fed 15 days subsequent to **CHAFF intro** (4 days)	Gherardi and Johnson (1995)
Rangeland		Bucks	26	0.706	8.8		11.88		84.2		10	Pellet A high cereal grain content fed 15 days subsequent to **HAY intro** (4 days)	Gherardi and Johnson (1995)
Rangeland		Bucks	26	0.714	7.6		11.88		52.6		8.3	Pellet B low cereal grain	Gherardi and Johnson (1995)

Breed	Age/ class	Sex / Birth Type	LW (kgs)	DMI (Kg)	ME		Protein		Growth rate g/d	FCE	Deaths (%)	Comment	Author
					/kg DM	MJ/ day	%	g/day					
												content fed 15 days subsequent to **CHAFF intro** (4 days)	
Rangeland		Bucks	26	0.701	8.8		11.9		63.2		3.3	Pellet B low cereal grain content fed 15 days subsequent to **HAY intro** (4 days)	Gherardi and Johnson (1995)
Boer x Rangeland - F1		Male							49.5			Dec-Mar GR increases with increasing day length	Going into Goats (2006)
Boer x Rangeland - F1		Male							62.9			Mar - June GR increases with increasing day length	Going into Goats (2006)
Boer x Rangeland - F1		Male							138.2			Jun - Aug GR increases with increasing day length	Going into Goats (2006)
Rangeland		Male							47			Dec-Mar GR increases with increasing day length	Going into Goats (2006)
Rangeland		Male							55			Mar - June GR increases with increasing day length	Going into Goats (2006)
Rangeland		Male							117			Jun - Aug GR increases with increasing day length	Going into Goats (2006)
Boer cross	Birth to weaning								114				Haas (1978) cited in Barry and Godke (1997)
Boer cross	Weaning to 12 mths								65				Haas (1978) cited in Barry and Godke (1997)
Small East African	Birth to weaning								84				Haas (1978) cited in Barry and Godke (1997)
Small East African	Weaning to 12 mths								32				Haas (1978) cited in Barry and Godke (1997)
Alpine, Angora & Nubian	6-8 mo		15-25						50			High quality wheat 78% IVOMD	Hart *et al.* (1993)
Alpine, Angora & Nubian	6-8 mo		15-25						10			Low quality dormant Bermuda grass 35% IVOMD plus 200g 24% CP supplement	Hart *et al.* (1993)
Rangeland (Australia)		Mixed	3-17						157			Spring pasture	Holst and Pym (1977) cited by McGregor (1985)
Angora	6 mo weaners		17						21-27			Angora weaners rangelands 600mm	Huston *et al.* (1993)
Damascus (Cyprus)		Male	20-50				20		240			Barley & Soybean	Louca *et al*. (1977) cited by McGregor (1985)
Damascus (Cyprus)		Castrate	18-40				20		210			Barley & Soybean	Louca *et al.* (1977) cited by McGregor (1985)
Damascus (Cyprus)		Female	18-37				20		190			Barley & Soybean	Louca *et al.* (1977) cited by McGregor (1985)
	Weaner kids		13.6	0.908	10.2		14		199				Luginbuhl and Poore (1998)

Breed	Age/ class	Sex / Birth Type	LW (kgs)	DMI (Kg)	ME		Protein		Growth rate g/d	FCE	Deaths (%)	Comment	Author
					/kg DM	MJ/ day	%	g/day					
Crossbred 50% Boer	Weaner		29			14.1			150				Luo *et al.* (2004c)
ex Angora	Growing goats		29					133	150				Luo *et al.* (2004b)
Saanen (Britain, Australia)		Castrate	15-25						210			Milk fed	McGregor (1980) cited by McGregor (1985)
Angora (Texas/ Australia)		Castrate	16-27						122			16.5% CP pellets	McGregor (1984b) cited by McGregor (1985)
Angora (Texas/ Australia)		Castrate	27-31						154			Spring pasture	McGregor (unpub) cited by McGregor (1985)
Rangeland (Australia)		Mixed	2-10						175			Does fed oats and lucerne	McGregor *et al.* (1982) cited by McGregor (1985)
Angora (Texas/ Australia)		Castrate	20-27						47			16.5% CP pellets & hay + zeranol	McGregor *et al* (1984) cited by McGregor (1985)
Angora (Texas/ Australia)		Castrate	20-27						73			16.5% CP pellets & hay + zeranol	McGregor *et al* (1984) cited by McGregor (1985)
Alpine	35 days		8-10	0.609					160 - 220			Weaners	Morand-Fehr *et al.* (1982)
Crossbred 50% Boer	Weaner		30	0.92		9.2			150				NRC (2007)
Boer	Growing goats		30					149	150			Crude protein	NRC (2007)
ex Angora	Growing goats		30					129	150			Total protein	NRC (1981)
Crossbred 50% Boer	Weaner		30	1.4		14			150				NRC (1981)
Indigenous / feral			20	0.72		7.24		108	150				NRC (2007)
Indigenous / feral			30	0.87		8.74		123	150				NRC (2007)
Saanen (Britain, Australia)		Male	12-24						222			Concentrates	Owen and Mtenga (1980) cited by McGregor (1985)
Boer	0-12 mths								200			Average daily weight gain; rangeland conditions	Patrick S and Patrick G (no date)
Boer	0-12 mths								>250			Average daily weight gain; intensive management or favourable conditions	Patrick S and Patrick G(no date)
Angora (Texas/ Australia)		Male					15		165			15% CP Pellets	Shelton and Huston (1966) cited by McGregor (1985)
Barbari (India)		Mixed	6-12						53			Berseem clover and barley	Singh *et al*. (1980) cited by McGregor (1985)
Barbari (India)		Mixed	6-12						29			Berseem clover	Singh *et al*. (1980) cited by McGregor (1985)
Tropical - Vietnam	16 weeks		18.3	50g/kg LW					96			Water intake 28ml/kg LW	Van *et al.* (2007)

Breed	Age/ class	Sex / Birth Type	LW (kgs)	DMI (Kg)	ME		Protein		Growth rate g/d	FCE	Deaths (%)	Comment	Author
					/kg DM	MJ/ day	%	g/day					
Tropical - Vietnam	16 weeks	**Lambs**	19.4	47g/kg LW					98			Water intake 36mls/kg LW	Van *et al.* (2007)
Boer	3 mo	Male	24.6	1.155			15.7		147.1	7.8:1		85 day trial - comparison between Boer & Kiko breeds - Boer preferred less hay (23.1% vs 31.5% DMI) and more grain (76.9% vs 68.5%), offered *ad lib* 80:20 pellets:hay	Solaiman *et al.* (2011)
Kiko	3 mo	Male	22.8	1.085			14.8		103.8	10.45:1		85 day trial - comparison between Boer & Kiko breeds - Boer preferred less hay (23.1% vs 31.5% DMI) and more grain (76.9% vs 68.5%), offered *ad lib* 80:20 pellets:hay	Solaiman *et al.* (2011)

Appendix 3: Nutrient requirements – authors other than NRC

Breed	Age/ class	Sex	LW (kgs)	DMI (Kg)	DMI (% of LW)	ME		Protein		Comment	Author
						/kg DM	MJ/ day	%	g/day		
	Lactating and growing goats				3.5 - 5%					Ensminger refers to meat goats as Angora or Spanish goats and quotes NRC 1981	Ensminger (1990)
Meat goats										ME and CP requirement of Boer kids and crossbreds not well established; protein requirements of meat (>50% Boer) goats is greater than for other goats	Fernandes *et al.* (2007)
Boer	Lactating goats	Does	45	1.6		8.9		14			Greyling *et al.*(2004)
Indigenous	Lactating goats	Does	32	1.0		8.9		14			Greyling *et al.* (2004)
Angora	Early preg	Does	34 - 36		2.7-3.8%					Intakes in ex of 4% difficult to achieve	Jordan (2011) goatworld.com
Angora	Late preg	Does	34 - 37		3.4-4.2%						Jordan (2011) goatworld.com
Angora	Lactating - single	Does	34 - 38		3.9-4.3%						Jordan (2011) goatworld.com
Angora	Lactating - twin	Does	34 - 39		4.3-4.8%						Jordan (2011) goatworld.com
Angora	Kids - pre weaning							15		Minimum	Jordan (2011) goatworld.com
Dairy	Maintenance	Does					11	6 - 8			McGregor (2005)
Dairy	Milk production	Does					26	15 -18			McGregor (2005)
Unspecified			10				2.27		33	Maintenance requirements - drought	McGregor (no date)
Unspecified			20				3.82		55	Maintenance requirements - drought	McGregor (no date)
Unspecified			30				5.18		74	Maintenance requirements - drought	McGregor (no date)
Unspecified			40				6.43		93	Maintenance requirements - drought	McGregor (no date)

Breed	Age/ class	Sex	LW (kgs)	DMI (Kg)	DMI (% of LW)	ME		Protein		Comment	Author
						/kg DM	MJ/ day	%	g/day		
Unspecified			50				7.6		110	Maintenance requirements - drought	McGregor (no date)
Unspecified			60				8.71		126	Maintenance requirements - drought	McGregor (no date)
Unspecified	Growing kid		20				5.53		51.8		NRC (1981) cited in Niver (2005)
Unspecified	Growing kid		20				5.69		76.5		NRC 2004 (unpublished) cited in Niver (2005)
Unspecified	Lactating goats	Does				4.9-5.2				Requirement dependent on method	Nsahlai *et al.* (2004)
3/4 Boer x Spanish 1/4	4 - 4.5 mo		17.6 - 19.4	ad lib					14	70% concentrate, confined	Prieto *et al.* (2000)
Boer	Lactating	Does	45				18.22		107	"Although future research to refine assumptions may improve accuracy"	Nsahlai *et al.* (2004)
Indigenous	Lactating goats	Does	32				14.56		84.3	"Although future research to refine assumptions may improve accuracy"	Nsahlai *et al.* (2004)

Appendix 4: Mature weights of a range of goat breeds

Breed	Genotype	Mature Wt (kgs)	Author
Alpine (France)	Dairy	80-90	Fehr *et al* (1976) cited by McGregor (1985)
Anglo-Nubian	Dual purpose	80-90	Going into Goats (2006)
Angora	Fibre	60-80	Going into Goats (2006)
Angora (Texas/Australia)	Fibre	50-60	Shelton & Huston (1966) cited by McGregor (1985)
Barbari (India)	Meat	35-45	Singh *et al.* (1980) cited by McGregor (1985)
Boer	Meat	100-110	Going into Goats (2006)
Boer - Improved (Sth Africa)	Meat	100-110	Campbell cited by Naude & Hofmeyr (1981) cited by McGregor (1985)
Condoblin	Rangeland	80-100	Going into Goats (2006)
Damascus (Cyprus)	Dairy	80-90	Louca *et al*. (1977) cited by McGregor (1985)
Kalahari	Desert	100-110	Going into Goats (2006)
Kambing/Katjang (Malaysia & Indonesia)	Meat	25-30	Devendra (1967) cited by McGregor (1985)
Rangeland	Rangeland	45-80	Going into Goats (2006)
Rangeland (Australia)	Rangeland	45-55	McGregor *et al* (1982) cited by McGregor (1985)
Saanan	Dairy	90-100	Going into Goats (2006)
Saanen (Britain, Australia)	Dairy	90-100	McGregor (1980) cited by McGregor (1985)

Appendix 5: Guide to liveweights at a range of ages

Breed	Age	Bucks (kgs)	Does (kgs)	Unspecified sex (kgs)	Author
Boer	Birth	3.7	3.4		Patrick S and Patrick G (no date)
Boer cross	Birth			2.6	Haas (1978) cited in Barry and Godke (1997)
Small East African Goats	Birth			2.3	Haas (1978) cited in Barry and Godke (1997)
Boer cross	6 weeks			8.3	Haas (1978) cited in Barry and Godke (1997)
Small East African Goats	6 weeks			6.9	Haas (1978) cited in Barry and Godke (1997)
Boer	Weaning	24	22		Patrick S and Patrick G (no date)
Boer	Weaner kids			20-25	Lu (2001)
Boer cross	5 months			19.7	Haas (1978) cited in Barry and Godke (1997)
Small East African Goats	5 months			14.9	Haas (1978) cited in Barry and Godke (1997)
Boer cross	6 months			21.8	Haas (1978) cited in Barry and Godke (1997)
Small East African Goats	6 months			16.2	Haas (1978) cited in Barry and Godke (1997)
Boer	7 months	40-50	35-45		Patrick S and Patrick G (no date)
Boer cross	9 months			28.2	Haas (1978) cited in Barry and Godke (1997)
Small East African Goats	9 months			20.2	Haas (1978) cited in Barry and Godke (1997)
Boer	12 months	50-70	45-65		Patrick S and Patrick G (no date)
Boer cross	12 months			34.3	Haas (1978) cited in Barry and Godke, (1997)
Small East African Goats	12 months			22	Haas (1978) cited in Barry and Godke (1997)
Boer	mature	90-130	80-100		Patrick S and Patrick G (no date)

Appendix 6: Nutritive value of rangeland species

Botanical name	**Common name**	**Toxicity**	**Palatability**	**Digestible DM %**	**ME (MJ/kg DM)**	**CP %**	**Source**
GRASSES							
Aristida spp	Wiregrass; kerosene grass		Dry	47.3-48.4	6.8-7	5.3-9.4	Productive Nutrition database
Astrebla lappacea	Curly mitchell grass					4.7-10.8	NSW DPI
Astrebla pectinata	Barley mitchell grass			36.9-73.5	4.5-11.3	3.3-23.1	Productive Nutrition database
Austrodanthonia spp	Wallaby grass			40.64-71.92	6.1-10.79	2.31-23.25	NSW DPI
Austrostipa spp	Speargrass			38.94-60.06	5.84-9.01	2.56-13.38	NSW DPI
Cenchrus spp	Buffel grass	Oxalates		48.43-68.21	7.26-10.23	4.69-16.31	Simmonds *et al.* (2000); NSW DPI
Chloris gayana	Rhodes grass	Prussic acid/cyanide		40.37-59.48	6.06-8.92	2.88-15.06	Everist (1974)
Chloris truncata	Windmill grass; umbrella grass	Prussic acid/cyanide		44.71-65.25	6.71-9.79	4.81-15.63	NSW DPI
Dichanthium sericeum	Queensland bluegrass			38-62	7.69	2-7	NSW DPI
Digitaria eriantha	Pangola grass; digit grass		Dry	45.87	6.88	2.75	NSW DPI
Enteropogon acicularis/rasmosus	Curly windmill grass		Young growth	37-62		5-13	NSW DPI
Eragrostis australasica	Tall / swamp canegrass			31.7-56.1	3.4-8.4	3.1-15.2	Productive Nutrition database
Eragrostis eriopoda	Woollybutt; neverfail			44.2-46.8	6-6.4	3.4-11.8	Productive Nutrition database
Hordeum leporinum	Barley grass			56.1-78.5	8-11.5	11.2-32	Productive Nutrition database
Lolium perenne	Perennial ryegrass	Alkaloids		59.2-73.5	8.6-11	12.9-27.7	Productive Nutrition database
Nassella trichotoma	Serrated tussock			44-51	5.5-7		NSW DPI
Panicum maximum	Guinea grass		Vegetative	65.35	9.8	16.19	NSW DPI
Paspalum dilatatum	Paspalum	Ergot infection of seed heads		41.44-61.72	6.22-9.26	5.06-13	NSW DPI
Poa labillardieri	Poa tussock		Dry	39.93-53.37	5.91-8.01	4.25-9.44	NSW DPI
Setaria incrassata	Purple pidgeon grass	Oxalates	Vegetative	47.57	7.14	6.94	NSW DPI
Sorghum halepense	Johnson grass	Nitrates / cyanide		46.47	6.97	6.88	Simmonds *et al*. (2000); NSW DPI
Themeda triandra	Kangaroo grass			44.44-53.77	6.67-8.07	4.81-6.38	NSW DPI
Zygochloa paradoxa	Sandhill canegrass			32.7-49.9	3.5-6.9	1.8-10.3	Productive Nutrition database

Botanical name	**Common name**	**Toxicity**	**Palatability**	**Digestible DM %**	**ME (MJ/kg DM)**	**CP %**	**Source**
HERBS/FORBS							
Brassica tournefortii	Wild turnip	Goitrogens	All stages	80.16	12.02	26.56	Everist (1974) / NSW DPI
Carduus nutans	Nodding thistle		Flowering				
Carduus pycnocephalus	Slender thistle	Nitrates	All stages				Everist (1974)
Carthamus lanatus	Saffron thistle		Flowering		12.1	14.4	Going Into Goats guide (2006)
Chondrilla juncea	Skeleton weed		Flowering		7.68	9.06	NSW DPI
Cirsium vulgare	Spear thistle	Nitrates	Flowering		7.25-11.3	8.13-20.25	NSW DPI
Craspedia spp	Billybuttons	Staggers	Flowering				Everist (1974)
Cynara cardunculus	Artichoke thistle		Leaves		11.5	14.8	Cunningham *et al*. (1992); McGregor (2005)
Echium plantagenium	Patterson's curse	Alkaloids	Flowering				Everist (1974)
Erodium spp	Crowfoot; geranium		Flowering	68-75	10.2-11.3	12.63-16.25	NSW DPI
Hypericum perforatum	St John's wort; goatweed	Hypericin (PS)	Seldom eaten	35-82	5.28-12.27	3.75-21.3	NSW DPI
Lactuca serriola	Prickly lettuce	Respiratory distress	All stages				
Lepidium spp	Peppercress		Flowering				
Maireana pyramidata	Black bluebush	Oxalates / salt	All stages	46.8-67	6.4-9.7	13-21	Productive Nutrition database; Simmonds *et al.* (2000)
Maireana aphylla	Cottonbush	Oxalates	All stages	41.4-72.2	5.9-10.8	5.6-29.5	Productive Nutrition database; Simmonds *et al*. (2000)
Marrubium vulgare	Horehound		Flowering/ leaves	42-67	5.3-10.8	9.5-21	Productive Nutrition database
Medicago falcata	Yellowflower lucerne		All stages				
Medicago minima	Woolly burr medic	Dermatitis /PS	Flowering	40.2-68	5.4-9.8	14.5-26.6	Productive Nutrition database
Medicago sativa	Lucerne	Saponins; nitrates	All stages	41.7-84.2	5.6-12.4	7.9-39.7	Productive Nutrition database; Everist (1974)
Meuhlenbeckia spp	Lignum		All stages	37.72	5.66	6.06	NSW DPI
Onopordum spp	Scotch thistle		Flowering	50.6-68	7.6-10.2	6.25-18.19	NSW DPI
Phytolacca octandra	Inkweed	Roots only-saponins	Flowering				Everist (1974)

Botanical name	Common name	Toxicity	Palatability	Digestible DM %	ME (MJ/kg DM)	CP %	Source
Plantago spp	Plantain		Flowering				
Pteridium esculentum	Common bracken	Thiaminases	Occasionally				Simmonds *et al.* (2000)
Rosa rubiginosa	Sweet briar		All stages	49.88	7.48-10.5	4.75-20.7	NSW DPI; Going Into Goats guide (2006)
Rubus fruiticosus	Blackberry		All stages	69.18	10.38-10.5	15.31-21	NSW DPI; Going Into Goats guide (2006)
Rubus fruiticosus	Blackberry		Young stems		10.5	21	Going Into Goats guide (2006)
Rubus fruiticosus	Blackberry		Old stems		7.4	6.1	Going Into Goats guide (2006)
Rumex crispus	Curled dock	Oxalates	Flowering				Simmonds *et al*. (2000)
Sclerolaena birchii	Galvanised burr	Oxalates	All stages	45.33-49.26	6.8-7.39	7-12.63	NSW DPI
Silybum marianum	Variegated thistle	Nitrates	All stages	72.51-80.53	10.88-12.08	19.38-24.13	Simmonds *et al.* (2000); NSW DPI
Sisymbrium spp	Mustard weed		Flowering				
Solanum carolinense	Carolina horse nettle	Solanine - diarrhoea	All stages				Simmonds *et al*. (2000)
Trifolium spp	Clovers		Mature				
Urtica incisa	Scrub nettle; tall nettle	Haemolytic saponins	All stages				Everist (1974)
Ventilago viminalis	Supplejack	Tannins	All stages	68.39-70.72	10.26-10.61	10.69-13.69	Simmonds *et al*. (2000); NSW DPI
Verbena bonariensis	Purpletop		Flowering				
TREES & SHRUBS							
Acacia acinacea	Gold-dust wattle		Leaves		7.2	14.7	McGregor (2005)
Acacia aneura	Mulga		All stages	50.07-54.8	7.3-7.8	7.81-10.9	Productive Nutrition database; NSW DPI
Acacia aneura	Mulga		Leaves		6.5	12	McGregor (2005)
Acacia dealbata	Silver wattle		Leaves		8.3	14.8	McGregor (2005)
Acacia escelsa	Ironwood		All stages	58.69	8.8	13.5	NSW DPI
Acacia farnesiana	Mimosa bush		Leaves		7.9	23	McGregor (2005)
Acacia homalophylla	Yarran		All stages	low	poor	good	Cunningham *et al.* (1992)
Acacia mearnsii	Black wattle		Flowering	41.18-59.83	6.18-8.97	5-15.94	NSW DPI
Acacia paradoxa	Kangaroo thorn		All stages				
Acacia pendula	Weeping myall; boree; balaar		Leaves	52.76-59.42	7.91-8.91	13.25-15.63	Cunningham *et al.* (1992); NSW DPI

Botanical name	**Common name**	**Toxicity**	**Palatability**	**Digestible DM %**	**ME (MJ/kg DM)**	**CP %**	**Source**
Alectryon oleifolius	Bullock bush		Leaves				
Apophyllum anomalum	Warrior bush; broombush; current bush		All stages	59.27-71.02	8.89-10.65	11.56-21	NSW DPI
Atalaya hemiglauca	Whitewood	Fruits poisonous	All stages				
Atriplex spp	Saltbushes	Nitrates & oxalates	All stages	42.8-82.5	5.7-12.2	9.6-26.7	Simmonds *et al.* (2000); Productive Nutrition database
Brachychiton populneus	Kurrajong	Seeds & fruits	All stages	44.77-57.8	6.72-8.67	8.38-11.56	NSW DPI
Brachychiton rupestris	Bottle tree	Nitrates	Leaves /trunk			2	Everist (1974)
Callitris columellaris	Native cyprus pine		Occasionally	20.12	3.02	0.75	NSW DPI
Callitris endlicheri	Black cyprus pine		All stages				
Capparis mitchellii	Wild orange; orange bush		All stages	59.97-67.70	8.99-10.15	12.13-17.56	NSW DPI
Cassia artemisioides	Silver cassia	Glycosides -seed pods	Occasionally				Simmonds *et al*. (2000)
Cassia eremophila	Punty bush; desert cassia	Glycosides -seed pods	Occasionally				Simmonds *et al.* (2000)
Cassinia spp	Dolly bush; chinese shrub; biddy bush; sticky cassinia		Isolated plants				
Casuarina cristata	Belah		All stages	48.22-69.06	7.23-10.36	6.56-13.88	NSW DPI
Chamaecytisus proliferus	Lucerne tree; tagasaste	Alkaloids	All stages	34.99-76.14	5.25-11.42	4.63-24.06	NSW DPI; Simmonds *et al.* (2000)
Chenopodium nitrariaceum	Nitre bush; nitre goosefoot	Nitrates & oxalates					Simmonds *et al*. (2000)
Crataegus spp	Hawthorn	Prussic acid	All stages				Everist (1974)
Cytisus scoparius	Scotch broom		All stages				
Dodoneae attenuata	Narrow-leaved hopbush		All stages	43.05-64.15	6.46-9.62	6.25-9.69	NSW DPI
Dodoneae viscosa	Broad-leaved hop bush		Flowering				
Eremophila longifolia	Emu bush	If fed alone (Everist, 1974)	All stages	46-56.7	6.3-8.1	7.4-11.5	Productive Nutrition database; NSW DPI
Eremophila mitchellii	Budda; false sandalwood		Occasionally				
Eucalyptus albens	White box		Flowering	58.95	8.84	7.31	NSW DPI
Eucalyptus	Yellow box		Sucker				Going Into Goats guide (2006)

Botanical name	**Common name**	**Toxicity**	**Palatability**	**Digestible DM %**	**ME (MJ/kg DM)**	**CP %**	**Source**
melliodora			regrowth				
Eucalyptus polyanthemos	Red box		Flowering				
Eucalyptus populnea	Bimble box; poplar box		Occasionally				Cunningham *et al*. (1992)
Eucalyptus spp	Box, gum & mallee		Sucker leaves				Going Into Goats guide (2006)
Geijera parviflora	Wilga		Occasionally	55.04-69.96	8.26-10.49	8.69-15.94	NSW DPI
Gomphocarpus fruticose	Narrow-leaved cotton bush	Cardiac glycosides	Rarely	51.47	7.72	12.13	Simmonds *et al*. (2000); NSW DPI
Heterodendrum oleifolium	Rosewood; boonery	Prussic acid	All stages	44.13-60	6.62-9	8.6-13.38	NSW DPI; Everist (1974)
Leptospermum juniperinum	Manuka		Leaves		8.6	6.4	McGregor (2005)
Lyceum ferocissimum	African boxthorn		Leaves		12.4	28.3	Going Into Goats guide (2006)
Lyceum ferocissimum	African boxthorn		Stems		9.2	11.6	Going Into Goats guide (2006)
Owenia acidula	Gruie; colane		All stages	59.4-67.33	8.9-10.1	10.4-13	NSW DPI
Schinus areira	Peppercorn		Occasionally		10.2	20.3	McGregor (2005)
Tamarix parviflora	Small flower tamarisk		New growth		9	20.2	McGregor (2005); Lovich (no date)
Tamarix aphylla	Athel pine		All stages				Badshah and Hussein (2011)

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