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Validation of metabolisable protein and energy systems to predict the productivity of meat goats fed tropical grass, legumes and protein supplements

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Thesis submitted for the degree of Doctor of Philosophy (MHMS) (Res)

in the College of Public Health, Medical and Veterinary Sciences
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Declaration

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. All information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

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The research presented and reported in this thesis was conducted within the guidelines for research ethics outlined in the National Statement on Ethics Conduct in Research Involving Humans (1999), the Joint NHMRC/AVCC Statement and Guidelines on Research Practice (1997), the James Cook University Policy on Experimentation Ethics; Standard Practices and Guidelines (2001), and the James Cook University Statement and Guidelines on Research Practice (2001).

The proposed research methodology received clearance from Animal Ethics Committee (A2085, A2122, and A2130) from the James Cook University.

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Statement of the Contribution of Others

I, the undersigned, the author of this thesis, would like to recognise that the completion of this thesis included:

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Abstract

Tropical pastures are dominated by tropical or C_4 grasses, which supply most of the forage material for grazing meat goats. In the typically long dry season of Northern Australia and West Timor, Indonesia, these grasses contain crude protein (CP) of 20 to 100 g/kg DM. This is equivalent to metabolisable protein (MP) content of 10.5 to 60.9 g/kg DM and metabolisable energy (ME) of 6.2 to 9.1 MJ/kgDM. These cannot meet the goats' requirements for MP and ME as recommended by the National Research Council (NRC) 2007. These nutritional issues cause low productivity in periparturient does for breeding and in weaner kids raised for red meat production.

A feeding strategy aimed at increasing the productivity of goats fed tropical grass hay was to provide protein supplements to meet the ammonia requirements for rumen microbes with the minimum requirement 20 to 50 mg N/litre (Nolan, 1981) and true protein for the animals.

Four general objectives were defined for this thesis:

- To meet the nutrient requirements of periparturient and lactating does and weaner kids for both rumen degradable and undegradable protein (RDP and UDP), from which metabolisable protein (MP) was derived.

- To categorise diets based on the relative and total estimated amounts of RDP, UDP, MP as well as metabolisable energy (ME) based on organic matter digestibility.

- To validate the NRC (2007) methodologies for the prediction of dry matter intake (DMI) and average daily gain (ADG) of weaner kids fed tropical forages using intakes of these protein fractions and ME.

- To recommend supplementation strategies that incorporate the RDP and UDP supplied by diets to improve growth and carcass yields of meat goats in the tropics, especially in East Nusa Tenggara (West Timor), Indonesia.

Four experiments were conducted and each experiment became one chapter of this thesis. Experiment 1 utilised twelve periparturient crossbred Boer does and their suckling kids. Each group of three animlas was offered Rhodes grass hay (RGH) as a basal diet (Control) or RGH

supplemented with urea (Urea), urea plus cottonseed meal (Urea-CSM) and cottonseed meal (CSM). The objectives were to limit doe body weight loss, prevent ketosis and to increase the ADG of their suckling kids by varying the quantities of UDP and RDP based on the NRC (2007) recommendation. Protein supplements did not prevent doe body weight loss, but Urea-CSM and CSM supplements reduced non-esterified fatty acids (NEFA) and β-hydroxybutyrate (BHB) in the blood plasma. Supplements did not affect milk concentration, but increased ADG in suckling kids in the first week of the lactation period. These body weights and blood metabolites responses were associated with intakes of UDP, RDP, ME and Nitrogen retention.

Experiments 2 and 3 were conducted to increase liveweight gain and carcass yield of crossbred Boer goats by varying the quantities of dietary concentrations of RDP and UDP according to NRC (2007) recommendation. In a five-treatment experimental design, the basal diet of Rhodes grass hay was supplemented with:

1. Urea (Urea),
2. Urea plus cottonseed meal (Urea-CSM),
3. Cottonseed meal (CSM),
4. Air dried *Gliricidia sepium* leaves (Gliricidia), and
5. *Desmanthus leptophyllus* dried leaves (Desmanthus) only.

The dietary crude protein concentrations in Experiments 2 and 3 were 137 g/kg DM and 195 g/kg DM, respectively. Five of the 25 growing female crossbred Boer kids were allotted one diet in Experiment 2 for 120 days. The results showed that goats supplemented with Urea, Urea-CSM or Gliricidia lost weight as much as 15, 3 or 3 g/head per day, respectively.. Goats supplemented with CSM gained weight at the rate of 7 g/d and this increased to 33 g/d when the goats were fed Desmanthus hay. This liveweight gain data was not associated with MP and ME requirements suggested for temperate goats by NRC (2007). Growing at these rates, it was apparent that weaner goats would not achieve market liveweight within a reasonable timeframe. Therefore, Experiment 3 was conducted by increasing the dietary crude protein concentration to 195 g CP/kg DM.

In Experiment 3**,** the goats were rearranged into the same five dietary treatments and raised indoors in individual pens for 130 days. Evidence from this study revealed that weaner goats fed Desmanthus grew faster at an ADG of 83 g/head per day and had heavier carcass with an average cold carcass weight of 12.1 kg and non-carcass components, followed by goats fed CSM, Urea-CSM, Gliricidia and Urea. Heavier carcass weight was associated with greater eye muscle area and fat depth at the 12^{th} to 13^{th} rib interface. The higher rate of liveweight gain, carcass and non-carcass components yields for goats fed the Desmanthus diet, compared with other treatments, was associated with increased intakes of UDP, RDP, MP and ME.

High intakes, growth rate and carcass weight in the goats was more likely associated with feed digestibility and nitrogen retention. Experiment 4 was therefore conducted to compare apparent digestibility and nitrogen retention in crossbred Boer kids fed tropical grass hay supplemented with an NPN-RDP source (urea) and a source of RDP and UDP of true protein origin (cottonseed meal) at a dietary crude protein level of 175 g/kg DM. Twelve growing, male crossbred goats were divided into four groups of three. The first, a control group, received a basal diet of RGH; the second, a Urea group, received RGH plus urea; the third, a Urea-CSM group, received RGH plus urea mixed with cottonseed meal and the fourth, a CSM group, received RGH plus cottonseed meal. Results indicated that higher feed intake, apparent digestibility of crude protein and digestible nutrient intake were associated with CSM and Urea-CSM supplements. Higher nitrogen retention, however, was associated with CSM supplementation.

Modeling to predict DMI and ADG was conducted using input data derived from Experiments 2 and 3. Dry matter intake was predicted using metabolic body weight and estimated dietary concentration of ME or DM digestibility or estimated dietary concentration of ME only. Results showed that these equations were generally not useful to predict DMI of goats. Specifically, it was evident that dietary concentration of UDP, not RDP or CP, was the better predictor of DMI. When ADG was predicted using MP and ME intakes incorporated with standard requirements by NRC (2007), the percentage of variation explained by the model as indicated by the coefficient of determination (R^2) was so low that the difference between predicted and actual ADG values was very large, hence predictability was poor. Metabolisable protein intake could predict ADG when goats were supplemented with Urea or fed Desmanthus only at a dietary CP level of 137 g/kg DM. Metabolisable energy intake could only predict ADG in goats supplemented with Gliricidia at a dietary CP level of 195 g/kg DM. Despite the high coefficient of determination (R^2) values above 0.70, a strong relationship between ADG and MP or ME intake in these two studies was not evident since the NRC (2007) equations could not accurately predict ADG for most of the treatments.

It can be concluded that protein supplementation to goats fed tropical grass should consider requirement for rumen microbes in the form RDP and the requirement for animal in the form of UDP. The combination of these two types of protein sources made of Urea and cottonseed meal at the dietary crude protein level of 143 g/kg DM maintained normal blood metabolites of periparturient does. Supplements of Urea, Urea plus cottonseed meal or cottonseed meal to lactating does increased average daily gain of suckling kids but weaner goats should be supplemented with RDP and UDP at a dietary crude protein level of 195 g/kg DM. Dry matter intake and ADG responses were associated with intakes of RDP, UDP and ME. Among these determinant factors, UDP is the best predictor for DMI. Both intakes of MP and ME were good predictors for ADG of weaner kids according to the NRC (2007) prediction methodologies. In adddition to Urea and cottonseed meal, Desmanthus hay provides RDP and UDP for weaner goats, which resulted in heavier body weight and carcass weight as compared to those fed Rhodes grass hay and supplemented with Urea and/or cottonseed meal.

List of Abbreviations

Abbreviation	Name
ADG	Average daily gain
ADIN	Acid detergent insoluble nitrogen
AFRC	Agricultural and Food Research Council
ATP	Adenosine triphosphate
BW	Body weight
CP	Crude protein
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSM	Cottonseed meal
d	Day
DE	Digestible energy
DIP	Degradable intake protein
dl	Decilitre
DM	Dry matter
DMD	Dry matter digestibility
DMTP	Digestible microbial true protein
DOMD	Digestible organic matter on dry matter basis
DP	Digestible protein
DUP	Digestible undegradable protein
FBW	Full body weight
FCR	Feed conversion ratio
g/d	Gram per day
g/L	Gram per litre
GE	Gross energy
HCW	Hot carcass weight
HSCW	Hot standard carcass weight
kg	Kilo gram
kJ	Kilo Joule
Mcal	Mega calorie
MCP	Microbial crude protein
ME	Metabolisable energy
MEg	Metabolisable energy requirement for growth

MEI	Metabolisable energy intake
MEm	Metabolisable energy requirement for maintenance
mg	Milligrams
MJ	Mega joule
mL	Millilitre
MP	Metabolisable protein
MPg	Metabolisable protein requirement for growth
MPI	Metabolisable protein intake
MPm	Metabolisable protein requirement for maintenance
MTP	Microbial true protein
NDF	Neutral detergent fibre
NE	Net energy
NEFA	Non-esterified fatty acids
NIR	Near infrared reflectance spectroscopy
NPN	Non-protein nitrogen
NRC (2007)	National Research Council (2007)
OMD	Organic matter digestibility
RDP	Rumen degradable protein
t DM/ha	Tonne dry matter per hectare
TDN	Total digestible nutrients
TMR	Total mixed ration
UDP	Undegradable dietary protein
UIP	Undegradable intake protein
VFA	Volatile fatty acids

Table of Contents

List of Tables

List of Figures

List of Publications from Thesis

Peer-reviewed Journal Papers

Aoetpah A, Parker A, Gummow B, Gardiner C, Maolin A, Walker G (2018) Growth rates of suckling kids, dam milk composition and plasma metabolite changes in periparturient Boer does supplemented with urea and/or cottonseed meal. ***Animal Production Science (submitted***).

Aoetpah A, Parker A, Gummow B, Gardiner C, Walker G (2018) Feed intake, digestibility and nitrogen balance of growing crossbred Boer goats fed Rhodes grass hay as basal diet supplemented with cottonseed meal and or urea. ***The Journal of Agricultural Science (submitted***)

Aoetpah A, Parker A, Gummow B, Gardiner C, Walker G (2018) The effect of varying the amounts of degradable and undegradable dietary protein in diets based on tropical pasture species on the rate of liveweight gain and carcass yield of goats. ***Small Ruminant Research (Draft***).

Aoetpah A, Parker A, Gummow B, Gardiner C, Walker G (2018) Validation of dry matter intake and growth of meat goats fed tropical grass hay and dried legumes using metabolisable protein and energy systems. ***Small Ruminant Research (Draft***).

Conference Papers

Aoetpah A, Gardiner C, Gummow B, Walker G (2018) Growth and eye muscle area of cross-bred Boer goats fed Desmanthus cultivar JCU 1 hay. Proceedings of the Australian Society of Animal Production Conference, Wagga Wagga New South Wales, Australia, **volume 58: page 2563**

Ockerby S, Gardiner C, Aoetpah A, Hannah I, Kempe N (2015) Sugarbush – A break-crop for sustaining sugarcane productivity in the tropics. Poster presented at the Tropical Agriculture Conference 2015, Brisbane, Australia [P046] page 97.

Chapter 1 General Introduction

Australia is the world's largest goat meat exporter (MLA, 2016), while Indonesia has the largest goat meat production among Southeast Asian countries, with the exception of Myanmar (FAOSTAT, 2015). Tropical grasses are the main forages that support this goat meat production system. The energy and protein content of the dominant pasture species in some areas, such as northern Australia (Nogueira *et al.,* 2016) and West Timor, Indonesia (Bamualim, 1996), vary seasonally, while pasture growth rates and standing biomass are determined largely by rainfall from December to March (Manu, 2013). For example, Mitchell grasses (*Astrebla* spp.) in northern Australia typically contain 7.7 MJ ME/kg dry matter (DM) and crude protein (CP) 26 to 100 g/kg DM (Orr, 1975; Robinson and Sageman, 1967). Some dominant grasses in West Timor, Indonesia, such as Bunch Spear grass (*Heteropogon contortus*), contain 23 g CP/kg DM in the dry months (April to November) and 90 g CP/kg DM in the rainy months (Manu, 2013). The CP content of grasses in the dry months in northern Australia and West Timor, Indonesia shows a similarly low quality to other pasture species. Low grass quality in the dry months highlights the importance of supplementation and the provision of legumes to supply the protein and energy required for optimal production in goats.

Some studies reported that production from ruminants fed tropical (C_4) grasses as a basal diet can be enhanced by legume supplementation. In addition, the success of the supplement was likely to be related to the protein fractions, such as CP, RDP, UDP, and MP, and ME. These reports suggested that the quality of protein and energy of the grasses and legumes is at least determined by the protein fractions and ME. For example, Leucaena, Gliricidia and Desmanthus, when added to C_4 grasses as supplements, have been shown to increase the amount of UDP, RDP and ME supplied by the diet. This typically results in increased total DMI and liveweight gain in steers (Abdulrazak *et al.,* 1996, Gardiner and Parker, 2012), meat sheep (Getachew *et al.,* 1994, Foster *et al.,* 2009) and goats (Kanani *et al.,* 2006). Similar findings were also reported for wool growth in merino sheep (Rangel and Gardiner, 2009), milk yield in dairy cows (Granzin and Dryden, 2002) and maintenance of liveweight with livestock grazing hayed-off C_4 pastures in the monsoonal dry season (Akinlade *et al.,* 2002).

Although the productive benefits of supplementing tropical grasses with legumes are well established, the mechanisms by which these supplements improve the intake and productivity of livestock are poorly understood and responses are not always consistent. For example, Granzin and Dryden (2002) proposed that a lack of RDP in Rhodes grass hay, a C_4 grass, limited organic matter digestibility and livestock productivity. Despite observing the expected increase in concentrations of rumen fluid ammonia and isobutyric, valeric and isovaleric acids in response to increasing levels of soybean meal and total crude protein in the diet, Granzin and Dryden (2002) reported that treatments had no effect on the concentations of rumen fluid total volatile fatty acids (VFA), acetate, propionate or butyrate or DM or organic matter (OM) intakes. They were of the opinion that this lack of response probably occurred because less RDP potentially reduced the activity of rumen microorganisms in utilising carbohydrates, and hence resulted in less VFA production. Supplementation with a high RDP source, such as a urea added to grass hay, could overcome the problem. Another solution could be to provide a supplement rich in a UDP source, such as cottonseed meal. Nevertheless, protein supplementation can cause different productive responses in the animal. For example, the digestibility of neutral detergent fibre (NDF) declines linearly with increasing intakes of soybean meal/crude protein, which resulted in milk yield increases (Granzin and Dryden, 2002). Soybean meal appears to increase the supply of protein and milk yield, but it does not provide energy for the fibrolytic rumen microorganisms to digest NDF.

Foster *et al.*, (2009) reported high intake of dry and organic matter when meat sheep (crossbred Dorper lambs) were fed a diet of tropical grass hay supplemented with either soybean meal or tropical legume hay. In this study, both supplements increased the rumen outflow rate, especially microbial crude protein and nitrogen retention. Digested organic matter and NDF also increased through feeding the sheep perennial peanut plant.

Kanani *et al*.,(2006) reported that growth rates of meat goats fed tropical grass hay increased upon supplementation with either Leucaena or Desmanthus. The intakes of Leucaena, however, were higher than those of Desmanthus possibly due to a lower voluntary intake of Desmanthus, given its lower content of crude protein or its higher secondary compounds, especially tannin. Low CP may reduce digestibility, while high protein that is strongly bound to tannin will reduce the use of protein, leading to low digestibility (Silanikove *et al.,* 2001), and hence decreased intake of Desmanthus. Edwards *et al.,* (2012) conducted *in vitro* studies in which Leucaena, Gliricidia and Trichantera were fermented with a C_4 grass (*Brachiaria arrecta*; Tanner grass), using the gas production method to determine rates of fermentation. They concluded that both Leucaena and Gliricidia leaf increased the rate of fermentation of Tanner grass up to 48 hours after inoculation. Gliricidia, however, provided more immediately soluble fermentable organic matter and sustained fermentation at a higher rate over 48 hours, compared to Leucaena. While the *in vitro* fermentation characteristics of these feeds provide information that could be used to predict DMI and ADG responses to their use as supplements, this study did not investigate intake or ADG. In addition, CSIRO (2007) reported that *in vitro* organic matter and dry matter digestibilities reflect the total amounts of MP and ME available to the small intestine. However, these MP and ME values do not necessarily translate into RDP and UDP needs of the animal. Therefore, RDP and UDP values of feed samples are required from *in vitro* studies in order to meet nutrient requirements.

The interplay or interactions between dietary protein fractions and metabolisable energy may explain why DMI and ADG, as productive responses, are sometimes not consistent with dietary crude protein level. These terms are used repeatedly in this study and their meanings are as follows. Crude protein (CP) represents the amount of feed nitrogen multiplied with 6.25, which was determined using Kjeldahl method (AOAC, 1990). Rumen degradable protein (RDP) and undegraded dietary protein (UDP) reflect the amount of protein degraded in rumen by microorganisms and enzymes and the undegraded protein for post ruminal digestion, which was determined with the *in sacco* method (AFRC, 1993). The RDP fraction enriches rumen microbial crude protein (MCP), which synthesis depends on metabolisable energy (AFRC, 1993). The NRC (2007) suggested estimation of ME based on total digestible nutrient (TDN), while the AFRC (1993) recommended estimating it based from fermentable organic matter (FOM). CSIRO (2007) also linked the digestibility of OM and DM with ME, where high digestibility is associated with high ME concentration of the diet. The sum of MCP and digestible UDP is metabolisable protein (MP) or amino acids that are required by the animals for maintenance and production (AFRC, 1993; NRC, 2007). The MP definition implied that protein supplementation should meet the requirements of ammonia or nitrogen for not only the host animals but also the rumen microbes. Metabolisable energy (ME) is gross energy in feed minus the sum of energy in faeces, urine and gas production. Therefore, ME is what is available for the animal for maintenance and production.

Information on amounts of RDP, UDP and fermentable orgnic matter of tropical legumes are required in order to inform livestock producers of the adequacy of diets to meet the production requirements of their animals. Whereas good data are available for predicting the MP and ME from temperate forage species and commonly used concentrate supplements, the values for RDP and UDP are largely unavailable for diets based on tropical grasses and legumes.

Consequently, using current feeding standards to formulate general recommendations for livestock producers is difficult, particularly regarding the relative cost benefit of feeding specific supplements (e.g., urea, protein meals, molasses and cereal grains/starchy root vegetables).

The research objectives in this thesis were:

1. To investigate whether dietary crude protein supplementation at levels up to 143 g/kg DM can limit body weight loss and potentially prevent metabolic disorders (ketosis) in periparturient crossbred Boer does;
2. To increase the average daily gain (ADG) in suckling kids by varying the quantity of UDP and RDP;
3. To compare liveweight gain, carcass and non-carcass component yields and meat quality in crossbred Boer kids fed isonitrogenous diets varying in UDP and RDP;
4. To validate the ME and MP minimum requirements suggested by the NRC (2007) in predicting ADG of growing Boer goats fed tropical legume hay only using *Desmanthus leptophyllus* or tropical grass hay supplemented with *Gliricidia sepium* legume or UDP and/or RDP protein sources.

Chapter 2 Literature Review

The main objective of the current project's proposed program of research is to find a nutritional approach to improve the productivity of meat goats in seasonal tropical rangeland environments typical of the East Nusa Tenggara province of Indonesia and Northern Australia. This review examines the potential to match the quantity and nutritive value of biomass derived from tropical (C_4) grasses to the production of meat goats in order to improve the economic, social and cultural wealth of the societies operating in these environments.

This review is presented in three sections. Section 1 describes opportunities other than supplementation that are believed to improve meat goat production from tropical pastures. The opportunities are grass production, the goat population and the feeding behaviour of the goats. Section 2 examines methods to evaluate MP and ME concentrations of tropical grasses, validates the MP and ME requirements by growing meat goats and predicts the goats' ADG using the MP and ME systems. These validations were conducted to see if the MP and ME systems contain opportunities to improve meat goat production from tropical pastures. Section 3 examined strategies to improve meat goat production by using feed supplementation, in order to increase dietary MP and ME concentrations to meet the requirements suggested by NRC (2007).

2.1 Opportunities to Improve Meat Goat Production from Tropical Pastures

2.1.1 Introduction

Tropical pastures are major sources of biomass supporting meat goat production in tropical regions including East Nusa Tenggara, Indonesia and Northern Australia. The production of meat goats from tropical grasses in the tropics is important because of its positive association with the social, cultural and economic life of the community. Smallholder farmers could tap into this potential to increase their well-being, but they require a basic knowledge of the opportunities extractable from the grasses and the goats that can be developed in order to improve meat goat production.

The availability of forage dry matter during the wet season declines from 2.1 to 1.2 tonnes DM/ha, while crude protein content decreases from 68 to 48 g/kg DM (Mullik and Permana, 2009). Tropical grasses in their vegetative growth phase during the wet season typically produce large quantities of biomass capable of supporting good rates of liveweight gain of goats in tropical rangeland environments of East Nusa Tenggara Province and northern Australia. In the dry season, these grasses move to a reproductive phase and hay off, resulting in standing biomass with a very high content of neutral detergent fibre (NDF) and a low content of crude protein (Mbwile and Uden, 1997). Consequently, metabolisable energy and protein available from these grasses are lower than is required for meat goats, as recommended by NRC (2007). To solve the problem, supplementation with agro-industrial by-products in order to increase crude protein and fermentable organic matter intake is routinely suggested by Alves *et al*., (2013). These supplements, however, are frequently unavailable to smallholder farmers, and alternative approaches to improving animal productivity from these pastures do exist. These approaches include enhancing the goat's capacity to select higher quality forage when given the opportunity, and improving the adaptive capacity of goats to increase productivity in response to changes in feeding and husbandry practices. Section 1 in this review describes some of these opportunities.

2.1.2 Tropical grasses as ruminant feedstuffs

2.1.2.1 Tropical grass production and availability throughout the year

Tropical grasses are also known as C_4 grasses, because the photosynthetic pathway utilises four carbon organic acids to efficiently fix CO_2 in condition of high light intensity. Under the right conditions of water and nutrients, C_4 grasses produce large amounts of biomass when compared with C_3 grasses. Ludlow (1985) reported that a high potential for biomass production of C_4 grasses is supported by high light intensity and temperature and a longer growing season, compared with temperate grasses. Under ideal conditions 30 to 85 T DM/ha biomass is achievable from C4 grasses, compared with a limit of 22 to 25 T DM/ha biomass from C_3 grasses (Ludlow 1985).

Sage *et al.,* (2011) reported that the production of C_4 grass biomass tends to cluster in the arid and semi-arid regions across four continents: central and south America, south East Asia, southern Africa and inland Australia. In these areas, despite being seasonally dry, summer rainfall results in high biomass production, which can underpin a potentially highly productive environment for meat goats. In the semi-arid regions of northern New South Wales and Queensland, Australia, about 72% of land supports the production of rangeland goats, with most of this land owned by individual farming families and pastoral companies (Nogueira *et al.,* 2016). In the province of East Nusa Tenggara, Indonesia, Bamualim (1996) reported that goat production was typically carried out on communal grazing land totalling 236,500 ha.

Another key point of difference between the two production systems is that Australia uses extensive grazing (Noguiera *et al*., 2016) while Indonesia uses a 'cut and carry' intensive animal production system (Fuah and Pattie, 1992).

Five dominant tropical pasture species underpin grazing in northern New South Wales and Queensland: Spear grass (*Stipa variabillis*); Mitchell grass (*Astrebla* sp.); Buffel grass (*Cenchrus cilliaris*); Summer grass (*Digitaria* sp.); and Flinders grass (*Iseilema macratherum*) (Nogueira *et al.,* 2016). The dominant grasses in the East Nusa Tenggara region are Black speargrass (*Heteropogon contortus*), *Bothriochloa timorensis*, and Centipede grass (*Ischaemum timorense*) (Manu, 2013). The usage of these tropical grasses as goat feed is restricted by the grasses' quantity, quality and seasonal availability.

Table 2.1 Dominant native pasture species in New South Wales and Queensland (Nogueira *et al.,* 2016)

Pasture species and references	DM Production (tonnes/ha per yr)	DOMD (g/kg DM)	ME (MJ/kg DM)	CP (g/kg DM)
Northern Australia				
Spear grasses $_{1, 3}$	2 to 25.6	558	8.9	26 to 84
Mitchell grasses $_{4, 54}$	0.4 to 2.2	482	7.7	26 to 184
Buffel grass $_{2, 5}$	2 to 24	432	6.9	60 to 160
Summer grass $_{2}$	10 to 20	570	9.1	90 to 140
Flinders grass $_{6, 5, 7}$	0.1 to 1.5	386	6.2	20 to 90
East Nusa Tenggara Indonesia				
Black Spear grass $_{8}$	0.5 to 8.7	537	7.5	32 to 50
Bothriochloa timorensis $_{9}$	1.3 to 1.9	523	8.4	45 to 65
Centipede grass $_{10}$	N/A	597	8.8	83 to100

ME = 0.16 DOMD (AFRC, 1993; CSIRO, 2007) where ME = metabolisable energy and DOMD = digestible organic matter based on dry matter
The subscript numbers in references column represent references for DM, DOMD and CP, respectively where Reference 1= (Playne, 1972) 2 = (Tropical Forages n.d), 3 = (Hunter and Siebert, 1980), 4 = (Orr, 1975), 5 = (Robinson and Sageman, 1967), 6 = (Lorimer, 1978), 7 = (Streeter, 2007), 8 = (Feedipedia n.d-b), 9 = (Mullik and Permana, 2009), 10 = (Feedipedia n.d-a)

Dry matter production, energy content and protein content of the grasses is highly variable (Table 2.1), with the lowest productive quantity and nutrient quality usually recorded in the dry months. For example, Manu (2013) reported that the biomass production of combined dominant grasses in East Nusa Tenggara was 0.61 tonne/ha, containing 23 g CP/kg DM in the dry months (April to November). However, in rainy months the production rose to 4.33 tonne/ha with 90 g CP/kg DM. This pattern of biomass production and nutritive value implies that even though a greater variety of grasses is available on pasture, the quantity and nutritive value of biomass available for animal production in the dry season is low, thus necessitating the need to focus on nutritional strategies to optimise animal production in these environments (Mahama *et al.,* 2018).

2.1.2.2 Nutrient content of tropical grasses

In general, the concentration of protein fractions, metabolisable energy and neutral detergent fibre (NDF) of C_4 grasses differed from those of C_3 grasses, with C_4 grasses having lower contents of nutrients. Reid *et al.,* (1990) reported some C_4 grasses have a CP content ranging between 63 and 89 g/kg DM, which was lower than that for C_3 grasses, which ranged between 114 and 131 g/kg DM. Reports for specific species also showed similar results. For example, Rhodes grass hay (*Chloris gayana*), a C_4 grass, contains 51 g CP/kg DM (Osuga *et al.,* 2012) while Timothy grass (*Phleum pratense*), a C_3 grass, contains 131 g CP/kg DM (Reid *et al.,* 1990). A study found that there was only a slight difference between C_4 and C_3 grasses in their concentration of undegraded dietary protein (UDP) and metabolisable protein (MP) (*Bowen et al.,* 2008). Fulkerson *et al.,* (2007), however, reported that the contents of UDP and MP grasses are associated with species and season.

Nutrient content of C_4 grasses that lower the quality of the grasses compared with C_3 grasses are the low soluble carbohydrate fractions, digestibility and metabolisable energy (ME), and high NDF. Kasuya *et al.,* (2008) reported that soluble carbohydrate fractions of the C_4 grasses were 30 to 160 as compared to 170 to 390 g/kg DM for C_3. This showed that C_4 grasses may supply insufficient nutrients for rumen microorganisms' requirements. The report of Fulkerson *et al.,* (2007), who found that C_4 grasses contain ME 9.10 to 9.90 MJ/kg DM-- slightly lower than 9.96 to 10.13 MJ/kg DM for C_3 -- showed less energy were derived from C_4 grasses when they were fed to animals. The NDF content of Rhodes grass (a C_4 grass), was 710 g/kg DM (Osuga *et al.,* 2012), higher than 640 g/kg DM for Orchard grass (a C_3 grass) (Reid *et al.,* 1990), when measured in phase 4 (hayed-off) stage of growth. The higher NDF in C_4 grasses may result in low solubility and digestibility of the grass, as the cell wall prevented the rumen microorganisms from degrading the high fibrous ingesta. Tiago *et al.,* (2016) concluded that C_4 grasses are slowly digested because the grasses contain high cell wall densities, leading to the carbohydrate concentration being less soluble.

Phases of plant growth and seasonal conditions have a profound effect on nutrient content. For example, the early growth leaves of Napier grass (*Pennisetum purpureum*) contain 9.4 MJ ME /kg DM and 95 g MP/kg DM, which is greater than the values at the vegetative stage, i.e. 8.9 MJ/kg and 63 g/kg DM (NRC 2007). Fulkerson *et al.,* (2007) and Safari *et al.,* (2011) reported higher concentrations of crude protein in the rainy season, while concentrations of NDF are higher in the dry season.

In general, biomass from C_4 grasses is typically high in tropical regions, and has the potential to support high levels of animal production in the wet season, when grasses are in their vegetative phase of growth. Reasonable levels of production can be achieved from C_4 grasses in the dry season (phase 4), when problems associated with low crude protein and soluble carbohydrate content, and slow rates of digestion of the NDF fraction can be overcome (Leng 1990).

2.1.3 The importance of meat goats in the tropics

Goats (*Capra aegagrus hircus*) are the most important source of meat, milk and fibre in the tropical and sub-tropical zones in North Africa, the Near East, the Indian sub-continent and South East Asia (Devendra, 2010). In 2007, the total goat population worldwide was approximately 851 million. This population consists of 1,156 breeds, of which 76% belonged to developing countries (Devendra, 2010). The East Nusa Tenggara province of Indonesia represents the most south easterly location in which goat is the predominant ruminant production animal (Livestock and Animal Health Statistics, 2017). Approximately 77% of the world's goat population occurs in seasonally dry semi-arid areas (Devendra, 2010). However, Johnson (1984) reported that goats can live in a wide range of ecosystems in the tropics and sub tropics because the animals are able to adapt to various rearing systems, whether in extensive grazing or total captivity. In addition, the adaptive capacity of goats is supported by their feeding behaviour, because they are more likely to graze at night and they consume meals more frequently than domesticated breeds of sheep and cattle (Morand-Fehr, 2005).

2.1.3.1 Meat goat population and production system in Northern Australia and East Nusa Tenggara Indonesia

The total goat population in Australia in 2011 was 6 million, with about 2.3 million in Queensland (MLA, 2016). The total goat population in Indonesia in 2017 was about 18.4 million, with about 650,000 in East Nusa Tenggara Province (Livestock and Animal Health

Statistics, 2017). The large areas of land available to raise goats in Australia means a grazier in Queensland may own from 150 to 12,500 animals (Nogueira *et al.,* 2016), while an Indonesian farmer typically owns 2 to 5 animals (Djajanegara, 1992). Another important difference is the purpose for which the animals are being raised. In Australia goats are typically raised on privately owned land for meat export, while in Indonesia they are mostly raised for local household consumption on pasture harvested from communally owned land, using a cut and carry system.

2.1.3.2 Productive potential of meat goats

Meat goats can be simply classified according to their frame size (i.e., dwarf; small; large) (Webb, 2014). However, differences between breeds, particularly in their genetic potential for rapid growth and their reproductive traits, can be extremely important when matching genetics to a particular production system (Browning and Leite-Browning, 2011). A simple classification system proposed by Webb (2014) classified the goats at 15 months. At that age, the dwarf breeds will never exceed 25 kg, the small breeds will weigh between 15 and 30 kg, and the large breeds could reach 55 kg. MLA (2013) reported that goats typically raised on the rangelands in Australia are a mixture of unknown genetics, including feral animals and crosses with breeds including Boer, Kalahari Red and Savannah. These types are classified as "large frame" according to Webb (2014). Djajanegara and Chaniago (1988) reported that the two most important meat goat breeds in Indonesia are Kacang and Etawah goats, which fall within the dwarf breed classification of Webb (2014), never exceeding 25 kg.

Under the nutritional and management approaches available to smallholder farmers in the province of East Nusa Tenggara, the dwarf goat varieties farmed typically produce a single kid. A large part of the productive potential of the large frame breeds, however, results from their capacity for multiple births of healthy kids when they are supported by good nutrition (Campbell, 2003). For example, a twin bearing meat-type doe with a live weight of 60 kg requires 139 g MP and 15.2 MJ ME each day during the late gestation period (NRC, 2007). During lactation, the same doe requires 152 g MP and 13.9 MJ ME each day in order to support twin kids, while a doe raising a single kid requires 116 g MP and 12.4 MJ ME each day (NRC, 2007). In Australia, intakes of MP and ME by livestock grazing on tropical pastures in the dry season are supported with protein and energy supplements, typically a mixture of urea, cottonseed meal or other protein meal, cereal grains, salt and other minerals (Nogueira *et al.,* 2016). With the exception of salt, urea and perhaps cassava, these supplements are not available in the province of East Nusa Tenggara. Thus, the current feeding systems in East Nusa Tenggara province, based on tropical grasses alone, will not support large frame does birthing multiple healthy kids.

A diet that provides sufficient MP and ME as recommended by NRC (2007) is required if goats are expected to produce multiple births (Noguiera *et al*., 2017) and weaners are to grow at rates of average daily gain of 50 g/head per day (Fuah and Pattie, 2013). The approach to supplying this MP can be with protein meals such as cottonseed meal, which is widely used in Australia. It is possible that a return to the use of browse or shrub legumes, such as Leucaena and /or Desmanthus, would also provide the additional MP and ME required to increase meat goat productivity in the province of East Nusa Tenggara.

When supported by sound nutrition, the high potential growth rate of weaners is a desirable trait in a goat breed or crossbred animal. Browning and Leite-Browning (2011) reported that Boer sires mated with other large frame breed does are capable of producing high birth and weaning weights of kids when dams were well fed. Improved rates of liveweight gain are reported by Poore *et al.,* (2013) who found that non-castrated male suckling kids grew at 167 g/d and weighed 16.1 kg when weaned at 75 d compared with their castrated counterparts, which grew at 147 g/d and weighed 14.5 kg when weaned at 75 days. However, Poore *et al.,* (2013) reported that feeding regimen was the most important factor determining the average daily gain and weaning weight of kids.

The final objective of the farming of goats for meat production is to yield a high carcass dressing percentage of acceptable meat quality. This result is influenced by both breed and nutrition. The breed effect is important. Webb (2014) reported that the dressing percentage of well-fed Boer, Florida native, Spanish x Florida native, and Nubian x Florida native goats breeds were 56, 52, 51 and 50%, respectively, when these animals were well fed. Turner *et al.,* (2014), however, report that Boer goats raised on C_3 pasture only had 50% dressing percentage carcass, which was raised to 51% by whole cottonseed supplementation.

2.1.4 Feed intake of meat goats

2.1.4.1 Feeding behaviour: A comparison between group and individual rearing systems of goats and cattle

Eating behaviour, i.e., the manner in which the animals select and consume either grazing or browsing material, and the nutrient content and energy density of the available biomass thereby acquired, is an important factor. This behaviour determines DM intake and thus the relative productivity of the animal. Goats are classified as browsers and foragers with a pronounced capacity for selection of high-quality forage. Their small flexible lips and shorter less flexible tongue anatomy promotes efficient selective browsing, compared with cattle (NRC, 2007). This anatomical structure is better adapted to selective foraging than that of sheep, which possess a split lip that allows for close cropping of herbage to near ground level, but with less capacity to selectively browse (NRC, 2007). As such, goats are better adapted to browsing than sheep and cattle and prefer a larger proportion of browse in their diet.

Goats are classified by NRC (2007) as selective grazers, preferring leaves to stems and green to non-green forage (Lu, 1988). This naturally depends upon seasonal nutrient supply (Nkosi *et al.,* 2012), as the seasonal availability of biomass varies in semi-arid areas. In the rainy season, when grass and herbs are abundantly available, goats consume more grass, but in the dry season more browse and forbs were eaten (Safari *et al.,* 2011; Webb *et al.,* 2005). Dumont *et al.,* (1995) reported goats foraging on rangeland pasture routinely achieved 89% to 99% of their DM intake from browsing. Evaluating the grazing pattern of goats in Mediterranean (northern Greece) pastures, Papachristou and Platis (2011) found that the higher total forage intake by goats was due to browsing a variety of plant species, including woody shrubs and herbaceous forbs. They argued that browsing different forages was a means to keeping the animal's rumen environment functioning well, and in a specific physiological and microbiological condition suited to fermentation of the browse. However, goats tend to avoid eating long feed, possibly due to the anatomy of their lips and tongue (NRC, 2007).

The differences in eating behaviour between goats and sheep or cattle results in differences in NDF intake and digestibility when all three species are fed the same diet. Reid *et al.,* (1990) reported that dry matter intake of C_4, C_3 and legume hays, when standardised to metabolic liveweight, did not differ between 'sheep' and 'sheep and goats' (65.8 and 68.6 g/kg $BW^{0.75}$, respectively. However, the dry matter intake of cattle was 92.6 g/kg $BW^{0.75}$, which was substantially more than that of small ruminants, when averaged across these forage classes (Reid *et al*., 1990). These authors also reported that dry matter digestibility for C_3 grasses did not differ between cattle, sheep and goats at 575, 570 and 580 g/kg DM, respectively, however, dry matter and NDF digestibility of C_4 grass hays were 580, 530 and 570 g/kg DM, respectively. Particle passage rates from the rumen did not differ between sheep and goats, but passage rates for both sheep and goats were better than for cattle. This finding is important in that it suggests that goats may have a nutritional advantage over cattle in a tropical rangeland grazing system.

Raising flocks of goats either on pasture or in a pen requires attention to the number and age of the animals, since hierarchy affects the DM intake and productivity. This effect is reported by Barroso *et al.,* (2000) who studied Granadina, Malaguena and Serrena goats in a semi-extensive rangeland production system. The study showed that the social rankings of dominance/subordination, and therefore access to feed, is primarily determined by body size, age and presence of horns. This means larger, older and horned animals have first access to limited feed resources (Barroso *et al.,* 2000). Prediction of feed intake in the grazing environment only becomes possible when herd management limits the effects of social hierarchy. Typically, this is achieved by ensuring increased feed resources through reduced stocking rates.

2.1.4.2 Prediction of feed intake of meat goats fed tropical grass and legumes

When the effects of social structure and dominance are removed, the prediction of dry matter intake depends on factors such as breed, level of productivity, metabolic live weight and physiological status (Mertens, 1987; Pulina *et al.,* 2013). Two models proposed to predict feed intake are the empirical model put forward by Pulina *et al.,* (2013) and the mechanistic model put forward by Mertens (1987). The empirical model of Pulina *et al.,* (2013) was established as a sum of factors affecting feed intake. For example, Pulina *et al.,* (2013) proposed a model where voluntary feed intake (VFI) is dependent on metabolic live weight (LW), live weight change (LWC), neutral detergent fibre (NDF) and crude protein (CP) content of the feed, represented by the formula VFI = a + bLW + cLWC + dNDF + eCP). The model is based on voluntary feed intake being dependent upon a positive linear relationship between an animal's metabolic live weight and rate of live weight change. This drives the capacity to eat, appetence and dietary factors where intake is limited by the neutral detergent fibre content of the diet and promoted by crude protein contents of the diet in question. This mechanistic modelling approach was developed to measure the way internal mechanisms that drive intake, including neuronal and hormonal factors, affect feed intake of the animals. However, the results achieved by using this mechanistic approach were not consistent (Mertens, 1987; Pulina *et al.,* 2013). Thus, in the current study, the empirical model is seen as preferable for use with actively growing meat goats.

Different methods to predict DM intake of growing goats have been compared in a review by Teixeira *et al.,* (2011). Their review emphasised the animal (body weight) and feed (dietary energy concentration) factors developed by AFRC (Equation 2.1), relative body size and diet digestibility developed by CSIRO (Equation 2.2) and an approach using relative body size only by NRC (Equation 2.3) as the most important variable to predict DM intake:

$$DMI\ \left(\frac{g}{d}\right) = (76.7 \text{ x } BW^{0.75}) \text{ x } (-0.666 + 0.319 \text{ x } ME - 0.015 \text{ x } ME^2)$$

Equation 2.1

$$DMI\ \left(\frac{kg}{d}\right) = (0.04 \text{ x } SRW) \text{ x } \left(\frac{N}{SRW}\right) \text{ x } \left(1.7\text{L} - \frac{N}{SRW}\right) \text{ x } [(1 - 1.7\text{L x } (0.8 - Dig)]$$

Equation 2.2

where SRW refers to standard reference weight (kg); N refers to normal body weight (kg), L refers to legume and Dig refers to digestibility of the diet.

$$I = 0.04 \text{ x } A \text{ x } Z\ (1.7 - Z)$$

Equation 2.3

where '*I'* is intake, '*A*' is the standard reference weight (SRW), which was the mature weight values in the nutrient requirement tables (NRC, 2007), '*Z*' is relative size, and expressed as the ratio between normal weight of a growing kid at a certain age and the mature weight.

It can be seen that the CSIRO model also applies a diet quality constraint, based on digestibility and legume proportion in the animals' diet. For the digestibility effect, the equation is Quality constraint = 1 – 1.7 (0.8 – Dig), where Dig refers to digestibility and is related to the given ME (NRC, 2007, p 34). For legume proportion in the diet effect, the equation is Quality constraint = 1 – 1.7 (0.8 – Dig) + 0.17L where *'L'* refers to the proportion of legume in the diet (NRC, 2007, p 34). Adopting the equation developed by Teixeira *et al.,* (2011), and factors suggested by NRC (2007) such as relative size, digestibility and legume proportion, an empirical model to predict DMI of a growing kid could be written as Equation 2.4 developed from NRC (2007) and Teixeira *et al*., (2011):

$$DMI\ \left(\frac{kg}{d}\right) = 0.04 \text{ x } SRW \text{ x } \left(\frac{N}{SRW}\right) \text{ x } \left(1.7 - \frac{N}{SRW}\right) \text{ x } [(1 - 1.7 \text{ x } (0.8 - Dig) + 0.17L]$$

Equation 2. 4

where all the abbreviations are as have been previously described.

The NRC (2007) has proposed an intake adjustment factor for does grazing on pasture, in which the number of kids the doe is suckling as well as days since kidding is included in the model:

$$I = 1.0 + 0.025\, n\, T^{1.4e(-0.05T)}$$

Equation 2.5

where *'n'* has a value of 1.0 for a doe with a single kid and 1.35 for a doe with twins, and *'T'* refers to time (days) since kidding.

The model used to predict intake of growing kids may be applied to lactating does by incorporate these inputs. A similar model can therefore be proposed for lactating does by including the intake factor to predict DMI of a lactating does could be used as Equation 2.6 that developed from NRC (2007):

$$DMI\left(\frac{kg}{d}\right) = 0.04 \text{ x } SRW \text{ x} \left(\frac{N}{SRW}\right) \text{x } \left(1.7 - \frac{N}{SRW}\right) \text{x } [(1 - 1.7 \text{ x } (0.8 - Dig) + \ 0.17L] \text{ x } \ (1.0 + 0.025\, n\, T^{1.4e((-0.05T))}$$

Equation 2.6

where all the abbreviations are as have been previously described.

These equations showed that metabolisable protein (MP) content of the diet was not included. Previous studies, however, revealed that supplementation with sources of non-protein nitrogen, rumen degradable true protein and particularly undegraded dietary true protein, under a range of feeding regimes that are low in crude protein, can increase DM intake. As a result, productivity can increase (Lallo, 1996; Solomon *et al.,* 2008). These categories of protein/protein fractions alternately feed the rumen microbes with ammonia and amino acids, as well as provide dietary true protein to the small intestine for digestion and absorption. Collectively, these protein fractions, when combined with fermentable organic matter intake, are available as dietary metabolisable protein. Therefore, equations to predict intake and average daily gain must utilise a combination of input factors. These factors describe the intake of MP and ME as well as factors that represent the animal's physiological state, particularly relative body size and the demands of lactation, where appropriate. Therefore, predictive equations should be developed to predict DM intake based on the protein supplementation effect on MP as well as ME intake.

2.1.5 Meat goats' requirements for protein and energy and goats' productive responses to different concentrations of dietary protein and energy

2.1.5.1 Protein and energy requirements of meat goats

Nutrient requirements of meat goats, as published by the NRC (2007), comprised dry matter, energy and protein. Energy requirements were in the forms of total digestible nutrients (TDN) and metabolisable energy (ME). Protein requirements were published in the forms of some fractions. Crude protein (CP) is divided into its percentage of undegraded intake protein (UIP), metabolisable protein (MP) and degradable intake protein (DIP) (NRC, 2007). In the current study, undegraded dietary protein (UDP) is used instead of UIP and rumen degradable protein (RDP) is preferred over DIP. Requirements for energy and protein fractions for meat goats in different physiological states have been summarised in Table 2.2 from the NRC (2007) data.

Table 2.2 Intake, energy and protein requirements for meat goats (adopted from NRC, 2007)

Class	BW (kg)	DMI % BW	Energy requirements		Protein requirements where CP at ...			MP g/d	RDP g/d
			TDN kg/d	ME MJ/d	20% DM UDP g/d	40% DM UDP g/d	60% DM UDP g/d		
Pregnant does with twins									
Early	50	2.51	0.66	10.0	124	118	113	83	60
Late	50	2.69	0.89	13.4	183	175	167	123	80
Lactating does with twins									
Early	50	3.08	0.82	12.3	202	193	185	136	73
Late	50	2.96	0.78	11.8	148	142	135	100	71
Growing kids at body weight 25 kg and different ADG (g/d)									
0	25	2.70	0.33	5.1	51	49	47	34	30
25	25	3.03	0.37	5.6	66	63	60	44	34
100	25	2.92	0.49	7.4	111	106	102	75	44
150	25	3.38	0.56	8.5	141	135	129	95	51

BW = body weight, DMI = dry matter intake, TDN = total digestible nutrients, CP = crude protein, UDP = undegraded dietary protein, MP = metabolisable protein, RDP = rumen degradable protein and ADG = average daily gain

When DM intake of any grass in Table 2.1 was known then the intakes of ME and CP of the grass could be compared with the requirements in Table 2.2 to see if the goats' requirements for ME and CP were being fulfilled. For example, Spear grass provided ME 8.9 MJ/kg DM and CP 26 to 84 g/kg DM (Table 2.1). If a 25 kg growing kid were to eat the grass as much as 3% BW, the kids would have DM intake 750 g/d, ME intake 6.7 MJ/d and CP intake of 75 g/d. The ME intake of the goat seems to be sufficient for a live weight gain of 50 g/d but the CP intake shows that the goat was likely to lose weight during the dry months and grow at a rate of 50 g/d during the rainy months. One of the drawbacks found from Table 2.1 was that the protein fractions of UDP, RDP and MP of the grass were not available to adequately predict average daily gain. This reinforces that the two basic needs in the preparation of the ration in meat goat production in East Nusa Tenggara are protein supplementation during the dry season and determination of protein fractions of the feedstuffs.

Scientific studies and operational meat goat farm diet formulations were usually aimed at meeting CP and energy requirements, in order to increase intakes and growth of the animals. However, the goats sometimes failed to eat as much as managers/scientists expected and failed to grow at the expected rate. This could be due to the fact that ME intake may not have been sufficient, despite DM intake having been fulfilled. Similarly, it could be due to insufficient MP, although the CP intake was achieved. Table 2.2 reveals that if the percentage of UDP is low, the dietary CP should be increased to enhance the kids' ADG, as has been studied in desert goats (Al Jassim *et al.,* 1991a). The importance of RDP is to supply the rumen's microorganism requirement for ammonia, amino acids and peptides that later will be used by the animal in the form of MP (Das *et al.,* 2014; McDonald *et al.,* 2011). Therefore, ration formulation to meet animals' nutrient requirements should be based on ME and MP instead of DM and CP. Estimation of MP, however, requires knowledge of the fermentable organic matter provided by the diet as well as its RDP and UDP concentrations.

2.1.5.2 Productive responses of pregnant meat goats to protein and energy diet

During the pregnancy period, the growth and development of the foetus depends partly on the nutrients and oxygen supplied from the doe to kids through the placenta (Wu *et al.,* 2006). This means that glucose and amino acids (Bell, 1995) should be sufficiently available from the diet. If not available, a metabolic adaptation would take place, where glucose is synthesised by gluconeogenesis in the liver and its usage from peripheral tissue is reduced, while fatty acids are drawn from adipose tissue and amino acids are catabolised from muscle (Bell, 1995). This adaptation may cause the pregnant doe to experience metabolic diseases. Deficient supply of protein and energy to the doe also can cause decreased birth weight in kids. For example, He *et al.,*, (2013 reported that the birth weight of kids from pregnant does fed a control diet that met energy and protein requirements was 1.8 kg. This was higher than 1.5 or 1.6 kg of kids from does on restricted protein or energy, respectively.

Contrary to expectations, Acero-Camelo *et al.,* (2008) was unable to enhance birth weight of the kids, despite the dietary ME of grazing does being increased from 3.8 to 7.5 MJ. This study documented the following results: litter size (1.6 vs. 1.3) and twinning rate (60 vs. 33%) were recorded for high and low energy, respectively, indicating that energy supplementation brings the birth of more twin kids per doe. The work of Nogueira *et al.,* (2017) supported the results of the previous study, reporting that ovulation rate was stimulated by offering maize to meat goats as a source of ME.

2.1.5.3 Productive responses of lactating meat goats to protein and energy diet

Lactating does grazing on tropical native pasture may not secrete sufficient milk for the suckling kids if the protein and energy consumed by the does are less than protein and energy requirements suggested by NRC (2007). The impact on animal productivity could be negative, for instance, the capability of a Boer doe to secrete milk up to 2.5 kg/d; containing 4.3% CP and 7.7% fat (Casey and Van Niekerk, 1988) may not be attained. Greyling *et al.,* (2004) recorded only 0.8 L/d of milk from grazing Boer does on pasture containing CP 67 g/kg DM, but when does were fed a complete diet containing CP 140 g/kg DM and ME 8.9 MJ/kg DM, 3.1 L/d of milk was recorded. The authors found a similar milk protein (5%) and a different milk lactose (4.5 vs. 5.0 %) for the two groups, respectively, suggesting that protein and energy supplementation most likely enhanced milk production and milk lactose but not milk protein content. Goetsch *et al.,* (2014) reported that kids' ADG of does browsing mimosa (*Albizia julibrissin* Durazz) trees twice a week, or once a week, or offered a supplement block, was 134, 120 and 111 g/d, respectively. These values were assumed to represent the amount and quality of milk suckled from the does which were offered a supplementation diet.

2.1.5.4 Productive responses of growing meat goats to protein and energy diet

Boer goats have a genetic potential to grow at an average rate of 124 g/d from birth to 41 kg. The goats grew very slowly (62 g/d) in the early stage (from birth to 10 kg), but faster (194 g/d) at the late stage (32 to 41 kg) (Van Niekerk and Casey, 1988). As a result, the NRC (2007) suggested providing an appropriate dietary protein and energy concentration in order to produce a certain ADG. Ghani *et al.,* (2017) fed two groups of crossbred Boer goats, one group with dietary CP 140 and another with 160 g/kg DM, and the authors found that ADG was increased linearly over seven months from 37 to 83 g/d and from 53 to 126 g/d for the two groups, respectively. The growth rate, however, was not only affected by the level of dietary CP: the protein degradability in the rumen also affected the growth rate, as shown in the study by Al Jassim *et al.,* (1991b) on sheep and goats.

Energy supplementation for grazing goats on pasture increased ADG, having a positive effect. Tadesse *et al.,* (2016) enhanced the ADG of indigenous goats grazing on pasture to 51 g/d by offering the goats a concentrate at the rate of 1.5% BW. Another study using Mubende and Mubende x Boer goats grazing on pasture showed that supplementation with concentrate and molasses significantly elevated the ADG (Asizua *et al.,* 2014). However, the effect of metabolisable energy (ME) on kids' ADG does not seem to be linearly related. A study on

Kamori kids (Abbasi *et al.,* 2012) discovered that the higher the energy content in the ration, the less the kids ate, but their ADG was the highest (257 g/d), compared with that in the medium group (235 g/d) and low group (158 g/d). Another study on energy supplementation for Boer goats in feedlots with dietary ME 11.3, 12.0 and 12.7 MJ/kg feed (Brand *et al.,* 2017), found that the goats' ADG on the three dietary energy levels was 222, 234 and 202 g/d, respectively. This growth pattern, where the highest ADG was recorded for 12.0 instead of 12.7 MJ dietary ME, supports the recommendation of the NRC (2007) to provide certain amounts of ME in goats' diet to yield a certain ADG in the growing goats. Energy supplementation above the animals' requirements was likely unnecessary.

2.1.5.5 Feeding to achieve good carcass weight and yield

As implied, the purpose for raising meat goats is to supply red meat as a food protein source for consumers. In order for goat producers to meet the market demand there should be a guiding standard for carcass yield. A basic set of categories for goat meat was developed by AUS-MEAT (Daniel n.d), and is based on dentition and hot standard carcass weight (HSCW). For example, dentition 1 - 2 is categorized as 'capra GC' for female or castrate male that has 1 to 2 permanent incisor teeth. In addition, there is a supplement-specific category for kid goats without permanent incisor teeth. This group is categorised as 'capretto kid GK', in which a slaughter kid's HSCW classifies them as 6, 8, 10, or 12, indicating kilograms of carcass weight (Daniel, n.d).

Currently, the nutritional management regime applied to meat goat production typically takes two years (Fuah and Pattie, 1992) or until the formation of four permanent teeth to produce an acceptable animal for meat production. The regimes available to farmers in East Nusa Tenggara have been shown to achieve an acceptable carcass in 12 to 15 months with better nutrition. The challenge then is to understand those nutritional principles that allow for improved productivity. The MP and ME system used by NRC (2007) is certainly a significant improvement over the use of the CP and dry matter intake systems currently used by the farmers in the goat meat sector in Indonesia. Studies have shown that meeting the ME requirement by providing sufficient ME in the diet of meat goats for maintenance and growth results in more daily gain and more muscle in the carcass. Solaiman *et al.,* (2011) reported that Boer goats had a hot carcass weight (HCW) of 18.2 kg at seven months old when fed concentrate and hay at a ratio of 80:20. Sheridan *et al.,* (2003) found that, at the age of 6.5 months, the HCW of Boer goats had increased from 15.3 to 17.1 kg as the dietary energy changed from 9.9 to 12.1 MJ/kg

DM. These studies revealed that goats are liable to have heavier carcasses at the same age if dietary ME sufficient for maintenance and productivity is supplied.

Feeding meat goats with a well-balanced ration to meet their MP and ME requirements (NRC, 2007) is recommended, as MP and ME would provide sufficient amino acids and adenosine triphosphate (ATP) to build up muscle (Hocquette *et al.,* 1998), and so HCW would be increased up to the meat goats' potential. However, research in MP on meat goats is rarely reported as compared to dairy cattle. Rashid *et al.,* (2016b) reported a well-balanced diet (ME 11.3 MJ and CP 154 g/kg DM) yielded 8.5 kg HCW for nine-month-old Black Bengal goats. Qualifying diet as balanced based on ME and CP seemed inappropriate, as an ideal balanced diet should be well matched between ME and MP. Formulating a diet based on protein fractions including RDP, UDP and MP to couple with ME as recommended by NRC (2007) will achieve this goal. AFRC (1993) suggested that MP should also include microbial crude protein (MCP). Assuming that MCP and protein from forages are adequately complementary to meet the MP required by the animal, then the animal is likely to reach acceptable carcass weights at a young age.

Meat goats that are offered sufficient MP and ME will achieve a slaughter weight and saleable carcass size at young age. These animals have a developed intermuscular and subcutaneous fat, qualities that determine good goat meat quality. Muscle development is easily measured by eye. The muscle area at the *longissimus dorsi* muscle of the caudal site of the 12th rib can be estimated, while fat thickness can be measured at the point of 110 mm from *spinous* to *transverse process* (White and Holst, 2006). In addition to muscle and fat quality, the protein and fat content of the carcass can be considered. Studies showed that an increase in the dietary protein content of indigenous Tanzanian goats (Mtenga and Kitaly, 1990) or an increased CP intake of Creole kids (Limea *et al.,* 2009) had no effect on the CP of the carcass. Madruga *et al.,* (2008) fed Moxotó and Canindé goats with a diet containing CP 195 g/kg DM at restricted feeding level but failed to show that feed restriction decreased protein content of goat meat. By comparison, other studies on South East African goats and their crossbred with Norwegian goats (Hozza *et al.,* 2014) or Canindé, Moxotó and Boer (Lopes *et al.,* 2014) showed that feed restriction significantly reduced meat protein from 22 to 19% and 18.1 to 16.3%, respectively.

Restricted feeding was actually aimed to increase protein but to reduce fat on the carcass (Hocquette *et al.,* 2001). In the study of Hozza *et al.,* (2014), the increased meat fat and the decreased meat protein were in line with the increased ME intake. Others (Mahgoub *et al.,* 2004; Sheridan *et al.,* 2003) supported the finding that increasing energy in the diet resulted in higher fat-content meat. Therefore, protein supplementation for meat goats on low energy and low protein tropical grasses should also consider the availability of energy. An excess of protein would be used as an energy source (McDonald *et al.,* 2011) or wasted through creatinine and urine (Sherwood *et al.,* 2005).

2.1.6 Conclusion

The higher meat goat population in tropical regions indicates that meat goats are well adapted to tropical conditions, giving farmers an opportunity to improve meat goat productivity in this environment. Australia has grasped this opportunity and become the largest goat meat exporter in the world, with its meat goat population rising to approximately six million in 2011 (MLA, 2016). Indonesia also took advantage of this opportunity by raising about 18 million meat goats in 2013 (Livestock and Animal Health Statistics, 2017). Of these, about 592,000 were raised in the East Nusa Tenggara region. These goats raised in Indonesia are for domestic consumption. This population increase was supported by the goats' genetic potential, where each doe usually gives twinning births if supported by good nutrition (Nogueira *et al.,* 2017).

Goats have eating patterns involving browsing on trees, shrubs and, selectively, on high-quality grasses because they have small flexible lips compared to cattle (NRC, 2007). In addition, Lu (1988) reported that goats prefer leaves to stems and green to non-green forages depending on seasonal nutrient supply. These eating behaviours are opportunities to increase meat goat productivity in the tropics because goats are able to select the most nutritious parts of the forages even during the dry season when the forage quality was generally lower.

The productive responses of meat goats are associated with dietary protein and energy concentrations for all physiological states. Pregnant does fed with high concentrations of ME most likely will have twinning births (Nogueira *et al*., 2017). Lactating does grazing on pasture containing high CP and ME produce more milk as compared those grazing on pasture containing low CP and ME. Legume supplementation to the lactating doe was also found to increase the live weight gain of suckling kids (Goetsch *et al*., 2014). Supplementation to increase MP and ME concentrations in goats' diets was reported to increase live weight gain of growing kids and carcass weight (Solaiman *et al*., 2011; Sheridan *et al*., 2013). These examples revealed that there is opportunity to increase meat goat productivity on tropical pasture by increasing dietary protein and energy concentrations.

2.2 Opportunities to Use Metabolisable Protein and Metabolisable Energy Systems to Improve Meat Goat Productivity from Tropical Pastures

2.2.1 Introduction

Section 1 identified that one of the problems causing a decrease in meat goat productivity in tropical pastures were the lower protein and energy concentrations of tropical grasses than are required by goats, as suggested by the NRC (2007). Supplementing with protein and energy sources sometimes fails to increase the productive responses of the goats. This failure is due to the fact that the protein feedstuff consists of different fractions, such as RDP, UDP and MP, which may be sufficient in the diet but insufficient for the requirements of rumen microorganisms in animals. Similarly, the goats may have sufficient dry matter intake but less fermentable organic matter in the rumen, which will supply less ME for maintenance and growth.

The implementation of MP and ME systems requires basic knowledge of how to evaluate the following: what are the MP and ME concentrations of the tropical forages, what are the MP and ME requirements of the goats, and can the intakes of MP and ME predict the ADG of the goats? Different methods are available to evaluate the MP and ME concentrations of forages. NRC (2007) has published the MP and ME requirements for meat goats, which should also be applicable for tropical conditions. Section 2, therefore, validates the methods to evaluate the MP and ME concentrations of tropical grasses, validates the MP and ME requirements by growing meat goats, and predicts the goats' ADG using the MP and ME systems. The objective was to determine if the use of MP and ME systems is an opportunity to improve meat goat productivity from tropical pastures.

2.2.2 Validation of the metabolisable protein (MP) content in tropical grasses and legumes

The NRC (2007) has published nutrient compositions of common feedstuffs, from which the MP concentration of feedstuffs can be quoted to formulate a diet for meat goats. Three problems remain: 1) the methods to determine the MP content of the published feedstuffs are different; 2) not all feedstuffs, especially tropical grasses and legumes, have been published; and 3) there is change from CP to MP in the animal's body. These problems highlight the need to understand how the MP content of feedstuff is determined.

2.2.2.1 Methods to determine the metabolisable protein content of feedstuff

Metabolisable protein is defined according to its origin, process and function in the animal's body. Metabolisable protein is true protein or amino acids derived from eaten dietary protein and rumen microbes, which are digested after the rumen and absorbed in the small intestine and used in the metabolism process, especially for maintenance and production (AFRC, 1993, NRC, 2007, McDonald *et al.,* 2011, Das *et al.,* 2014). This definition signals that efforts to measure the MP content of a certain feedstuff require the measurement of undegraded dietary protein (UDP) and microbial crude protein (MCP). Six methods that available to determine the MP content of feedstuff are dicussed.

2.2.2.1.1 In vivo method to determine MP content of feedstuff

The *in vivo* method uses live animals which are cannulated in the rumen and small intestine because the MP concentration of feedstuff is measured to determine the degradability of feed in the rumen and its absorption in the small intestine. Rumen degradable protein (RDP) is in the form of MCP, which is primarily measured using internal markers, such as diaminopimelic acid and nucleic acids, and external isotopic markers, such as ^{15}N and ^{35}S (Broderick and Merchen, 1992). The authors suggested calculating UDP as the difference between the total protein flow in the form of non-ammonia nitrogen (NAN) and MCP. Choi and Choi (2003) reported that components of soluble NAN are free amino acids, peptide and soluble protein, which can be assessed using a ninhydrin assay. If NAN and MCP have been determined, then the UDP should be easy to calculate. Another method to determine MCP synthesis is based on the ME concentration in the diet. There is approximately 8.25 g MCP/MJ of ME (CSIRO, 2007) or 9 to 11 g MCP/MJ of fermentable ME (AFRC, 1993). Because ME equals 0.16 DOMD or digestible organic matter on a dry matter basis (AFRC, 1993, CSIRO, 2007), the DOMD resulting from *in vivo* and *in vitro* studies can be useful for estimating the MCP. This method does not provide an empirical equation to calculate MP but it provides the UDP and MCP as components of MP.

2.2.2.1.2 In sacco method to determine MP content of feedstuff

The *in sacco* method requires rumen-cannulated animals. Approximately 5 g of feed samples are placed in nylon or Dacron bags for incubation in the rumen (Orskov and McDonald, 1970, Orskov *et al.,* 1980, AFRC, 1993). Although the feed sample is considered small, this method takes into consideration the dynamic conditions in the rumen, such as retention time, outflow rate, and lag phase (Orskov and McDonald, 1970). The protein fractions measured are water soluble nitrogen (*a*), potentially degradable nitrogen (*b*) and fractional rate of degradation of feed nitrogen per hour (*c*) (AFRC, 1993). There are more fractions described, which ultimately allow MP to be calculated as the sum of MCP and digestible UDP (AFRC, 1993). Krishnamoorthy *et al.,* (1983) divided the protein into soluble nitrogen, total nitrogen and acid detergent insoluble nitrogen (ADIN). Later, ADIN was one component for estimating the digestible UDP (known as DUP), as suggested by the AFRC (1993), where DUP (g/kg DM) equals 0.9 UDP minus 6.25 ADIN (Eq. 33).

2.2.2.1.3 In vitro method to determine MP content of feedstuff

The *in vitro* method was developed to simulate the degradation of feed in the rumen and digestive process by proteolytic enzymes in the small intestine (Tilley and Terry, 1963). This method is an alternative to the laborious and expensive use of cannulated animals. The protein content analysed from the incubation residue has been used to estimate the protein degradation of concentrate and grasses in sheep, even though the *in vitro* results were slightly lower than the *in sacco* results (Chaudhry and Mohamed, 2011). Some studies have shown enzymatic treatment as another method to estimate the digestibility of protein in the small intestines. For example, Calsamiglia and Stern (1995) proposed a three-step *in vitro* procedure, in which the residue of a feed sample from rumen incubation was incubated further with pepsin, pancreatin and trichloroacetic acid. The proposed estimation of MP by the AFRC (1993) should be measurable using the *in vitro* method because the MP components, such as CP degradability in the rumen and digestible undegradable protein (DUP) in the small intestine, have been collected from this two-stage method. The comparison between MP *in vitro, in sacco* and *in vivo* is required to determine if the result vary widely.

2.2.2.1.4 Wet chemistry method to determine MP content of feedstuff

The wet chemistry method employs the work of Krishnamoorthy *et al.,* (1983) in order to determine the rumen undegraded dietary protein (UDP). The MP of feedstuff is not reported in wet chemistry results. However, equations and inputs are available to calculate the MP using the results from wet chemistry analysis. The AFRC (1993) proposed that UDP (g/d) equals CP minus RDP (Eq. 31) and DUP (g/kg DM) equals 0.9 UDP minus ADICP (Eq. 33). The NRC (2007) proposed that the MCP equals 0.13 TDN if energy is the limiting factor and the MCP equals 0.85 RDP if protein is the limiting factor. Using all these inputs and equations, the MP can be estimated as MP (g/d) = 0.6375 MCP + DUP (AFRC, 1993) Eq. 23.

2.2.2.1.5 Near infrared reflectance spectroscopy (NIR) method to determine MP content of feedstuff

The principles, practices and application of the NIR method have been explained (Givens *et al.,* 1997). One of the advantages of NIR is the absence of chemical analysis. It uses the wavelength of infrared light when the electromagnetic radiation interacts with the elements of feedstuff, such as carbon, hydrogen, and nitrogen (Stuth *et al.,* 2003). Therefore, protein, fibre and energy of forages can be detected (Dryden, 2003). Reports provided as part of the NIR's service to laboratories include rumen degraded protein but not MCP. The NRC (2007) suggests estimating rumen microbial synthesis as 0.13 TDN intake or 0.85 RDP intake. The results of the MCP estimation then can be incorporated into the rumen undegraded protein to determine the MP, but calibration with data of other methods is required (Klopfenstein *et al.,* 2001).

2.2.2.1.6 Digestible protein as a predictor of MP content of feedstuff

Unlike all other methods, the NRC (2007) process estimates the MP of feedstuff from the apparent digestibility of protein. The method is based on data that show 90% of the CP diet is truly digested, about 3% of CP disappears in faeces and 70% of digestible protein is metabolisable. The suggested equation is

$$\boldsymbol{MP}\ \left(\frac{\boldsymbol{g}}{\boldsymbol{d}}\right) = \left((\boldsymbol{CP}\ \mathbf{x}\ \mathbf{0.9}) - \mathbf{3}\right)\mathbf{x}\ \mathbf{0.7})$$

Equation 2.7

This is a practical and simple method. Once the protein digestibility of feedstuff is known, the MP of the feedstuff can be estimated. However, the estimation results may cause bias because the chosen fixed factor of 0.9 applies for the apparent digestible protein for all feedstuffs. This will result in a similar MP value for a rapidly soluble protein source, such as urea and a slowly degraded protein source, such as legume. Another downside of this method is that it only considers metabolic faecal protein while losses through urine and methane are ignored.

2.2.2.2 Changes of crude protein to metabolisable protein in the animal's body

Dietary crude protein (CP) supplied to animals is degraded, digested, absorbed, and metabolised to meet the animal's requirements and the waste is excreted. Figure 2.1 presents these changes that occur in the mouth, rumen, abomasum, small intestine, and animal's tissues (McDonald *et al.,* 2011).

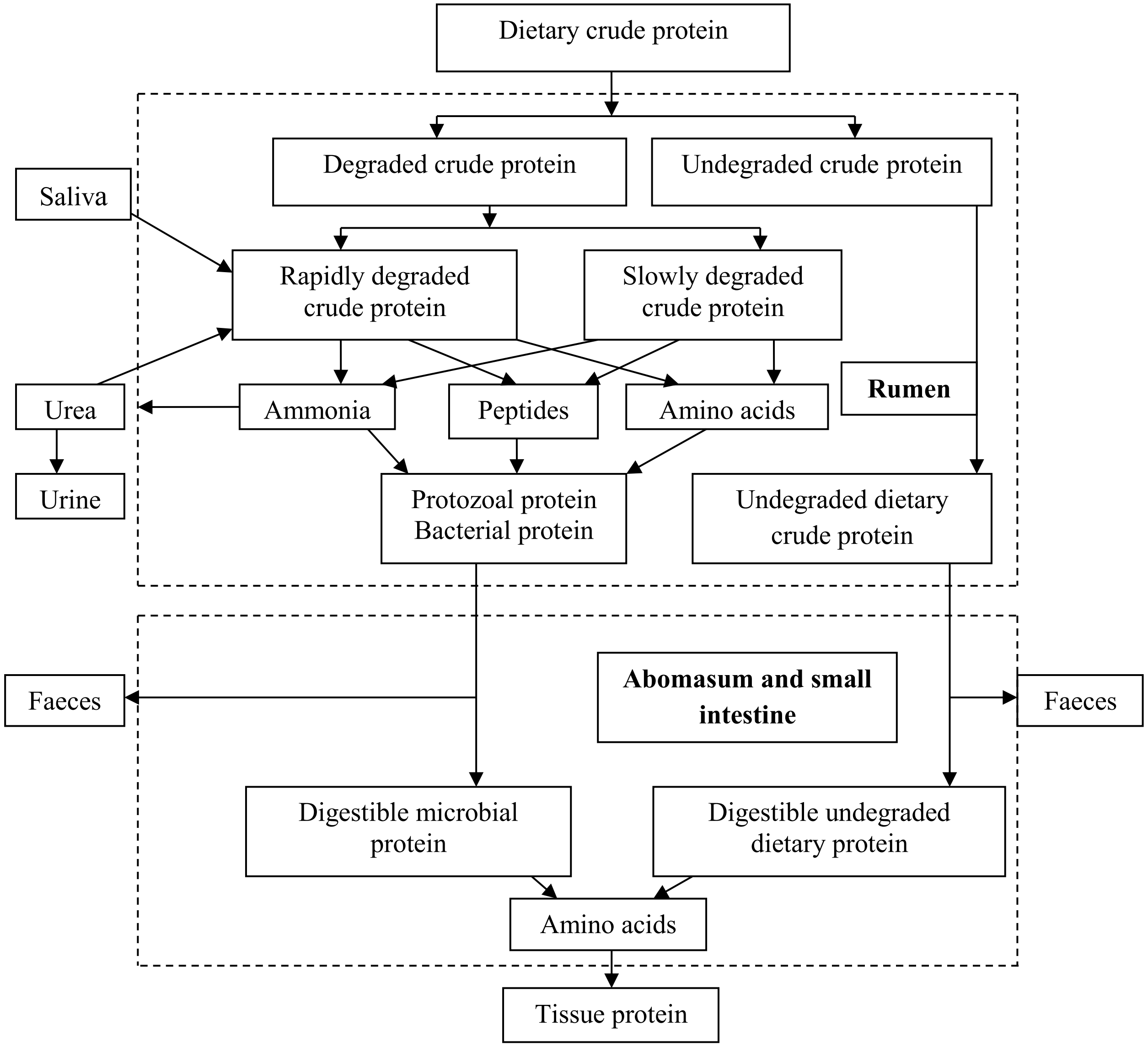

Figure 2.1 Changes in dietary crude protein in ruminants (McDonald *et al.,* 2011)

Protein supplementation does not appear to guarantee maximum animal productivity due to changes throughout the body. From diet to tissue, the eaten CP is converted to at least eight forms. In the mouth, the animal consumes dietary CP and it is degraded or undegraded as the ingesta is swallowed into the rumen (McDonald *et al*., 2011). The degradable protein is characterised by its rate of degradation; thus, there is rapidly or slowly degraded CP. Each of these two degradable forms of CP is converted to ammonia, peptides and amino acids, which are then utilised by rumen microbes as protozoal and bacterial protein. In the abomasum and small intestine, dietary CP is derived in the forms of digestible microbial crude protein (MCP) and digestible undegradable dietary protein. These two digestible proteins form amino acids, which are known as metabolisable protein (AFRC, 1993, NRC, 2007), and are absorbed and used as tissue protein. A dietary formulation to increase meat goat productivity should be based on MP instead of CP because MP is readily functioning for animals while CP is subject to changes.

2.2.2.2.1 Dietary crude protein

Dietary CP reflects the amount of nitrogen contained in the feedstuff. The nitrogen concentration is analysed using the Kjeldahl method and multiplied by a factor of 6.25 to derive CP, but the nitrogen includes urea, amides, nucleic acids, and free amino acids (AOAC, 1990). Diets for meat goats are usually formulated based on the CP content, and the level of dietary CP is increased to increase productivity. However, a higher dietary CP sometimes fails to increase goat productivity. For example, empty body weight and carcass weight of Tunisian kids was not influenced by the dietary CP level (Atti *et al.,* 2004). This failure of a CP effect on goats can be explained if the concentrations of other protein fractions, such as RDP, UDP and MP in the diet have been calculated, and are compared with the goats' requirements.

2.2.2.2.2 Degraded crude protein

Protein that rapidly or slowly degrades in the rumen becomes amino acids, peptides and ammonia, which are later used by protozoa and bacteria. This protein, termed rumen degradable protein (RDP) or degradable intake protein (DIP) (NRC, 2007) or ruminally degraded intake protein (DIP) (Soto-Navarro *et al.,* 2003), provides not only nitrogen for rumen microorganisms to function, but also supplies a moiety of MP for the host animal. In the current study, RDP is used. Different types of rumen microorganisms and fermentation products have been reported (Castillo-Gonzalez *et al.,* 2014). In the case of supplementing high dietary fibre grass with protein for meat goats, the yield of RDP by rumen microorganisms and volatile fatty acids (VFA) as an energy source from grass degradation are the important products (Thirumalesh and Krishnamoorthy, 2013). Satter and Slyter (1974) suggested dietary CP of 120 to 140 g/kg DM to yield the optimal production of VFA and NH_3-N. However, further work is needed to calculate the RDP supplied from any formulated ration, because the standard requirements of RDP by meat goats for maintenance and an expected body weight gain have been published (NRC, 2007).

2.2.2.2.3 Rapidly and slowly degraded crude protein

In the *in sacco* method, the rapidly degraded CP is the soluble component that is degraded rapidly in the rumen or is the water soluble nitrogen which escapes from nylon bags by washing with water without incubation in the rumen (Ørskov *et al*., 1980). Urea is one example of rapidly degraded CP, which will be converted to ammonia for the rumen microorganisms' needs, but if the energy is unavailable, the excess ammonia will be converted to urea and excreted through urine or recycled (Figure 2.1). Therefore, supplementing it to a fibrous feed should be coupled with sufficient energy; otherwise the goats will fail to gain weight (Laudadio and Tufarelli, 2010; Starke *et al.,* 2012). Patterson *et al.,* (2009) reported that Boer cross goats fed sorghum-Sudan hay and supplemented daily with 200 mg/kg BW of urea and 0.2% BW of dextrose had greater nitrogen retention and higher ADG compared to the goats on urea or dextrose only.

Slowly degraded CP is used to express the rate of degradation of nitrogen feedstuff every hour (AFRC, 1993). Kibont and Ørskov (1993) reported that *Sterculia setigera* increased the ADG of Borno goats at 62 g/d because of its slow and constant rate of degradation. Because the basal diet of goats is fibrous grasses that reside longer in the rumen, supplementing with this type of protein will offer more benefit by increasing the digestibility and ADG.

2.2.2.2.4 Protozoal and bacterial protein

Protozoal and bacterial protein forms MCP; only 75% is in the microbial true protein (MTP) and useful for tissue protein, while 25% is in nucleic acids, which cannot be used (AFRC, 1993). Approximately 85% of MTP is predicted to be digestible in the intestine, termed digestible microbial true protein (DMTP), and the AFRC (1993) suggested calculating it as follows:

$$DMTP\ \left(\frac{g}{d}\right) = 0.75 \times 0.85 \times MCP = \ 0.6375\ MCP\ (\frac{g}{d})$$

Equation 2.8

If the quantity of MCP is measured, then the amount of DMTP contributing to the MP can be calculated. Research data on the quantity of MCP at this stage is required, which depends on the level of feeding, rumen synchrony, forage quality and composition of supplements (Dewhurst *et al.,* 2000). Santos *et al.,* (2014) found that MCP yielded from goats fed Leucaena hay was 73 g/d, which is significantly higher than 64, 62 and 51 g/d for cottonseed meal, cassava hay and soybean meal, respectively. This finding highlights the idea of utilising the role of rumen microorganisms in enriching the MP for the goats using a low-cost protein supplement. Soto-Navarro *et al.,* (2003) concluded that highest MCP production was achieved when the diet for meat goats contained CP 90 to 100 g/kg DM and the RDP to TDN ratio was 0.073. The AFRC (1993) links the dependence of MCP to energy because every MJ of fermentable metabolisable energy intake yields 8 to 11 g MCP. McDonald *et al.,* (2011) reported that the amounts of MCP yielded from non-fermented feed, mostly feed, and rapidly fermented feed in the rumen are 130, 200, and 260 g/kg digestible organic matter, respectively. These findings highlight the association between OM digestibility, types of feed and MCP.

2.2.2.2.5 Undegraded crude protein

Undegraded crude protein is known as rumen undegradable protein (RUP), undegraded dietary protein (UDP) or undegraded intake protein (UIP). In the current study, the preferred term is UDP. This protein fraction is detected in the residues of feed samples after incubation from the *in vitro* or *in sacco* methods. The standard requirement for CP by goats has been based on the percentage of UDP, in which the requirement for CP increases with decreasing UDP in the diet (NRC, 2007). This standard shows that a ration formulation based on CP should be complemented with the UDP content of the ingredients, which can be found in published studies or independently determined. Serrato-Corona *et al.,* (2010), reported that lactating goats supplemented with 35, 30 and 25% UDP have 75, 15 and 44 g/d of ADG. Al Jassim *et al.,* (1991b), reported that higher dietary UDP enhanced nitrogen retention in sheep and goats but a lower dietary UDP increased dry matter, organic matter and fibre digestibility. These two studies showed that low and high dietary UDP have a positive effect on the goats' productive responses. Because some studies were concerned about the inefficiency and high cost of high-quality protein supplements such as soy bean meal (Brun-Bellut *et al.,* 1990), formaldehyde was used to protect the feed supplement from rumen microorganism degradation. However, for small-scale goat farming in the tropics, the use of legumes instead of formaldehyde-treated soy bean meal would be reasonable, practicable and cost-effective, provided that the protein degradability of the legumes has been determined (Kabi *et al.,* 2005, Morales *et al.,* 2008).

2.2.2.2.6 Digestible undegraded dietary intake protein

The real quality of the UDP of feed is determined by the amount digested in the abomasum and small intestine, which primarily occurs due to enzymatic activity. Enzymatic activity breaks down protein into amino acids with secretions from the pancreas and enzymes of trypsin and pepsin (NRC, 2007). Digestibility in the small intestine is usually measured from the duodenum and ileocecal junction using a mobile nylon bag technique (McDonald *et al.,* 2011). In the *in vitro* system by Tilley and Terry (1963), digestion in the abomasum and the small intestine was mimicked using hydrochloric acid (HCl) and pepsin. Another *in vitro* study using a three-step enzymatic procedure - *Streptomyces griseus* protease, pepsin HCl, and pancreatin solution - (Hippenstiel *et al.,* 2015) found that the intestinal protein digestible of the UDP of a few feedstuffs varied widely between 500 and 800 g/kg CP. The AFRC (1993) estimated digestible undegraded intake protein (DUP) as 90% (UDP – 6.25 ADIN, acid detergent insoluble nitrogen).

2.2.2.2.7 Amino acids or metabolisable protein

In the abomasum and small intestine, the sum of digestible microbial true protein (DMTP) and digestible undegraded intake protein (DUP) is the metabolisable protein (MP) or amino acids. The AFRC (1993) proposed the following equation:

$$\boldsymbol{MP\ \left(\frac{g}{d}\right) = 0.6375\ MCP + \ DUP}$$

Equation 2.9

where MP refers to metabolisable protein; 0.6375 MCP is as explained in Equation 2.8, and DUP refers to the digestible undegraded intake protein.

The NRC (2007) proposed an equation to calculate MP as

$$\boldsymbol{MP}\ \left(\frac{g}{d}\right) = (\boldsymbol{DP}\ \mathrm{x}\ \mathbf{0.7}))$$

Equation 2.10

where DP refers to digestible protein predicted from CP, assuming that 90% is truly digestible and 3% is metabolic faecal protein.

The two methods to calculate the MP are clearly different. Up to this point, the MP (amino acid) appears to be an ultimate form of protein feedstuff ready to be absorbed in the small intestine, enter the blood or lymphatic system then to be distributed to the body (NRC, 2007). Therefore, measuring the MP of feedstuff is likely to be a better method for three reasons. First, the MP of feedstuff is actually used by goats while others, as described earlier, are subject to change. Second, a diet formulation based on MP should be as simple as the CP-based diet once the protein fractions are determined. Finally, the formulated dietary MP can be adjusted to meet the required standards proposed by the NRC (2007).

2.2.3 Validation of metabolisable protein requirement by growing meat goats and prediction of ADG

2.2.3.1 Validation of metabolisable protein requirements by growing meat goats

Once the MP has been absorbed in the small intestine, it goes through the blood or lymphatic system to be distributed throughout the animal's body. The amounts of MP required for the maintenance (MPm) and growth (MPg) of meat goats have been published (NRC, 2007). These values are based on other predictions (Luo *et al.,* 2004b) of regression between the MP intake and ADG.

Table 2.3 Some examples of actual and predicted ADG of crossbred Boer goats based on predicted MP intake

Study	MP diet (g/kg DM)	Predicted MP intake (g/d)	MPm (g)	MPg (g)	Predicted ADG (g/d)	Actual ADG (g/d)	Bias (g/d)
1	71	52	27.4	17.1	42	76	-34
1	107	76	27.4	34.1	84	90	-6
1	144	100	27.4	51.0	126	30	41
1	191	142	27.4	80.0	198	86	98
2	114	131	34.2	67.7	167	53	115
2	114	96	29.9	46.3	115	32	83
3	93	108	33.9	52.1	129	147	-18
4	92	83	36.8	32.2	80	33	47
4	132	125	36.8	62.0	154	49	105
4	132	121	36.8	58.7	145	38	107
4	168	151	36.8	79.6	197	51	146
5	116	94	30.1	44.4	110	99	11
5	109	84	30.1	37.8	94	88	6
5	109	86	30.1	39.1	97	83	14
5	110	74	30.1	30.9	76	67	9
6	130	115	29.0	60.1	149	103	46
6	130	124	29.0	66.4	164	129	35
6	130	139	29.0	76.9	190	171	19

1. Four groups of 24 heads of ¾ Boer x ¼ Spanish and 24 heads of Spanish wethers were fed grass hay and a concentrate mixture with dietary CP 102, 142, 183, and 236 g/kg DM (Prieto *et al.,* 2000)
2. Nine heads of 50% Boer x Dorper and 9 heads of 25% Boer x Dorper were offered native grass and concentrate to form a dietary CP of 150 g/kg DM (Tilahun *et al.,* 2014)
3. Six purebred Boer were fed with Bermuda grass hay and concentrate with dietary CP 127 g/kg DM (Solaiman *et al.,* 2011)
4. Twenty four crossbred Boer wethers were offered Orchard grass hay and either soybean meal, soy hull mixture, wheat midd mixture or corn gluten feed mixture with dietary CP 125, 170, 170 or 210 g/kg DM (Moore *et al.,* 2002)
5. Twenty four pure Boer and 12 half Boer were offered Orchard grass hay and concentrate mix by increasing whole cottonseed level to form dietary CP 152, 144, 144, and 146 g/kg DM (Luginbuhl *et al.,* 2000).
6. Twenty four Boer bucks were offered basal diet without supplement or supplemented with dried *Andrographis paniculate* (AP) leaf powder or whole plant AP to form dietary CP 168 g/kg DM (Yusuf *et al.,* 2014)

The NRC 2007 values are useful as guidelines for predicting an animal's productivity. However, for a few reasons, the reliability of these standard values to the meat goat production system in the tropics is open to question. First, the MP requirement for tropical goats is different. The MPm and MPg for meat goats is 3.07 g/kg $BW^{0.75}$ and 0.404 g/g ADG (NRC, 2007). Salah *et al.,* (2014) reported that the MPm of meat goats in the tropics was 3.51 g/kg $LW^{0.75}$ and the MPg was 0.12 to 0.24 g MP/g ADG. Second, the methods for predicting the ADG are different. The NRC (2007) regressed MP intake on ADG while Salah *et al.,* (2014) regressed MP on nitrogen retention. Third, the goat production system in the tropics, Asia for example, relies on an extensive system (Devendra, 2007) while all the standard values were generated from intensive productive systems.

Some relevant studies (Table 2.3) have been compiled to compare the actual and predicted ADG based on the MP intake. The dietary CP was converted to dietary MP as MP = ((CP x 0.9) – 3 x 0.7) (NRC, 2007) and the MP intake was predicted as a multiplication of MP diet by DM intake. Equation 2.11 can be used to predict the ADG for goats, assuming that the efficient MP intake for tissue accretion is 0.7 (NRC, 2007, p. 56). A slight difference for the MPm and MPg, however, would produce a deviation from the actual ADG.

2.2.3.2 Predicting the ADG of meat goats using the metabolisable protein systems

The fixed MP requirements partitioned for maintenance and growth for meat goats are 3.07 g/kg $BW^{0.75}$ and 0.404 g/g ADG (NRC, 2007). Using these two values, the actual measured ADG of a growing goat should be confirmed by the predicted ADG. In other words, live weight gain should be quantified based on MP intake in relation to fulfilment of MP requirements. Because growth resumes after the maintenance requirement is reached, an empirical equation to predict the ADG of growing meat goats can be expressed as

$$\boldsymbol{ADG = \left(\frac{MPI - MPm}{MPg}\right)}$$

Equation 2.11

where ADG refers to the predicted average daily gain (g/d), MPI to MP intake, MPm to MP for maintenance (3.07 g/kg $BW^{0.75}$), and MPg to MP for gain (0.404 g/g ADG).

Goats' ADG is predictable if the goats' requirement for MP is known. Although the MP system has been published (AFRC, 1993, NRC, 2007), the studies listed in Table 2.4 still formulate the ration based on the CP content of feedstuff. The diet formulation system makes linking the

ADG to the MP difficult. For example, a study on Boer goats showed a significantly different ADG, although the offered CP diet was similar (Yusuf *et al.,* 2014). This finding is likely to be associated with dietary MP concentration. Therefore, MP based diet should be used if ADG prediction is desired. Different methods that cause variability in the dietary MP concentration may result in an under or over prediction of MP intake, leading to significant variation between the actual and predicted ADG.

Several models are available to predict the ADG, such as the Small Ruminant Nutrition System version 1.9.4468 (http://nutritionmodels.tamu.edu/srns.html). In this model, under the two main variables, more variable inputs are required, namely the animal and feedstuff. In comparison, Equation 2.11, which was developed based on the NRC (2007) model, is simpler and more applicable.

2.2.3.3 Blood plasma metabolites as indicators of protein metabolism

2.2.3.3.1 Total Protein

The normal total protein of blood plasma for a healthy goat is 64 to 70 g/L (Gwaze *et al.,* 2010). Several studies have found that the total protein of goats varied around this normal range and is related to gastrointestinal parasites (Gwaze *et al.,* 2010), physiological states (Janků *et al.,* 2011) or a combination of physiological states and feeding (Sahlu *et al.,* 1995, Chiofalo *et al.,* 2009).

Pregnant and parturient white shorthaired goats have similar total protein levels (61 g/L), but these increased to 65 and 71 g/L after a week and a month of lactation, respectively (Janků *et al.,* 2011). Chiofalo *et al.,* (2009) found a significantly higher blood serum total protein (59 g/L) in prepartum Maltese goats (-10 d to -1 d) fed vetch hay and concentrate, compared to 55 g/L for goats fed hay treated with propylene glycol. These values increased during the postpartum period (1 d to 40 d) but there was no significant difference (67 vs. 68 g/L), indicating that lactating goats may have a physiological mechanism to maintain their total protein level regardless of the feed process. As shown by a study on Maltese goats (Chiofalo *et al.,* 2009) and pregnant dairy goats (Sahlu *et al.,* 1995), it appears that increasing the dietary energy concentration lowers the total protein of blood plasma.

2.2.3.3.2 Blood Urea Nitrogen

A healthy goat has a blood urea nitrogen level of 3.6 to 7.1 mmol/L (Gwaze *et al.,* 2010). Sahlu *et al.,* (1995) studied dairy goats and reported that protein supplements enhanced their blood urea nitrogen, but within the normal range, compared to those with no supplements and a high ME feed (Sahlu *et al.,* 1995). Chiofalo *et al.,* (2009) reported similar findings, in which prepartum goats fed hay and supplemented with concentrate had similar blood urea nitrogen levels to goats with propylene glycol-treated hay (4.3 vs. 4.2 mmol/L). By comparison, the two groups of lactating goats on the two diets increased their blood urea nitrogen to 5.3 mmol/L. Bronzo *et al.,* (2010) reported that the plasma urea of dairy goats offered hydrogenated palm oil (PO) was 4.6 mmol/L during pre-partum and increased to 5.5 mmol/L during the post-partum period. These values were similar to those of goats offered protected fish oil (FO), namely 4.6 and 6.0, during the two periods. These studies showed that the blood urea nitrogen levels might be modified by protein supplementation but not by energy supplementation, and that lactating animal has a separate bodily mechanism that is not dependent on dietary protein to enhance blood urea nitrogen levels.

2.2.4 Validation of metabolisable energy content in tropical grasses and legumes

Metabolisable energy is the difference between the gross energy in feedstuff and energy recorded for faeces, urine and combustible gas. It is the energy retained in the body to maintain bodily functions and growth (NRC, 2007, McDonald *et al.,* 2011). This ME definition suggests that efforts to determine the ME content in feedstuff should measure the gross energy of the feed, faeces, urine and gas. Practitioners who want to quote the ME content of certain feedstuff in formulating goats' diet should be aware of the different methods used to determine the ME concentration of the feed and the changes in energy in the animal's body when the feed is eaten.

2.2.4.1 Methods to determine the metabolisable energy content of feedstuff

2.2.4.1.1 Digestible energy as a predictor of ME feedstuff

Digestible energy (DE) represents the difference in gross energy in feed eaten and the gross energy in faeces excreted by the animals (McDonald *et al.,* 2011). The general equation to predict ME is ME (MJ) equals 0.82 DE because the energy loss through urine and methane is assumed to be 0.18 (CSIRO, 2007, NRC, 2007, McDonald *et al.,* 2011).

2.2.4.1.2 *Digestibility of DM, OM and OMD as a predictor of ME feedstuff*

The metabolisable energy content of roughage can be estimated using the digestibility of dry matter (DMD), organic matter (OMD) and organic matter based on dry matter or DODM (CSIRO, 2007). This ME estimation is based on the apparent digestibility of a basal diet as a single ingredient. If concentrated feed is included in the basal diet, digestibility data for the feed concentrate can be measured using the difference technique proposed by Khan *et al.,* (2003). Equations proposed by CSIRO (2007) to estimate ME roughages based on digestibility are ($ME = 0.172\ DMD - 1.707$), ($ME = 0.169\ OMD - 1.986$) and ($ME = 0.194\ DODM - 2.577$). Bruinenberg *et al.,* (2002) calculated the ME of grass (kJ) as 14.2 x DOM + 5.9 x DCP. Other studies generally predicted the ME feed as ($ME = 0.16\ DOMD$) (AFRC, 1993). The NRC (2007) estimated that each kilogram of total digestible nutrients (TDN) contains 15.06 MJ of ME. The fact that volatile fatty acids and glucose, as the two energy sources for the animals, are yielded from the fermentation of organic matter in the rumen and their digestion in the small intestine (McDonald *et al.,* 2011), explains the reason for using digestibility to estimate the ME of feedstuff.

2.2.4.1.3 *In vitro digestibility as a predictor of ME feedstuff*

Similar to the *in vivo* digestibility study, the dry and organic matter digestibility from the *in vitro* method (Tilley and Terry, 1963) can be used to calculate the ME using previously described equations: ($ME = 0.172\ DMD - 1.707$), ($ME = 0.169\ OMD - 1.986$) and ($ME = 0.194\ DODM - 2.577$) or ($ME = 0.16\ DOMD$ (AFRC, 1993, CSIRO, 2007). Some studies (Getachew *et al.,* 2002, Hind *et al.,* 2014) employed the *in vitro* gas production technique and estimated the ME concentration of feedstuff from crude protein and crude fibre contents, as well as the amount of gas produced after 24 h incubation. As Getachew *et al.,* (2002) reported, there is a variation between forage and concentrate feed as well as the results reported by laboratories; therefore, the ME of *in vitro* studies should be validated.

2.2.4.1.4 *Feed composition as a predictor of ME feedstuff*

Another method to determine the energy of a feedstuff is based on its nutrient content. The NRC (2007) stated that the gross energy of feedstuff derived from each gram of glucose, starch, protein, and fat was 15, 18, 23, and 39 kJ/g, respectively. CSIRO (2007) reported the same values, in which each kilogram of carbohydrates, crude protein and fat has a gross energy of 17.6, 24 and 39 MJ, respectively. This implies that fibrous feed may have a low ME, protein-rich feed may have a medium ME, and fatty feed may contain a high ME. However, the gross energy of a feedstuff does not reflect its importance until it is eaten by an animal and its digestible energy and metabolisable energy are measured. Therefore, a comparison of the ME values collected from *in vitro* and *in vivo* studies is necessary.

2.2.4.2 Changes of gross energy to metabolisable energy in the animal's body

The energy content of feedstuff is usually expressed as the total digestible nutrient (TDN), digestible energy (DE), metabolisable energy (ME), and net energy (NE) (NRC, 2007), in addition to gross energy (CSIRO, 2007, McDonald *et al.,* 2011). Once eaten by an animal, the energy of feedstuff or diet changes to different forms (Figure 2.2).

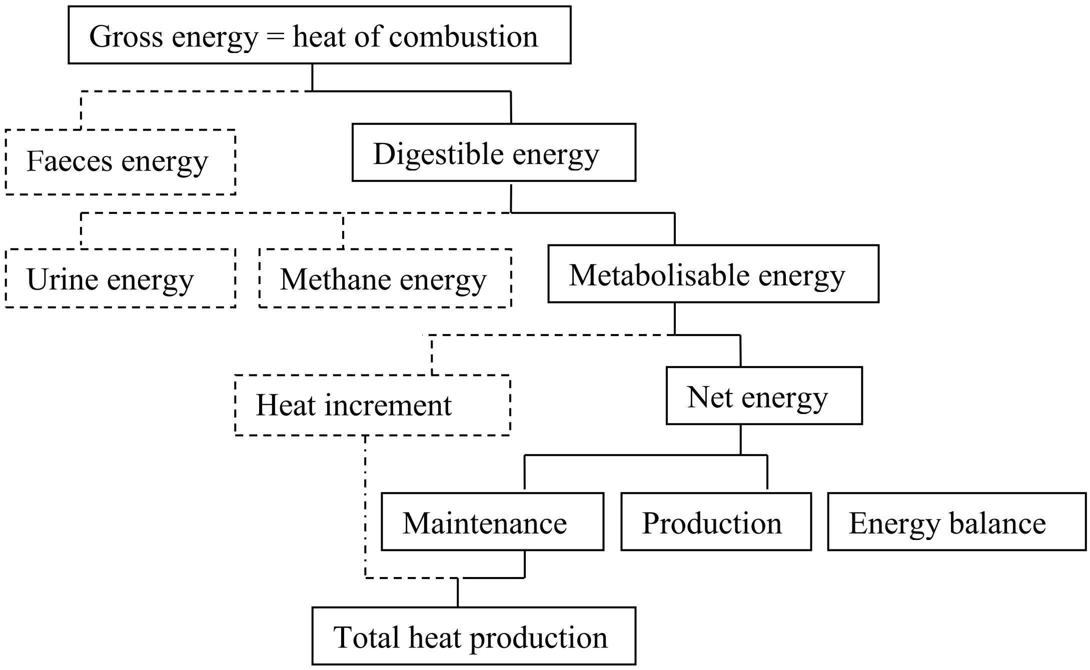

Figure 2.2 Energy partition of feedstuff. Losses of energy are shown in the boxes with broken lines (McDonald *et al.,* 2011)

2.2.4.2.1 Gross energy

The gross energy (GE) of feedstuff has rarely been reported, possibly because it does not reflect the amount of energy utilised by the animals. Some selected feed in the tropics, especially grasses, legumes and concentrates, contain a mean GE of 16.2, 17.5 and 19.5 MJ/kg DM, respectively (Mlay *et al.,* 2006). These values are not markedly different because all carbohydrates have similar ratios for carbon, hydrogen and oxygen, which, when oxidised, will give the same heat (McDonald *et al.,* 2011). The importance of GE would technically be visible when used as an input to calculate the DE and ME (AFRC, 1993) or predict methane production (Charmley *et al.,* 2016). A method to determine the GE is carried out by using a combustible adiabatic calorimeter (AFRC, 1993, McDonald *et al.,* 2011). Another method is based on measuring the concentration of glucose, starch, protein, and fat in feedstuff (NRC, 2007, CSIRO, 2007).

2.2.4.2.2 Digestible energy

Digestible energy is generally measured as the difference between the GE of feedstuff and faeces (*in vivo*) or, alternatively, *in vitro* with rumen fluid and enzyme, or by near-infrared reflectance spectroscopy (CSIRO, 2007). The ideal DE of feedstuff is derived from feeding goats with the selected single feedstuff and determining the energy from faeces and feed, but feeding goats with concentrate or supplement feed only is very expensive. Alternatively, these feeds are mixed into the diet. Khan *et al.,* (2003) suggested a method for calculation. However, there will be an associative effect (Sundstol, 1993), in which digestibility may increase or decrease due to the basal feed or concentrate feed. Using *in vitro* and enzymatic solubility methods, some grasses, legumes and concentrates in the tropics were estimated to contain DE 8.4, 8.9 and 14.5 MJ/kg DM, respectively (Mlay *et al.,* 2006). Compared to the GE (16.2, 17.5 and 19.5 MJ/kg DM), almost half of the energy for grasses and legumes, and only about one quarter of that for concentrate, was not digested.

The DE content of every single feedstuff from every reference might be different depending on the evaluation method. For example, Mlay *et al.,* (2006) and NRC (2007) reported that the DE of rice bran was 9.2 vs. 13.4 MJ/kg DM, and the DE of fish meal was 18.8 vs. 13.8 MJ/kg DM, respectively. These differences highlight that the DE content of one feedstuff obtained from published references and used in a diet formulation may be insufficient or exceed the animals' requirements. Therefore, a validated DE content of selected feedstuff in a diet of meat goats is required.

2.2.4.2.3 Metabolisable energy

Metabolisable energy is the amount of energy retained in the body and utilised for tissue, milk, and conceptus, or lost as heat (NRC, 2007). Technically, ME is the difference between GE feedstuff and DE plus energy in urine and combustible gas (AFRC, 1993, McDonald *et al.,* 2011). Alternate methods have been proposed because the *in vivo* method to measure the ME of feedstuff requires a laborious feeding trial in order to measure the energy in faeces, urine and methane gas. *In-vitro* gas production after 24 h incubation and crude protein feedstuff (Menke *et al.,* 1979) are commonly used for ME determination (Akinfemi *et al.,* 2012, Kumar *et al.,* 2015).

The ME content of common feedstuffs found in published books or articles is derived from different methods of measurement or prediction, which may account for the variation in ME of any single feedstuff. For example, Mlay *et al.,* (2006) reported that the ME content of fish meal and rice bran was 15.4 and 7.5 MJ/kg DM, whereas it was 11.3 and 10.9 MJ/kg/DM, respectively, in the list of common feed (NRC, 2007). Therefore, quoting the ME content of any feedstuff from published references in order to formulate a diet that fulfils the ME requirements of meat goats may not satisfactorily match goat productivity, in part due to the unreliability of the quoted values. In this case, the ME of feedstuff needs to be validated by different evaluation methods: *in vitro, in vivo* and *in sacco*.

2.2.4.2.4 Net energy

The net energy of feed is the amount of energy digested from the feed and used by the animal for maintenance and productivity (AFRC, 1993, McDonald *et al.,* 2011). Net energy is the difference between the ME and the heat increment. The heat increment is the energy in the form of heat produced over and above that of basal metabolism after a fasting animal eats a certain feedstuff (McDonald *et al.,* 2011). McDonald *et al*., (2011) explained further that this heat is derived from digestion and metabolism processes after eating. The authors reported that it is measured by way of comparative slaughter, respiration calorimetric and CO_2 entry rate, and was reported to amount to 298 kJ/kg $BW^{0.75}$ (Luo *et al.,* 2004a). The ME system proposed by the NRC (2007) to predict the average daily gain (ADG) of meat goats should be applied carefully because there are two forms of energy (net energy and heat increment) to consider.

2.2.5 Validation of metabolisable energy requirement of growing meat goats and prediction of ADG

2.2.5.1 Validation of metabolisable energy requirement by growing meat goats

The objective of determining the ME content of feedstuff is to ensure the fulfilment of the goat's ME requirement from the diet. After establishing the ME feedstuff, the next task is to determine the amount of ME required by goats for maintenance and productivity. The NRC (2007) published the ME requirement for meat, dairy, indigenous, and fibre goats based on physiological status, such as suckling, growing and maturing. Two ways of presenting data are the fixed values and tables of ME requirements. A growing meat goat, for example, was reported to have a fixed requirement of metabolisable energy for maintenance (MEm) 0.489 MJ/kg $FBW^{0.75}$ and growth (MEg) 0.0231 MJ/g ADG. From the requirement tables (NRC, 2007), a range of body weights has been derived from the position an expected ADG can be found to match the ME requirement. For example, a Boer goat weighing 20 kg, expected to gain weight at a rate of 100 g/d, was found to require ME 6.6 MJ/d (NRC, 2007).

These two data calculations from the NRC 2007 are useful in research and farming. Because the standard values were generated from data meta-analysis (Luo *et al.,* 2004c), it should represent a wide range of meat goat production systems. However, the values of MEm (0.489 MJ/kg $FBW^{0.75}$) and MEg (0.0231 MJ/g ADG) by NRC 2007 contradict the reports from tropical regions. Abate (1989) reported the MEm and MEg of goats in Kenya to be 0.556 MJ/kg $BW^{0.75}$ and 0.0279 MJ/g ADG. Salah *et al.,* (2014) reported a consistently high ME requirement for goats in the tropics of 0.542 MJ/kg $BW^{0.75}$ for MEm and 0.0243 MJ/g ADG for MEg. The factors determining these high requirements are presumably the activity, acclimatisation, and efficiency of the metabolism (NRC, 2007). Consequently, validation of the ME requirement for goats in the tropics is achieved through a production experiment or feeding trial.

2.2.5.2 Prediction of ADG using the metabolisable energy systems

If the ME requirements for the maintenance and production of growing meat goats are well established, the ME feedstuff well evaluated and the ME diet well calculated, then knowing the ME intake should allow a reliable prediction of the ADG. As the kids start growing, their MEm is met; hence the ADG can be predicted as follows:

$$\boldsymbol{ADG = \left(\frac{MEI - MEm}{MEg}\right)}$$

Equation 2.12

where ADG refers to the average daily gain; MEI, MEm and MEg refers to ME intake, maintenance (0.489 MJ/kg $BW^{0.75}$) and gain (0.0231 MJ/g ADG), respectively.

Some relevant studies have been carried out using Equation 2.12 and they showed that the ME model (NRC, 2007) can be used to predict the ADG of meat goats in the tropics (Table 2.4). However, when the kids' ADG were predicted using Equation 2.12, the values deviated widely from the actual values measured. Only two studies predicted less than 10% error, namely Sheridan *et al*., (2003) with dietary ME 12.11 MJ/kg DM and Rashid *et al*., (2016b) with dietary ME 10.28 MJ/kg DM. Most found between 20 and 50%, and the ADG of grazing goats (Study 2) was estimated poorly. This under- and over-estimation was probably related to ME utilisation efficiency (Tovar-Luna *et al.,* 2007), or possibly using the net energy model would work better (Cannas *et al.,* 2007). Alternatively, the under- and over-estimation may have been because of differences in the standard requirement and method to determine the ME content of feedstuff.

Table 2.4 Some examples of actual and predicted ADG of crossbred Boer goats based on predicted ME intake

Study	ME diet (MJ/kg DM)	Predicted ME intake (MJ/d)	MEm (MJ)	MEg (MJ)	Predicted ADG (g/d)	Actual ADG (g/d)	Bias (g/d)
1	9.89	11.2	5.7	5.5	237	183	54
1	9.89	11.2	5.7	5.5	237	152	85
1	12.11	10.5	5.7	4.8	210	217	-7
1	12.11	10.5	5.7	4.8	210	162	48
2	9.9	9.9	6.2	3.6	159	100	59
2	13.1	17.6	6.2	11.3	490	160	330
2	12.9	13.3	6.2	7.1	306	140	166
3	10.28	4.3	2.8	1.4	63	68	-5
3	9.25	3.3	2.8	0.4	19	41	-22
3	11.30	4.9	2.8	2.0	87	71	16
4	11.3	7.4	4.8	2.6	112	91	21
4	9.9	7.1	4.6	2.5	107	90	17
4	11.3	7.3	6.1	1.2	51	64	-13
4	9.9	7.5	5.9	1.6	71	100	-29

1. Thirty two Boer goats were divided into two groups and fed with low and high energy diets (9.89 vs. 12.11 MJ/kg DM) and sub-divided into 28 d and 56 d of measurement (Sheridan *et al.,* 2003)
2. Forty-eight head of Mubende x Boer crossbred were allowed to graze during the day and offered three regimes of energy at 9.9, 13.1 and 12.9 MJ/kg DM (Asizua *et al.,* 2014)
3. Fifteen castrated male Black Bengal goats were fed with Napier grass and concentrate at three levels of energy: standard, low and high (10.28, 9.25 and 11.30 MJ/kg DM (Rashid *et al.,* 2016b)
4. Ten crossbred 87.5% Boer x 12.5% Spanish goats were offered hay and concentrate (25:75 and 50:50) with ME diet (11.3 and 9.9 MJ/kg DM) and the body weight measured at the first and second 12 weeks (Urge *et al.,* 2004)

2.2.5.3 Blood plasma metabolites as indicators of energy metabolism

2.2.5.3.1 Ketone bodies (acetoacetate and β-hydroxybutyrate)

Carbohydrates are converted to acetate and butyrate, which are volatile fatty acids, by rumen microbial fermentation. They then become ketone bodies in the form of acetoacetate and β-hydroxybutyrate (βHBA), as they are absorbed through the rumen epithelium (McDonald *et al.,* 2011). Using data from the literature, Heitmann *et al.,* (1987) reviewed the use of ketone bodies in periparturient ruminants and ketogenesis in the liver. They concluded that the blood plasma acetoacetate of fed and fasted sheep was 40 and 17 µM while the βHBA was 362 and 743 µM, respectively. The acetoacetate of pregnant and lactating sheep was 47 and 40 µM, while βHBA was 572 and 702 µM, respectively (Heitmann *et al.,* 1987). A study of pregnant fasting goats (Hefnawy *et al.,* 2010) also showed that, within a 72 h fasting time, βHBA increased while glucose decreased. These findings show that the decreased concentration of acetoacetate and the increased concentration of βHBA in the blood plasma indicated that the animal was either starving or lactating. Pregnant and lactating goats are special cases; these animals are more likely to be exposed to ketosis because more glucose is required for foetus development and lactose synthesis (McDonald *et al.,* 2011). If the dietary energy is insufficient or the organic matter digestibility of the feed is low (CSIRO, 2007), gluconeogenesis occurs or body fat is mobilised for energy, and in this fat mobilisation, acetyl-CoA is converted to ketone bodies that accumulate in the blood plasma (McDonald *et al.,* 2011).

2.2.5.3.2 Non-esterified fatty acids

As indicated in Table 2.3, the energy requirements of late pregnant and early lactating goats are increased. Some studies have utilised the measurement of blood plasma non-esterified fatty acids (NEFA) as an indicator of the energy balance for pregnant and lactating goats. Dunshea *et al.,* (1988) examined non-lactating, non-pregnant Saanen does, and reported a negative relationship between NEFA and ME intake. They found that plasma NEFA of the does that have a ME intake at maintenance was 134 µmol/L, but the NEFA increased to 437 µmol/L when the ME intake was reduced by 0.25 maintenance. Dunshea *et al.,* (1990) also studied early lactating goats and found that the blood plasma NEFA was 328, 196 and 186 µmol/L on days 10, 38 and 76 of lactation, respectively. The authors argued that mobilisation of adipose tissue occurs in order to supply energy for milk secretion. The decreased NEFA, along with the increasing lactation period, reflects the decrease in lipid mobilisation, or possibly a normal energy intake that supplied sufficient glucose. A review by Bowden (1971) emphasised NEFA as an indicator of the nutritional status of an animal, although other factors could be involved.

2.2.6 Conclusion

The MP system provides an opportunity to improve meat goat productivity in the tropics due to its comprehensive approach related to feed, the effects on goats and prediction of ADG. First, the unpublished protein fractions, such as UDP, RDP, and MP for tropical forages can be evaluated with the available methods. Second, the mode of actions of these fractions has been well documented. The optimal activity of rumen microbes is supported by RDP, which is subsequently available as a microbial crude protein (MCP) for the animal. The true protein is available as the UDP that escapes the degradation of rumen microbes but is absorbed in the small intestine. Digestible MCP and UDP that is absorbed in the small intestine and abomasum is the MP, which is used for maintenance and production by the goats. Third, the ADG of growing meat goats is predictable from MP intake and requirements suggested by the NRC (2007).

The ME system is equally good to improve meat goat productivity in the tropics due to the fact that it considers all the energy fractions in the forages, the role of these energy fractions in the animals and the use of ME in predicting the goats' ADG. The nature of tropical forages, especially those with high fibre, may result in less fermentable energy being available to the animals. Metabolisable energy reflects the amount of energy retained in the body and available for tissue accretion, milk synthesis or conceptus. The ME system can be used to predict goats' ADG, thus providing a means to assess meat goat productivity when the ME concentration of the diet or tropical forages is known.

2.3 Feeding Strategies to Improve Meat Goat Productivity from Tropical Pastures

2.3.1 Introduction

Section 2 reported that protein supplementation is not about providing crude protein in the diet but more about providing sufficient RDP, UDP and MP required by rumen microorganisms in the goats. Energy supplementation is not about providing dry matter but more about providing fermentable energy and metabolisable energy for the optimal rumen function and meeting the energy requirements of the goats.

Section 3 describes supplementation with different types of feedstuff rich in protein and energy as one of the feeding strategies to increase the dietary MP and ME concentrations. Increasing the MP and ME to meet the goats' requirements is expected to increase the goats' productivity responses. The objective is to determine if supplementation can improve meat goat productivity on tropical pastures.

2.3.2 Feeding strategy to improve metabolisable protein

2.3.2.1 Supplementation with tropical browse legumes to enhance metabolisable protein

Tropical browse legumes are plant species used intensively as CP supplementation for ruminant animals. Leucaena (*Leucaena leucocephala*), Gliricidia (*Gliricidia sepium*) and Desmanthus (*Desmanthus virgatus*) are common forages used in goat diets. Leucaena is a tree legume forage rich in CP. Garcia *et al.,* (1996) reviewed five decades of published articles on the characteristics of Leucaena. They reported that Leucaena's CP was 290 g/kg DM, digestible energy varied from 12 to 13 MJ/kg DM, the apparent digested CP ranged from 650 to 780 g/kg DM, and its rumen degradable protein (RDP) was 420 g/kg DM. The nutrient content indicated that Leucaena is a good potential source of protein and energy.

Supplementation of Leucaena has been studied on Jamnapari male goats fed *Pennisetum typhoides* (Srivastava and Sharma, 1998) and castrated Boer x Spanish crossbred kids fed Sudan grass (*Sorghum sudananse*) (Kanani *et al.,* 2006). The results of these studies vary, but in general, Leucaena supplementation had a positive effect on the productive performance of the animals. Srivastava and Sharma (1998) reported that, despite increasing DM intake, the apparent digestibility of all nutrients decreased with a higher level of dried leucaena leaves, leading to a lower total body weight gain. This suggests that a higher DM intake does not necessarily lead to body weight gain. The lower body weight gain was presumably due to low metabolisable energy (ME) as a consequence of lower digestibility (CSIRO, 2007), or due to the larger amount of nitrogen and energy excreted through faeces, urine and methane (Haque *et al.,* 2008, McDonald *et al.,* 2011). This lower weight gain was also possibly the result of a higher level of mimosine, which increased from 6 to 22 g/kg DM as the level of leucaena was increased, highlighting that secondary compounds can have a negative impact on goat meat productivity.

Kanani *et al.,* (2006) found that legume supplementation increased DM intake and ADG but the largest amounts were observed in the Leucaena group, which could be a result of the higher level of palatability of Leucaena legume. The use of mixed legumes results in better productive performance. Similar positive effects are also found when legumes are used to substitute for concentrates. Mixing *Leucaena leucocephala* and *Calliandra calothyrsus* (Pamo *et al.,* 2006) resulted in the birth of more kids and prevented the loss of doe body weight during the dry season. Bosman *et al.,* (1995) reported that a mixture of Gliricidia and Leucaena on West African dwarf goats increased the digestible DM intake, resulting in a higher ADG. Some studies suggested using up to 50% Leucaena as a substitute for soybean (Paengkoum and Paengkoum, 2010) or concentrate (Pal *et al.,* 2010) in goats' diets in the tropics. Despite the positive effects of Leucaena, Haque *et al.,* (2008) recorded more energy loss through urine and methane gas when Leucaena leaves and twigs were offered to Jamnapari goats.

The nutrient content and *in vitro* dry/organic matter digestibility of Gliricidia contributes to the productive performance of goats. This tree legume contains 192 to 265 g CP/kg DM (Abdulrazak *et al.,* 1997, Edwards *et al.,* 2012). Each kg of DM of this legume has an NDF of 240 to 577 g, gross energy of 17.2 MJ and tannin level of 83 g (Ondiek *et al.,* 1999, Edwards *et al.,* 2012, Foroughbakhch *et al.,* 2012). The inclusion of Gliricidia to tanner grass by the *in vitro* method increases organic matter digestibility and degradability (Edwards *et al.,* 2012) and *in vitro* dry matter digestibility (Foroughbakhch *et al.,* 2012).

As a protein supplement source, Gliricidia has been added to *Moringa oleifera* for West African Dwarf goats (Asaolu *et al.,* 2011) and Rhodes grass (*Chloris gayana*) hay for Toggenburg x Saanen dairy goat kids (Ondiek *et al.,* 1999). The results showed that Gliricidia failed to increase apparent digestibility; even nitrogen retention was lower than that for Moringa alone (65% vs. 85% of total nitrogen intake) (Asaolu *et al.,* 2011). This finding agreed with the *in vitro* study by Edwards *et al.,* (2012), in which the protein of Gliricidia is highly degraded during *in vitro* ruminal fermentation. Ondiek *et al.,* (1999) showed that Gliricidia supplementation increased the DM intake of kids fed Rhodes grass hay (474 vs. 604 g/d). The same study reported the ADG and rumen NH_3-N concentration of the kids was enhanced by Gliricidia and a mixture of Gliricidia with maize bran, but not by maize bran alone, indicating that supplementation by mixing rich CP and energy diets is better than a single diet.

The *in vitro* dry matter digestibility of Gliricidia and Leucaena was 685 vs. 562 g/kg DM (Foroughbakhch *et al.,* 2012). Another study by Edwards *et al.,* (2012) found that *in vitro* organic matter degradability (OMD) at 24 h and 48 h incubation was similar utilising Tanner grass only or when supplemented with Gliricidia and Leucaena. In addition, the levels of supplementation with Gliricidia at 7.5% to 22.5% increased OM digestibility, but then decreased as the supplementation level was increased to 30% at 24 h and 48 h. These findings highlight the importance of the level of Gliricidia supplementation to C_4 grass, and the superiority of Gliricidia over Leucaena.

The Desmanthus legume family consists of variable species; however, only the nutrient characteristics of two species are discussed here. Supplementation of tropical grass by these two species is an ideal choice for the basal diet of ruminant animals because Desmanthus contains a high CP, low fibre and is highly degraded in the rumen. *Desmanthus bicornutus* contains CP 215 g/kg DM and NDF 236 g/kg DM (Kanani *et al.,* 2006). Another species, *Desmanthus virgatus*, was reported to have a lower CP of 178 g/kg DM, higher cell wall of 259 g/kg DM and tannin levels of 89 g/kg DM (Ramirez *et al.,* 2000). A rumen degradability study of *Desmanthus virgatus* on Pelibuey sheep showed that approximately 460 g/kg DM of the cell wall was degraded in the rumen at a rate of 5.4%/h; the potential DM degradability was 680 g/kg DM (Ramirez *et al.,* 2000).

Desmanthus (*Desmanthus bicornutus*) has been offered as a CP supplement to growing crossbred Boer x Spanish wethers with a basal diet of Sudan grass (*Sorghum sudananse*) hay containing CP 78 g/kg DM and NDF 632 g/kg DM (Kanani *et al.,* 2006). The concept of browse forage supplementation is that the supplement should contain a low NDF but higher CP digestibility (Osuga *et al.,* 2012); Desmanthus meets these conditions. However, when grass was supplemented with legumes (Kanani *et al.,* 2006), the feed intake and ADG of goats fed with Leucaena was higher than those fed with Desmanthus, which appears to be due to palatability and tannin concentrations. Leucaena and *Desmanthus virgatus* contain as much as 10 g/kg DM (Garcia *et al.,* 1996) and 89 g/kg DM tannins (Ramirez *et al.,* 2000), respectively. The negative effects of tannins by reducing intake and protein digestibility were clearly demonstrated in studies on Mamber goats (Silanikove *et al.,* 1996, Silanikove *et al.,* 1997), but the authors showed that adding polyethylene glycol overcame these negative effects. The authors explained that dietary protein is chemically bound to tannin so that it is not digested completely. However, the comprehensive process after the protein-bound tannin is eaten by animals is not completely understood.

2.3.2.2 Supplementation with urea and cottonseed meal to enhance the metabolisable protein

Urea, chemical formula $CO(NH_2)_2$, is not a protein source of feedstuff; it is a non-protein nitrogen source. However, urea has been used as a source of protein supplementation for goats because it contains 2880 g CP/kg DM and 2070 g MP/kg DM (NRC, 2007). Brun-Bellut *et al.,* (1990) reported that urea is a high rumen degradable protein (RDP) while the NRC (2007) states that the intake protein from urea is degraded completely in the rumen. If the dietary RDP exceeds the requirements for ruminal microorganisms, then CP is degraded to NH_3-N, absorbed, metabolised to urea in the liver, and then excreted through the urine (Bach *et al.,* 2005). One strategy to reduce this nitrogen loss is to avoid the losses through urine excretion.

The results from studies using urea as a protein supplement on growing goats vary, depending mostly on the protein: energy ratio. Uza *et al.,* (2005) reported that the ideal ratio between urea as a protein source and cassava peels as an energy source was 4 g urea/kg cassava peels, causing the goats to grow at a rate of 62 g/d. Another study, by Wambui *et al.,* (2006), who sprayed urea over maize stover (10 g/kg) as a basal diet, with 100 g maize germ fed to German Alpine x Small East Africa bucks, reported that the animals lost weight (-15 g/d). In the same study, the other four groups were also supplemented with *Tithonia diversifolia* forage, and gained weight, indicating the best result for growth is to incorporate urea with other sources of protein with complementary degradability role in the rumen.

In pasture conditions, grazing goats are exposed to gastro-intestinal nematode infections. Therefore, Kioumarsi *et al.,* (2012) suggested including urea in molasses, minerals and medicated blocks. Kioumarsi *et al.,* (2012) reported that growing Boer goats fed a urea molasses mineral block (UMMB) plus medicated UMMB (MUMMB) had the highest ADG (216 g/d) and hot carcass weight (19 kg). This study was more comprehensive because it supplied not only most of the required nutrients, but also a drug to combat the parasites. Molasses appears to be a readily fermentable carbohydrate that is well matched with urea as a rapid RDP (Galina *et al.,* 2004, Kioumarsi *et al.,* 2012). Galina *et al.,* (2004) recommended formulating urea with other ingredients as a way to allow the goats to eat it slowly for 8 to 10 h, so that it would be available during the period for rumen microorganisms.

Soto-Navarro *et al.,* (2003) concluded that soybean meal, as a true protein, and urea as a non-protein nitrogen (NPN), had similar effects on microbial growth and the digestion of yearling Boer x Spanish wether goats. The explanation for this finding was that nitrogen from urea was converted to NH_3-N, amino acids and peptides in the rumen, which is used for growing rumen microorganisms (Bach *et al.,* 2005). The authors also explained that the true protein was degraded into peptides and amino acids, which were then deaminated to NH_3-N or were taken to be part of the rumen microbial protein. Considering the cost of both ingredients, the use of urea in an animal diet will be more beneficial than the use of soybean meal.

Urea supplementation for pregnant and lactating meat goats has rarely been reported. Most studies have been on Alpine (Brun-Bellut *et al.,* 1990) and Jonica (Laudadio and Tufarelli, 2010) dairy goats. These findings showed that urea supplementation of the basal diet of Alpine goats increased the nitrogen intake, CP digestibility, and milk urea level, emphasising the positive effect of urea on lactating goats (Salem, 2008). The results from the Jonica goat study showed that urea or corn gluten meal had a similar effect on the DM intake and milk yield but, compared to the urea study results, the milk fat, protein and casein concentrations were enhanced by corn gluten meal (Laudadio and Tufarelli, 2010). Thus, the energy and protein supplementation should be coupled together in order to enhance milk quality.

Cottonseed meal (CSM) is a protein and energy source because it contains 480 g CP/kg DM, 336 g MP/kg DM and 11.72 MJ ME/kg DM (NRC, 2007). Its protein character in the rumen was described as 202 g UDP/kg DM (NRC, 2007), but others considered its protein to be highly non-degradable (Mishra and Rai, 1996) or very lowly degraded (Wang *et al.,* 2012) and slowly degraded in the rumen of sheep (Walker, 1997). Wang *et al.,* (2012) formulated an experimental diet for Liuyang black wether goats by increasing the rumen degradable protein (RDP), adding soybean meal and rapeseed meal but decreasing the RDP through adding CSM to the rations. The authors suggested that mixing high and low RDP sources into the diet is a more efficient method for using nitrogen for goat productivity.

A drawback of CSM supplementation is the presence of a constituent, gossypol, a secondary compound that can have a negative effect on animal productivity. Solaiman *et al.,* (2009) varied the gossypol intake of Nubian cross goat kids from 0 to 539 or 1416 mg/kg DM, and found a quadratic pattern for the DM intake and ADG, which means that only a certain amount of gossypol has a negative effect on the goats.

The uses of urea and CSM as supplements in diets have limitations. Urea can cause hyperammonemia (Fernandez *et al.,* 1997) and CSM can adversely affect the blood parameters (Solaiman *et al.,* 2009). These negative effects are only present if the level of supplementation is too high. Consequently, these two sources of nitrogen supplementation can be combined at lower levels. Alves *et al.,* (2013) increased the milk production of lactating goats to 1.73 kg/d by supplementing the animals' diet with a mixture of urea and CSM. Urea increases microbial

CP while the undegraded CP of CSM passes into the abomasum and small intestine, where both act as a precursor to MP (AFRC, 1993, McDonald *et al.,* 2011). The MP supports maintenance and increases the milk production of the animals. In addition, the use of slowly degraded CSM (Walker, 1997) leads to higher digestion of fibre. As explained by Ben Salem and Smith (2008), cellulolytic rumen bacteria require a continuous supply of degradable protein to digest fibre. As fibre degrades, more energy is available for the animal.

2.3.3 Feeding strategy to increase metabolisable energy

A feeding strategy is aimed at meeting the energy requirements of the goats in different physiological states. However, tropical pastures and tropical grasses are low in metabolisable energy, which will not support the meat goats' productivity.

Dietary ME concentration is determined by the ME concentration of the ingredients. Feedstuff nutrient content can be found in published books, such as NRC (2007), but the main factor to be considered is that the feed must be low in cost and contain low fibre. One strategy to increase the ME content of the diet is to vary the concentration of ingredients in the formulation. For example, Abbasi *et al.,* (2012) increased the ME level from 9.1 to 10.7 MJ/kg by increasing the proportion of molasses and ground wheat to feed female Kamori goat kids. Another energy supplement strategy to enhance energy levels from 10.0 to 11.9 MJ/kg DM for grazing female goats was to increase the percentage of maize and polished rice (Hossain *et al.,*, 2003).

The studies of Abbasi *et al.,* (2012) and Hossain *et al.,* (2003) showed that increasing dietary ME causes different responses in goat productivity. Abbasi *et al.,* (2012) found that the ADG of Kamori goat kids was higher using a high-energy diet than in using a low-energy diet (257 vs. 158 g/d). In the same study, the DM intake showed the opposite trend, higher in low-energy diet compared to that in the high-energy diet (2.03 vs. 1.87 kg/d). Hossain *et al.,* (2003) reported that increasing the ME of grazing female goats had a positive correlation with digestibility and birth weight, but a negative correlation with the DM intake. These two studies show that goats fed low concentrations of dietary energy are more likely to eat more to fulfil their energy requirements.

Energy supplementation for pregnant and lactating goats has a greater effect on milk production than on feed intake. For example, de Souza *et al.,* (2014) studied peripartum dairy goats, and found that an increase in the level of ME did not influence body weight and DM intake but increased the total digestible nutrient (TDN) and milk quality. Energy supplementation for pregnant grazing goats with corn (Ramirez-Vera *et al.,* 2012) showed that the total colostrum and blood glucose of supplemented does were higher than those of the control group, and their newborn kids were more active than their control counterparts.

Therefore, energy supplementation has a positive effect on the productive responses of goats. Of these studies (Hossain *et al.,* 2003, Abassi *et al.,* 2012, Ramirez-Vera *et al.,* 2012, de Souza *et al.,* 2014), only Abassi *et al.,* provided an economic evaluation of the dietary energy treatment. This is important because the DM intake, live weight gain and feed conversion ratio (FCR) have economic benefits. For example, goats offered a low-energy diet eat 2.0 kg/d, gain 9.5 kg of weight and have an FCR of 12.9, whereas goats on high-energy diet ate 1.8 kg/d, gained 15.4 kg of weight and had an FCR 6.9 (Abbasi *et al.,* 2012). The FCR values imply that offering a high-energy diet to kids only requires half the amount of feed to gain the same amount of body mass as low-energy diet fed kids.

2.4 Conclusion

Protein supplementation is a feeding strategy that can improve meat goat productivity from tropical pastures. The protein supplements that can be used include tropical browse legumes, urea and cottonseed meal. Although these feedstuffs are protein feed sources, the concentrations of protein fractions vary widely (Kanani *et al*., 2006, Brun-Bellut *et al*., 1990, Wang *et al* 2012). Tropical browse legumes contain high CP but not all tropical legumes and their protein fractions have been reported. Urea is a source of RDP that should be coupled with sufficient fermentable energy when supplemented to the diet. Cottonseed meal is a source of UDP that supplies sufficient true protein for goats. The mixture between RDP and UDP could be a better supplementation strategy because it provides the animals with RDP and UDP that will increase meat goat productivity.

Energy supplementation is also another feeding strategy that can improve the productivity of meat goat grazing on tropical pastures. Energy supplements include wheat bran, rice bran, cassava meal and molasses. These feedstuffs in general contain low fibre, the opposite of tropical grass hay. The inclusion of feeds in the diet increases organic matter digestibility and ME concentration, thereby meeting the goats' requirements and increasing meat goat productivity.

Chapter 3 Growth Rates of Suckling Kids, Dam Milk Composition and Plasma Metabolite Changes in Periparturient Boer Does Supplemented with Urea and/or Cottonseed Meal

Abstract. This study aimed to limit body weight loss, prevent metabolic disorders in periparturient crossbred Boer does and to increase average daily gain (ADG) in suckling kids. Twelve pregnant Boer does (average BW 62.19±6.30 kg) were randomly allocated to four dietary treatments: Rhodes grass (*Chloris gayana*) hay (Control) or Control supplemented with urea (Urea), urea plus cottonseed meal (Urea-CSM) or cottonseed meal (CSM) in a randomised complete block design. Another twelve does (average BW 61.8±6.25 kg) were housed separately for digestibility study. The supplemented diets were isonitrogenous (crude protein 143 g/kg DM) with varied undegradable and rumen degradable protein. The does had *ad libitum* access to the basal diet, fresh drinking water and mineral lick. The fixed effects of dietary treatment, physiological period and their interactions on growth, milk and plasma metabolite parameters were tested at the $P<0.05$ threshold. Results showed that Urea-CSM supplement enhanced DM digestibility and nitrogen retention. Urea-CSM and CSM supplements increased DM, protein fractions and metabolisable energy intakes. Despite the high intakes, there were no impacts on milk composition and body weight loss in lactating does. Protein supplements enhanced ADG in suckling kids in week one. Compared to Control, Urea-CSM supplementation reduced NEFA and BHB by 0.14 and 0.28 mmol/L, respectively. Urea, Urea-CSM and CSM supplements respectively increased BUN by 42.5, 35 and 12.5% higher than the Control. In summary, protein supplements offered to periparturient crossbred Boer does on a basal tropical grass hay improved ADG in suckling kids.

Keywords: periparturient does, supplementation, metabolisable protein/energy

3.1 Introduction

Tropical grasses are typically the main basal diet for ruminants including meat goats, but the nutritional quality is not uniform year-round. For example, Rhodes grass (*Chloris gayana*) has a linear decrease in crude protein (CP) and *in vitro* organic matter digestibility, but a linear increase in neutral detergent fibre and lignin from young immature to mature growth stages (Mbwile and Uden, 1997). Mature Rhodes grass hay therefore, has insufficient metabolisable protein and energy contents to meet the nutritional requirements of periparturient Boer (NRC, 2007). Consequently, the does could experience metabolic disorders (Vasava *et al.,* 2016), produce less milk or lose weight (Raats, 1988). Supplementation can be utilised to overcome these hurdles by aiming to increase DM intake and to meet the protein and energy requirements of the does (Raats, 1988; Greyling *et al*., 2004).

Past studies on lactating Boer goats on pastures showed that supplementation increased milk yield, reduced bodyweight losses and enhanced liveweight gain of their suckling kids. Raats (1988) found that lactating Boer does browsing on paddocks with 760 g of mixed corn meal and commercial premix (198 g CP/kg DM) supplement yielded 2.3 L/d of milk and lost 4.4 kg liveweight over 12 weeks. By comparison, the does without supplementation in the same study, had 2.0 L of milk/d and lost 9.9 kg liveweight. Greyling *et al.,* (2004) observed that lactating Boer does grazing on pasture (67 g CP/kg DM) compared to intensively fed does on 2 kg/d of a pelleted diet (140 g CP/kg DM) yielded 0.8 vs. 3.1 L/d of milk, lost 6 vs. gain 3% liveweight and the kids gained 76 vs. 158 g/d of liveweight on average, respectively. Goetsch *et al.,* (2014) reported that suckling Boer kids gained 111 g/d liveweight when the lactating does grazed pasture (130 to 195 g CP/kg DM) and were supplemented with multi-nutrients block (200 g CP/kg DM). Liveweight gain in kids increased to 120 and 134 g/d when the does browsed mimosa (*Albizia julibrissin* Durazz) once or twice a week. These studies showed that protein and energy supplements help to maintain milk production and support the growth of suckling kids. Less bodyweight losses (Raats, 1988) and a minor increase in liveweight gain in supplemented lactating Boer does (Greyling *et al.,* 2004) suggests that tissue mobilisation of nutrient reserves from the body may occur. However, these studies focused mainly on energy supplementation as shown by the high proportion of maize in the diets. The usage of protein supplement with different sources from industrial by products or non-protein nitrogen could also prevent the does' metabolic disorder.

The use of protein supplements such as urea, copra and soybean meal for meat goats have been previously reported (Nogueira *et al.,* 2016). To the author's knowledge, protein supplements focussing on RDP and UDP have only been reported for pregnant and lactating dairy goats (Alves *et al.,* 2013; Brun-Bellut *et al.,* 1990; Laudadio and Tufarelli, 2010). Among the common supplements, urea is an NPN-RDP source while sunflower meal, soybean meal, cottonseed meal and corn gluten meal are mostly true dietary protein RDP and UDP sources with 103 to 109, 172 to 194, 202 to 230, and 267 to 402 g UDP/kg DM, respectively (NRC, 2007). The inclusion of these protein sources in supplementary diets will vary the relative amount of UDP and RDP even when the diet is isonitrogenous.

Studies on lactating dairy goats showed that supplementation with urea and other protein sources elicited similar DM intake, but different feed digestibility and milk composition results. Brun-Bellut *et al.,* (1990) fed three diets containing urea, soybean meal, dried beet pulp, barley and hay (117, 132 to 147 g CP/kg DM) to lactating dairy goats and found similar DM intake, but a higher RDP diet caused a higher CP digestibility and milk urea levels. Alves *et al.,* (2013) found that lactating dairy goats fed coast-cross hay with soybean meal, urea plus soybean meal, or urea plus cottonseed meal (147, 145, and 141 g CP/kg DM) had similar DM intake and protein milk concentrations, but variable RDP increased organic matter and CP digestibilities. Laudadio and Tufarelli (2010) fed lactating dairy does with two isonitrogenous total mixed rations (175 g CP/kg DM); a high RDP diet containing urea, soybean meal and sunflower meal and a low RDP diet containing corn gluten meal and found similar DM intake for both diets. They also reported that the high RDP diet increased crude fibre digestibility and milk urea nitrogen, while the low RDP diet increased crude protein digestibility and milk protein concentration. These findings reveal that DM intake, digestibility and milk composition were not only dependent on dietary CP concentration, but also on the relative amount of dietary RDP and UDP. When urea was mixed with other UDP sources to vary RDP up to 145, 147 or 175 g/kg DM, the feed intake response was similar. High RDP increased digestibility if the CP diet differed, but with an isonitrogenous diet, both high and low RDP diets had an equal benefit in increasing DM intake, digestibility and milk quality in lactating dairy goats. The increasing digestibility of organic matter and crude protein indicated an increasing metabolisable energy and metabolisable protein (CSIRO, 2007; NRC, 2007).

Studies on lactating Boer goats grazing on pasture revealed that energy and protein supplementation enhanced the productive performances of the does and the suckling kids. The association between these performances and the fulfilment of ME and MP requirements recommended by the NRC (2007), however, was uncertain because of the technical difficulties in recording intakes of ME and MP for grazing does.

The hypothesis was that urea as a source of NPN-RDP and cottonseed meal as a source of RDP and UDP or the mixture of urea and cottonseed meal will elicit different productive and physiological responses in periparturient meat goats and their suckling kids despite the diets being isonitrogenous. Therefore, the main objectives of this study were: (1) To investigate if dietary crude protein supplementation at levels up to 143 g/kg DM can limit body weight loss and potentially prevent metabolic disorders (ketosis) in periparturient crossbred Boer does; and

(2) to increase average daily gain (ADG) in suckling kids by varying the quantity of UDP and RDP.

3.2 Materials and Methods

3.2.1 Animal ethics

The animal usage and research protocol was approved by the Animal Ethics Committee of James Cook University (Approval Number A2085). The experiments followed the guidelines and regulations of the 2013 Australian Code of Practice for the Care and Use of Animals for Scientific Purposes.

3.2.2 Location of study and experimental animals

This study was conducted in the experimental animal shed at James Cook University, Townsville, (19º19'30'' S; 146º45'44'' E), North Queensland, Australia, from August to October 2014. Twelve adult crossbred periparturient Boer does (average BW of 62.19±6.30 kg) were penned individually for a minimum of 14 d prepartum and a minimum of 14 d postpartum. Another twelve pregnant Boer does (average BW of 61.8±6.25 kg) were housed in individual metabolic crates for the total tract digestibility and nitrogen retention component of the study. The does were on similar dietary treatments as the peripartum study. A separator was placed under each metabolic crate to direct urine to a plastic bucket containing 5 mL of concentrated H_2SO_4, while faeces was collected in a plastic bag. This study lasted for two weeks and the does were removed from the crates at parturition. The choice of two weeks was simply because of animal ethics and welfare concerns.

The health condition of the animals was assessed for internal parasites using faecal egg count (Hutchinson, 2009), FAMACHA score and packed cell volume. Two g of fresh faeces per doe was collected for worm egg counts before the experiment commenced and infected does with more than 500 egg per count (Love and Hutchinson, 2007) were dewormed with Zolvix monepantel at 1 ml/10 kg body weight. This was repeated a week later to ensure all does were free from internal parasites. The FAMACHA scoring system was also applied and the results showed that the does were not suffering from anaemia because the FAMACHA scores were between the normal value of 1 and 2 (Glaji, *et al.,* 2014). Ten mL of blood was drawn from the jugular vein to determine packed cell volume and the values of 25 to 30% confirmed that the does were not anaemic or dehydrated.

3.2.3 Design of experiment and diet preparation

A randomised complete block design with four dietary treatments having three animals per treatment serving as replicates was used for this study. The does were randomly allocated into treatments based on liveweight and body condition score. The diets comprised Rhodes grass hay (RGH), flaked corn as an energy source, urea as an NPN-RDP source and cottonseed meal as an RDP and UDP mostly true protein source. The four dietary treatments were RGH + corn (Control), Control + urea (Urea), Control + urea + cottonseed meal (Urea-CSM) and Control + cottonseed meal (CSM).

Rhodes grass hay in bales were chaffed (SFC 2340 'Star', machinery chaff, Jas Smith, Ballarat, Australia) at 5 – 10 cm lengths and stored in plastic bins. The *ad libitum* RGH offered was adjusted daily based on one and a half of RGH intake over two previous days allowing for refusals. Proportions of steamed flaked corn for the Control was 90 g DM. For the Urea and Urea-CSM treatments, the urea solution (3: 10, w/w) in clean tap water was prepared and manually mixed into the hay before morning feeding. Urea proportions for Urea and Urea-CSM treatments were 10.2 and 5.1 g DM, respectively. Cottonseed meal was mixed thoroughly with RGH at 32.5 and 65.1 g DM for the Urea-CSM and CSM treatments, respectively. Mineral licks (Rumevite® Fermafos) were provided in a small separate bucket for each doe and fresh clean drinking water was offered *ad libitum*.

3.2.4 Diet formulation and feeding regime

The diets were formulated to be isocaloric and isonitrogenous in their relative amounts of dietary UDP and RDP. Dietary CP concentration for the Control group was 107 g/kg DM. Dietary CP concentrations for the supplemented groups were adjusted to 143 g/kg DM as this concentration was expected to support optimum productivity (Satter and Slyter 1974). Nutrient compositions of the experimental diets are presented in Table 3.1.

Laboratory analysis for DM, OM and CP were carried out at James Cook University, Australia. About 10% sample of feed offered and feed refused were collected daily, placed in airtight sealed plastic bags and stored at 3°C. At the end of the study, another 10% sample was obtained, dried in an oven at 60°C, ground to pass through 1 mm sieve and analysed for DM, OM and CP (AOAC, 1990).

Table 3.1 Ingredients and composition of dry matter, protein fractions and metabolisable energy of experimental diets fed to periparturient goats

Item	Dietary treatments			
	Control	Urea	Urea-CSM	CSM
Ingredients (g DM)				
Rhodes grass hay	602	602	602	602
Cottonseed meal	0	0	32.5	65.1
Urea	0	10.2	5.1	0
Maize	90	90	90	90
Chemical composition				
DM (g/kg fresh wt)	903	907	904	902
OM (g/kg DM)	906	908	907	906
CP (g/kg DM)	107	142	143	143
UDP (g/kg DM)	37	37	43	49
RDP (g/kg DM)	70	105	100	94
EE (g/kg DM)	24	24	33	41
ADF (g/kg DM)	374	368	361	355
NDF (g/kg DM)	582	573	560	548
ME (MJ/kg DM)	10.1	9.9	10.1	10.2

CSM = cottonseed meal, DM = dry matter, CP = crude protein, RDP = rumen degradable protein, UDP = rumen undegradable dietary protein, EE = ether extract, ADF = acid detergent fibre, NDF = neutral detergent fibre, and ME = metabolisable energy

Feeds were offered in equal quantities twice daily: in the morning (08:00 h) and afternoon (16:00 h). Feed intake was calculated as the amount of feed offered minus that refused within 24 h for each doe. Similar calculation was computed for DM intake. Intakes of protein fractions and energy were on dry matter basis. Concentrations of protein fractions (RDP, UDP) and ME of RGH were quoted from SCA (1990), while those for urea and CSM were quoted from NRC (2007). Metabolisable energy is the primary measurement used in the current study, in which the unit measurement of Mcal/kg DM was converted into MJ/kg DM by multiplying the value with 4.184 (NRC, 2007).

3.2.5 Measurement of digestibility and nitrogen retention

Feed intake was measured as well as digestibility and nitrogen retention after three weeks of adjustment to feed and a week of faecal and urinary collection. Apparent DM digestibility was calculated as the difference between DM intake and faeces divided by DM intake multiplied by 100 (McDonald *et al.,* 2011). Nitrogen retention was calculated as nitrogen intake minus nitrogen excreted in faeces and urine.

3.2.6 Measurement of bodyweight changes

Body weight gain was measured in the lactating does and suckling kids, but not in the pregnant does because some does started kidding few days after the experiment was commenced, earlier than the scheduled time to measure body weight. During pregnancy, BW of does was measured once 6 - 26 d to parturition. Body weight changes in the does during the postpartum period were measured as the difference between BW immediately after parturition and BW at final data collection, divided by the number of lactating days.

Body weight changes in suckling kids were measured twice a week from birth. Average daily gain (ADG) for suckling kids was calculated as the difference between total kids (single, twins or triplets) BW regardless of sex at the end of data collection and total birth weight divided by the number of lactating days. Weekly ADG was also calculated based on the first week BW minus birth weight; and the second week BW minus BW of the first week.

3.2.7 Milk composition and plasma metabolite analyses

Milk was collected twice weekly by hand milking into a 70 mL plastic tube (NAT Sarstedt, Australia) containing 0.5 mL of 20% bromopol as a preservative and stored in a fridge at 3ºC, pending laboratory analysis. Fat, protein and lactose milk concentrations were determined by infrared analysis (Bentley Instruments, Fourier Transform Spectrometer – FTS/FCM 500 Combi's; http://bentleyinstruments.com/products/componenet-analysis/nexgen), at TasHerd Milk Testing Laboratory in Hadspen, Tasmania, Australia.

Approximately 10 ml of blood was drawn from the jugular vein of each doe two to four h after feeding, using a vacutainer and needle (20 g x 1.5”) into two heparin containing tubes (LH 170 IU, Belliver Industrial Estate, UK) every two days. The tubes were then centrifuged (Eppendorf centrifuge 5702 R, Hamburg, Germany) at 3ºC and 3000 rpm for 20 minutes to harvest 5 mL of plasma, stored in duplicate plastic vials and frozen at -21ºC, pending analysis. The concentrations of non-esterified fatty acids (NEFA), β-hydroxybutyrate (BHB), total protein (TP) and blood urea nitrogen (BUN) were analysed using Randox reagents and a commercial test kit (Randox, Australia, www.randox.com/powerline) at James Cook University, Townsville, Australia.

3.2.8 Statistical analysis

Statistical analyses were conducted in two separate phases in which the effect of treatment on body weight changes, digestibility and nitrogen retention was tested using One-way ANOVA; while General Linear Models procedure by SPSS 2014; SPSS Statistics for Windows, Version 23.0, IBM Corp., Armonk, NY, USA was utilised in fitting the fixed effects of dietary treatment and period of measurement and their second order interactions on milk composition, plasma metabolites and feed intake. Dietary fixed factors were Control, Urea, Urea-CSM and CSM. Periodical fixed factors for intake were pregnancy and lactation. Periodical fixed factors for milk were d1 – d5, d6 – d10 and d11 – d15. Periodical fixed factors for blood metabolites were later pregnant, d1 – d4 postpartum and d5 – d10 postpartum. If there were differences between these factors at a 0.05 significance level, then the Post hoc Duncan multiple range test was employed.

3.3 Results

3.3.1 Intakes of dry matter, protein fractions and metabolisable energy

Dry matter digestibility, nitrogen digestibility and nitrogen retention of pregnant does are presented in Table 3.2.

Table 3.2 Digestibility (g/kg DM) and nitrogen retention in supplemented crossbred pre-parturient Boer does

Item	Dietary treatments				sem
	Control	Urea	Urea-CSM	CSM	
DM digestibility (g/kg DM)	579[a]	576[a]	612[c]	584[b]	5.24
Nitrogen intake (g/d)	14.66[a]	20.61[b]	26.36[c]	20.18[b]	2.14
Nitrogen digestibility (g/kg DM)	480[a]	628[b]	653[b]	603[b]	24.56
Nitrogen retention (g/d)	-3.12[a]	1.74[b]	6.05[c]	1.61[b]	0.23

Different subscript letters in the same row differ significantly; $P < 0.05$ and no subscript letters = not significantly different

CSM = cottonseed meal, sem = standard error of the mean, DM = dry matter

Urea plus CSM or CSM supplements increased dry matter digestibility in pregnant does. All these three supplements increased nitrogen digestibility, but urea plus CSM supplement increased nitrogen retention by about six times than for the other two supplements.

Intakes of DM, protein fractions and metabolisable energy of the supplemented Boer does at a minimum 14 d prepartum and 14 d postpartum are presented in Table 3.3. It was evident that total DM intake was increased ($P<0.05$) by Urea-CSM and CSM supplements for the two periods of pregnancy and lactation.

The inclusion of urea, Urea-CSM and CSM enhanced CP intakes by 30, 81 and 67 g respectively, higher than the Control.

Rumen degradable protein intake was enhanced by supplementation, but Urea-CSM increased the intake by about 82%, while Urea or CSM was about 43 and 59% higher than the Control. UDP intake was not affected by Urea supplement, but Urea-CSM and CSM increased the intake of UDP by 18 and 21 g UDP respectively, compared to the Control.

Metabolisable energy intake was enhanced by supplementation with Urea-CSM or CSM. The increase in ME intake was about 3 and 2.2 MJ for the two supplements, respectively.

Intakes of DM, protein fractions and ME were higher during lactation compared to the pregnancy period, but the differences were not significant ($P>0.05$). It was also evident that there was no interaction effect between period and dietary treatment on intakes of DM, protein fractions and ME of the does.

Table 3.3 Intakes of dry matter (g/d), protein fractions (g/d) and metabolisable energy (MJ/d) in supplemented crossbred pregnant and lactating Boer does

Item	Dietary treatments				sem
	Control	Urea	Urea-CSM	CSM	
Pregnant period					
Supplement	90	95	125	155	
Rhoddes grass hay	972	879	1255	1106	
Total dry matter	1062^{ab}	974^{a}	1380^{b}	1261^{ab}	63.07
Crude protein	114^{a}	139^{ab}	197^{c}	180^{bc}	39.11
UDP	40^{a}	36^{a}	59^{b}	62^{b}	13.27
RDP	74^{a}	103^{ab}	138^{c}	118^{bc}	27.63
ME	10.7^{ab}	9.7^{a}	13.8^{b}	12.8^{ab}	2.24
Lactating period					
Supplement	90	95	125	155	
Rhodes grass hay	1022	999	1274	1159	
Total dry matter	1112	1094	1399	1314	54.56
Crude protein	120^{a}	156^{ab}	199^{c}	188^{bc}	21.70
UDP	42^{a}	41^{a}	60^{b}	64^{b}	3.59
RDP	78^{a}	115^{b}	139^{b}	124^{b}	7.67
ME	11.2^{ab}	10.9^{a}	14.1^{b}	13.4^{ab}	0.56

Different subscript letters in the same row differ significantly; $P < 0.05$ and no subscript letters = not significantly different

CSM = cottonseed meal, sem = standard error of the mean, UDP = rumen undegradable dietary protein, RDP = rumen degradable protein, and ME = metabolisable energy

3.3.2 Body weight changes

Mean values of body weight changes in supplemented periparturient Boer does and their suckling kids are presented in Table 3.4. Protein supplement had no effect on bodyweight changes in lactating does.

Table 3.4 Mean values of body weight changes in supplemented pregnant and lactating Boer does and their suckling kids

Variables	Dietary treatments				sem
	Control	Urea	Urea-CSM	CSM	
	Pregnant and lactating does				
Initial LW pre-partum (kg/doe)	62.6	61.3	62.6	62.2	1.82
Liveweight at parturition (kg/doe)	53.1	51.4	56.5	52.6	1.57
Final LW post-partum (kg/doe)	51.5	49.1	55.3	50.5	1.64
Average LWG post-partum (kg/doe per d)	-1.6	-2.3	-1.2	-2.1	0.26
	Suckling kids				
Male/Female/Kids number	2/4/6	4/1/5	4/1/5	2/4/6	-
Averagebirth weight (kg)	18.7	17.4	17.6	20.3	0.43
Average final liveweight (kg)	31.5	33.1	30.7	34.8	0.63
Average liveweight gain (kg)	12.8	15.7	13.1	14.5	0.41
ADG total (g/kid per d)	138	186	233	189	16.68
ADG week 1 (g/kid per d)	152^{a}	229^{ab}	274^{b}	225^{ab}	31.36
ADG week 2 (g/kid per d)	117	182	185	154	14.53

* *P*-Values marked by different superscripts in the same row differ significantly ($P < 0.05$); no superscripts = not significantly different ($P>0.05$)

CSM = cottonseed meal, LW = liveweight, LWG = liveweight gain, ADG = average daily gain

The ADG of suckling kids at three different periods varied. Protein supplements increased the ADG of suckling kids during week one ($P<0.05$).

3.3.3 Milk composition

The percentages of fat, protein and lactose in milk of supplemented lactating Boer goats during early lactation are presented in Table 3.5.

Table 3.5 Early lactation milk composition of supplemented Boer does

Period (P)	Dietary treatment (D)				Mean	SEM	*P*-value		
	Control	Urea	Urea-CSM	CSM			P	D	P x D
				Fat (%)					
d1 – d5	7.5	7.5	7.7	6.8	**7.4[b]**	0.56	**0.00**	**0.64**	**0.88**
d6 – d10	5.4	4.9	2.9	3.4	**4.2[a]**	0.78	-	-	-
d11 – d15	4.6	3.1	2.4	4.4	**3.6[a]**	0.74	-	-	-
Mean	**5.8**	**5.2**	**4.4**	**4.8**	-	-	-	-	-
SEM	0.77	0.75	0.90	0.81	-	-	-	-	-
				Protein (%)					
d1 – d5	7.4	5.2	7.7	6.5	**6.7[b]**	0.44	**0.00**	**0.36**	**0.96**
d6 – d10	5.4	4.0	4.7	4.6	**4.7[a]**	0.61	-	-	-
d11 – d15	4.1	3.5	4.4	4.3	**4.1[a]**	0.58	-	-	-
Mean	**5.6**	**4.3**	**5.6**	**5.1**	-	-	-	-	-
SEM	0.61	0.59	0.71	0.64	-	-	-	-	-
				Lactose (%)					
d1 – d5	4.1	4.7	4.5	4.8	**4.5[a]**	0.15	**0.01**	**0.65**	**0.53**
d6 – d10	5.1	5.2	5.5	4.9	**5.2[b]**	0.21	-	-	-
d11 – d15	5.4	5.2	5.5	4.7	**5.2[b]**	0.20	-	-	-
Mean	**4.8**	**5.0**	**5.2**	**4.8**	-	-	-	-	-
SEM	0.21	0.20	0.24	0.22	-	-	-	-	-

* *P*-Values with different superscripts in the same row (diet) or column (period) differ significantly ($P < 0.05$); no superscripts = not significantly different (P>0.05)

Supplementation with urea and/or CSM had no effect on the proportions of fat, protein and lactose in milk within the first 15 days after parturition. These milk fractions, however, depended on lactating days (P<0.05). Fat and protein percentages decreased while lactose percentage increased over the sampling period. On average, the decrease in fat was 3.8% which equated to 51.4% times that of the early week. The decrease in protein was 2.6% which equated to 38.8% that of the early week. The increase in lactose on average, was 0.7% (about 15.5% that of early week).

3.3.4 Blood plasma metabolites

Blood plasma metabolites of the supplemented periparturient Boer does are presented in Table 3.6.

Table 3.6 Plasma metabolite profiles of supplemented Boer does during late pregnancy and early lactation

Period (P)	Dietary treatment (D)				Mean	sem	*P*-value		
	Control	Urea	Urea-CSM	CSM			P	D	P x D
				Non-esterified fatty acids (mmol/L)					
Late preg.	0.29	0.47	0.38	0.34	0.37	0.06	**0.41**	**0.04**	**0.15**
0 – 4 d lact.	0.49	0.73	0.22	0.19	0.41	0.06	-	-	-
5 – 10 d lact.	0.47	0.62	0.24	0.65	0.49	0.07	-	-	-
Mean	**0.42^{ab}**	**0.61^{b}**	**0.28^{a}**	**0.39^{ab}**	**-**	**-**	**-**	**-**	**-**
SEM	0.07	0.08	0.07	0.07	-	-	-	-	-
				β-hydroxybutyrate (mmol/L)					
Late preg.	0.59	0.72	0.52	0.36	0.55	0.07	**0.27**	**0.00**	**0.30**
0 – 4 d lact.	0.84	1.27	0.44	0.38	0.73	0.08	-	-	-
5 – 10 d lact.	0.83	0.74	0.44	0.65	0.66	0.09	-	-	-
Mean	**0.75^{b}**	**0.91^{b}**	**0.47^{a}**	**0.46^{a}**	**-**	**-**	**-**	**-**	**-**
SEM	0.09	0.11	0.09	0.09	-	-	-	-	-
				Total protein (g/L)					
Late preg.	56.8	58.4	58.6	49.1	55.75	1.75	**0.49**	**0.01**	**0.96**
0 – 4 d lact.	58.6	64.8	57.9	51.9	58.30	1.81	-	-	-
5 – 10 d lact.	58.4	60.7	61.8	53.2	58.54	2.13	-	-	-
Mean	**57.9^{b}**	**61.3^{b}**	**59.5^{b}**	**51.4^{a}**	**-**	**-**	**-**	**-**	**-**
SEM	2.14	2.38	2.13	2.14	-	-	-	-	-
				Blood urea nitrogen (mmol/L)					
Late preg.	3.7	5.4	5.2	4.8	4.79	0.30	**0.79**	**0.00**	**0.42**
0 – 4 d lact.	3.8	6.5	5.0	5.4	5.08	0.31	-	-	-
5 – 10 d lact.	4.6	5.5	5.8	3.6	4.88	0.37	-	-	-
Mean	**4.0^{a}**	**5.7^{d}**	**5.4^{cd}**	**4.5^{bc}**	**-**	**-**	**-**	**-**	**-**
SEM	0.37	0.41	0.37	0.37	-	-	-	-	-

* *P*-Values with different superscripts in the same row (diet) or column (period) differ significantly ($P < 0.05$); no superscripts = not significantly different

Non-esterified fatty acids (NEFA), β-hydroxybutyrate (BHB), total protein (TP) and blood urea nitrogen (BUN) of supplemented periparturient Boer does were influenced by protein supplements ($P<0.05$), but not by period of measurements and the interactions between diet and period. Urea-CSM and CSM supplement reduced the mean NEFA but were similar to that of the Control. Inclusion of Urea-CSM and CSM lowered the mean BHB compared with those in the other two groups. A significantly low ($P<0.05$) mean TP was recorded for the CSM does compared to those in the other three groups. Urea supplement increased BUN significantly by 43% compared to the Control.

3.4 Discussion

3.4.1 Intakes of dry matter, protein fractions and metabolisable energy

3.4.1.1 Prepartum

The observation that Urea limited DM, UDP and ME intakes, while Urea-CSM and CSM promoted intakes in periparturient Boer goats could be associated with feed palatability, digestibility, BUN, and dietary concentrations of UDP and RDP. The bitter taste of urea could have depressed feed intake (Tadele and Amha, 2015). The higher DM digestibility in the Urea-CSM and CSM goats would encourage the does to eat more because the high digestibility could result in a more rapid flow of digesta leaving the digestive tract leading to more space available for ingesta. This reasoning is supported by the work of Solomon *et al.,* (2008) who found a linear correlation between digestibility and intake. The higher BUN in Urea does possibly triggers a negative feedback mechanism to the animals to reduce their intake (Provenza, 1995). Higher relative amounts of UDP and RDP in the Urea-CSM diet and the CSM diet was probably supplying more nitrogen for rumen microbes to actively degrade the ingesta and improve digestibility. Wang *et al.,* (2012) found that low, medium, or high RDP diets had similar effects on DM intake of goats.

3.4.1.2 Postpartum

The higher intakes of DM and protein fractions in the Urea-CSM and CSM treatment groups but lower intakes in the Urea treatment group showed that intakes of lactating does may also be driven by palatability, digestibility, BUN and concentrations of dietary UDP and RDP. The finding that intakes of DM and protein fractions for lactating does were higher than those for pregnant does could be related to space availability in the abdomen (McDonald *et al.,* 2011). It could also be driven by the increased requirements for glucose, amino acids and fatty acids in the does and suckling kids which drives their behaviour (Bell, 1995). When these nutrient requirements are not met, a metabolic adaptation takes place in the form of gluconeogenesis in the liver and changes in the synthesis and catabolism of amino acids and usage of fat for energy (Bell, 1995).

An interesting observation during early lactation not seen in late pregnancy was that the RGH intake across all treatments was similar. This similar RGH intake could be driven by the protein and energy requirements for milk synthesis when rumen fill is not a limiting factor. Protein supplementation still has a strong influence on intakes of periparturient does.

3.4.2 Body weight changes

3.4.2.1 Body weight changes in does

The higher intakes in Urea-CSM and CSM goats did not prevent doe body weight loss, the normal range being 52 to 57 kg (Van Niekerk and Casey, 1988). The absence of difference in BW loss could be due to the short period of dietary treatment (Greyling *et al.,* 2004), or because intakes of protein fractions and ME were deficient (NRC, 2007). These weight losses indicated that nutrient mobilisation from tissue reserves occur, which can be detected in milk composition and blood plasma metabolites (McDonald *et al.,* 2011).

3.4.2.2 Body weight changes in suckling kids

The higher ADG of supplemented suckling kids during the first week of lactation in this study indicated an increase in milk yield of the dam (Sangare and Pandey, 2000). This suggests that both UDP and RDP supplements gave similar benefits to the suckling kids. The UDP escapes rumen degradation, absorbed in the small intestine as amino acids and used for milk synthesis. The RDP enriches microbial crude protein, which is later absorbed in the small intestine and used for milk synthesis. This suggests that when DM intake is limited, does lose weight because of the need to meet the suckling kids' requirements for glucose, amino acids and fat. If these requirements derived from tissue catabolism of the does and nutrient intakes, then the does on RGH only were most likely to have insufficient nutrients to support the growth of their suckling kids.

The suckling kids' ADG in the present study were higher than previous values of 62 - 124 g/d (Van Niekerk and Casey, 1988) and 97 to 122 g/d (Htoo *et al.,* 2015), but within the normal expected scale of 250 g/d (NRC, 2007). These different values were probably related to different protein and energy concentrations in the various diets.

3.4.3 Milk composition

The results showing that Urea and/or CSM supplement had no effect on milk fat and protein agreed with the previous results in Boer does by Greyling *et al.,* (2004) who utilised both intensive and extensive diets (CP 140 vs. 67 g/kg DM). Milk fat is usually depended on ME intake and fat catabolism from body reserves. These two mechanisms may have explained fat milk in the present study. Higher ME intake in the Urea-CSM and CSM does might have maintain the milk fat, while the lower ME intake in the Control and Urea does may have obtained energy from fat mobilisation. The higher blood plasma NEFA and BHB in the present study confirmed the energy mobilisation to support glucose requirement for the suckling kids. This might also explain the lack of difference in milk lactose in the current study. Overton and Waldron (2004) explained that homeorhetic adaptation occurs during early lactation, where body fat is mobilised in the form of NEFA, enters the bloodstream and is carried into the mammary gland to become a component of milk.

The absence of any significant difference in milk protein between treatments in the present study may be due to the goats' metabolic process (Bell, 1995) and intakes of protein fractions. The increased of intakes of UDP and RDP by urea and/or CSM treatments in the present study might have increased absorption of amino acids and microbial crude protein that become milk protein. The Control does with low intakes of RDP and UDP might have derived amino acids or ammonia from tissue mobilisation as shown by similar concentration of total protein of blood plasma with the supplemented does.

The observation that fat and protein in milk decreased while lactose increased with advancing lactation is supported by an earlier report by Greyling *et al.,* (2004). Fat, protein and lactose in milk are derived from MP and ME intake (Walker *et al.,* 2004) as well as mobilisation from protein tissue (Overton and Waldron, 2004). As the lactation period progresses, fat and protein supplies from the body reserve become limited, which results in low fat and protein in milk. The increased milk in lactose in advancing lactation period allows volatile fatty acids (acetic, propionic and butyric acids) from the rumen to be absorbed into the blood, and converted into milk to supply energy (McDonald *et al.,* 2011). Milk production was not measured in the present study however, the ADG of suckling kids increased, indicating the amount of milk secreted increased.

3.4.4 Blood plasma metabolites

The lowest mean of NEFA in the Urea-CSM experimental group was likely due to the highest ME intake as reported in a previous study on dairy goats (Celi *et al.,* 2008). Fat deposits are usually catabolised for energy (Sahlu *et al.,* 1995) for foetal development or milk synthesis if dietary energy is limiting. Herdt (2000) reasoned that metabolic adaptation to this limiting energy condition was by way of mobilising energy, changing the substrate or converting energy in the adipose tissue, liver, skeletal muscle and mammary gland. Urea-CSM supplement seems to supply sufficient energy, and so there was only a minor metabolic adaptation required.

The concentration of blood NEFA for a healthy pregnant doe is 0.29 mmol/L and higher levels up to 1.67 mmol/L are considered toxic enough to cause pregnancy toxaemia (Vasava *et al.,* 2016). Using these NEFA values, it can be justified that Urea-CSM supplement maintained the normal NEFA level in the experimental does in our current study.

The low blood plasma BHB for the Urea-CSM and CSM experimental groups coincided with the higher ME intake compared to the Control. This observation is similar to previous findings in dairy goats (Bronzo *et al.,* 2010; Sahlu *et al.,* 1995). High ME intake supplies sufficient glucose and prevents gluconeogenesis (McDonald *et al.,* 2011). High ME intake may also provide sufficient BHB from the rumen, so less body fat was mobilised for energy and fewer ketone bodies were formed (McDonald *et al.,* 2011; Ospina *et al.,* 2013).

The does in this study appeared to be free from metabolic disorder because Vasava *et al.,* (2016) reported that blood plasma BHB for a healthy pregnant doe is 0.46 mmol/L and pregnancy toxaemia occurs when this value increases to 4.82 mmol/L. Using this BHB standard, the CSM and Urea-CSM does in the current study had normal BHB concentration.

The reason for the lowest TP in the CSM does was unclear because both CSM and Urea-CSM groups had higher intakes of protein fractions. This conflicts with a study by Sahlu *et al.,* (1992) who found that the TP of Angora doelings depended on protein intake. The standard TP references for a healthy goat have been reported to be 63.2 g/L (Hefnawy *et al.,* 2010), 64 to 78 g/L (Komala *et al.,* 2011) or 60 to 70 g/L (Samira *et al.,* 2016). Hefnawy *et al.,* (2011) found that pregnancy toxaemic goats had TP levels of 31.9 g/L. Therefore, it can be justified that all experimental does in the present study had normal TP concentrations.

The highest BUN concentration observed in the Urea treatment group implied that dietary urea was directly absorbed into the blood stream of does. The higher BUN in all supplemented groups compared with that of the Control group was consistent with previous observations in dairy does (Barbosa *et al.,* 2012; Sahlu *et al.,* 1995). McDonald *et al.,* (2011) explained that urea is converted to ammonia and absorbed into the blood. All experimental does in the current study did not have abnormal BUN concentration because Vasava *et al.,* (2016) reported that the standard BUN references for a healthy pregnant goat and pregnancy toxaemic goat were 6.63 and 7.94 mmol/L, respectively.

3.5 Conclusion

Average daily gain of suckling kids and milk lactose content increased, while plasma concentrations of NEFA and BHB decreased, as lactation progressed in does supplemented with Urea-CSM and CSM. This study provides valuable experimental evidence that Urea-CSM and CSM supplements maintained normal plasma levels of NEFA and BHB in lactating does, but dietary CP at 143 g/kg DM was insufficient to prevent doe weight loss. Therefore, during the critical first week of lactation, dietary CP levels higher than 143 g/kg DM are needed to minimise the impact of negative energy balance and subsequent mobilisation of body fat reserves for milk synthesis resulting in LWT and body condition losses. Dietary ME concentration should be optimum enough to prevent body fat mobilisation. In West Timor, Indonesia, goat farmers have limited funds for supplements. During the dry season, a controlled loss of weight may be a good economic option provided it does not interfere with reproduction.

Chapter 4 Undegradable Dietary Protein Limits Growth and Carcass Yields in Crossbred Boer Kids Fed Desmanthus or Rhodes Grass (*Chloris gayana*) Hay Supplemented with Urea and/or Cottonseed Meal or Gliricidia

Abstract. The objective of this study was to compare liveweight gain, carcass and non-carcass component yields and meat quality in crossbred Boer kids fed *isonitrogenous* diets varying in undegradable (UDP) and rumen degradable (RDP) dietary protein sources. Twenty-five female crossbred Boer kids were randomly allocated into five dietary treatments: Rhodes grass hay (RGH) supplemented with either urea (Urea), urea plus cottonseed meal (Urea-CSM), cottonseed meal (CSM), Gliricidia (Gliricidia). while *Desmanthus leptophyllus* (Desmanthus) was fed as a sole diet. The diets were formulated to supply 195 g CP/kg DM. The Urea diet provided 150 and 45 g/kg DM of RDP and UDP, respectively. Urea-CSM diet provided RDP and UDP quantities of 143 and 52 g/kg DM; CSM diet provided 137 and 58 g/kg DM; Desmanthus diet provided 112 and 83 g/kg DM and Gliricidia diet provided 125 and 70 g/kg DM of RDP and UDP, respectively. After 138 days of supplementation, goats fed the Desmanthus diet had the highest liveweight gain and heaviest average cold carcass weight (83 g/d and 12.1 kg). This was followed in descending order, by CSM (58 g/d and 9.6 kg), Urea-CSM (48 g/d and 7.8 kg), Gliricidia (41 g/d and 7.6 kg) and Urea (6 g/d and 6.0 kg). Heavier carcass weight was associated with greater eye muscle area and fat depth at the 12th rib. AUSMEAT Beef Colour Standard scores of 3-4 for the eye muscle of goats fed Desmanthus and CSM diets compared to scores of 1C-2 in other diets meant that the darker meat in Desmanthus and CSM diets was associated with heavier carcass weight and a more rapid rate of decline in carcass pH. High liveweight gains and yields of carcass and non-carcass components in goats fed a basal diet of RGH and supplemented with either urea, CSM or Urea-CSM were positively correlated with the quantity of UDP in the diet. The higher rate of liveweight gain and yield of carcass and non-carcass components for goats fed the Desmanthus diet compared with other treatments was associated with increased DM, UDP, RDP, MP and ME intakes.

Keywords: Goats; carcass; degradable/undegradable protein; supplementation

4.1 Introduction

Liveweight gain in meat goats fed a basal diet of tropical grass generally increases in response to feeding tropical legume supplements high in crude protein content such as Alfalfa, Desmanthus, Leucaena, Lablab in combination with Sudan grass (Kanani *et al.,* 2006). Other studies using urea and/or soybean cake with *Digitaria decumbens* Stent (Limea *et al.,* 2009) or cottonseed cake and sunflower cake with Rhodes grass hay (Mtenga and Kitaly 1990) have also reported increases in liveweight gains. The level of response for any given basal diet, however, is not consistently predicted by the concentration of crude protein in the diet, but varies with the source of crude protein (Al Jassim *et al.,* 1991b).

Supplements derived from protein-rich seed meals generally produce a consistent increase in liveweight gains (Mtenga and Kitaly, 1990; Solomon *et al.,* 2008). Mtenga and Kitaly (1990) fed goats with Rhodes grass hay (66 g CP/kg DM diet) and offered 200 g supplement containing maize bran, molasses and minerals and varying amounts of cottonseed cake and sunflower cake with dietary CP content varying from 102 to 177 g/kg DM. They found that liveweight gain increased linearly from 45 g/day at 102 g CP/kg DM to 63 g/day at 177 g CP/kg DM. Solomon *et al.,* (2008) fed one group of goats with natural grass hay only and the other three groups with grass hay without fermentable carbohydrates but with cottonseed meal at crude protein concentration levels of 94, 146, 167 and 177 g/kg DM diet consumed. They found that the goats gained 10, 42, 65 and 56 g/d, respectively. The increased liveweight in these studies indicate that cottonseed cake, sunflower cake and cottonseed meal are good sources of UDP (NRC, 2007) that would be absorbed as true protein and made available for growth. Increasing the amount of supplemental crude protein derived from a mixture of protein-rich seed meals and non-protein nitrogen from urea at levels of 150, 159 or 119 g CP/kg DM diet consumed has been demonstrated to produce a consistent increase in liveweight gain (Limea *et al.,* 2009; Uza *et al.,* 2005; Wambui *et al.,* 2006). Limea *et al.,* (2009) fed four groups of Creole kids with *Digitaria decumbens* Stent (108 g CP/kg DM) as a basal diet and supplemented the kids with a protein and energy rich concentrate, comprised of ground maize, soybean cake, wheat bran, urea, vitamins and minerals (209 g CP/kg DM). The authors found linear liveweight gain responses of 42, 61, 72 and 84 g/d to total crude protein concentrations of 99, 124, 148 to 150 g/kg DM diet consumed, respectively.

Uza *et al.,* (2005) treated cassava peels with 0, 4, 6 and 8% of urea and fed it to five groups of goats on natural herbage as the basal diet and reported linear total crude protein concentrations ranged from 111 to 146 g/kg DM diet consumed but led to non-linear liveweight gains. This finding revealed that the optimum liveweight response of goats to urea supplementation as an NPN-RDP source with cassava peels as readily fermentable carbohydrate source was 4%.

Another study (Wambui *et al.,* 2006) found an opposite result where goats lost weight by 15 g/d when they were fed maize stover sprayed with urea and supplemented with maize germ as a carbohydrate source with a crude protein concentration of 64 g/kg DM diet consumed. Wambui *et al.,* (2006), however, found that the goats gained 11, 24, 36 and 44 g/d when the urea treated maize stover was supplemented with maize germ and *Tithonia diversifolia* foliage at crude protein concentrations of 79, 90, 110 to 119 g/kg DM diet consumed, respectively. These studies demonstrated that the use of urea as an NPN-RDP was effective in increasing liveweight gain in goats when fermentable carbohydrate was available. In addition to fermentable carbohydrates, the use of urea was more effective when mixed with another source of protein feed.

Studies aimed at increasing liveweight gain by supplementing goats with different sources of legumes have produced inconsistent results. For instance, Kanani *et al.,* (2006) offered crossbred grower goats a basal diet of Sudan grass at 60% of total diet DM supplemented with either Leucaena, Alfalfa, Lablab or Desmanthus at 40% of total diet DM. They found that liveweight gain was highest (94 g/day) in goats on the Leucaena supplemented diet, consistent with the highest CP concentration of 275 g CP/kg DM. Goats on the Alfalfa diet gained 82 g/day despite its comparatively lower CP content of 203 g/kg DM. Lablab and Desmanthus supplements had the same CP content (215 g CP/kg DM) but produced liveweight gains of 77 and 61 g/day, respectively. With the exception of Leucaena, these contrasting responses could not be explained by differences in neutral (NDF) and acid (ADF) detergent fibres or acid detergent lignin (ADL) contents (Kanani *et al.,* 2006) or by typical digestibility values or tannin contents reported on Feedipedia (https://www.feedipedia.org/; retrieved 23 Feb 2018).

Recommendation for protein supplement utilisation could be established on the basis of the highest liveweight gain response, but opinion in the published literature is divided about the best protein supplement for goats. Limea *et al.,* (2009) suggested that concentrate diets were better utilised than non-concentrate diets, but did not emphasise the use of soybean cake and urea. Mtenga and Kitaly (1990) recommended increasing protein supplementation levels up to 200 g/kg DM without discussing the effect of such an increase on the utilisation of cottonseed cake and sunflower cake. Kanani *et al.,* (2006) were of the opinion that Leucaena was better than Desmanthus but gave no insight regarding degradability of these legumes. Without an understanding of why particular diets produce better responses than others, productivity responses to novel use of protein supplements may be predictable.

In the present study, it was hypothesised that *growth and carcass yields in goats will be driven by the quantities of UDP and RDP rather than types of protein supplements or concentrations of dietary CP*. Therefore, the primary objective of this study was to compare liveweight gain, carcass and non-carcass component yields and meat quality in crossbred Boer kids fed isonitrogenous diets varying in UDP and RDP.

4.2 Materials and Methods

4.2.1 Location, animals and management

Two experiments were conducted at the James Cook University Animal House, Townsville (19º19'30'' S; 146º45'44'' E), tropical North Queensland, Australia. The use of animals and experimental protocols were approved by the Animal Ethics Committee of James Cook University (Approval Number: A2122). In Experiment 2, 25 Boer x Rangeland crossbred female kids (average BW of 19.60±1.86 kg), five months old, were fed in individual pens (2.2 m x 1.1m x 1.7 m) for 78 d. The floor was covered with rubber matting with an apron at the back allowing for cleaning of the floor. At the start of the experiment, the degree of internal parasitic infection was determined with the flotation technique (Hutchinson, 2009) and infected goats were treated with *Zolvix monepantel* 1 ml/10 kg BW. Faecal egg count was repeated one week later to ensure that all experimental kids were free from internal parasites. Ten ml of blood was drawn from the jugular vein three times on the first day (d 1), middle (d 79) and at the end (d 120) of the experiment, where packed cell volumes (PCV) in the animals were measured and confirmed to be within the normal reference range of between 26% and 27%. In Experiment 3, the same twenty-five goats (average BW of 20.14±2.13 kg) were randomly allocated into the five dietary treatments and goats returned to single pens for another 130 d of supplementary feeding trial. A randomised complete block design with five dietary treatments comprising five animals per treatment was used for these two studies. The first four dietary treatments were Rhodes grass (*Chloris gayana*) hay (RGH) supplemented with either urea (Urea), mixed urea and CSM (Urea-CSM), cottonseed meal (CSM) or air-dried Gliricidia (*Gliricidia sepium*) leaves (Gliricidia). The fifth dietary treatment was Desmanthus (*Desmanthus leptophyllus*) dried leaves that fed as a sole diet (Desmanthus).

4.2.2 Forages and feeding system

Rhodes grass hay (RGH) bales were purchased regularly from local farms by the James Cook University. The RGH was chaffed (SFC 2340 'Star', Ballarat, Australia) at 5 to 10 cm lengths and separated into three forms: plain RGH for the CSM and Gliricidia goats, RGH 50% urea for the Urea-CSM goats and RGH 100% urea for the Urea goats. In Experiment 2, the amount of urea offered was 3.1 and 6 g/kg DM RGH and that in Experiment 3 was 8.8 and 17.3 g /kg DM RGH for the Urea-CSM and Urea goats, respectively. Urea was diluted with clean tap water (3: 10, w/w) then sprayed on the RGH while mixing (Calan Super Data Ranger Mixer) to the desired CP content in the diet. Gliricidia was harvested from the University paddock while *Desmanthus leptophyllus* hay bales were supplied by Agrimix Ltd. The chaffed RGH was stored in plastic bins ready to feed the animals for several days. In Experiment 2, Desmanthus hay was chaffed and offered in a mixture of leaves and stems. In Experiment 3, Desmanthus leaves were manually separated from the stems, stored in plastic bins and only leaves fed to the goats.

A representative offered or refused feed sample was collected daily for each animal, kept in airtight bags, stored in a 3ºC room, and eventually ground to pass through a 2 mm sieve (Retsch GmbH 5657 HAAN, West Germany). After mixing, an equal proportion of offered and refused feedstuff from each animal was collected according to the dietary treatment and sent for wet chemistry analysis at the Forage Lab Australia, Victoria, Australia (www.foragelabaustralia.com.au) an affiliate of Cumberland Valley Assay Service (CVAS), USA.

4.2.3 Chemical composition and measurement of intakes

Nutrient composition of the experimental diets is shown in Table 4.1. Feed samples were analysed for DM, OM and CP (AOAC, 1990) within one week of starting the experiments. All dietary treatments were formulated to contain CP of 137 g CP/kg DM in Experiment 2 or 195 g CP/kg DM in Experiment 3, in accordance with the CP content of the Desmanthus leaves and stems in Experiment 2 or the Desmanthus dried leaves in Experiment 3.

Table 4.1 Ingredients and nutrient composition of the experimental diets

	Diets				
	Urea	**Urea-CSM**	**CSM**	**Desmanthus**	**Gliricidia**
Item			**Experiment 2**		

Ingredients (g DM)					
Rhodes grass hay	602	602	602	0	0.71
Cottonseed meal	0	20.25	41	0	0
Urea	6	3.11	0	0	0
Desmanthus	0	0	0	1	0
Gliricidia	0	0	0	0	0.29
Nutrient composition					
DM (g/kg fresh wt)	911	910	909	915	911
CP (g/kg DM)	137	137	137	137	137
UDP (g/kg DM)	35	37	40	55	46
RDP (g/kg DM)	102	100	97	82	91
MP_{TDN} (g/kg DM)	14	16	19	27	22
MP_{RDP} (g/kg DM)	65	65	65	65	65
ME (MJ)	7.8	8.0	8.1	8.9	8.5
Experiment 3					
Ingredients (g DM)					
Rhodes grass hay	602	602	602	0	0.11
Cottonseed meal	0	67	138	0	0
Urea	17.3	8.8	0	0	0
Desmanthus	0	0	0	1	0
Gliricidia	0	0	0	0	0.89
Nutrient composition					
DM (g/kg fresh wt)	905	903	902	890	911
CP (g/kg DM)	195	195	195	195	195
UDP (g/kg DM)	45	52	58	83	71
RDP (g/kg DM)	150	143	137	112	124
MP_{TDN} (g/kg DM)	21	28	34	32	38
MP_{RDP} (g/kg DM)	98	98	98	83	95
ME (MJ)	7.7	8.1	8.5	8.8	9.6

DM = dry matter, CP = crude protein, RDP = rumen degradable protein, UDP = rumen undegradable dietary protein, MP_{TDN} = metabolisable protein based on total digestible nutrient, MP_{RDP} = metabolisable protein based on rumen degradable protein and ME = metabolisable energy

Equal amounts of the supplementary diets were offered to animals in individual pens twice a day in the morning (08:00 h) and in the afternoon (16:00 h). To allow for refusals, one and a half times of the average intake of two previous days was offered. All experimental animals had access to Rumevite complete mineral mix. The forages were mixed at afternoon (13:00 h) as the preparation of fresh feed encouraged the animals to eat. Fresh drinking water was available *ad libitum*.

Feed intake was measured as the difference between feed offered and refused within 24 h. The multiplication of nutrients from wet chemistry analysis by the amount of feed offered and refused on a dry matter basis was determined as intake of nutrients. Wet chemistry service provided protein fractions of crude protein (CP), acid detergent fibre insoluble protein (ADICP) and rumen degradable protein (RDP), while energy was provided in total digestible nutrient (TDN) and metabolisable energy (ME). Equations (AFRC, 1993; NRC, 2007) were incorporated with the wet chemistry results to determine protein fractions: Undegraded dietary protein [UDP] (g/d) = [CP – RDP] (AFRC, 1993) Equation 31. Digestible undegradable protein [DUP] (g/kg DM) = 0.9 [(UDP) – (ADICP)] (AFRC, 1993) Equation 33. The equation for predicting MP as suggested by AFRC (1993) was [MP] (g/d) = 0.6375 MCP + DUP. NRC (2007) suggested estimating microbial crude protein (MCP) as 0.13 TDN if energy is a limiting factor or 0.85 RDP if protein is a limiting factor. Combining the equations, [MP_{TDN}] (g/d) = [(0.6375 x 0.13 TDN g/d) + (0.9 UDP – ADICP g/kg DM)] (AFRC, 1993) Equation 23; where fermentable energy is limiting the production of MCP. When RDP is limiting, then the equation used to estimate [MP_{RDP}] (g/d) = [(0.6375 x 0.85 RDP g/d) + (0.9 UDP – ADICP g/kg DM)]. This study, therefore, expressed MP as MP_{TDN} and MP_{RDP}. There was sufficient RDP to meet the needs of rumen microbes because all the experimental diets were supplemented with rich protein sources or Desmanthus.

4.2.4 Slaughter procedure, carcass dissection and measurement of carcass quality

4.2.4.1 Slaughter procedure

All experimental animals were humanely slaughtered at the end of Experiment 3 in the Nutrition Shed at James Cook University Veterinary Sciences by a licensed Veterinarian. Standard procedures for slaughter and measurement of carcass parameters have been described in detail elsewhere (Maia *et al.,* 2012; McGregor, 1990; Safari *et al.,* 2011).

Three rooms were utilised for the series of activities: slaughtering, measuring meat pH and temperature, as well as determining cold carcass weights. Carcass pH and temperature were measured in a cooling room at 4°C for 24 h. Carcasses were then moved and stored in a mobile cold room at 3ºC for 8 h before cold carcass weight, meat colour, eye muscle area, fat depth and kidney' weight were measured.

Three to six goats were slaughtered daily over five days. Each goat was weighed, body condition scored and dentition recorded prior to slaughter. The goat was stunned with a captive bolt, cut and hung by its Achilles tendon on a hook to bleed out the animal. The skin was immediately cut opened in the abdominal area for evisceration. Viscera were removed, stored in a plastic bucket and kept in a cooling room pending dissection and measurement.

After evisceration and skinning, the head was removed at the first vertebrae with the tongue left in place. The sternum, thoracic organs and all related tissues were removed but the skirt was left. The forefeet were removed at the carpal-metacarpal joint while the hind feet were removed at the tarsal-metatarsal joint.

4.2.4.2 Carcass and dissection

Hot carcass weight (HCW) was measured within fifteen minutes before the first meat pH and meat temperature were determined (meat pH-mV-temperature model WP-80 M MSA version 4.7, TPS Pty Ltd, Australia). The hot carcass was then moved into a 5ºC room and stored for 24 h where meat pH and temperature were measured regularly. The ultimate meat pH and temperature were determined at the time of moving the carcass to the cold room, and kept at 3ºC for chilling. Cold carcass weight, meat colour, eye muscle area, fat depth, fat colour and kidney weight were determined after 8 h chilling. Both left and right sides of the 12^{th} rib were removed using a knife and an electric saw. Meat colour was determined at the rib eye muscle (*longissimus dorsi*) at the caudal side. Meat and fat colours were scored against the AUS-MEAT Colour Chart for Beef (Daniel n.d). Eye muscle area (square centimetres) was manually measured by counting the number of 1 x 1 mm squares marked on a clear plastic grid covering the surface area of the *longissimus dorsi* muscle (including fascia) on the caudal side of the 12^{th} rib. Fat depth (mm) was measured at the point of 110 mm from *spinous* to *transverse process* (White and Holst, 2006)). Kidneys and attached fat tissue were removed and weighed.

4.2.4.3 Carcass temperature and pH

Carcass temperature and pH were measured six times post-mortem at the same point on the *semitendinosus* muscle in accordance with Meat Standards Australia protocols. The sixth regular set times were 15 minutes, 1, 2, 4, 6 and 24 h post-mortem. Temperature was measured using an electrode probe (pH-mV-Temperature), while meat pH was measured by a meat pH meter (Model WP-80 M MSA, TPS Pty Ltd Springwood Brisbane, Australia 4127).

4.2.4.4 Non-edible carcass components and dissection

Non-carcass portions were weighed after six hours of storage in the cool room. These included weights of the empty digestive tract, fat attached to the digestive tract, skin, head with tongue, feet, heart, lungs, trachea, liver and spleen. Other edible parts were also measured, including sternum, while kidneys were left in the carcass.

4.2.5 Statistical analyses

Collected data for intake, liveweight changes, weights of carcass and non-edible carcass components, eye muscle area and fat depth were analysed using a one-way analysis of variance (SPSS 2014; SPSS Statistics for Windows, Version 23.0, IBM Corp., Armonk, NY, USA) to test for the effect of treatment. The differences between treatment means were subjected to Duncan's multiple range test at $P < 0.05$ threshold. Carcass temperature and pH data were analysed using a Generalised Linear Model (GLM) fitting the fixed effects of dietary treatment and time of measurement as well as their second order interactions. If there were differences due to these factors at the 0.05 level of probability, then the post Hoc Tukey pairwise mean comparison analysis was employed.

4.3 Results

4.3.1 Feed and nutrient intakes

Nutrient intakes are presented in Table 4.2. Total DM intake of goats in Desmanthus group was significantly higher than their counterparts in other treatments for both Experiments. Animals supplemented with urea only had the lowest total DM intake. Total DM intakes of goats fed RGH and supplemented with CSM, Urea-CSM or Gliricidia were similar. Rhodes grass hay intake as a basal diet in the Gliricidia goats in Experiment 2 was comparatively lower than those in other diets, but these RGH intakes were similar across the supplemented goats in Experiment 3.

Table 4.2 Daily intakes of dry matter, protein fractions and metabolisable energy intakes by crossbred Boer goats

Item	Dietary treatments					sem
	Urea	Urea-CSM	CSM	Desmanthus	Gliricidia	
Experiment 2						
Intake (g) Dry matter	312^{a}	344^{ab}	377^{b}	652^{c}	358^{ab}	26.41
Crude protein	43^{a}	47^{ab}	51^{b}	89^{c}	49^{ab}	3.61
UDP	11^{a}	13^{ab}	15^{bc}	35^{d}	16^{c}	1.85
RDP	32^{a}	34^{a}	36^{a}	54^{b}	33^{a}	1.81
MP_{TDN}	5^{a}	6^{ab}	7^{bc}	18^{d}	9^{c}	0.96
MP_{RDP}	20^{a}	23^{ab}	24^{b}	42^{c}	23^{ab}	1.70
ME (MJ)	2.6^{a}	2.7^{ab}	3.0^{b}	5.8^{c}	3.0^{b}	0.25
Experiment 3						
Intake (g)						
Dry matter	432^{a}	561^{b}	636^{b}	1027^{c}	591^{b}	42.91
Crude protein	84^{a}	109^{b}	124^{b}	200^{c}	115^{b}	8.37
UDP	19^{a}	29^{b}	37^{c}	85^{d}	42^{c}	4.72
RDP	65^{a}	80^{bc}	87^{c}	115^{d}	73^{ab}	3.90
MP_{TDN}	9^{a}	16^{b}	21^{c}	32^{d}	23^{c}	1.62
MP_{RDP}	42^{a}	55^{b}	63^{b}	85^{c}	56^{b}	3.11
ME (MJ)	3.3^{a}	4.5^{b}	5.4^{c}	9.0^{d}	5.7^{c}	0.40

Different superscript letters in the same row differ significantly; $P < 0.05$ and no superscript letters = not significantly different

CSM = cottonseed meal, sem = standard error of the mean, UDP = rumen undegradable dietary protein, RDP = rumen degradable protein, MP_{TDN} = metabolisable protein based on total digestible nutrient, MP_{RDP} = metabolisable protein based on rumen degradable protein

Goats in the Desmanthus treatment had significantly higher protein and metabolisable energy (ME) intakes (P<0.05) than goats in the other treatments in both Experiments. Cottonseed meal increased the intakes of protein fractions and ME more than other protein supplements in Experiment 3 but some of these intakes were similar in goats supplemented with Gliricidia or Urea-CSM in Experiment 2. Goats in the Urea treatment had the lowest intakes of protein fractions and ME in both Experiments.

4.3.2 Liveweight changes, carcass yields and carcass qualities

Liveweight changes, carcass yields and carcass qualities are presented in Table 4.3.

4.3.2.1 Experiment 2

Boer goats lost weight when they were offered RGH as a basal diet supplemented with urea, Urea-CSM or Gliricidia at the dietary CP concentration of 137 g/kg DM diet. Goats in the Urea treatment lost 15 g/d of liveweight, which was about five times higher than those in the Urea-CSM and Gliricidia goats. Goats offered RGH and supplemented with CSM and dietary CP concentration at 137 g/kg DM gained 7 g/d. Goats fed with chaffed dried leaves and stems of Desmanthus containing 137 g CP/kg DM diet gained 33 g/d over 78 d of the feeding trial.

4.3.2.2 Experiment 3

Fed as a sole diet, the Desmanthus goats gained 83 g/d equivalent to double the gain in goats on Gliricidia and Urea-CSM supplements as the dietary CP concentration increased to 195 g/kg DM diet. The other two treatments had similar ADG and liveweight as the CSM goats.

Boer goats offered Desmanthus yielded the heaviest carcasses compared to goats offered RGH and other protein supplements (P<0.05). Among the supplemented treatments, CSM goats had the heaviest carcasses, while the other three groups had similar responses (P>0.05).

Table 4.3 Liveweight changes, average daily gain, carcass weights, fat depth and eye muscle area in supplemented crossbred Boer goats

Item	Treatment					sem
	Urea	Urea-CSM	CSM	Desmanthus	Gliricidia	
	Experiment 2					
Initial LW (kg)	20.1	19.6	20	19.3	19.1	0.4
Final LW (kg)	19.1	19.4	20.4	21.4	18.9	0.4
Average LWG (kg)	-.9[a]	-.2[ab]	0.4[b]	2.1[c]	-.2[ab]	0.2
ADG (g/d)	-15[a]	-3[ab]	7[b]	33[c]	-3[ab]	3.9
	Experiment 3					
Final LW (kg)	20.0[a]	25.5[b]	27.6[bc]	30.3[c]	24.7[b]	0.8
Average LWG (kg)	0.7[a]	5.6[b]	6.7[b]	9.6[c]	4.7[b]	0.6
ADG (g/d)	6[a]	48[b]	58[b]	83[c]	41[b]	5.5
FCR (g/g)	37.3[b]	10.6[a]	10.4[a]	11.6[a]	14.2[a]	5.4
Hot carcass wt. (kg)	6.5[a]	8.2[b]	10.1[c]	12.6[d]	7.9[a]	0.5
Cold carcass wt (kg)	6.0[a]	7.8[b]	9.6[c]	12.1[d]	7.6[ab]	0.5
CCW to LW (%)	29.4[a]	30.4[a]	34.3[b]	39.6[c]	30.4[a]	0.8
CCW to HCW (%)	91.8[a]	95.6[b]	95.9[b]	96.0[b]	94.9[b]	0.5
EMA (cm^2)	2.4[a]	3.5[ab]	3.9[b]	5.5[c]	3.3[ab]	0.26
Fat depth (mm)	n. d	<1	2.4	4.6	<1	-

Different superscript letters in the same row differ significantly; $P \leq 0.05$ and no superscript letters = not significantly different

LW = liveweight, LWG = liveweight gain, ADG = average daily gain, FCR = feed conversion ratio (g gain/g feed), wt = weight, HCW = hot carcass weight, CCW = cold carcass weight, EMA = eye muscle area and n.d = not detectable

About 4% loss of HCW after cooling was detected from carcasses of goats offered Desmanthus, similar to those in the supplemented groups (P>0.05), except for the Urea group. The HCW loss in Urea supplemented goats reached 8.2% after cooling, which was about double those in other groups.

Meat colour for the Desmanthus goats was 3.75 and only one deviation at 1C. Meat colour for the CSM goats was 3.5. Gliricidia goats recorded a colour score of 2.66. The majority of the Urea goats (80%) had a meat colour of 1C while the Urea-CSM goats had more variable meat colours: 60% had 1C, 20% had 1B and another 20% had 2. The average fat colour scores for goats were 4 (CSM and Desmanthus), 2.6 (Gliricidia), 2.4 (Urea-CSM) and 1.8 (Urea).

4.3.3 Carcass temperature and pH

A decrease in carcass temperature was associated with dietary treatment and post-mortem duration (P<0.05). The highest (22.41ºC) and the lowest (20.79ºC) mean carcass temperatures were recorded in Desmanthus and Urea supplemented goats, respectively.

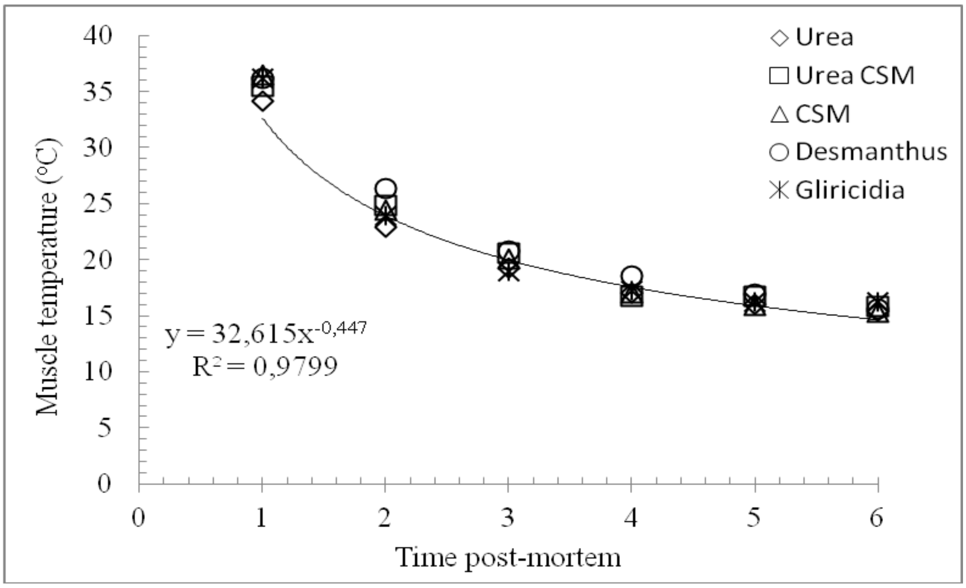

Figure 4.1 Carcass temperature of supplemented Boer goats 1 = 15 min., 2 = 1 h, 3 = 2 h, 4 = 4 h, 5 = 6 h and 6 = 24 h post mortem

Carcass temperature dropped sharply from 35.7 to 24.5ºC within 1 h, decreased further to 20.0ºC after 2 h and stabilised at the lowest temperature of 15.7ºC after 24 h post-mortem.

Mean of carcass pH was associated with dietary treatment and post-mortem duration (P<0.05). In regards to diet effect, the highest mean pH (6.31) was detected in Urea goats, similar to Gliricidia and Urea-CSM, yet significantly higher than those of CSM (6.18) and Desmanthus

(6.13) goats. The mean carcass pH (6.90) measured within 15 minutes decreased to 5.66 24 h post-mortem.

4.3.4 Non-carcass components and other non-edible parts of the carcass

Table 4.4 shows the mean weight of non-carcass and other non-edible parts of the carcass.

Table 4.4 Weights of organs and non-edible parts of the carcass in supplemented Boer goats

Variables	Treatment					
	Urea	Urea-CSM	CSM	Desmanthus	Gliricidia	
Organs (g)						**sem**
Heart	80^{a}	91^{ab}	112^{b}	114^{b}	107^{b}	4.3
Lungs	159^{a}	164^{ab}	231^{bc}	248^{c}	191^{ab}	11.6
Trachea	90^{a}	109^{ab}	103^{ab}	130^{b}	114^{ab}	4.8
Liver	208^{a}	295^{b}	360^{c}	426^{d}	336^{bc}	16.9
Kidney plus fat	67^{a}	105^{b}	139^{c}	254^{d}	101^{b}	15.4
Spleen	28^{a}	36^{b}	37^{b}	39^{b}	30^{a}	1.6
Total non-carcass (g)	828^{a}	1144^{b}	1286^{b}	1579^{c}	1201^{b}	60.5
Non-edible parts of the carcass (g)						
Empty digestive tracts	1429^{a}	1846^{abc}	1904^{bc}	2223^{c}	1609^{ab}	80.7
Fat of digestive tract	87^{a}	179^{ab}	407^{b}	687^{c}	276^{ab}	52.6
Skin	1270^{a}	1712^{b}	1979^{b}	2083^{b}	1690^{b}	76.8
Head and tongue	1481^{a}	1650^{a}	1903^{b}	1881^{b}	1576^{a}	45.2
Feet	551^{a}	621^{ab}	684^{bc}	756^{c}	630^{ab}	18.4

Row means bearing different superscripts differ significantly ($P < 0.05$)

Goats in the Desmanthus treatment had the heaviest organs and non-edible carcass components ($P<0.05$) compared to other treatments.

4.4 Discussion

Goats fed *Desmanthus* had the highest intakes of DM, CP, RDP, UDP and as a result, estimated high values of MP and ME. *Desmanthus* was associated with the highest rates of liveweight gain, heaviest hot and cold carcass weights, largest eye muscle area and thickest fat depth after 138 days of growth when compared to all other diets. These high intakes recorded in goats on the *Desmanthus* diet are likely the result of higher palatability and DM digestibility, sufficient RDP and branched chain VFA than goats supplemented with urea, Urea-CSM or CSM or on RGH only. This finding is consistent with the report of Ngo (2012) when growing sheep on Flinders grass hay were supplemented with freshly harvested *Desmanthus*.

Goats on basal RGH diet supplemented with CSM had higher DM, CP, RDP, and UDP intakes and estimated MP and ME when compared with Urea and Urea-CSM supplements despite the diets being iso-nitrogenous (195 g CP/kg DM). The lower intakes observed in goats on Urea-CSM supplement were likely due to lower palatability associated with the urea component of the supplement that had been coated onto the RGH. This is because RGH with CSM and RGH with Urea-CSM diets had similar DMD (Table 5.2) and supplied similar quantities of RDP and UDP. The RGH + Urea diet, however, provided less UDP compared with the diets containing CSM. This suggests that rumen function in the goats supplemented with Urea alone, was limited by insufficient branched chain amino acids and VFA (volatile fatty acids) as all goats had access to a complete mineral mix with adequate macro and micro minerals for a balanced rumen fluid ammonia concentration. Apparent minor differences in dietary RDP and UDP concentrations resulted in substantial differences in DM, RDP, and UDP intakes and therefore, MP and ME, as goats supplemented with CSM only grew approximately 21% faster and achieved 23% heavier carcass weights after 130 days of feeding compared with goats fed RGH supplemented with Urea-CSM.

Goats fed the urea diet consumed the same amount of RGH as goats supplemented with either Urea-CSM or CSM alone. This indicates that urea did not limit DM intake. This observation is at odds with other observations of lower palatability in cattle and sheep supplemented with urea and basal diets of tropical grasses. Urea-CSM treatment did not stimulate intake of the basal diet despite the presence of a source of rumen degradable true protein and minerals sufficient to meet the nutritional requirements for amino acids, ammonia-N, branched chain fatty acids and macro and micro minerals.

Despite supplying less CP, RDP and UDP, the total DM intake of goats fed Gliricidia was similar to CSM and Urea-CSM diets. This response suggests that protein was not limiting and that there is an advantage to feeding tropical as well as temperate legumes. The preference for browsing behaviour of goats and their ability to select leaf over stem was also apparent in this study. As browsing ruminants, goats seem to select leaves rather than stems and prefer legumes than grass.

The UDP caused more nitrogen to be retained in the body while the RDP supplied nitrogen for rumen microorganisms, increasing their activity to degrade the diet physically or enzymatically, such that DM, OM, N and NDF digestibilities were enhanced (Al Jassim *et al.,* 1991b). Furthermore, in the abomasum and small intestine, digestible microbial crude protein (MCP) originating from RDP and digestible UDP, were absorbed as precursors of metabolisable protein (MP) and functions to maintain normal biological life processes of the animals and to provide tissue protein (AFRC, 1993; McDonald *et al.,* 2011; NRC, 2007). The MP requirement for the present experimental goats was 75 g to grow at the rate of 100 g/d (NRC, 2007). However, the greater palatability of Desmanthus resulted in adequate MP for tissue synthesis as evidenced by higher ADG, heavier carcass and wider eye muscle area.

The higher liveweight gain and wider eye muscle area in the Desmanthus goats could be explained by the ratio between MP and ME i.e. 10 g MP/MJ ME (NRC, 2007). The higher intake of ME provides sufficient energy to match RDP and UDP availability. Importantly, this proper ratio fulfilled the energy and protein requirements better than other diets. Another possible explanation for low liveweight gain in the Urea goats could be due to energy cost for ammonia excretion. Excessive ammonia that was formed from urea in the rumen required energy to be excreted through urine. The lower ME intake in the Urea goats would have been used primarily for urine excretion rather than to build up tissue for growth.

The 8.2% loss of HCW after chilling recorded in carcasses from the goats on Urea was probably due to carcass fat covering or shrinking cells. Thinner fat in the Urea carcass compared with 4.6 mm fat depth in carcass of goats fed Desmanthus, resulted in the muscle of goats in the Urea treatment to cool rapidly. This rapid cooling caused the cells to shrink, resulting in increased extracellular spaces, more drips or evaporation, leading to higher carcass weight loss (Carmichael *et al.,* 2012; Listrat *et al.,* 2016).

The thicker fat in carcass of goats fed Desmanthus as compared to the Urea carcass suggested that high ME intake in the Desmanthus goats met needs for Net energy for maintenance and growth. Goats were more physiologically mature such that extra energy/metabolites were directed to fat deposition in the digestive tract, kidney and muscle. Fat detected from these three depots in the Desmanthus goats indicated that the difference of 10.1 MJ ME intake and 7.4 MJ ME requirement (NRC, 2007) is sufficient to build up fat in all depots. The darker yellow fat colour in carcass of goats fed Desmanthus may be due to the amounts of beta-carotene and similar pigments found in the Desmanthus leaves. Goats naturally have more myoglobin in their meat and this explains the overall darker colour of goat meat compared with lamb or beef (Suman *et al.,* 2009). The darker red colour in carcass of goats fed Desmanthus compared with other carcasses, however, could be due to the iron mineral in the diet (Beriain *et al.,* 2000; Calnan *et al.,* 2014). Iron may enrich haemoglobin in blood, myoglobin and myofibrillar proteins in meat, leading to the darker red colour of the carcass.

The highest and the lowest mean carcass temperatures recorded in goats fed solely with Desmanthus or fed RGH and supplemented with Urea 24-h post mortem was an indication of the amount of energy stored in the muscle. The energy derived from ME intake is stored in the muscle and liver as glycogen and converted to lactic acid or pyruvic acid to produce ATP. Energy in the form of ATP, formed right before slaughter, is still used for chemical reaction until it is all used (Hocquette *et al.,* 2001). After the ATP is used, the energy in glycogen is converted to form lactic acid. The highest temperature in carcass of goats fed Desmanthus indicated that more energy was stored in glycogen.

The lowest mean pH in carcass of goats fed Desmanthus indicated that more glycogen had been converted to lactic acid. The opposite results explain the lowest temperature and the highest pH in the Urea carcass. Carcass pH is associated with glycolysis (Casey and Webb, 2010) where each g of muscle requires about ≤ 50 μ mol muscle glycogen to produce a lactic acid for the final pH to be achieved. Another explanation was the volume effect where a skinnier carcass has more surface area to mass ratio so that it can loss heat more quickly leading to low carcass temperature.

The decreasing pattern of carcass temperature in this study was curvilinear, similar to the findings in Saanen goats (Kannan *et al.,* 2006). This curvilinear pattern reflects the relationship between energy supply and glycolysis. The sharp fall in muscle temperature during the early hours following post-mortem suggests that energy supply from the rumen or muscle had ceased followed by a slow and steady glycolytic process. Cooling of the carcass in the cold room is due to heat loss as the carcass temperature reaches equilibrium with that of the environment.

The maintenance requirements of a larger animal increase with liveweight and are higher for a given liveweight at a higher level of ME intake. The Desmanthus goats had high intake and were growing at a rapid rate. This meant they had a higher metabolic rate at the same metabolic liveweight.

Weights of non-carcass components and other non-edible parts of the carcass are usually considered to be of secondary importance compared with carcass attributes (Abbasi *et al.,* 2012; Limea *et al.,* 2009). These components however, reflect metabolic function. In addition, these components represent substantial value to the producer given that the omental fat is sold as suet and channel and kidney fat can be harvested for sale. The liver, heart and kidneys are also high value components. In this study, the Desmanthus treatment produced more of these edible non-carcass components and represent significant value to the producer.

The findings in the present study have demonstrated that liveweight gain, carcass yields, eye muscle area, and non-carcass weights were higher in Desmanthus goats, similar in CSM, Urea-CSM, and Gliricidia goats, and lower in Urea goats.

4.5 Conclusion

Liveweight gain, carcass yields, eye muscle area, fat depth and mass of non-carcass components of crossbred Boer goats are affected by UDP, RDP, MP and ME intakes when different amounts of UDP and RDP are provided in the diets. Goats offered dried-leaves Desmanthus only as a tropical legume had a significantly higher liveweight gain, heavier carcass yield, greater eye muscle area, thicker fat depth and heavier mass of non-carcass components. These high values were followed in descending order by those of CSM, Urea-CSM, Gliricidia and Urea treatments. Mean carcass temperature and pH during 24 h post-mortem also aligned with other productive performance responses, a consequence of different protein fractions and ME intakes in varying amounts of UDP and RDP in the diets.

Chapter 5 Supplementation of Crossbred Boer Goats with Cottonseed Meal and/or Urea Enhances Feed Intake, Crude Protein Digestibility and Nitrogen Retention

Abstract. This study aimed to evaluate feed intake, apparent digestibility, and nitrogen retention responses of crossbred Boer kids supplemented with urea or cottonseed meal utilising tropical Rhodes grass (*Chloris gayana*) hay as basal diet. Twelve, eight months old crossbred Boer bucks with an average liveweight of 23.9±1.1 kg were randomly allocated to one of the following four dietary treatments in a completely randomised design: (1) Control – Rhodes grass hay only; or Rhodes grass hay plus (2) Urea; (3) Urea mixed with cottonseed meal (Urea-CSM); and (4) cottonseed meal (CSM). All goats had *ad libitum* access to the basal hay diet and fresh drinking water in addition to the supplements in individual metabolic crates for 21 days (11 days of adaptation and 10 days collection period). A one-way ANOVA in SPSS fitted the fixed effect of treatment and Duncan's multiple range test separated significant means at P<0.05 threshold. Results indicated higher feed intake, apparent digestibility of crude protein and digestible nutrient intake in goats supplemented with CSM or Urea-CSM. High nitrogen retention (300%) was correlated with dietary CSM supplement. Urea and Urea-CSM mixture increased feed intake of Boer goats on tropical grass hay by 13 and 20%, respectively. Supplementation with Urea, Urea-CSM, and CSM improved apparent digestibility of crude protein by 9.7, 15.7 and 15.1%, respectively. Put together, our results provide definitive empirical data supporting achievable higher productivity performance opportunities associated with supplementing Boer goats on Rhodes grass basal diet in tropical production systems.

5.1 Introduction

In the dry season, tropical pastures increase in neutral detergent fibre (NDF) content, vascular tissues become lignified and nutrient digestibility is drastically reduced due to low metabolisable energy (ME) and metabolisable protein (MP) contents (Evitayani *et al.,* 2005). Mullik and Permana (2009) reported that dry matter availability of native pasture in West Timor varied from 1.2 to 2.1 tonne DM/ha, while crude protein varied from 48 to 68 g/kg DM in the wet season. As a result, meat goats fed these pastures may have insufficient ME and MP to support optimal liveweight gain (LWG) necessary for attaining saleable liveweights of 35 kg or 75 to 100 g LWG/day over 12 months. Achieving these rates of LWG requires improvement in both feed ME and MP to meet the optimal growth requirements suggested by the National Research Council, NRC (2007). One method to supply sufficient levels of ME and MP to goats is to offer dietary protein supplements in addition to such fibrous forages with the aim of increasing digestibility of organic matter (OM) and crude protein (CP), which in turn will provide ME and MP (CSIRO, 2007; NRC, 2007).

Urea is a common dietary source of non-protein nitrogen and rumen degradable protein (NPN-RDP), while Cottonseed meal (CSM) can provide true protein in the form of either readily degradable (RDP) or undegraded dietary protein (UDP) as exemplified by the work of Solomon *et al.,* (2008). The authors fed four groups of Sidama goats with grass hay only or grass hay supplemented with 200, 300 or 400 g of CSM. The results showed that CP intake was enhanced from 44, 79, 93 to 105 g/d for the four groups, respectively. Using the degradability value of 0.65 for tropical grasses and 0.70 for cottonseed meal (SCA, 1990), Solomon *et al*., (2008) reported that estimated RDP intakes of the four groups of Sidama goats were 29, 54, 64 and 72 g/day, respectively, while UDP intakes were 15, 25, 29 and 33 g/day, respectively. They also reported linear increases in OM and CP digestibility coefficients from 650 to 750 g/kg DM and 410 to 730 g/kg DM, respectively, and associated well with the intakes of CP, RDP and UDP. The shorter the rumen retention time and quicker rate of passage of CSM UDP through the gastrointestinal tract, the better the degradation, absorption and utilisation of by-pass amino acids in the abomasum compared to fibrous forages with a longer rumen retention time and slower degradability. When given a choice, animals on a basal hay diet supplemented with dietary protein sources adjust their RDP and UDP intakes to match fermentable organic matter intake (Solomon *et al.,* 2008).

Urea, an NPN-RDP, mixed with soybean meal, has been reported to increase OM digestibility in goats (Lallo 1996). In the Lallo (1996) study, urea provided a rapidly available RDP source, while soybean meal provided slowly available RDP and urea turn-over to the rumen to support organic matter fermentation. The study reported a linear increase in apparent digestibility of nitrogen from 262 to 742 g/kg DM and nitrogen retention from 0.49 to 5.74 g/d as the estimated amounts of RDP increased from 46 to 121 g/d and UDP increased from 4 to 18 g/d (Lallo, 1996). The mixture of urea and soybean meal to increase dietary CP to 127 g/kg DM enhanced microbial crude protein yield and absorption in the abomasum and small intestines, thereby increasing nitrogen digestibility and retention in line with Satter and Slyter (1974) who reported that optimal production of ammonia and volatile fatty acids was at 120 g CP/kg DM diet.

The effect of varying the concentration of RDP and UDP in the diet on OM digestibility seems to differ widely. Lallo (1996) found that the highest OM digestibility (670 g/kg DM) was at

108 instead of 127 g CP/kg DM. By comparison, Solomon *et al.,* (2008) reported the highest OM digestibility at 177 g CP/kg DM. From these studies, it is apparent that an increase in OM digestibility could be determined by RDP and UDP rather than dietary CP concentration. The lower dietary CP associated with urea supplement compared to the higher dietary CP from CSM supplement suggests that the use of urea as NPN-RDP source can be increased. However, the work of Satter and Slyter (1974), suggests that there is a dietary RDP content threshold for optimising the production of microbial protein in order to increase digestibility. The highest digestibilities were recorded at an RDP to fermentable organic matter ratio of 0.14 (Solomon *et al.,* 2008) and 0.25 (Lallo, 1996). This showed that although both ammonia N and amino acids were required to promote the digestion of fermentable OM, there was a higher requirement for Urea RDP than CSM RDP to increase microbial crude protein flow from the rumen and total metabolisable protein available from the diet.

The amount of RDP in the diet must match available fermentable organic matter (OM_F) consumed in order to optimise microbial crude protein yield (AFRC, 1993; CSIRO, 2007). Patterson *et al.,* (2009) fed one group of goats with sorghum-Sudan hay (CP 69 g/kg DM) only and supplemented three other groups with urea, dextrose or urea plus dextrose. Crude protein concentrations for the four diets were 69, 88, 68 and 97 g/kg DM, respectively. The study found that OM digestibility was the same for all treatment groups, however, nitrogen retention in the urea plus dextrose supplement was 4.8 g/d, almost twice as high of that in grass hay only (2.3 g/d) and hay plus urea (2.5 g/d) (Patterson *et al.,* 2009). The nitrogen retention values implied that RDP gave better results when mixed with fermentable carbohydrates. In comparison, Lallo (1996) reported that OM digestibility increased as the CP concentration increased from 51 to 108 g/kg DM diet, while Patterson *et al.,* (2009) found that when CP concentration varied between 69 and 97 g/kg DM, OM digestibility was not influenced. This indicated that Urea, as an RDP source, produced better outcomes when mixed with an UDP source such as CSM.

Current study hypothesised that *CSM, as a source of slow release RDP that matches the slowly released fermentable nutrient from grass hay for efficient microbial growth will increase both OM and CP digestibilities when fed to Boer goats on a basal diet of tropical Rhodes grass hay*. In contrast, urea will decrease digestibility due to its rapid ammonia release and dissipation that will not match the slowly released fermentable nutrients from grass hay for efficient microbial growth. It was also hypothesised that *a mixture of Urea and CSM will result in a digestibility value that is between that of CSM and Urea in goats*. Therefore, the main objective of this study was to compare feed intake, apparent digestibility and nitrogen retention in crossbred Boer kids fed a basal diet of tropical Rhodes grass and supplemented with diverse dietary protein sources with varying ratios of RDP and UDP.

5.2 Materials and Methods

5.2.1 Animal ethics

The use of animals and experimental procedures in this study were approved by the James Cook University Animal Ethics Committee (Permit Number A2130). All experiments were performed in accordance with relevant guidelines and regulations of the 2013 Australian Code of Practice for the Care and Use of Animals for Scientific Purposes.

5.2.2 Experimental animals

Twelve growing male crossbred Boer kids, eight months old (average BW of 23.9±1.1 kg) were housed in individual metabolic crates for 21 days (11 days adaptation and 10 days collection). Prior to random allocation into treatment groups, the kids were treated against internal parasites and sorted from the lightest to the heaviest body weight, divided into three groups (light, medium, and heavy) thus ensuring a uniform average liveweight of kids between treatments.

At the early adaptation period, two g of fresh faecal droppings was collected for egg worm count and two kids were detected as being infected with *Trichostrongylus colubriformis*. The two kids were treated with Q-drench (Jurox) at a dose rate of 1 ml/5 kg body weight and found to be negative for worm infection a week later. Ten ml of blood samples drawn from the jugular vein at the beginning and end of the study revealed that packed cell volume (PCV %) of the kids ranged between 27.7 and 32.7% indicating no internal parasite infection. During both adaptation to feed and collection periods, the kids were observed for any signs of discomfort. Daily feed intake and refusals were weighed and recorded to estimate dry matter intake (DMI) to ensure it met the nutrient requirements of the goats. Liveweights and average daily gains were recorded at the beginning of adaptation and collection periods and at the end of collection period.

The animals were housed in individual metabolic crates at the James Cook University Veterinary Science shed, Townsville, Queensland, Australia. A basal diet feed trough for Rhodes grass hay was mounted by the side of the metabolic crate where another small bucket for the supplement was also placed. All experimental animals had *ad libitum* access to clean, fresh, drinking water and the room was illuminated at night.

5.2.3 Experimental procedures

A completely randomised design comprising four dietary treatments and twelve bucks (three bucks per treatment) was used. Dietary treatments were formulated using Rhodes grass hay as the basal diet and supplemented with flaked corn as an energy source, cottonseed meal as an UDP and urea as an RDP source. The four dietary treatments were: Rhodes grass hay + corn (Control), Control + urea (Urea), Control + urea + cottonseed meal (Urea-CSM) and Control + cottonseed meal (CSM).

The Rhodes grass hay was chopped into 5 – 10 cm size, stored in a barn and fed out to experimental animals in plastic bins. The proportion of steam flaked corn in the diet was 60 g/kg DM. The proportion of urea in the Urea and Urea-CSM diets was limited to 1% DMI (MLA, 2013). The proportion of cottonseed meal in the Urea-CSM and CSM diets was 141 and 169 g/kg DM, respectively. Urea was ground into a fine powder to mix completely with the corn and/or cottonseed meal according to the dietary treatment.

5.2.4 Diet formulation and feeding regime

The concentrations of RDP for Rhodes grass hay were achieved from wet chemistry analysis by the Forage Lab Australia, Victoria, Australia (www.foragelabaustralia.com.au), an affiliate of the Cumberland Valley Assay Service (CVAS), USA. Concentrations of RDP for cottonseed meal, corn and urea were quoted from NRC (2007) published values. The nutrient compositions of the dietary treatments are presented in Table 5.1.

The total amount of the basal diet offered was based on average DMI during the 11-d adaptation period. During the collection period, the amount of basal diet offered was adjusted daily based on the average DMI of the two previous days multiplied by 1.5 allowing for refusals. The experimental diet was formulated to meet the bucks' nutrient requirements as per NRC (2007) – being DM 810 g, ME 8.2 MJ/d, and RDP 49 g/d. Crude protein in the Urea treatment was lower than recommended as the amount of urea was limited to 1% DMI to avoid ammonia poisoning (MLA, 2013). Loose lick minerals (Rumevite® Fermafos) were provided with the supplements and fresh drinking water was freely available.

Table 5.1 Ingredients and nutrient composition of dry matter, organic matter, protein fractions and metabolisable energy of the experimental diets

Item	Treatments			
	Control	Urea	Urea-CSM	CSM
Ingredients (g DM)				
Rhodes grass hay	602	602	602	602
Cottonseed meal	0	0	72	128
Urea	0	16	7	0
Maize	50	50	50	50
Nutrient composition				
DM (g/kg fresh wt)[a]	890	892	893	894
OM (g/kg DM)[a]	896	899	900	902
CP (g/kg DM)[a]	106	175	175	175
UDP (g/kg DM)[b]	35	34	42	47
RDP (g/kg DM)[b]	71	141	133	128
ME (MJ/kg DM)[b]	10.3	10.1	10.3	10.4

CSM = cottonseed meal, DM = dry matter, OM = organic matter, CP = crude protein, UDP = undegraded dietary protein, RDP = rumen degradable protein and ME = metabolisable energy

[a] values were from Laboratory analysis at James Cook University, Australia, methods according to AOAC (1990)

[b] values were predicted as the proportions of individual feedstuff multiplied with wet chemistry analysis for Rhodes grass hay or from NRC (2007) for cottonseed meal, corn and urea

Rhodes grass hay was offered *ad libitum* in a feed trough at 08.00 h and 16.00 h. Mixed supplements amounting to 0.064, 0.073, 0.206 and 0.224 kg DM basis for Control, Urea, Urea-CSM and CSM diets, respectively, were separately placed in a plastic bucket and fed twice a day at the same amount prior to offering the basal diet.

5.2.5 Digestibility and nitrogen retention measurements

Individual daily feed refusals were weighed every morning for the duration of the 10-day data collection period. About 10% of the sub-sampled feeds was placed in an air tight sealed plastic container and stored in a cool room at 3ºC. At the conclusion of the experiment, the total refused Rhodes grass hay was mixed thoroughly, sub-sampled (50%), oven dried at 60ºC and ground twice to pass through a 1.5 mm (Retsch GmbH, West Germany) and 0.1 mm sieve (Retsch cyclone mill, www.mep.net.au), respectively.

A separator under each metabolic crate enabled faecal collection into a plastic bag, while urine was directed into an eight-L plastic bucket containing 5 mL of concentrated H_2SO_4 to avoid nitrogen evaporation. Each morning after cleaning and feeding, collected faecal matter was mixed thoroughly and one third was oven dried at 60°C. The oven dried faecal samples were then mixed, sub sampled at 10% and ground to pass through 1.5 and 0.1 mm sieve for proximate analysis. Excreted urine was collected every morning, weighed, sub sampled (10% of the total weight), poured into a plastic jar and stored in a cool room at 3°C pending nitrogen analysis.

The apparent digestibility coefficient (ADC) of nutrients in the diets was calculated using the equation of McDonald *et al.,* (2011) and Khan *et al.,* (2003) as follows:

$$\text{ADC of nutrient (\%)} = \left(\frac{\text{Nutrient intake} - \text{Nutrient in faeces}}{\text{Nutrient intake}}\right) \text{x}100$$

Equation 5.1

The unit measurement (%) was then converted into g/kg DM as gram digestible nutrient in 100 gram diet multiplied by 1000 gram diet and divided by 100 was equivalent to the g/kg DM unit measurement. Digestible nutrients (g/d) were calculated as the difference between the nutrients in the consumed diet and faeces. Estimated MP intake (g/d) was calculated as 0.7 of the digestible crude protein (NRC, 2007). Estimated ME intake (MJ/d) was calculated as M/D = 0.194 DOMD – 2.58 (CSIRO, 2007 Eq. 1.12C), where M/D refers to metabolisable energy (MJ/kg feed dry matter) and DOMD refers to digestible organic matter in dry matter.

Nitrogen retention was calculated as:

$$\text{Nitrogen (N) retention } (g) = \text{N intake (g)} - (\text{Faecal N} + \text{Urinary N})(\text{g})$$

Equation 5.2

5.2.6 Chemical analysis

Proximate analysis (AOAC, 1990) was conducted to determine dry matter, organic matter, ash, and crude protein contents of Rhodes grass hay offered and refused, supplements offered and faeces. Representative samples of the basal and supplemental diets were dried at 60°C over 72h, cooled, weighed and ground to pass through a 1 mm sieve using a Laboratory Mill (Thomas Model 4 Wiley® Mill; Thomas Scientific) and analysed using standard methods of

AOAC (1990) for DM (g/kg as fed). Organic matter and ash contents were determined after oven-drying and combusting the samples in a furnace at 550ºC for four hours.

Total nitrogen in the feed, faeces and urine was analysed by the Kjeldahl method (AOAC, 1990). Approximately 0.2 g of faecal and feed samples or 1.0 g of urine samples were weighed into digestion tubes in duplicates, digested with 6 ml concentrated sulphuric acid (H_2SO_4) and a catalyst (3.5 g K_2SO_4 and 3.5 mg Se) added using a Tecator system 2040 digester at temperature 380 - 420ºC. After cooling, the samples were diluted with 30 ml of deionised water, neutralised with 30 ml of sodium hydroxide, distilled (2100 Kjeltec distillation unit) into a boric acid solution containing 4% boric acid with 150 mL of bromocresol blue and titrated with a standard 0.5056 M HCl reagent to a pH = 4.67 end point. Samples of blank, recovery $(NH_4)_2SO_4$ and standard glycine were run with each analysed batch to ensure there was no carry-over between samples. The equation for estimating nitrogen content was:

$$\text{g \%N} = \left(\frac{(\text{Normality of acid x (ml sample titrant } - \text{ ml blank titrant)}}{\text{Dry weight of sample (g)x 10}}\right)\text{x14.01}$$

Equation 5.3

CP = N x 6.25

5.2.7 Statistical analysis

Feed intake, digestibility and nitrogen retention data were analysed as respondent variables using the One-way analysis of variance test (SPSS Statistics for Windows, Version 23.0, IBM Corp. Released 2014, Armonk, NY, USA) with treatment as a fixed effect. The differences between treatments were compared using Duncan's multiple range test at a P<0.05.

5.3 Results

5.3.1 Feed and nutrient intakes

The dietary CP and ME concentrations for the supplemented treatment groups were isonitrogenous and isocaloric, respectively (Table 5.1). Daily feed and nutrient (DM, OM, and CP) intakes in the experimental goats are presented in Table 5.2. Intakes of dry matter, organic matter and crude protein for supplement with the exception of DMI and OMI of Rhodes grass hay (RGH), were influenced by protein supplementation (P<0.05). Control goats ate about 9 to 13% more RGH (P<0.05) compared with RGH intake in the supplemented goats. Higher total DMI was recorded in the CSM and Urea-CSM goats compared to their counterparts in Urea goats. This total DMI equated to 2.5% of BW for the CSM and Urea-CSM goats compared with 2.3 and 2.1% in Control and Urea groups, respectively.

Table 5.2 Dry matter, organic matter and crude protein intakes in supplemented crossbred Boer goats

Item	Treatments				sem	*P*-values
	Control	Urea	Urea-CSM	CSM		
Intake of dry matter (g/d)						
Supplement	46±0.0$_a$	50±0.0$_b$	164±1.3$_c$	186±1.5$_d$	0.49	0.000
Rhodes grass hay	451±14.3$_b$	413±8.8$_a$	398±9.6$_a$	411±32.7$_a$	9.50	0.312
Total	497±14.3$_a$	463±8.7$_a$	562±8.7$_b$	597±30.5$_b$	9.18	0.003
Total (% of BW)	2.3±0.0$_{ab}$	2.1±0.1$_a$	2.5±0.1$_b$	2.5±0.1$_b$	0.04	0.032
Intake of organic matter (g/d)						
Supplement	45±0.0$_a$	49±0.0$_b$	152±1.0$_c$	172±1.5$_d$	0.44	0.000
Rhodes grass hay	399±13.1	365±13.5	353±14.6	363±50.3	8.46	0.323
Total	444±13.1$_a$	414±7.8$_a$	505±7.8$_b$	535±27.8$_b$	8.17	0.003
Intake of crude protein (g/d)						
Supplement	4±0.0$_a$	16±0.5$_b$	79±1.2$_c$	78±0.8$_c$	0.28	0.000
Rhodes grass hay	52±2.6$_b$	53±0.8$_b$	42±0.6$_a$	52±2.7$_b$	0.83	0.005
Total	56±1.7$_a$	69±0.9$_b$	121±0.0$_c$	130±2.2$_d$	0.72	0.000

CSM = cottonseed meal, sem = standard error of the mean and BW = body weight

Row means bearing different superscripts differ significantly (P < 0.05)

The increases in total OMI for the CSM and Urea-CSM groups were 21 and 14%, respectively, compared to Urea and Control goats. Protein supplementation significantly affected (P<0.05) total CPI with goats receiving Urea, Urea-CSM and CSM supplements having 23, 116 and 132% increase in intake, respectively, compared to the Control group. However, the difference between Control group and Urea group was not significant (P>0.05.

5.3.2 *Apparent digestible coefficient, digestible nutrient intakes and predicted MP and ME*

Apparent digestibility coefficients and digestible nutrient intakes are presented in Table 5.3. ADC of CP significantly differed (*P*<0.007) between the dietary treatments as depicted on Table 5.3.

Table 5.3 Apparent digestibility (g/kg DM), digestible nutrient intakes (g/d) and estimated intakes of metabolisable protein (g/d) and metabolisable energy (MJ/d) in supplemented Boer goats

Item	Treatment				sem	*P*-values
	Control	Urea	Urea-CSM	CSM		
Apparent digestibility (g/kg DM)						
Dry matter	595±32.9	595±13.3	618±12.9	622±19.1	9.75	0.725
Organic matter	622±30.5	624±12.7	648±14.7	653±16.8	9.49	0.592
Crude protein	668±29.8$_{a}$	733±5.7$_{b}$	773±3.8$_{b}$	769±12.4$_{b}$	14.51	0.007
Digestible nutrient intakes (g/d)						
Dry matter	295±11.4$_{a}$	273±7.5$_{a}$	345±9.5$_{b}$	370±13.3$_{b}$	12.45	0.001
Organic matter	275±8.8$_{a}$	256±6.7$_{a}$	326±9.2$_{b}$	349±11.9$_{b}$	11.94	0.000
Crude protein	37±1.5$_{a}$	50±1.2$_{b}$	93±0.3$_{c}$	100±1.5$_{d}$	8.20	0.000
Estimated intakes of MP and ME						
MP (g/d)[a]	26±0.8$_{a}$	35±0.8$_{b}$	65±0.3$_{c}$	70±1.0$_{d}$	5.74	0.000
ME (MJ/d)[b]	9.5±0.6	9.5±0.2	10.0±0.3	10.1±0.3	0.18	0.605

CSM = cottonseed meal, sem = standard error of the mean, MP = metabolisable protein and ME = metabolisable energy

[a] Estimated intake of MP was calculated as 0.7 of the digestible crude protein (NRC 2007).

[b] Estimated intake of ME was calculated as M/D = 0.194 DOMD – 2.58 (CSIRO 2007) Eq. 1.12C, where M/D refers to metabolisable energy (MJ/kg feed dry matter) and DOMD refers to digestible organic matter in dry matter.

Row means bearing different superscripts differ significantly (P < 0.05)

The inclusion of CSM only or CSM mixed with urea gave the same results with regard to digestible DM and OM intakes, but the intakes differed (P<0.05) from those of Urea treatment and Control group which were also similar. The three protein supplements significantly increased (P<0.05) estimated MP intakes, but the estimated ME intakes were numerically higher with CSM and Urea-CSM supplements without statistical significance relative to the Urea and Control groups.

5.3.3 Excreted faeces and urine, nitrogen intake and retention

Excreted faeces and urine, nitrogen intake and retention values are presented in Table 5.4. The quantity of excreted faeces and urine was not influenced by protein supplementation (*P*>0.05).

Table 5.4 Excreted faeces and urine, nitrogen intake and retention in supplemented Boer goats

Item	Treatments				sem	*P*-values
	Control	**Urea**	**Urea CSM**	**CSM**		
Total excretion						
Faeces (g/d)	202±19.7	185±6.9	213±8.8	226±20.6	7.91	0.356
Urine (g/d)	574±62.1	522±23.6	788±142.9	575±7.6	45.67	0.160
Nitrogen intake (g/d)						
Supplement	$0.6 \pm 0.0_a$	$2.5 \pm 0.0_b$	$12.6 \pm 0.1_c$	$12.4 \pm 0.1_c$	1.66	0.000
Rhodes grass hay	$8.2 \pm 0.2_b$	$8.3 \pm 0.1_b$	$6.7 \pm 0.2_a$	$8.4 \pm 0.5_b$	0.23	0.007
Total	$8.8 \pm 0.2_a$	$10.8 \pm 0.2_b$	$19.3 \pm 0.0_c$	$20.8 \pm 0.4_d$	1.56	0.000
Nitrogen excretion (g/d)						
Faeces	$2.9 \pm 0.3_a$	$2.9 \pm 0.0_a$	$4.3 \pm 0.0_b$	$4.8 \pm 0.1_b$	0.26	0.000
Urine	$4.6 \pm 0.5_a$	$4.8 \pm 0.4_a$	$11.3 \pm 0.1_b$	$10.8 \pm 0.3_b$	0.97	0.000
Total	$7.5 \pm 0.2_a$	$7.7 \pm 0.4_a$	$15.6 \pm 0.5_b$	$15.6 \pm 0.1_b$	0.57	0.000
Nitrogen retention (g/d)	1.3±0.4a	$3.1 \pm 0.5_b$	$3.7 \pm 0.2_b$	$5.2 \pm 0.1_c$	0.44	0.000

CSM = cottonseed meal and sem = standard error of the mean
Row means bearing different superscripts differ significantly (P < 0.05)

The addition of CSM or Urea-CSM doubled nitrogen intake in goats fed urea supplement or basal diet only. Similarly, nitrogen excretions in the CSM and Urea-CSM goats were twice as high as in the other two groups. Urinary nitrogen in all treatments was almost twice as high as faecal nitrogen.

Crude protein digested and absorbed by the goats was completely different across all treatment groups; it was highest in CSM, followed by Urea-CSM, Urea and lowest in the

Control diets. As expected, all the three protein supplements caused a significant amount of nitrogen retention ($P<0.05$). Despite nitrogen excretion between the CSM goats and the Urea-CSM goats being similar, nitrogen retained in CSM goats was significantly higher than that in Urea-CSM goats. Urea-CSM goats had a higher nitrogen intake compared to Urea goats, but because nitrogen excretion followed a similar pattern, nitrogen retention in the two groups were similar.

5.4 Discussion

The decrease in hay intake as protein supplement was added and the increased total DMI in the CSM and Urea-CSM goats emphasized the relationship among protein supplements, feed intake and digestibility. Solomon *et al.,* (2008) found that total intakes of feed and nutrients and digestibility of nutrients are linearly correlated with an increase in CSM supplement. Lu and Potchoiba (1990) demonstrated that feed intake has a positive linear relationship with dietary protein content. This relationship could be used to explain the finding in the present study where low hay intake in the supplemented goats was partly due to nitrogen limitation. As the goats are offered more protein, proteolytic rumen microbes, instead of cellulolytic or fibrolytic microbes, are likely to be actively degrading the ingesta (Bach *et al.,* 2005), therefore, CP digestibility increases but not DM and OM digestibility. This increased CP digestibility allows more space available in the digestive tract, which promotes feed intake (Jones, 1972).

The highest DMI of RGH in the Control group in the present study showed that protein supplementation led to a substitution effect resulting in depressed intake of the tropical grass hay. This finding agreed with previous studies (Alemu *et al.,* 2010; Osuga *et al.,* 2012; Yinnesu and Nurfeta, 2012) that reported decreased hay intake when protein-source supplements were added to the diet. CSM in the current study seems to substitute RGH because the total dietary DMI was enhanced as evidenced by the 30% increase in total DMI in the CSM and Urea-CSM groups, which was three times higher than that for the Control and Urea groups. The substitution effect agrees with the report by Solomon *et al.,* (2008) who found that an increased intake of CSM in Sidama goats caused a decrease in hay intake.

Another possible explanation for the observed intake pattern could be related to energy and nitrogen supplies to both rumen microorganisms and the goats. The Control goats could have increased RGH intake to meet their energy and protein requirements, but the gut-fill effect from the reticulorumen (Allen, 1996) limited dry matter intake. Fibrous feeds are usually ruminated and fermented slowly, staying in the rumen longer (Morand-Fehr, 2005), and preventing the animal from eating more.

The low total DMI of goats fed urea diet is consistent with a previous study by Wambui *et al.,* (2006) who reported that goats had low DMI when fed with maize stover sprayed with urea (Control diet) as compared to goats fed with Control diet and Tithonia foliage. Bach *et al.,* (2005) explained that there is an energy cost for over-supplied RDP such as urea to be converted into ammonia, absorbed, metabolised and excreted in urine. Unless sufficient energy is available (Uza *et al.,* 2005; Patterson *et al.,* 2009), the goats lose weight as demonstrated by Wambui *et al.,* (2006) which could be as a consequence of tissue energy mobilisation.

The observation that an inclusion of CSM only or mixed with urea increased CP digestibility and supplied more CP and MP to the goats was consistent with previous studies (Solomon *et al.,* 2008; Alemu *et al.,* 2010). This can be explained by the function of CSM and urea as high-protein nitrogen sources. Rumen microbes degrade dietary intake protein into peptides, amino acids and ammonia to meet the requirements of rumen microbes (Bach *et al.,* 2005). High degradability in the rumen leads to more substrates for the microbes which flow into the abomasum and small intestines as microbial crude protein that contributes to MP (AFRC, 1993).

The higher digestible CP and predicted MP in the CSM fed goats compared with that of Urea-CSM or Urea fed goats, could be linked to feed intake and degradable protein characteristics of the feeds. As a cause-effect relationship, goats that have higher digestibility and eat more are expected to have higher digestible nutrient intake. In regards to degradability, Mishra and Rai (1996) found that increasing the intake of rumen UDP such as provided by cottonseed cake, resulted in an increase in CP digestibility. Therefore, the higher CP digestibility in the present study was due to CSM being a source of UDP feeds. Urea as a high RDP, on the other hand, would have been highly degraded by rumen microbes to ammonia (Bach *et al.,* 2005) which was due to limiting dietary energy.

The higher quantity of retained nitrogen in the supplemented goats demonstrates the benefit of protein-source feeds supplying nitrogen or protein to the goats. However, the higher amount retained nitrogen in the goats fed CSM than those in the goats fed Urea-CSM or Urea indicates that UDP was better than RDP, a similar observation in other reports (Solomon *et al.,* 2008; Wang *et al.,* 2012). The highest nitrogen retention was also confirmed by the highest predicted intakes of MP in the CSM goats. A similar explanation by Bach *et al.,* (2005) was that CSM would be less degraded by rumen microbes to ammonia, the UDP of CSM would be readily absorbed in the small intestines, hence more nitrogen retained in the goats. Some workers had optimised the usage of RDP e.g. urea to enhance retained nitrogen by mixing urea with dextrose (Patterson *et al.,* 2009) or to reduce the degradation of high RDP, such as soybean meal treated with formaldehyde (Al Jassim *et al.,* 1991).

5.4 Conclusion

Total dry matter, organic matter and crude protein intakes of crossbred Boer goats on a basal diet of tropical Rhodes grass hay was increased by cottonseed meal as a source of RDP and UDP, or a mixture of cottonseed meal and urea as a source of NPN-RDP. Similarly, crude protein digestibility, digestible nutrient intake, estimated intake of metabolisable protein and metabolisable energy were enhanced by CSM and CSM plus urea. The improved nitrogen retention was associated with all protein supplements compared to the Control group in this study but CSM supplement retained more nitrogen compared to others.. Put together, our results provide definitive empirical data supporting achievable higher productivity performance opportunities associated with supplementing Boer goats in tropical production systems relying solely on Rhodes grass basal diet.

Chapter 6 Using Metabolisable Energy and Protein Systems to Validate Dry Matter Intake and Average Daily Gain of Meat Goats Fed Tropical Grass and Legume Hay

Abstract. Two experiments were conducted to validate the National Research Council's metabolisable energy (ME) and metabolisable protein (MP) systems in predicting dry matter intake (DMI) and average daily gain (ADG) in crossbred Boer goats fed tropical forages. Twenty-five female Boer goats were randomly allocated to the following five dietary treatments: Rhodes grass (*Chloris gayana*) hay supplemented with urea (Urea), urea plus cottonseed meal (Urea-CSM), cottonseed meal (CSM), Gliricidia (Gliricidia) and Desmanthus hay (Desmanthus). Urea and cottonseed meal were utilised to vary dietary rumen degradable protein (RDP) and undegradable protein (UDP). The diets were formulated to provide crude protein and MP sufficiently for both maintenance and growth. Actual and estimated DMI were compared using a paired t-test using three equations: metabolic body weight with dietary ME, DM digestibility or dietary ME only. Actual and predicted ADG based on estimated ME and MP intakes for maintenance and gain were also compared. In Experiment 2, these equations were unable to predict DMI. In Experiment 3, DMI was predictable using DM digestibility by goats fed CSM, but only tended to be predictable in Desmanthus fed goats. ME was able to predict ADG in Gliricidia fed goats in Experiment 3. MP based on total digestible nutrients (TDN) was unable to predict ADG of goats in both Experiments. MP based on RDP was able to predict ADG of goats on Urea and Desmanthus in Experiment 2, but it was unable to predict ADG of goats in Experiment 3. DMI of meat goats on tropical grass hay was predictable using DM digestibility when CSM as an RDP and UDP (mostly as true protein source), was fed as a supplement, but it tended to be predictable when Desmanthus legume was fed at dietary CP 195 g/kg DM. The dietary ME concentration of Desmanthus legume was able to predict DMI of goats at dietary CP of 195 g/kg DM. ME was valid in predicting ADG of Gliricidia goats supplemented at dietary CP 195 g/kg DM. MP was valid in predicting ADG of Boer goats on tropical forages supplemented with urea as a source of NPN-RDP or fed with Desmanthus only at dietary CP 137 g/kg DM. In summary, models by NRC using dietary ME and MP concentrations of tropical forages could be applied to certain feedstuffs to predict DMI and ADG of crossbred Boer goats in the tropics.

Keywords: goats, supplementation, prediction, production, energy, protein

6.1 Introduction

Rhodes grass (*Chloris gayana*) is typically the basal diet for meat goats in the tropics, but biomass production, energy and protein contents of such tropical grasses decline as they mature (Mbwile and Uden, 1997). Consequently, dietary energy and protein supplies tend to be lower than the minimum levels needed to meet nutritional requirements recommended by the NRC (2007) for maintenance and normal growth of animals. Therefore, supplementation of the goats becomes necessary. The benefit of supplementation can be assessed based on dry matter intake (DMI) and average daily gain (ADG) to predict profitability of the meat goat farming enterprise.

Metabolisable energy (ME) of a diet has always had an inconsistent relationship with DMI, but a positive correlation with ADG in goats. For example, Hossain *et al.,* (2003) allowed three groups of goats to graze during the day but at night, they were offered supplemental diets containing 10, 11 and 12 MJ ME/kg DM, which gave DMI of 406, 374 and 362 g/d and ADG of 38, 44 and 53 g/d, respectively. In another study by Rashid *et al.,* (2016a), both DMI and ADG increased linearly with increased concentrations of ME in the diets. These authors fed three groups of goats with Napier grass as a basal diet and supplemented them with pellets containing 9.3, 10.3, and 11.3 MJ ME/kg DM. The goats recorded DMI of 444, 486, and 517 g/d and 41, 68, and 71 g/d ADG, respectively. More recently, Brand *et al.,* (2017) also found a negative linear relationship between dietary ME and DMI but a curvilinear relationship between dietary ME and ADG. The authors fed three groups of Boer goats in a feedlot with diets containing 11.3, 12.0 and 12.7 MJ ME/kg and reported DMI of 1236, 1169 and 1002 g/d and ADG of 221, 235 and 202 g/d, respectively. Dietary protein concentration may account for this inconsistent relationship because rumen function also depends on branched chain fatty acids, ammonia and minerals.

Protein supplementation affects DMI and ADG differently depending on protein sources such as undegradable protein (UDP) sources include cottonseed meal or rumen degradable protein (RDP) sources such as urea. For example, Solomon *et al.,* (2008) fed four groups of Sidama goats with native grass hay as basal diet and supplemented them with cottonseed meal (CSM). The CSM as a UDP source, was offered to varying CP intakes of 42, 79, 97 and 108 g/d. They found that total DMI increased to 482, 569, 570 to 652 g/d with ADG of 10, 42, 65 and 56 g/d, respectively. They showed that protein requirements in goats were met at DMI of 570 g/d with CP intake of 97 g/d, which means that supplying CSM above 300 g/d as UDP source had no additional benefit. Uza *et al.,* (2005) fed five groups of West African Dwarf goats with herbage only. CP intake of 36 g/d or herbage with fresh cassava peels treated with urea as an RDP source varied CP intake at 23, 27, 28 and 40 g/d. They reported total DMI of 324, 223, 250, 381 and 313 g/d and ADG of 24, 27, 62, 31 and 16 g/d, respectively. Goats with DMI of 250 g/d on 40 g urea/kg daily of supplement in the diet met their protein requirements without the need for an additional RDP source.

In northern Australia's subtropical/tropical semiarid regions, Desmanthus is a relatively new pasture legume particularly for clay soils and is promoted as a productive, well adapted companion legume for native and introduced pasture grasses in such environments where goats, sheep and beef cattle are produced (Gardiner, 2016). The nutritive evaluation of the species is not extensive. However, Gardiner and Parker (2012) found improved ADG in beef cattle grazing Desmanthus/buffel pasture compared to buffel grass only. Ngo *et al.,* (2017) found that Merino wethers had improved DMI when Desmanthus was included in the diet. Rangel and Gardiner (2009) found that total DMI of Merino sheep increased because of the mixture of Desmanthus and Mitchell grass. *Gliricidia sepium* is a shrub legume used throughout the tropics particularly in South East Asia and Central and South America. Gliricidia is reported to increase liveweight of steers and lamb (Cook *et al.,* 2005). These studies provide evidence that the highest dietary energy and protein concentrations, DMI and ADG, are not always achieved simultaneously. The adoption of these research findings on farm therefore was likely based on the highest ADG. However, the application of one single research finding may deviate from the expected results, although dietary energy and protein were similar, because of the different characteristics of feed supplements. In addition, the regular measurement of the effect of supplements on the DMI and ADG of goats that graze in extensive pasture systems may be difficult to conduct. Prediction of DMI and ADG using existing equations and nutrient requirements derived from meta-data analyses, is an alternative method of evaluating productive responses in animals. Teixeira *et al.,* (2011) predicted DMI from metabolic body weight and dietary ME in goats. The NRC (2007) predicted DMI of sheep based on dry matter digestibility. The NRC (2007) indicated that 0.489 MJ and 3.07 g/kg $FBW^{0.75}$ were the ME and MP requirements respectively for the maintenance of growing Boer goats. For production, the goats need 0.0231 MJ ME and 0.404 g MP for each gram of body weight gain. These recommended values emanated from a large number of studies in the temperate regions, but their application in a specific breed of meat goat in the tropics fed with tropical forages needs to be validated.

It was hypothesised in the current study that DMI could be reliably predicted from dietary ME in meat goats on tropical forages supplemented with UDP and RDP protein sources. It was also hypothesised that ME and MP intakes would be reliable predictors of ADG in goats using the minimum requirements of ME and MP for maintenance and growth as recommended by the NRC (2007).

The first objective of these two Experiments was to validate the existing ME system to predict DMI. The second objective was to validate the ME and MP minimum requirements suggested by the NRC (2007) in predicting ADG of growing Boer goats fed tropical legume hay only using *Desmanthus leptophyllus* as a sole diet or tropical grass hay supplemented with *Gliricidia sepium* legume or UDP and/or RDP protein sources.

6.2 Materials and Methods

6.2.1 Animals, experimental methodology and feeding management

Specific aspects of animals, experimental methodology and feeding management have been described in detail in Chapter 4.

6.2.2 Prediction of dry matter intake (DMI)

Actual DMI (g/d) was the net result of the difference between the number of feedstuffs offered and that refused based on dry matter content. Predicted DMI was achieved using three equations to see if they gave the same result. Firstly, DMI was predicted based on metabolic body weight and dietary ME (Teixeira *et al.,* 2011) using the following equation:

$$DMI\ (\text{g/d}) = (76.7\ x\ BW^{0.75})\ x\ (-0.666 + 0.319\ x\ ME - 0.015\ x\ ME^2)$$

Equation 6.1

where DMI = dry matter intake, $BW^{0.75}$ = metabolic body weight (kg), ME = metabolisable energy of the diet (MJ/kg DM).

DMI was also predicted based on digestibility as a quality constraint (NRC 2007) using the following equation:

$$DMI\ \left(\frac{g}{d}\right) = \left(1 - 1.7\ x\ (0.8 - Dig)\right) x\ 1000$$

Equation 6.2

where Dig refers to DM digestibility. Dig values for Urea, Urea-CSM, and CSM were 0.595, 0.618, and 0.622, respectively (Table 5.3) and Gliricidia 0.622 (Ondiek *et al.,* 2000). Dig values for Desmanthus leaves and stems and leaves were 0.770 and 0.665 %, respectively (www.progardes.com.au/research/; (www.tropicalforages.info/key/forages/media/html/Desmanthus-leptophyllus.htm) (Agrimix Pastures 2016; TropicalForages n.d).

Predicted DMI based on dietary ME excluding metabolic body weight factor (Teixeira *et al.,* 2011) was computed as follows:

$$DMI\ (g/d) = (-0.666 + 0.319\ x\ ME - 0.015\ x\ ME^2) x\ 1000$$

Equation 6.3

6.2.3 Prediction of average daily gain (ADG)

Actual ADG (g/d) was the difference between BW at commencement and end of feeding period divided by the number of days of feeding.

Predicted ADG from MEI (g/d) was achieved by reducing MEI with 0.489 MJ/kg $FBW^{0.75}$ as the ME required for maintenance (ME_m) and then the reduction value was divided by 0.0231 MJ as the ME required for gain (ME_g) (NRC, 2007). The empirical equation was:

$$ADG\ (g/d) = \left(\frac{MEI - MEm}{MEg}\right)$$

Equation 6.4

where ADG = average daily gain (g/d), MEI = metabolisable energy intake (MJ/d), and ME_m and ME_g are net metabolisable energy for maintenance and gain, respectively.

Predicted ADG from MPI (g/d) was achieved by reducing MPI with 3.07 g/kg $FBW^{0.75}$ as the MP required for maintenance (MP_m) and then the reduction value was divided by 0.404 g as the MP required for gain (MP_g) (NRC, 2007). The empirical equation was:

$$ADG\ (g/d) = \left(\frac{MPI - MPm}{MPg}\right)$$

Equation 6.5

where ADG = average daily gain (g/d), MPI = metabolisable protein intake (g/d), and MP_m and MP_g are net metabolisable energy for maintenance and gain, respectively.

The MP value was derived using [Equation 6.6], where microbial crude protein (MCP) was determined based on TDN [Equation 6.10] or RDP [Equation 6.11]. These calculations gave rise to MPI_{TDN} and MPI_{RDP}.

6.2.4 Prediction of MEI and MPI

Metabolisable energy intake, MEI (MJ) was the difference between ME in feed offered and refused on dry matter basis. Metabolisable protein intake, MPI (g) was the difference between MP in feed offered and refused on dry matter basis. The MP of feeds was integrated with wet chemistry data using the AFRC (1993) equations (23, 33 and 31) and NRC (2007) recommendation to estimate microbial crude protein (MCP). The AFRC (1993) Equation 23 for calculating MP was:

$$MP\ (\mathrm{g/d}) = 0.6375\ MCP + DUP$$

Equation 6.6

where MP = metabolisable protein, MCP (g) = microbial crude protein and DUP (g) = digestible undegradable protein.

The AFRC (1993) Equation 33 for calculating DUP was:

$$\mathrm{DUP\ (g/kg\ DM)} = 0.9\ [[UDP] - 6.25\ [ADIN]]$$

Equation 6.7

where DUP = digestible undegradable protein, DM = dry matter, UDP = undegradable dietary protein and ADIN = acid detergent insoluble nitrogen.

Since the wet chemistry results reported values of acid detergent fibre in protein (ADICP), Equation 33 of AFRC (1993) was modified by removing the 6.25 constant for nitrogen such that the modification becomes:

$$\text{DUP (g/kg DM)} = 0.9\ [[UDP] - [ADICP]]$$

Equation 6.8

where ADICP = acid detergent fibre in protein derived from wet chemistry.

Equation 31 of the AFRC (1993) used to compute UDP was:

$$\text{UDP (g/d)} = [CP] - [RDP]$$

Equation 6.9

where UDP = undegradable dietary protein, CP (g) = crude protein and RDP (g) = rumen degradable protein.

Microbial crude protein was calculated depending on two limiting factors. If dietary energy is limiting, NRC (2007) recommended MCP to be calculated as:

$$[MCP = 0.13\ x\ TDN]$$

Equation 6.10

where MCP = microbial crude protein and TDN = total digestible nutrients derived from wet chemistry analysis.

When protein is limiting in the diet, the MCP was calculated as per AFRC (1993) and (NRC 2007):

$$[MCP = 0.85\ x\ RDP]$$

Equation 6.11

where MCP = microbial crude protein and RDP = rumen degradable protein.

MPI_{TDN} and MPI_{RDP} were calculated as:

$[MP_{TDN}]$ (g/d) = [(0.6375 x 0.13 TDN g/d) + (0.9 UDP – ADICP g/kg DM)] (AFRC 1993) where fermentable energy is the limiting factor in the production of MCP. When RDP is limiting, then the equation used to estimate [MP_{RDP}] (g/d) = [(0.6375 x 0.85 RDP g/d) + (0.9 UDP – ADICP g/kg DM)].

6.2.5 Statistical analysis

One-way analysis of variance test (IBM SPSS Statistics for Windows, Version 23.0, IBM Corp. Released 2014, Armonk, NY, USA) was performed to compare the effect of dietary treatments on production responses. The differences across treatments as post-hoc multiple comparisons were compared with Duncan's multiple range test. The data were presented as mean and standard error mean (sem) and a significant difference was set at a level of 0.05. Differences between actual and predicted DMI and ADG were analysed using a paired samples t-test in SPSS. The data were presented as mean bias, indicating the difference between actual and predicted values. The two-tailed significant levels were set at 0.05. A non-significant (P>0.05) reading suggested that the actual value of DMI or ADG was reliably predicted by the models while the significant (P<0.05) reading was not.

6.3 Results

6.3.1 Feed and nutrient intake

Feed and nutrient intakes in Experiments 2 and 3 are presented in Table 4.2 Chapter 4. In Experiment 2, DMI of the Desmanthus group was 3.2%, about twice as high as that of the Urea group while the other three groups were approximately 2%. The lowest total DMI was recorded in Urea goats, while supplementation with CSM and Urea-CSM was similar to that of the Gliricidia group.

In Experiment 2, the meat goats offered Desmanthus hay had the highest protein fractions and metabolisable energy intakes compared to all other groups. Among supplemented groups, CSM goats had the highest protein fractions and metabolisable energy intakes (P<0.05), while Urea goats had the least.

In Experiment 3, crossbred Boer goats supplemented with Desmanthus hay only had the highest total DMI (1027 g), almost twice that of goats on RGH. No protein supplementation effect was observed in the amount of RGH consumed by goats. No significant difference was detected in total DMI between CSM, Urea-CSM and Gliricidia goats (P>0.05)

Protein fractions and metabolisable energy intakes of goats increased with Desmanthus hay compared with goats offered RGH with protein supplements ($P<0.05$). Among the supplemented groups, CSM goats had the highest intakes of protein fractions and metabolisable energy.

6.3.2 Dry matter intake (actual vs. predicted)

Actual and predicted DMI based on metabolic body weight with dietary ME, DM digestibility, or dietary ME only for supplemented Boer kids are presented in Table 6.1. The three equations were not able to predict the DMI of the goats in Experiment 2.

Table 6.1 Actual, predicted, estimates of bias and statistical significance (P-values) in predicting dry matter intake using body weight (BW) and dietary ME, DM digestibility and ME of crossbred Boer goats

Treatment	Actual DMI (g/d)	BW and dietary ME (g/d)			DM digestibility (g/d)			Dietary ME (g/d)		
		Predicted	Bias	*P*	Predicted	Bias	*P*	Predicted	Bias	*P*
Experiment 2										
Urea	312±19.2	636±24.3	-324	0.00	652±0.0	-339	0.00	911±0.0	-598	0.00
Urea-CSM	344±17.2	653±11.2	-309	0.00	691±0.0	-347	0.00	923±0.0	-579	0.00
CSM	377±11.3	665±20.8	-289	0.00	697±0.0	-320	0.00	934±0.0	-557	0.00
Desmanthus	652±25.2	702±21.1	-50	0.02	771±0.0	-119	0.01	985±0.0	-333	0.00
Gliricidia	358±19.9	686±38.2	-328	0.00	697±0.0	-339	0.00	959±0.0	-601	0.00
Experiment 3										
Urea	432±21.3	635±14.8	-203	0.00	652±0.0	-220	0.00	899±0.0	-467	0.00
Urea-CSM	561±24.8	676±17.7	-115	0.01	691±0.0	-130	0.01	935±0.0	-374	0.00
CSM	636±49.9	719±41.2	-82	0.01	697±0.0	-61	0.29	962±0.0	-326	0.00
Desmanthus	1027±29.7	728±21.1	299	0.00	949±0.0	78	0.06	980±0.0	47	0.19
Gliricidia	591±23.0	731±27.7	-141	0.01	697±0.0	-106	0.01	1014±0.0	-423	0.00

$P>0.05$ reading suggested that the actual value of DMI was reliably predicted by the models while the significant ($P<0.05$) reading was not at 0.05.
ME = metabolisable energy, BW = body weight, and CSM = cottonseed meal

In Experiment 3, total DMI of goats supplemented with CSM was predictable using DM digestibility, while DMI of goats on Desmanthus tended to be predictable. The estimated dietary ME of Desmanthus can predict total DMI of the goats (Figure 6.1).

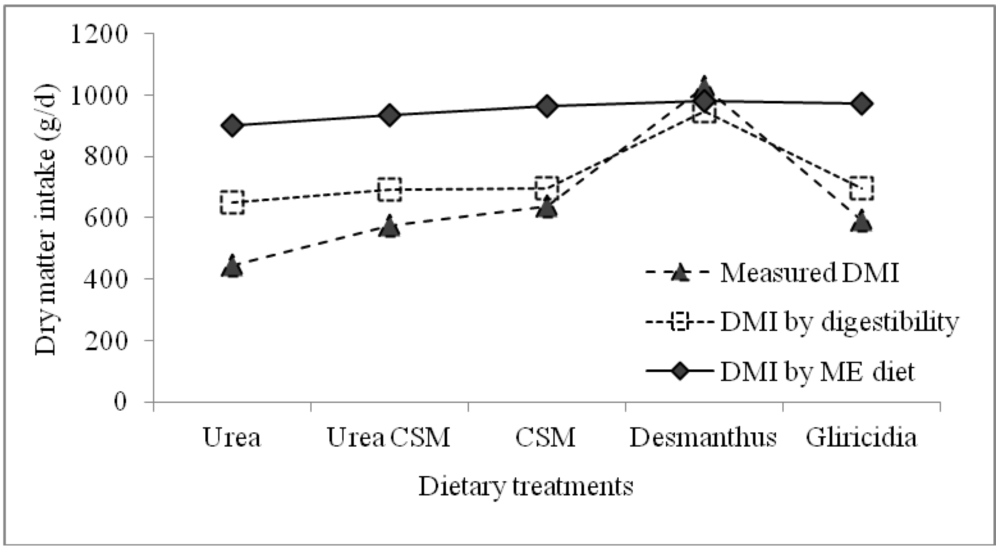

Figure 6.1 Experiment 3 Actual and predicted dry matter intake based on dry matter digestibility and dietary metabolisable energy in crossbred Boer kids

6.3.3 Liveweight changes

Growth rate responses of growing Boer goats on protein supplementation are presented in Table 4.3 Chapter 4.

In Experiment 2, initial and final liveweights of the experimental goats were not different between treatments. Boer goats fed Desmanthus only gained 2 kg liveweight or ADG of 33 g/d after 78 d of feeding. Supplementation with CSM increased liveweight by as much as 0.4 kg or ADG of 7 g/d. Boer goats offered RGH and supplemented with Gliricidia, Urea or Urea-CSM lost weight.

In Experiment 3, growing goats fed Desmanthus leaf hay had a liveweight gain of almost 10 kg over 130 d of feeding. Liveweight gain of goats on RGH as basal diet was enhanced by 0.7, 5.6, 6.8 and 4.8 kg over the same period in Urea, Urea-CSM, CSM and Gliricidia goats, respectively. These values were comparatively lower than that of Desmanthus. The ADG of goats fed CSM, Urea-CSM and Gliricidia did not differ significantly ($P>0.05$) amongst themselves, but were significantly lower ($P<0.05$) than ADG for Desmanthus.

6.3.4 Average daily gain (actual vs. predicted)

Actual and predicted ADG based on MEI, MPI_{TDN} and MPI_{RDP} are presented in Table 6.2. In Experiment 2, the ADG of Boer goats on Urea supplement or Desmanthus only were predictable by MPI_{RDP} model. In Experiment 3, only the growth rate of Gliricidia goats from estimated MEI was predictable.

Table 6.2 Actual, predicted, estimates of statistical bias and significance (P-values) in predicting ADG using MEI, MPI_{TDN} and MPI_{RDP} of crossbred Boer kids in different dietary treatments

Treatment	Actual ADG (g/d)	MEI (g/d)			MPI_{TDN} (g/d)			MPI_{RDP} (g/d)		
		Predicted	Bias	*P*	Predicted	Bias	*P*	Predicted	Bias	*P*
Experiment 2										
Urea	-15±2.3	-95±5.1	80	0.00	-61±2.1	46	0.00	-22±2.1	7	0.09
Urea-CSM	-3±6.9	-78±6.9	75	0.00	-57±1.4	53	0.00	-15±2.9	12	0.05
CSM	7±2.5	-68±4.0	75	0.00	-54±1.7	61	0.00	-11±1.5	18	0.00
Desmanthus	33±6.9	57±4.3	-23	0.01	-27±1.2	60	0.00	34±1.9	-1	0.83
Gliricidia	-3±5.8	-62±9.8	60	0.00	-50±3.0	48	0.00	-12±3.7	10	0.02
Experiment 3										
Urea	6±3.7	-51±7.8	58	0.01	-48±1.7	54	0.00	34±5.0	-28	0.03
Urea-CSM	48±3.2	-3±7.1	51	0.00	-33±1.7	81	0.00	64±5.1	-16	0.03
CSM	58±7.4	28±7.6	30	0.00	-21±1.2	79	0.00	80±8.2	-23	0.00
Desmanthus	83±6.7	186±6.4	103	0.00	7±1.0	76	0.00	137±4.1	-54	0.00
Gliricidia	41±5.2	46±9.3	5	0.61	-16±2.7	57	0.00	67±5.0	-26	0.01

P>0.05 reading suggested that the actual value of ADG was reliably predicted by the models while the significant (P<0.05) reading was not at 0.05.

MEI = metabolisable energy intake, MPI_{TDN} = metabolisable protein intake based on total digestible nutrient, MPI_{RDP} = metabolisable protein intake based on rumen degradable protein and CSM = cottonseed meal

6.4 Discussion

The ability of the DM digestibility equation to predict DMI of goats supplemented with CSM with concentration of 195 g CP/kg DM revealed that the prediction could not be applied to all CP concentrations in the diets. In diets with low CP, the ability of CSM in enhancing total DMI might be too small to be detected. In diets with high CP, the UDP of cottonseed meal that escapes degradation from rumen microbes is available as amino acids absorbed in the small intestine (Leng, 1990). This absorption leads to increased digestibility, ensuring that more space is available in the digestive tract, thereby signalling the animal to eat more (Hackmann and Spain, 2010; Sartin *et al.,* 2011). In the current study, UDP was superior to RDP in driving feed intake. Nitrogen from Urea or Urea-CSM treatments was degraded into ammonia and used by rumen microbes to synthesise microbial crude protein to the host, some of it recycled and some excreted in urine (Nolan and Stachiw, 1979). Consequently, microbial crude protein absorbed in the small intestine was likely insufficient to drive feed intake up to the level of predicted DMI.

The tendency for DM digestibility to predict DMI of goats on Desmanthus leaf hay (P=0.06) as measured with Equation 6.2 could be associated with high dietary CP and UDP concentrations, leaf to stem ratio, and outflow rate of the ingesta because Desmanthus dried leaves with low fibre have rapid outflow rates (Pathak, 2008), thus increasing digestibility and enhancing feed intake due to predictable cause-effect relationship.

The finding that estimated dietary ME of Desmanthus was able to predict DMI, but not the supplemented Rhodes grass hay, could be associated with the nature of both feeds. Kasuya *et al.,* (2008) reported that tropical grasses are less soluble in the rumen, resulting in less fermentable energy derived from microbial fermentation compared with low fibre of the legume. The fibrous grass resides longer in the rumen for microbial fermentation and this will have a 'gut-filling' effect that prevents the goats from eating more (Forbes, 1980). In comparison, low fibrous legumes have a rapid flow rate out of the rumen (Pathak, 2008), hence trigger more feed intake. The estimated ME equation used to predict DMI was based on studies using temperate grasses characterised by low fibre and high fermentable energy. This equation is apt and applicable to Desmanthus diet in the present study because of the similarity in feed characteristics between temperate grasses and Desmanthus (tropical legume).

The ability of estimated ME intake to predict ADG for goats supplemented with Gliricidia showed that ME requirement recommended by NRC (2007) is applicable. The inclusion of tropical legumes in tropical grass feeding systems increased available and readily fermentable organic matter content. The failure of estimated ME intake to predict ADG in other treatments might be related to ME requirements for maintenance (MEm) and gain (MEg) not being adequately met. Except for Desmanthus, all predicted ADGs were less than actual ADGs. If one of the recommended values of MEm or MEg was increased, then the predicted ADG would probably become closer to the actual ADG. This speculation was suggested because the animals' activity and acclimatisation in the tropics would require more energy and protein. Abate (1989) and Salah *et al.,* (2014) reported 0.556 and 0.542 MJ/kg $BW^{0.}75$, respectively for the tropical goats' MEm as compared to 0.489 MJ/kg $BW^{0.75}$ (NRC, 2007). They also reported 0.0279 and 0.0243 MJ/g ADG for the tropical goats' MP as compared with 0.0231 MJ/g ADG (NRC, 2007).

The calculation of MPI_{TDN} and MPI_{RDP} assumed that microbial crude protein yield was limited by dietary energy and protein supplies, respectively (NRC, 2007). The ability of estimated MPI_{RDP} in Experiment 2 to predict ADG of goats on urea and Desmanthus diets revealed that the MP requirements suggested by the NRC (2007) are applicable in tropical conditions. Urea supplement seems to supply sufficient ammonia required by rumen microbes to increase microbial crude protein yield. Unlike the goats on Urea supplement, those on Desmanthus had sufficient supplies of RDP, UDP and fermentable organic matter to support liveweight gain, indicating that growth rates were likely driven by RDP, UDP and ME. Underpredicted ADG using estimated MP in Experiment 3 when the CP diet was increased to 195 g/kg DM showed that RDP in the high CP diet might be less efficiently utilised.

The predictable ADG using MPI_{RDP} confirmed that 3.07 g/kg $BW^{0.75}$ of MP required for maintenance and 0.404 g/g ADG for gain (NRC 2007) was valid for protein supplements rich in RDP being associated with dietary energy, protein and microbial crude protein. These recommended values of nutrient requirements were not valid for UDP dietary sources such as CSM in tropical grass hay feeding system.

Put together, these results showed that energy and protein are required for normal rumen function, while the ME and MP availability of ammonia and volatile fatty acids as rumen fermentation products, determines feed intake and growth rate in goats (Satter and Slyter, 1974; Thirumalesh and Krishnamoorthy, 2013).

6.5 Conclusion

Estimated ME concentration of dried leaves of Desmanthus with 195 g CP/kg DM was able to predict DMI of growing Boer goats. This estimation method cannot be applied to supplemented goats fed basal diet of Rhodes grass hay (RGH). Dry matter digestibility was able to predict the DMI of growing Boer goats fed Desmanthus hay only or fed RGH with CSM as a source of RDP and UDP, mostly as true protein at the dietary CP concentration of 195 g/kg DM. Estimated ME intake was valid in predicting ADG of Boer goats on RGH and Gliricidia diets at dietary CP of 195 g/kg DM. The application of the MP recommended requirements suggested by NRC (2007), and estimated MP_{RDP} intake predicted the ADG of the goats on RGH with Urea supplement or on Desmanthus hay only at dietary CP of 137 g/kg DM. It could be concluded that models used for temperate forages to predict DMI and ADG of goats could be used for some tropical forages. The application of the models requires determination of metabolisable protein and metabolisable energy concentrations of forages or protein supplement sources, differentiation between RDP and UDP sources and level of dietary CP.

Chapter 7 General Discussion

Meat goats in Northern Australia are about 80% raised for sale as packaged meat in the global market (MLA, 2016), while in East Nusa Tenggara, Indonesia, the animals are raised for domestic consumption (Livestock and Animal Health Statistics, 2017). Although the market orientation differs between the two locations, each has similar objectives in that they are looking to optimize rate of liveweight gain by utilising the available tropical pasture biomass. The research focus of this study was on growing kids from late pregnancy (healthy twin foetuses) through to suckling kids and the growth of weaners until slaughter.

Maximum daily liveweight gain of growing kids is achieved when the rumen that supports their nutrition functions optimally and the protein required is sufficient and well matched to the available energy from dry matter (Dutta *et al.,* 2009). This paradigm applies as much to the rumen of a periparturient doe supporting a foetus as it does to the lactating doe supporting suckling kid/s and the weaned animal undergoing growth and development (Goetsch *et al.,* 2014). The primary objective of this study, therefore, was to meet the nutrient requirements of periparturient and lactating does and weaner kids for both rumen degradable and undegradable dietary protein (RDP and UDP), from which metabolisable protein (MP) was derived. The second objective was to categorise diets based on the relative and total estimated amounts of RDP, UDP, MP as well metabolisable energy (ME) based on organic matter digestibility. The third objective was to validate the National Research Council (2007) methodologies for the prediction of dry matter intake and average daily gain of weaner kids fed tropical forages using intakes of these protein fractions and ME. The last objective was to recommend supplementation strategies that incorporate the RDP and UDP supplied by diets to improve growth and carcass yields of meat goats in the tropics, especially in East Nusa Tenggara, Indonesia.

In this general discussion, four sub-topics are discussed; these focus more on the above-mentioned general objectives and on specific objectives as follows. Objective one will explore the type of protein supplementation to the pregnant does that best supported the birth of two healthy kids (as far as possible using breeding technologies) that are suckled with good colostrum with the doe remaining healthy with a low risk of pregnancy toxaemia/ketosis. The two suckling kids per doe were expected to be weaned at 90 days and weighing on average 10 kg. Protein supplementation was aimed at increasing dietary metabolisable protein intake which is, in large part, dependent upon fermentable organic matter intake (FOMI). An optimum supply of MP is also achieved when requirements for RDP and UDP are adjusted relative to fermentable organic matter intake and hence ME are met.

Objective two was to optimize the rate of liveweight gain and carcass yield of weaner kids according to limitations of a basal diet consisting of a phase three (vegetative) C_4 tropical grass hay (Rhodes grass hay). Protein supplementation was aimed at increasing dietary MP intake, based on supplying sufficient RDP to support fermentable organic matter intake and sufficient UDP to meet the needs for growth that were not met by microbial true protein leaving the rumen. The estimated MP intakes of the doe recorded for optimal growth of suckling kids and estimated MP intakes recorded for weaner kids are discussed with respect to the requirements published by NRC (2007).

Objective three was to determine if the methodologies to predict dry matter intake and average daily gain of supplemented weaner kids published by NRC (2007) can accurately and reliably be applied to the phase 3 C_4 tropical hay diets and tropical legumes used in this research program. The discussion was focused more on the relationship between determinant factors and dependent factors. Factors that determined dry matter intake, such as metabolic body weight, dietary metabolisable energy concentration and digestibility are discussed. Factors that determined average daily gain, such as intakes of metabolisable protein and metabolisable energy are also discussed.

Objective four was to recommend an approach to the protein supplementation of periparturient and lactating does and weaner kids that encompasses the need of the animal to consume both RDP, to support optimal rumen fermentative function, and UDP, to ensure that MP intake matches the animal's ME intake. This recommendation focuses on the ability of a protein supplement to supply either NPN-RDP from a source such as urea or true protein-RDP and UDP from CSM. The capacity of two types of tropical legume (Gliricidia and Desmanthus), that differ in their ability to supply RDP and UDP and support fermentable organic matter intake are also discussed.

7.1 Characterisation of the UDP and RDP Fractions of the Diet is Essential to Understanding the Growth Response of Crossbred Boer Goats from Birth to Slaughter Weight when Fed Tropical Forages

The hypothesis in this study was that when the given mineral requirements of the animal are met, the supply of RDP, both as non-protein nitrogen and amino acids with respect to fermentable organic matter (FOM) in the rumen, is the first limiting factor leading to low dry matter intake and productivity of meat goats. If this hypothesis is correct, then diets that supply extra RDP as NPN and amino acids from urea and CSM will lift dry matter intake and the productivity of the does and/or weaner kids. Once the supply of RDP to fermentable organic matter is met, then the next most limiting component of the diet is the availability of UDP as true protein for the growth of the animals. It is also of interest to know whether, in an animal that is replete with all mineral requirements, a supplement of legume leaf with a tropical grass and/or legume fed alone, will provide further productive benefits.

7.2 RDP and UDP Requirements of Periparturient Crossbred Boer Does to Achieve Good Doe Health and Liveweight Gain of Suckling Kids

The current feeding strategy to support the protein nutrition of periparturient meat goats fed tropical grass hay in East Nusa Tenggara is targeted at providing urea supplements with salt to does (Manu *et al.,* 2007). Noguiera *et al.,* (2016) also reported that urea, salt and other minerals are routinely utilised for rangeland goat enterprises in New South Wales and Queensland, Australia. Manu *et al.,* (2007), however, recommended that in East Nusa Tenggara, Indonesia between a suitable protein and energy rich supplement for does in late pregnancy and during lactation should include liquid palm sugar, pumpkin, gebanga (*Corypha gebanga*) palm flour and coconut meal, plus urea as the only significant source of supplemental (non-protein nitrogen-RDP) protein. Evidence from Experiment 1 challenged the effectiveness of these supplementation strategies for periparturient and lactating does. In this experiment, feeding a supplement of urea to increase intake of NPN-RDP, in order to increase crude protein intake from 107 to 143 g CP/kg DM to meet total crude protein requirements reported by NRC (2007), did not increase intakes of dry matter or estimated ME by does over and above the unsupplemented RGH di*et al*one. Both the Control diet and Urea diet produced significant body weight loss in does over the first two weeks of lactation. These two diets were also associated with elevated concentrations of blood plasma β-hydroxybutyrate and NEFA across the periparturient period. Inclusion of some seed protein meal from CSM, either with urea or without urea, in order to achieve isonitrogenous diets of 143 g/kg CP DM, however, did support increased intakes of dry matter and estimated MP and ME. While the rate of liveweight loss in does did not differ significantly between dietary treatments, does in the first two weeks of lactation fed either the urea-CSM (143 g CP/kg DM at 30% UDP) or CSM diets (143 g CP/kg DM at 34% UDP) had lower blood plasma β-hydroxybutyrate and NEFA concentrations compared with does fed the control treatments (107 g CP/kg DM at 35% UDP) and urea (142 g/kg CP at 26% UDP). Kids suckling from the urea-CSM treatment does had significantly higher rates of liveweight gain in week 1 compared with the control, while the other two treatments (urea; CSM) produced rates of liveweight gain intermediate between the control and urea-CSM treatments. This is consistent with the extra MP and ME intakes being directed to increased production of milk solids (Sangare and Pandey, 2000) while supporting a metabolic profile associated with a reduced risk of ketosis. Previous studies on dairy goats (Bronzo *et al.,* 2010; Sahlu *et al.,* 1995) also showed similar responses to feed supplementation of periparturient does with seed protein meals. Ospina *et al.,* (2013) explained that when high ME intake supplied sufficient β-hydroxybutyrate from rumen, less body fat would be mobilised to supply energy requirements of the doe, so that risk of pregnancy toxaemia/ketosis would be reduced. In this experiment, it is not possible to know definitively whether the responses (increased growth rate of suckling kids and improve metabolic profile) resulted from an increase intake of either true protein-RDP or UDP, or both. The digestibility study that utilised similar diets to those of Experiment 1, involving does in the last two to three weeks of pregnancy does show a clear benefit to feeding the urea-CSM diet over the CSM diet. In this case it was clear that does offered the urea-CSM supplement were able to consume more ME compared with all other treatments, and this was consistent with the significantly higher N retention compared with the CSM diet. Does fed either the control diet or supplemented with urea had a negative N balance in late gestation, indicating that they were catabolizing their own tissues to meet the needs of the rapidly growing foetus.

It was not possible to distinguish between N retained by the doe or directed to the foetus (including all products of conception) with either the urea-CSM diet or the CSM diets in the digestibility study. It is clear, however, that the CSM treatment was inferior to the combination of urea-CSM, in that does on the CSM treatment retained significantly less N than does fed the urea-CSM treatment. The significant reduction in N retention for the CSM diet when compared with the urea-CSM diet, over an apparently small reduction in RDP intake and increase in UDP intake, suggests that the rumen benefited greatly from at least some of the RDP being supplied as true protein. Extra UDP to replace some of the true protein-RDP in the diet beyond that supplied by the urea-CSM diet provided no further benefit to the overall estimated ME intake by the doe. These findings point to the importance of supplying the rumen of the periparturient and/or lactating doe fed a diet based on a C_4 (tropical) grass hay, with both NPN-RDP as well as a source of true protein-RDP, in order to support rumen ammonia concentration and fermentative capacity. This finding is consistent with the findings of Satter and Slyter (1974), who reported that an optimal rumen fermentation and microbial crude protein production from fermentable organic matter occurred at a dietary crude protein concentration of 120 to 140 g CP/kg DM. In the present study, however, it was clear that a significant proportion of this should be as true protein-RDP.

7.3 RDP and UDP Requirements of Crossbred Weaner Boer Kids to Achieve Maximum Liveweight Gain and Carcass Yields

In Experiment 1, periparturient does fed a diet of Rhodes grass hay, supplemented with either urea, urea-CSM or CSM, had higher estimated ME intakes compared with periparturient does receiving no protein supplement. Does fed Rhodes grass hay with urea-CSM, however, had higher N retention in late pregnancy and lower circulating concentrations of β-hydroxybutyrate and NEFA in plasma, compared with either the urea or the CSM treatments during the periparturient period. This indicated the urea-CSM treatment was much better at reducing the catabolism of body tissues by the doe, in order to support the foetus in late pregnancy and the growth and development of the suckling kid in the first weeks of lactation. The conclusion that can be drawn from these findings was that there was a clear benefit to supplementing periparturient does with a source of true protein-RDP in order to support rumen fermentative capacity and, therefore, enhance ME intake. Supplying extra UDP to the diet by removing urea and feeding more CSM provided no further benefits to the doe. The growing and developing weaner kid, however, is much more likely to be UDP protein dependent (NRC, 2007). In addition, seed protein meals are unavailable to livestock producers in the Indonesian Province of East Nusa Tenggara. The required intakes of protein can be achieved through the use of forage legumes. The next research questions were "Will weaner kids fed a similar diet to the does achieve better weight gains on the CSM diet when compared with the urea-CSM diet?", and, "Is there advantage to supplying extra RDP and UDP from a legume?" The two legumes utilised in this part of the study were Gliricidia leaf and Desmanthus hay.

Diets in Experiment 2 were structured similarly to Experiment 1 diets, with the exception that the crude protein content of the treatments containing Rhodes grass hay with urea and/or CSM were formulated to be isonitrogenous at 137 g CP/kg DM. This was consistent with the CP content of a chaff made from the legume Desmanthus. In this study, the urea diet supplied 26% of CP as UDP, the Urea-CSM diet supplied 27% of CP as UDP, with a larger fraction of RDP as true protein-RDP and the CSM diet supplied 29% of CP as UDP. The leaf fraction of the legume Gliricidia was added to Rhodes grass hay to achieve a 137 g CP/kg DM diet, resulting in 34% of CP as UDP. The Desmanthus treatment supplied 40% of CP as UDP. Importantly, all the diets based on Rhodes grass hay gave values determined using an *in vitro* fermentation technique, for ME content around 7.8 MJ/kg DM for the Urea treatment, approximately 8.0 MJ/kg DM for the Urea-CSM treatments, 8.5 MJ/kg DM for the Gliricidia treatment and 8.9 MJ/kg DM for the Desmanthus treatment. These values were at the low end of values reported by NRC (2007) that will support positive rates of liveweight gain for Boer weaner kids.

None of the treatments produced acceptable rates of liveweight gain. Kids lost weight on the Urea treatment and failed to gain weight on the Urea-CSM, CSM and Gliricidia treatments. These responses were consistent with the calculated values for MP and ME intake either falling below maintenance MP and ME requirements for the Urea treatment or just meeting MP and ME requirements for maintenance for the Urea-CSM, CSM and Gliricidia treatments, according to values published by the NRC (2007). The Desmanthus treatment produced moderate positive weight gains of 33 g/day, also consistent with kids consuming MP and ME above maintenance requirements, according to NRC (2007). Consistent with the findings for the Urea treatment applied to the periparturient does, weaner kids fed the Urea treatment to provide a diet with supplemental protein as NPN-RDP lost weight. Again, this supports the hypothesis that the rumen must have a supplemental source of true-protein RDP to function effectively. Inclusion of a true protein source of RDP, however, only supported maintenance requirements for MP and ME for diets providing 137 g CP/kg DM at intakes of UDP from 27% to 34% of CP. The response to the Desmanthus treatment suggested that the higher intakes of both true protein-RDP and UDP were useful. However, in this case the treatment also had higher organic matter digestibility so that the rumen was working more efficiently per unit of dry matter intake compared with the treatments based on Rhodes grass hay. The ability of the Rhodes grass hay to support reasonable rates of liveweight gain in weaner kids was limited by the ME concentration of the diet.

This finding raised a new research question, which was whether increasing the CP concentration of the diet would increase organic matter digestibility, and therefore ME concentration sufficiently to achieve intakes of both MP and ME, leading to acceptable rates of liveweight gain. To achieve this increase in CP concentration of the diet, Desmanthus hay was sieved to produce a leaf rich fraction with 195 g CP/kg DM at 36% of CP as UDP. Rates of inclusion of urea and/or CSM and Gliricidia were adjusted to achieve isonitrogenous diets where Urea, Urea-CSM, CSM and the Gliricidia diets supplied 23, 27, 30 and 36% of CP as UDP, respectively.

The most important finding to note from Experiment 3 was that overall intakes of dry matter increased, but the intake pattern was very similar to that seen in Experiment 2, in which the Urea treatment has the lowest intakes, Desmanthus has the highest and the other three treatments achieved intermediate intakes. The Urea treatment did not support liveweight gains, but, on average, the animals did not lose weight, so that MP and ME requirements for maintenance on this diet were approximately met. Increasing the amounts of CSM and Gliricidia fed with Rhodes grass hay increased the diet estimated ME concentrations and estimated MP and ME intakes, which resulted in liveweight gain for kids on these treatments. The responses, however, were not consistent with the change in ME concentration of the diet. They were consistent with the concentration of UDP in the diet where the Gliricidia treatment had the highest ME concentration (9.6 MJ/kg DM), but did not achieve ME intakes above those of the CSM treatment with an ME concentration of 8.5 MJ/kg DM. Both treatments resulted in the similar UDP intake (37 and 42 g/day, CSM and Gliricidia treatments, respectively). The rate of liveweight are not similar. Statistical difference was not detectedprobably because of small smaple size. The Desmanthus treatment, however, achieved the highest intake of ME. This was approximately 40% above that of the CSM and Gliricidia treatments, with an intermediate ME concentration of 8.8 MJ/kg DM. It provided the highest concentration of UDP across all treatments. This finding implied that adding more NPN-RDP source in order to increase intakes of goats fed tropical hay as a basal diet is not effective at achieving acceptable rates of liveweight gain in weaners fed a C4 (tropical) grass hay. Strategies that increased the UDP concentration in crude protein and in the diet overall, however, appear to have achieved increases in liveweight gain approximately in proportion to the increase in dietary UDP content. Carcass weights and yields, eye muscle area and fat depth all increased in a manner consistent with increased intake of MP and ME across treatments. The exception to this was the Desmanthus diet, where increased intakes of MP and ME also resulted in substantially higher contents of channel, kidney and omental fat. This fat is of high value to the people of East Nusa Tenggara because of its excellent eating qualities compared with coconut oil as a cooking additive.

Liveweight gain and carcass weight are indicators for absorption of protein fractions and metabolisable energy intakes. Higher liveweight gain and carcass weight means more metabolisable protein, and metabolisable energy has been absorbed in the small intestine and can be utilised for tissue accretion. Absorption also triggers intakes as a consequence of more space being available in the digestive tract. The next research question was "Does diet digestibility explain liveweight gain, carcass weight and intakes of weaner goats?" Experiment 4 has been conducted to answer this question.

7.4 Protein Supplementation Effect on Diet Digestibility in Weaner Goats

Dry matter digestibility in weaner goats (Experiment 4) was similar across the treatments but the highest nitrogen retention resulted from the CSM supplement. This higher nitrogen retention could be explained by the nature of its degradability, where cottonseed meal is slowly releasing nitrogen and undegraded dietary protein that will result in higher nitrogen retention (Bach *et al* 2005). Consequently, body weight and carcass yield in weaner goats supplemented with CSM in Experiment 3 were higher than that of goats supplemented with urea. The findings suggested that any strategy to improve productivity of meat goats was not dependent on the dietary CP concentration but on the RDP, UDP, and fermentable organic matter to support rumen function and to provide sufficient MP and ME meeting the maintenance and production requirements suggested by the NRC (2007).

Digestible crude protein intake in weaner goats supplemented with cottonseed meal provided 70 g MP/d (Table 5.2), which was 5 g higher than that for the Urea-CSM goats and twice higher for goats fed Rhodes grass hay only or supplemented with Urea. NRC (2007) suggested that a 20-kg weaner goat requires 39 to 69 g MP/d to grow at the rate of 25 to 100 g/d. The estimated MP data from Experiment 4 could explain the ADG and carcass weight data in Experiment 3. This finding highlighted that both nitrogen retention and estimated MP data derived from the digestibility study were predictors for liveweight gain and carcass yield of meat goats fed tropical grass.

As found in Experiment 4, digestibility and feed intake were interconnected, where weaner goats supplemented with Urea-CSM or CSM have high DM intakes as compared to that of goats with Urea supplement. Urea plus CSM or CSM alone was probably providing sufficient nitrogen required for the rumen microbes that actively digest the ingesta. The increasing digestibility causes a higher passage rate of ingesta, leaving the digestive tract less full, therefore encouraging the goats to eat more (Jones, 1972). The lower intake in the Urea goats could be because of the negative feedback from the higher concentration of blood urea nitrogen (BUN) (Provenza, 1995). The lower dry matter intake in the unsupplemented goats could be due to the filling effect in the reticulorumen (Allen 1996), as a consequence of slow fermentation of the fibrous diet (Morand-Fehr 2005), or simply due to a nitrogen deficiency that leads to low digestibility.

Dry matter intake and average daily gain of the goats in Experiment 2 and 3 were different, despite that the diets offered were isonitrogenous. The two next research questions were: 1) "Do dietary concentrations of RDP and UDP predict dry matter intake of weaner goats?", and 2) "Is the average daily gain of growing meat goats predictable using MP and ME systems suggested by NRC (2007)?" Modeling to predict DMI and ADG of growing meat goats based on the results and data obtained from Experiments 2 and 3 has been conducted to answer these questions.

7.5 Prediction of Dry Matter Intake and the Use of Metabolisable Protein and Metabolisable Energy Systems to Predict Average Daily Gain of Growing Meat Goats

7.5.1 Prediction of DMI

Total DMI of the goats fed CSM in Experiment 2 was predictable from DM digestibility. Similarly, total DMI of the goats fed Desmanthus in Experiment 2 was also predictable from dietary ME. The ability of these two equations to predict DMI of weaner goats fed tropical grass hay with different protein supplements or tropical legumes at different dietary crude protein concentrations reveals that not all equations were appropriate to apply in the tropical conditions encountered. The possible explanations for this finding could be related to the method of determining the dietary energy concentration or determining the requirements of the goats. Metabolisable energy of the diet that can be measured using methods of digestibility (CSIRO, 2007), *in vitro* (Getachew *et al.,* 2002; Hind *et al.,* 2014), or nutrient content (NRC, 2007; CSIRO 2007) would give different results. Another reason could be related to the fibre concentration of the feeds. These equations were applied for temperate grasses containing low fibre as compared to tropical grasses (Kasuya *et al.,* 2008). Fibrous material that resides longer in the digestive tract for fermentation or digestion prevents the goats from eating more (Forbes, 1980). Low fibrous legumes on the other hand have a rapid flow, rapidly leaving the digestive tract, hence increasing DMI (Pathak, 2008).

The general pattern of the DMI response of crossbred Boer goats to protein supplementation of tropical grass and the usage of tropical legumes was identified in Experiments 2 and 3. The negative relationship between dietary RDP concentration and DMI (Figure 7.1) could be related to the main function of RDP, providing ammonia to the rumen microbes (AFRC, 1993). Nolan and Stachiw (1979) reasoned that ammonia is used for rumen microbes, recycled or excreted in urine. Once the ammonia requirement for rumen microbes has been met, the addition of RDP in the form of urea will cause more urine to be excreted. Bach *et al.,* (2005) explained that RDP conversion to ammonia and urine excretion required energy. Reducing DMI of a diet containing NPN-RDP appears to be a mechanism employed by goats to reduce the energy cost of urine excretion. The low DMI of goats supplemented with urea was also due to the distasteful nature of urea.

The implication of this negative association is that supplementation with Urea to tropical grass hay was likely to reduce the DMI of the growing goats. An alternative protein supplementation regime suggested for meat goat enterprises in the tropics is to provide goats with protein supplements rich in UDP.

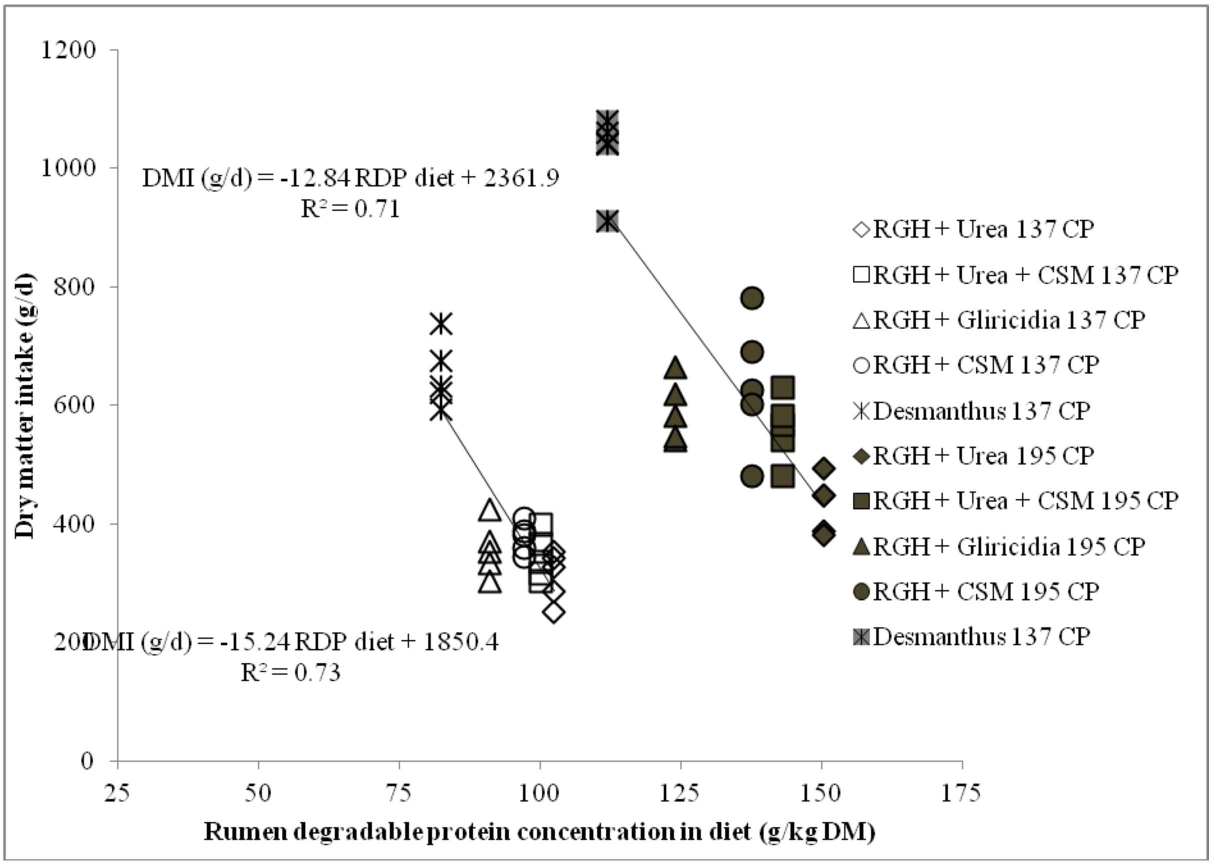

Figure 7.1 Relationship between concentrations of RDP in the diet with DMI of supplemented growing kids

The positive relationship between dietary UDP concentration and DMI could be explained by how UDP functions in relation to digestibility, absorption and feed intake. True protein or UDP will be absorbed in the small intestine as MP. This absorption increases digestibility, leaving more space in the digestive tract, leading to high DMI (Jones, 1972). This explanation was supported by the finding in Experiment 4, in which goats supplemented with CSM had higher digestible crude protein and nitrogen retention.

Importantly, UDP concentrations in the diet have a consistently positive relationship with DMI of the goats in Experiment 2 and Experiment 3 (Figure 7.2). As the two parallel lines are continuous in both Experiments, Figure 7.3 was drawn. It revealed that the concentration of UDP in the diets explains 80.5% of variation in dry matter intake at two vastly different concentrations of dietary crude protein.

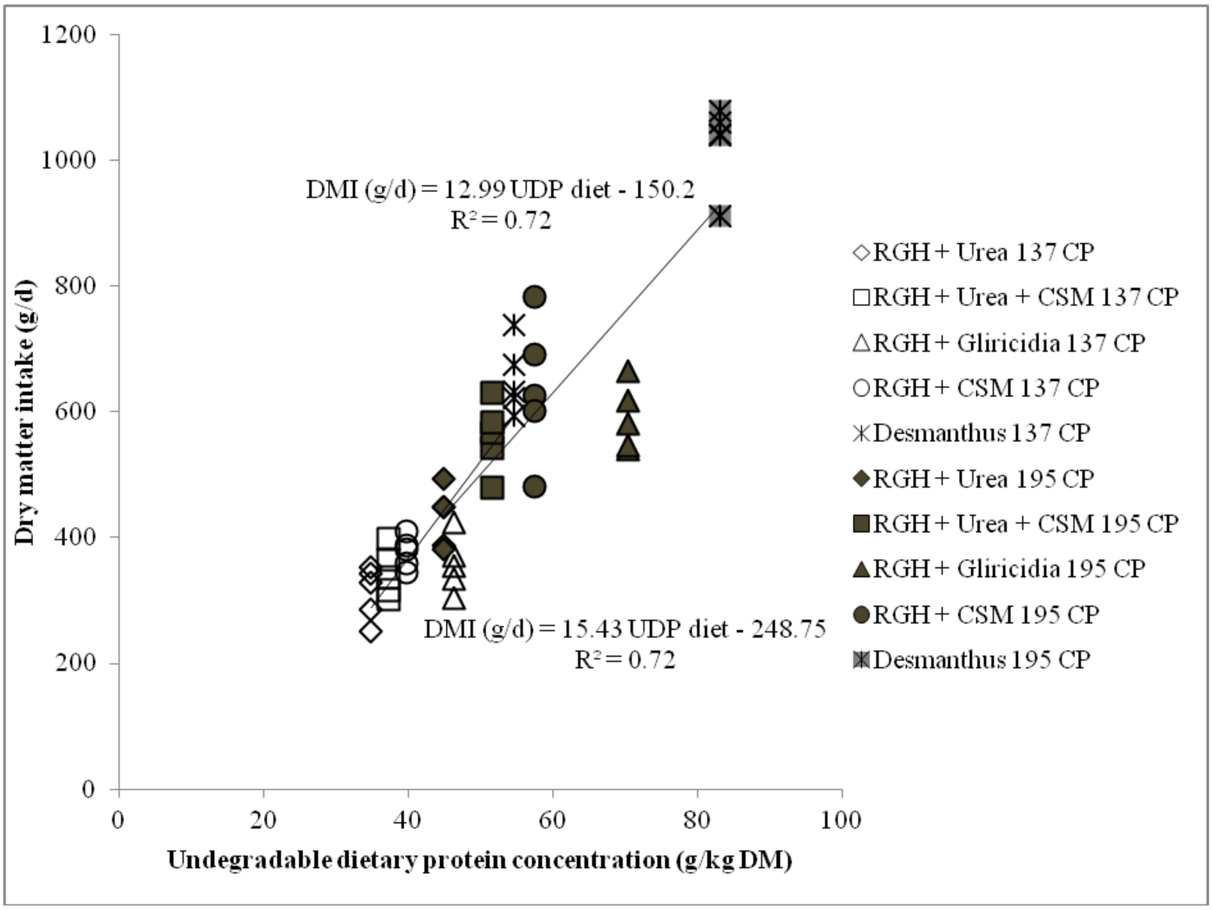

Figure 7.2 Relationship between concentrations of UDP in diet in two data set with DMI of supplemented growing kids

This finding showed that UDP is the driver for DMI of growing kids fed tropical forages supplemented with different types of protein supplement.

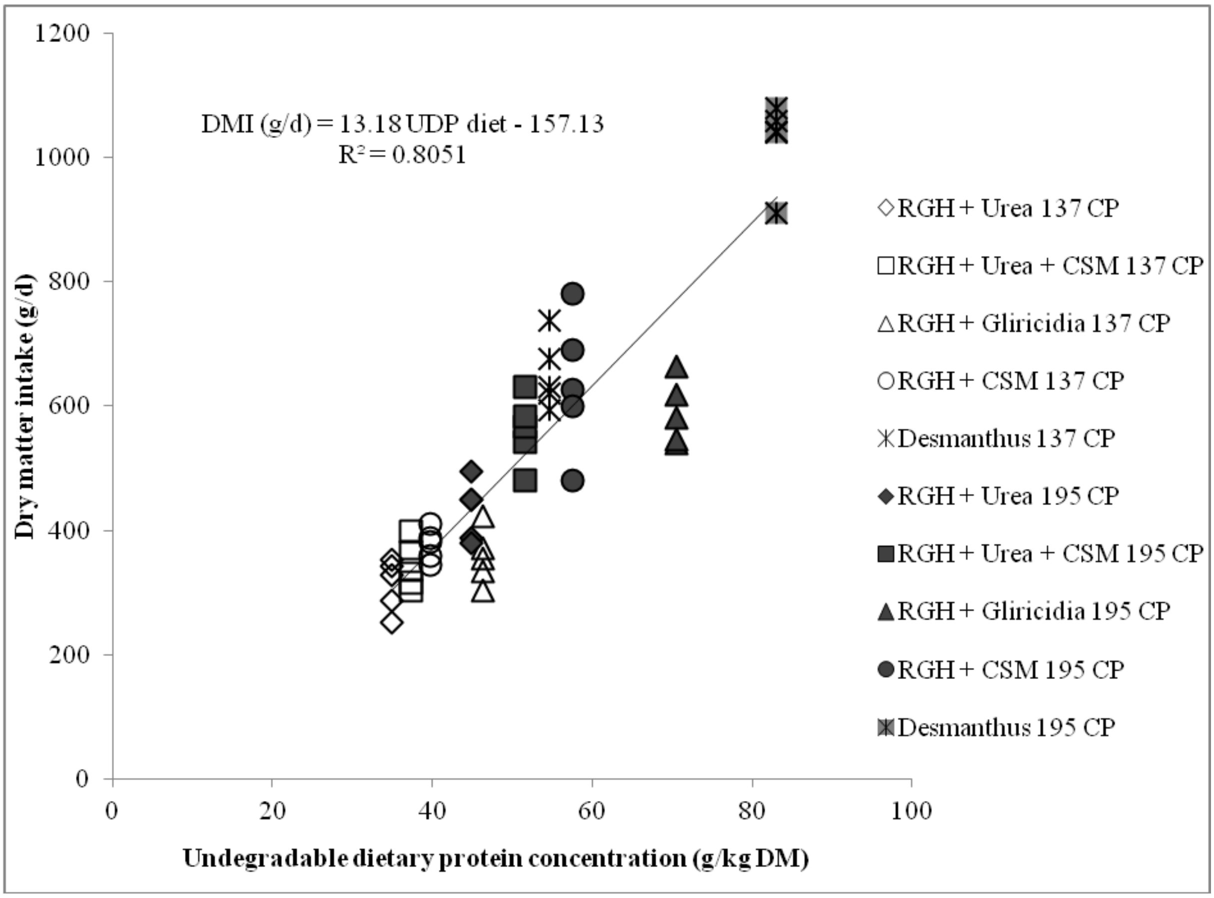

Figure 7.3 Relationship between concentrations of UDP in diet in one data set with DMI of supplemented growing kids

The finding that UDP is the best predictor of the DMI of growing goats highlights the importance of feeding strategy for meat goats in the tropics. The source of UDP in these studies was cottonseed meal, a supplement that is easily found in Australia. However, in East Nusa Tenggara, Indonesia cottonseed meal is not available. Therefore, identification of protein feedstuff sources that have higher UDP was required. Some potential feedstuff sources include forage legumes, such as Gliricidia and Desmanthus.

7.5.2 Prediction of ADG

Increase in ADG appears to be associated with intakes of MP and ME. However, not all forages or supplements were able to predict ADG in Experiment 2 and Experiment 3 reveals that the standard requirement intakes suggested by NRC (2007) could not be applied to the tropical forages. This inability to predict ADG could be because meat goats in the tropics required higher energy for maintenance and productivity (Abate, 1989; Salah *et al.,* 2014) as compared with the requirements proposed by NRC (2007).

The ability of estimated ME intake to predict the ADG of the Gliricidia supplemented goats in Experiment 3 revealed that ME standard requirements (NRC, 2007) are applicable in the tropical conditions but limited to RGH plus Gliricidia supplement at 195 g CP/kg DM diet. The explanation for this finding was not clear, but the over-estimated prediction of ADG from other treatments might be related to the efficiency of the ME intake.

The ability of estimated MP_{RDP} intake to predict the ADG of the Urea and Desmanthus supplemented goats in Experiment 2 showed that MP standard requirements (NRC, 2007) are applicable in tropical conditions but limited to RGH plus urea supplement or Desmanthus hay only at 137 g CP/kg DM diet. The explanation for this finding was not well understood. This could be associated with urea as an NPN-RDP source and Desmanthus that is rich in RDP and fermentable organic matter. Urea and Desmanthus might have enriched microbial crude protein (MCP) yields as a component of MP but at the higher dietary protein concentration, the usage of MP might not be efficient.

In addition, regression analysis used to determine the relationship between average daily gain and MP intake or ME intake showed a strong positive relationship as R^2 values are above 0.70 (Table 7.1).

Table 7.1 Average daily gain as predicted by MP intake and ME intake in supplemented growing Boer goats

Predictor	Model	R^2
	Experiment 2	
MP_{RDP} intake (g/d)	ADG (g/d) = 1.97 MP intake – 48.51	0.72
ME intake (MJ/d)	ADG (g/d) = 12.98 ME intake – 40.45	0.71
	Experiment 3	
MP_{RDP} intake (g/d)	ADG (g/d) = 1.54 MP intake – 45.38	0.75
ME intake (MJ/d)	ADG (g/d) = 11.46 ME intake – 16.94	0.70

MP_{RDP} = metabolisable protein based on rumen degradable protein, ME = metabolisable energy, MP = metabolisable protein, ADG = average daily gain

All the given MP or ME intakes in the regression model of intakes on ADG are positive, indicating that additional intakes MP or ME as determinant factors will increase liveweight gain. The negative constant values on the model revealed that goats that consumed diets deficient in MP or ME would likely experienced body weight loss.

The highest coefficient R^2 at 0.75 in the model of MP intake as a determinant factor for live weight gain in Experiment 3 showed that MP was likely be a better predictor for live weight gain of meat goats fed tropical forages. This should be applied with caution to the goats that may have low MP intake from urea supplement compared to MP intake of other protein supplements or Desmanthus.

Chapter 8 Conclusion

This research found that protein supplementation to periparturient crossbred Boer does or weaner kids fed Rhodes grass hay as a basal diet increased the animals' productivity. However, these responses varied widely depended on sources of protein supplements, despite that the diets offered were isonitrogenous. To be specific, the DMI and ADG responses were associated with dietary concentrations of rumen degradable protein (RDP), undegradable dietary protein (UDP), and metabolisable protein (MP) rather than crude protein (CP). Metabolisable energy was also determined all these responses.

The literature review and wet chemistry analyses that were largely employed in the diet formulation in the current study showed that Urea, cottonseed meal and legumes all provide different protein fractions. Urea is a source of non-protein nitrogen and rumen degradable protein (NPN-RDP). Cottonseed meal provides RDP and UDP mostly true protein. Legumes are sources of RDP and UDP in different proportions.

Supplementation with Urea, Urea-CSM or CSM to periparturient does fed Rhodes grass hay failed to prevent body weight loss in the does. Urea-CSM supplements, however, reduced concentrations of non-esterified fatty acids and β-hydroxybutyrate of blood plasma, indicating fewer fat deposits were mobilised to supply the energy requirements of the suckling kids. Urea-CSM meal supplement increased nitrogen retention in the does but the three supplements gave a similar positive effect in increasing body weight gain in suckling kids. The kids performance were influenced by intakes of RDP, UDP and ME.

Feeding the weaner kids with Rhodes grass hay supplemented with Urea, Urea-CSM, CSM or Gliricidia at a dietary crude protein concentration of 137 g/kg DM could not enhance liveweight gain at a rate to meet the marketable carcass size within timeframe. Weaner kids supplemented with Urea-CSM, cottonseed meal or Gliricidia grew approximately 7 to 10 times bigger than those supplemented with Urea. The kids supplemented with urea grew at 6 g/d when dietary crude protein was increased to 195 g/kg DM. Desmanthus hay, when fed as a sole diet, caused a higher ADG at a rate of 83 g/d. Data for carcass weight, eye muscle area and fat depth were in line for ADG. All these responses were positively in association with intakes of RDP, UDP, MP and ME. Weaner goats supplemented with cottonseed meal improved nitrogen retention.

The recommended equations which entail the use of metabolic body weight, estimated concentration of dietary metabolisable energy and dry matter digestibility could not predict dry matter intake of goats fed tropical grass as a basal diet. The present study found that dietary UDP concentration is a good predictor of dry matter intake as compared with dietary RDP concentration. Methods to predict average daily gain of weaner goats using intakes of metabolisable protein and metabolisable energy, as combined with the MP and ME requirements recommended by NRC (2007), cannot be utilised for all tropical diets. The present study found that the ADG of weaner goats can be explained by 70% of intakes of metabolisable protein and metabolisable energy.

Chapter 9 Recommendations

9.1 Opportunities for Implementation and Recommendations for Further Research

1. Addition of urea and cottonseed meal to Rhodes grass hay to feed periparturient crossbred Boer does at 143 g CP/kg DM can maintain the normal metabolic function of the does and increase live weight gain in the suckling kids. Further research is required to determine if the increase of RDP, UDP, MP and ME by the use of protein supplements above 143 g CP/kg DM will prevent body weight loss in the does;

2. Protein supplementation for weaner goats fed Rhodes grass hay as a basal diet should enhance dietary crude protein up to 195 g/kg DM. These supplements should contain the RDP and UDP that can be found in Urea-CSM, CSM or Gliricidia. Further research needs to be conducted in East Nusa Tenggara to determine the concentrations of RDP, UDP, MP and ME of local feedstuffs using *in vitro, in sacco,* and *in vivo* methods. if possible wet chemistry and near infrared spectroscopy analysis would be beneficial.

3. It was suggested that Desmanthus be fed to the weaner goats if it can be established in the tropical areas. Future research in Northern Australia is required to determine if Desmanthus establishment in tropical pastures can increase the carcass yield of meat goats. Future research in East Nusa Tenggara, Indonesia is also required to determine if Desmanthus can be established in the dry land areas and can increase carcass yield of Kacang goats, the area's indigenous goats.

4. Dry matter intake of growing meat goats can be predicted using dietary UDP concentration. Further research is required to predict DMI based on different dietary UDP concentrations at different dietary crude protein concentrations.

5. Live weight gain of growing meat goats can be predicted to some extent using MP and ME standard requirements for maintenance and gain (NRC 2007). Future research is required to determine if the prediction is valid for all tropical forages with specific protein supplements rich in NPN-RDP or RDP and UDP mostly true protein. Concentrations of protein fractions and ME of feedstuffs based on *in vitro* digestibility, *in sacco* degradability and near infrared spectroscopy methods should be determined and compared.

6. Another study proposed for East Nusa Tenggara involves validating the requirements for energy and protein fractions suggested by the NRC (2007) in Kacang goats, as an indigenous goat in East Nusa Tenggara. Another future study is required to estimate the DMI and ADG of these goats using the available equations, with determinant factors of metabolic body weight, estimated metabolisable energy concentration of the diet, dry matter digestibility, MP requirements and ME requirements.

9.2 Recommendations to Increase Meat Goats' Intakes and Liveweight Gain in the Tropics

Protein supplementation to increase intakes and liveweight gain of meat goat fed tropical grass hay should consider dietary concentrations of RDP and UDP. The current study found that levels of protein supplementation for pregnant does and weaner kids were different and the following types of protein sources are appropriate or efficient.

1. A protein supplement for pregnant and weaner crossbred Boer goats fed tropical grass hay which has either an NPN-RDP source such as Urea mixed with a true protein source or a true protein such as CSM or Gliricidia seminal of considerable RDP and UDP quantities.
2. Desmanthus legume was recommended to feed as a sole diet to weaner goats in the tropics, especially in East Nusa Tenggara Province, Indonesia. This recommendation was based on th following reasons:
    - Desmanthus provides RDP and UDP,
    - Urea supplements could not increase dry matter intake and average daily gain, although it is cheap and available in East Nusa Tenggara, Indonesia,
    - Cottonseed meal is not available in East Nusa Tenggara, Indonesia, although it increased dry matter intake and average daily gain of crossbred weaner Boer goats.

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Appendices

Appendix 1: Goat meat production from tropical pastures: A review

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Abstract. Tropical or C_4 grasses and meat goats (*Capra hircus*) are two resources mostly found in semi-arid regions. These grasses are abundantly available as forage on native and introduced pastures in Australia and Indonesia for ruminant grazing but in the dry season, the grasses deteriorate containing low metabolisable energy (ME) and metabolisable protein (MP). Finishing post-weaning Boer or Kacang goats (Indonesian goats) for red meat productivity on such pasture cannot meet the animals' requirements for MP and ME, consequently, goats grow slowly and produced low carcass yields. Monitoring goats' feed intake on pasture, determining pasture quality and comparing intake with the suggested energy and protein requirements should be exercised to ensure that the grazing animals have sufficient nutrients. Intakes of ME and MP are preferred attributes to measure instead of dry matter and crude protein because ME and MP consider energy and true protein used for maintenance and growth while dry matter might be as a bulk only and crude protein is subject to degradation for rumen microbes. Therefore, feeding strategy using available energy-source or protein-source feedstuff to promote live weight gain and carcass yield of meat goats on pasture should be based on their ME and MP concentrations.

Keywords: Goats meat; carcass; tropical pasture; supplementation

Introduction

Australia produces large amount of goat meat and dominates the worlds' goat meat exports (MLA 2016) while Indonesia, besides Myanmar, has the largest goat meat production amongst the Southeast Asian countries (Faostat 2015). Goat meat productions in Australia and Indonesia in 2012 were respectively 29.8 and 65.2 thousand tonnes of meat, which increased by 20.1%

and 2.4%, respectively in 2016 (Faostat 2015). This increasing production trend demonstrates the potential market for meat goat producers.

The availability of pasture is one of the main determinates of meat goat production because it provides forages for the animals. Tropical grasses are the main forages but typically, their biomass productions are not continuously available throughout the year especially in the semi-arid tropics due to annual dry seasons and low rainfall. In addition, energy and protein concentrations of the hayed off grasses are low in the dry season and typically may not meet the animals' nutritional requirements as recommended by the National Research Council (NRC 2007). Pasture in these regions often also lack adapted quality pasture legumes (Gardiner 2016) and or do not adequately supplementary feed their goats during the dry season (Nogueira *et al.,* 2016). Due to these facts weaned meat goats, grazing on such poor-quality pasture cannot efficiently convert the forages into red meat, and cannot grow and produce carcasses to their genetic potential.

Goat carcass yield and chevon quality depended mainly on nutrition and feeding practices, management and breeding, these factors have been reviewed by Goetsch *et al.,* (2011). Although this review has broadly articulated all factors in regards to the nutritional aspects, little attention was given to goat meat production in association with specific tropical pastures of Australia and Indonesia. This review focuses on potential productivity of tropical pastures and Boer goats in Australia and Kacang goats in Indonesia, feed intake, the goats' requirements for energy and protein, and strategies to increase metabolisable energy and metabolisable protein of meat goats to yield an optimum carcass meat.

Potential productions of tropical grasses and goats

Potential productivity of tropical grasses

The basal diet for ruminant livestock is grasses and or other forages harvested from pastures, therefore goat enterprise effort must be start from the knowledge of grass productivity, their nutrient quality and availability throughout the year. Tropical grasses, are C_4 species, which are well adapted to the tropical environment but differ from C_3 species (legumes and temperate grasses) in that they adapt to low carbon dioxide in the atmosphere, use water and nitrogen more efficient to grow rapidly in suitable temperatures (Crush and Rowarth 2010). The C_4 grasses tend to cluster in the arid and semi-arid regions across central and South America, South East Asia, southern Africa and central Australia (Crush and Rowarth 2010). About 173 million ha of native pasture occur in Queensland (Walker and Weston 1990) and are the main resource to supply forage for grazing ruminants. A recent survey in New South Wales and Queensland found that depending on rainfall the area of typical goat producers varied from as low as 121 ha (high rainfall tropical) to as high as 43,546 ha (in semi-arid regions) where 15 to 72% of the area was used for goat production (Nogueira *et al.,* 2016). The number of goats per farm ranged from 150 to 12,233 heads. Nogueira *et al.,* (2016) survey of goat producers found the five dominant pasture species across the regions to be: Spear grass (*Stipa variabillis*), Mitchell grass (*Astrebla* sp.), Buffel grass (*Cenchrus cilliaris*), Summer grass (*Digitaria* sp.) and Flinders grass (*Iseilema macratherum*). Climate of the regions varied widely between hot desert climate with annual rainfall 130 to 250 mm and tropical monsoon climate with summer wet season receiving annual rainfall 2010 mm (Nogueira *et al.,* 2016).

Appendix Table 1 Dominant native pasture species in New South Wales and Queensland (Nogueira, Gardiner, *et al.,* 2016)

Pasture	DM (tonnes/ha)	DOMD (%)	ME (MJ/kg DM)	CP (g/kg DM)	References
Spear grass	0.5 to 8.7	55.8	8.9	20 to 100	1, 3, 2
Mitchell	0.4 to 2.2	48.2	7.7	26 to 184	4, 5, 4
Buffel grass	2 to 24	43.2	6.9	60 to 160	2, 5, 2
Summer grass	10 to 20	57	9.1	90 to 140	2, 2, 2
Flinders	0.1 to 1.5	38.6	6.2	20 to 90	6, 5, 7

ME = 0.16 DOMD (AFRC 1993; CSIRO 2007) where ME refers to metabolisable energy and DOMD to digestible organic matter based on dry matter
The three numbers in references column represent references for DM, DOMD and CP, respectively where Reference 1= (Feedipedia n.d), 2= (TropicalForages n.d), 3= (Hunter and Siebert 1980), 4= (Orr 1975), 5 = (Robinson and Sageman 1967), 6 = (Lorimer 1978), 7= (Streeter 2007)

Different from Australia, meat goat production in Indonesia is integrated with food crops, rubber plantations or three tier forage systems (Devendra 2007). In the high dense human population islands such as Java and Bali, only 2 to 5 goats are typically raised by each farm family (Djajanegara 1992). These goats were kept in the backyard, fed via a cut and carry system with unspecified grasses, some food crop leaves such as banana, cassava, jackfruit and legume forages (Johnson and Djajanegara 1989). In Sulawesi and Bali, grass and legumes were integrated with coconut plantation (Mullen *et al.,* 1997).

The climate in the western part of Indonesia is tropical humid where most months receive rain throughout the year resulting in minor differences of CP content of the grasses. For example, common grasses identified for pasture in Sumatra were Gamba grass (*Andropogon gayanus*), carpet grass (*Axonopus compressus*), signal grass (*Urochloa decumbens*) and star grass (*Cynodon plectostachyus*) containing 106 to 162 g CP /kg DM in rainy season and became lower at 87 to 120 g/kg DM in dry season (Evitayani *et al.,* 2005).

In eastern Indonesia, including West Timor and Sumba, the human population is relatively low and because these islands are dominated by a semi-arid climate, a more open extensive grazing system is utilised. Bamualim (1996) estimated that communal grazing land in the province of East Nusa Tenggara was approximately 2,365 km^2 which receives 1,500 mm rainfall per annum. Dominant grasses in this province were: *Heteropogon contortus, Digitaria sanguinalis, Bothriochloa timorensis, Ischaemum timorense, Digitaria spp and Cyperus rotundus* which produced 0.61 to 4.33 tonnes of forage/ha containing 23 g CP/kg DM in dry months (April to November) and 90 g CP/kg DM in rainy months (Manu 2013). The feeding value and productivity of these reported pastures seems to be based on mixture of these forage species. Different species of pasture forages, however, have been reported to modify live weight gain. For example, Aregheore (2001) found that ADG of Anglo-Nubian goats fed signal grass was higher than those fed guinea or batiki grass.

Pasture productivity is often based on biomass production e.g. kg DM/ha which helps in the calculation of carrying capacity or stocking rate and the sustainability of forage availability throughout the year. Pastures in New South Wales and Queensland have stocking rate 0.3 to 6.2 goats/ha (Nogueira *et al.,* 2016) while stocking rate of pasture in Sumba, Indonesia was 1.5 AU/ha (Winrock 1986); equals 7.5 heads of 20-kg goats. The decrease of pasture biomass in the dry season required adjustment of numbers of animal/ha or feeding management such as the use of supplementary feed.

One measure of the quality of pasture is the feed conversion ratio (FCR) which reflects the amount of feed an animal consumes as compared to the amount of body weight gain, expressed as a ratio. A study on housed goats reported that FCR for Kamori goats on a high-energy diet was 6.9 while that for low-energy diet was 12.9 (Abbasi *et al.,* 2012). Another study found that FCR of Kacang goats on native grass was 12.2 while that for goats with fish meal supplement was 7.2 (Kustantinah *et al.,* 2017). These studies implied that carcass yields from a low-quality pasture were most likely only half of a high energy and protein diet.

Potential productivity of meat goats

Meat goats in Australia consists of feral/rangeland goats and several domesticated breeds including Boer, Kalahari Red and Savannah (MLA 2013) while the two important breeds in Indonesia are Kacang and Etawah goats (Djajanegara and Chaniago 1988). These domesticated goat breeds have different genetics but the important features are litter size, growth rate and carcass yield. About 61.4% of Boer kids born were twins (Campbell 2003), the kids grew very slowly (62 g/d) in the early stage (from birth to 10 kg) but faster (194 g/d) at the late stage (32 to 41 kg) (Van Niekerk and Casey 1988) and have a 56% dressing percentage (Webb 2014). By comparison, Indonesian Kacang goats has a litter size of 1.29, the kids were weaned at 10 kg, grew at a rate of 20 to 40 g/d, attained their mature weight at 27 kg (Djajanegara and Chaniago 1988) and have 47% dressing percentage (Adiwinarty *et al.,* 2016). In West Timor Kacang goats were reported to grow at the rate of 25 g/d (Fuah and Pattie 2013). This data suggests that there is potential to improve growth rates via improved genetics, feed intake and pasture productivity. Several authors showed that for example ADG can be enhanced by increasing the concentration of dietary energy (Brand *et al.,* 2017), protein (Adiwinarty *et al.,* 2016) or protein and energy (Restitrisnani *et al.,* 2013).

A basic system for categorising goat meat was developed by AUSMEAT (Daniel n.d) is based on dentition and hot standard carcass weight (HSCW). For example, kid goats without permanent incisor teeth is categorised as 'capretto kid GK', where a slaughter kid's HSCW classifies them as 6, 8, 10, or 12, indicating kilogram of carcass weight (Daniel n.d). Meeting the ME requirement of meat goat for maintenance and growth by providing sufficient ME in the diet should result in more daily gain and muscle in carcass. A study showed that Boer goats had a hot carcass weight (HCW) of 18.2 kg at seven months old when fed concentrate and hay at a ratio of 80: 20 (Solaiman *et al.,* 2011). Sheridan *et al.,* (2003) found that at the age of 6.5 months, the HCW of Boer goat increased from 15.3 to 17.1 kg as the dietary energy changed from 9.9 to 12.1 MJ/kg DM. Hocquette *et al.,* (1998) suggests this is because in mitochondria, ATP is produced and if sufficient amino acids are available, then muscle protein is synthesised, increasing growth and carcass yield. Rashid *et al.,* (2016) reported a well-balanced diet (ME 11.3 MJ and CP 154 g/kg DM) yielded 8.5 kg HCW for nine-month-old Black Bengal goats. Feeding meat goats with a well-balanced ration to meet their MP and ME requirements (NRC2007) is recommended because it would provide sufficient ATP and amino acids to build up muscle (Hocquette *et al.,* 1998), resulting in an increased HCW thus increasing the potential productivity of meat goats.

Feed intake and predicting feed intake

Feed intake simply indicates the amount of forage eaten by animals but it becomes more complex to calculate because many factors are involved in controlling it. Some existing reviews explain that factors affecting feed intake in ruminants are forage characteristics (Baumont *et al.,* 2000), feed palatability (Baumont 1996), feedback after the animal have eaten the diet (Provenza 1995), nutrient content of the diet (Jones 1972), energy balance in the animal body (Baile and Forbes 1974) or physiological mechanisms (Forbes 1980). Although each review had emphasised only on one aspect, it appears that the more complete description concerns interrelationship among these factors. Several studies that are more recent and are outlined below confirm the factors.

Animal effect on feed intake

The amount of feed eaten depends on the animal's body size as shown that dry matter intake was calculated based on the percentage of body weight (NRC 2007), which seems to be in correlation with rumen capacity. The fact that goats grow slowly in early stage and faster in late stage (Van Niekerk and Casey 1988) indicates that as the animal grow, rumen develop occurs and so the animal eat more, as a consequence more nutrients were supplied for the animal to grow faster. The animals' physiological status also drives feed intake because nutrient requirements for growth, pregnancy or lactating are different (NRC 2007) and the animal eats to meet this requirement. The animals' body size will also be a determining factor in social hierarchy where bigger goats are more likely to eat more on pasture or manger but this social hierarchy on pasture is less visible (Barroso *et al.,* 2000).

Goats use their sensory receptors consisting of sight, smell, touch and taste which were mediated by neurons (Provenza 1995) to select forage on pastures determining palatability of the forage (Baumont 1996). Some studies reported that these receptors help goats avoid eating harmful feed (De Rosa *et al.,* 1995) and that odours of the plant controls feed intake in goats (De Rosa *et al.,* 2002). Sweet tastes promoted intake, bitter depressed intake, salty tastes sometimes increased or decreased intake while sour taste has no clear effect (Ginane *et al.,* 2011).

Once the feed is eaten there are mechanic and chemical senses that provide feedback that can promote or limit feed intake of the goats. The mechanical sense was related to physical forms of the forage. Hay intake was suppressed by ruminal distension and plasma osmolality

(Sunagawa and Nagamine 2016). The high cell wall concentration of eaten forage was less and slowly degraded in the rumen, so it fills up the rumen and stays longer for fermentation, preventing the animal to eat (Baumont *et al.,* 2000). This high fibre forage flowed very slowly to the next digestive organ, having filling effect and causes distension on the reticulorumen that limit feed intake (Allen 1996). Aban, *et al.,* (2015) who reported that if forage pH increased, rumen pH was also increased as well as voluntary feed intake demonstrating the role of forage and rumen pH in affecting feed intake.

Chemical sense was related to the products of the ingesta after being digested, fermented or metabolised in the animals' body. These products consist mainly of volatile fatty acids (VFA), amino acids and fat that when mixed with hormones or enzymes regulates feed intake. Reports for VFA effect on feed intake were mostly from infusion studies using confined animals. De Jong (1981) reported that acetate, propionate and n-butyrate were increased rapidly and largely after feeding and in turn these VFAs control feed intake by giving feedback signal. Because VFAs provide half to three quarters of the energy for goats, their infusion to rumen depressed feed intake (Faverdin 1999). In addition to energy effect, the VFA effect on feed intake was related to osmolarity (Faverdin 1999) and transmitted by neurons (Baile and Forbes 1974).

Protein promotes feed intake because they are required by rumen microbes to digest the ingesta and as the digestibility increased, feed intake was enhanced (Faverdin 1999). Wang *et al.,* (2012) found that with goats a low rumen degradable protein such as cottonseed meal increased dry matter intake while a high rumen degradable protein such as soybean seed meal reduced dry matter intake. Feed intake is controlled by peptides in the central nervous system. Opiate peptides give signals to the hungry animal to eat while cholecystokinin peptides signal the intake has been satisfied and for the goat to stop eating (Baile and Della-Fera 1981). The lateral neuronal system in hypothalamus gives signals to the animal to eat while the ventromedial system signals the animal to stop eating (Wolfe 1979).

The inclusion of fat into the diet of meat goats is very rarely reported. It is common for lactating ruminants to enhance dietary energy and to prevent fat mobilization from the body (Faverdin 1999). Excess of energy in the diet of growing meat goats will be stored as fat deposits, so feed intake control is predominantly from tissue that went through hepatic oxidation process (Allen *et al.,* 2009; Allen 2014). Hormones and blood metabolites will be transported from the liver by mediation of neurons to the central nervous system (CNS) where energy balance and feed intake were regulated (Baile and Forbes 1974).

A study from feedlot found that feed intake of Boer goats decreased accordingly to the increased dietary energy but the highest live weight gain and dressing percentage was recorded for the goat with 12 MJ ME/kg DM while a better feed conversion ratio was on the goats with 12.7 MJ ME/kg DM (Brand *et al.,* 2017). In grazing situations, the goats required more energy and so the animals have higher feed intake. For example, Beker *et al.,* (2009) reported that Boer goats on pasture spent 13.4 MJ/d to travel 3.08 to 4.10 km/d and spent 7.9 h grazing. Tovar-Luna *et al.,* (2011) supported this reporting that goats that continuously grazing in a paddock spent 5.75 h grazing while the goats confined at night only spent 4.47 h eating. Berhan *et al.,* (2005) found that allowing the animals to graze for 8 h or 24 h resulted in the animals having similar ME intake but the 8-h goats spent less energy.

Feed forms characteristics effect on feed intake

Studies have found that goats prefer to browse than to graze (Dumont *et al.,* 1995), and prefer to eat green material than dry grass, and leaves rather than stems (Lu 1988). They prefer grasses than legumes and within in some legumes prefer for example leucaena to Desmanthus (Kanani *et al.,* 2006). Others reported that goats eat more grass in rainy season but browse other forages in dry season (Safari *et al.,* 2011; Webb *et al.,* 2005) showing that seasonal biomass availability determines feed intake. These reports confirmed that goats are selective browsers but lush green grasses with legumes are preferred, which may not however be found in dry season.

Goats have preferences of different physical forms of forage. Mkhize *et al.,* (2014) found that goats preferred forage species with broad leaves and long shoots. Basha *et al.,* (2012) found also that goats browse more broad leaf species in early wet season, while for all year-round fine leaf and dry fallen leaves were preferred. Yayneshet *et al.,* (2008) found that feed intake of goats was higher for herbaceous species in rainy seasons and woody species for dry season.

Environmental effects on feed intake

Goats are diurnal animals that actively graze on pasture during the day in between 07:00 and 20:00 h but sometimes rest to ruminate (Tovar-Luna *et al.,* 2011). High ambient temperature and scarcity of water are typical for tropical pastures and both reduce feed intake but the mechanism differs. Silanikove (1992) reasoned that less drinking water reduced saliva secretion so feed intake decreased, but because the ingesta stays longer in the rumen, digestibility increased. Heat load increased body temperature and the animal response to cope with heat load is to reduce feed intake (Al-Dawood 2017; Hirayama *et al.,* 2004; Silanikove

1992). Forbes (1980) explained that if the difference between body temperature and ambient temperature is very small, heat generated from rumen after feeding was likely difficult to be released to the environment and so the animal experiencing heat load.

Heat load affects feeding behaviour, hormonal changes and VFA production. Feeding behaviour, such as time spent grazing, ruminating, and resting, used to be monitored manually, but new methods like GPS collar, IceTag activity monitor, ultrasound device and heart rate monitor have been introduced (Goetsch *et al.,* 2010). These feeding behaviours and heart rate are useful measures of energy expenditure (Beker *et al.,* 2009). Hirayama *et al.,* (2004) reported that a hot environment reduced feed intake of goats to almost half of that in a thermo neutral zone, with the result that growth hormone becomes 0.9 and 1.7 µU/mL blood plasma for the two conditions. This study also reported that high ambient temperature elevated insulin and insulin-like growth factor-1 (IGF-1) but depresses total VFA and acetic acid, while thermo neutral zone increased glucose.

Predicting feed intake

Attempts to predict feed intake in grazing goats by considering all of the determinant factors seems unlikely. Therefore, some authors limit the number of the causative factors to predict feed intake. Pulina *et al.,* (2013) associated feed intake with live weight, fibre content and protein content of the diet. Teixeira *et al.,* (2011) predicted feed intake by using animal body weight and dietary metabolisable energy as the independent factors while NRC (2007) included digestibility, relative size of the animal body, intake factor and quality constraint in predicting feed intake.

Forbes (1980) suggested two methods to predict feed intake. Firstly, feed intake could be regressed against multi independent variables such as live weight, feed digestibility and nutrient contents of the feed. Secondly, feed intake could be simulated using a model including metabolism and digestibility as the significant factors affecting feed intake. Mertens (1987) and Pulina *et al.,* (2013) proposed that feed intake can be predicted using an empirical or a mechanical model. The empirical model was established as a sum of factors affecting feed intake while the mechanistic model explains the mechanism how the physiological process affects feed intake. The two models appear to be applicable as long as the factors are measurable and the interactions with other factors are separated.

Goats' requirement for energy and protein *vs.* energy and protein content in diets

The most predominant factor is whether energy and nutrients from the consumed diet from pasture meets the animal requirements for maintenance and productivity. Table 1 shows that when a 25-kg growing Boer kid for any reasons had only 5.1 MJ ME/d and 34 g MP/d or a 20-kg growing Kacang kid with 4.3 MJ ME/d and 29 g MP/d, the kids are almost certainly not growing since the ME and MP are sufficient only for maintenance. In this case, problem identification should be based on the determination of pasture productivity and quality or calculation of feed intake.

Appendix Table 2 Intake, energy and protein requirements for meat goats (adopted from NRC, 2007)

Class	BW (kg)	DMI % BW	Energy requirements		Protein requirements where CP at ...			MP g/d	DIP g/d
			TDN kg/d	ME MJ/d	20% UIP g/d	40% UIP g/d	60% UIP g/d		
Growing Boer kids at body weight 25 kg and different ADG (g/d)									
0	25	2.70	0.33	5.1	51	49	47	34	30
25	25	3.03	0.37	5.6	66	63	60	44	34
100	25	2.92	0.49	7.4	111	106	102	75	44
150	25	3.38	0.56	8.5	141	135	129	95	51
Indigenous local goat at body weight 20 kg and different ADG (g/d)									
0	20	2.85	0.28	4.3	43	41	39	29	25
25	20	3.20	0.32	4.8	54	52	49	36	28
100	20	3.10	0.41	6.2	86	82	79	58	37
150	20	3.60	0.48	7.2	108	103	99	73	43

BW refers to body weight, DMI to dry matter intake, TDN to total digestible nutrients, ME to metabolisable energy, CP to crude protein, UIP to undegraded intake protein, MP to metabolisable protein, DIP to degraded intake protein and ADG to average daily gain

Goats that graze on pasture should have fulfilled their feed intake, which can be monitored manually (Basha *et al.,* 2012) or using advanced monitoring tools (Goetsch *et al.,* 2010). Live weight gain appears to increase linearly with intakes of DM, ME, CP and MP (NRC 2007). This suggested considering sufficiency of feed and all nutrient concentrations in the diet. The growing goats may fail to achieve the expected live weight gain just because ME intake is not sufficient, despite DM intake having been attained. Similarly, CP intake may have sufficient according to the NRC (2007) recommendation but the growing goats did not gain weight just because MP availability is less than required or because the protein degradability of the grasses are not well determined. For example, although a growing goat had a maximum DM intake 757 g/d on pasture in New South Wales and Queensland (Table 1), the ingesta would supply only 15 to 68 g CP/d in dry season, 68 to 139 g CP/d in rainy season and 4.7 to 6.9 MJ ME/d. The animal clearly had an insufficient CP in dry season (Table 2) that could probably cause body weight loss. In this condition, protein feed supplement is required.

Validation of MP grasses and forages

Metabolisable protein (MP) is true protein or amino acids yielded from both eaten dietary protein and microbial crude protein, which are digested after the rumen and absorbed in the small intestine, then is used for the metabolism process, especially for maintenance, growth and productivity (AFRC 1993; NRC 2007; McDonald *et al.,* 2011; Das *et al.,* 2014). By comparison, crude protein (CP) reflects the amount of nitrogen in the feedstuff (Galyean 2010). Since MP has considered sources, process and function of the true protein while CP has just considered nitrogen content of the diet, it is more convenient to assess forage quality based on MP instead of CP.

The NRC (2007) has published the composition of common feedstuff from which the MP of certain feedstuff can be quoted to formulate a diet for meat goat. Three problems remain: 1) the methods to determine the MP content of the published feedstuff are different, 2). Not all feedstuff, especially tropical grasses and legumes, have been published, and 3). There is a change of CP to MP in the animal's body, therefore the MP content of feedstuff needs to be validated.

Methods available to determine MP grasses and forages are in *vivo* (Broderick and Merchen 1992; Choi and Choi 2003), *in sacco* (Orskov and McDonald 1970; Orskovn *et al.,* 1980; AFRC 1993), *in vitro* (Tilley and Terry 1963; Calsamiglia and Stern 1995), wet chemistry (Krishnamoorthy *et al.,* 1983), near infrared reflectance spectroscopy (Givens *et al.,* 1997; Stuth *et al.,* 2003) and digestible protein (NRC 2007). All these methods determine microbial crude protein (MCP) and rumen degradability dietary protein which when combined then the MP can be estimated as MP (g/d) equals 0.6375 MCP plus digestible undegradable protein in the small intestine (AFRC 1993) Eq. 23.

Validation of MP requirement by goats

The amounts of MP required for maintenance (MPm) and growth (MPg) of meat goats have been published (NRC 2007). These values are based on others' prediction (Luo *et al.,* 2004*a*) of a regression between MP intake and ADG. The NRC (2007) values are useful as guidance for predicting animals' productivity. However, the reliability of these standard values' application to the meat goat production system in the tropics is open to question for a few reasons. Firstly, MP requirement for tropical goats are different. The MPm and MPg for meat goats is 3.07 g/kg $BW^{0.75}$ and 0.404 g/g ADG (NRC 2007). Salah *et al.,* (2014) reported that the MPm of meat goats in the tropics was 3.51 g/kg $LW^{0.75}$ and MPg was 0.12 to 0.24 g MP/g ADG. Secondly, the methods for predicting ADG are different. The NRC (2007) regressed MP intake against ADG while Salah *et al.,* (2014) regressed MP against retained nitrogen. Thirdly, the goat production system in the tropics, Asia for instance, relies on an extensive system (Devendra 2007) while all of the standard values were generated from intensive productive systems.

Validation of ME grasses and forages

Metabolisable energy is the difference between gross energy in feedstuff and energy recorded for faeces, urine and combustible gas; it is the energy retained in the body that helps to maintain bodily function and growth (NRC 2007; McDonald *et al.,* 2011). This ME definition implies that efforts to determine ME content of feedstuff should measure gross energy of the feed, faeces, urine and gas.

The general equation to predict ME is ME (MJ) = 0.82 DE because it is assumed that energy loss through urine and methane is as much as 0.18 (CSIRO 2007; NRC 2007; McDonald *et al.,* 2011). Metabolisable energy content of roughages can be estimated using digestibility of dry matter (DMD), organic matter (OMD) and organic matter based on dry matter or DODM (CSIRO 2007) because VFA and glucose were yielded from fermentation in the rumen and digestion in the small intestines (McDonald *et al.,* 2011). Dry and organic matter digestibility measured by *in vitro* technique (Tilley and Terry 1963) can be applied to calculate ME. Some studies (Getachew *et al.,* 2002; Hind *et al.,* 2014) employed the *in vitro* gas production technique and estimated ME concentration of feedstuff from crude protein and crude fibre content and the amount of gas in 24 h incubation. Glucose, starch, protein and fat have various concentrations of energy, and so concentrations of these compounds in feedstuff can be used to predict ME (CSIRO 2007; NRC 2007). All these various analyses may result in different ME content of every single forage; therefore, validation is required.

Validation of ME requirement by goat

The NRC (2007) has published the ME requirement for meat, dairy, indigenous and fibre goats based on physiological status like suckling, growing and maturing. Two ways of data presentation are fixed values and tables of ME requirements. A growing meat goat, for instance, is reported to have a fixed requirement value of metabolisable energy for maintenance (MEm) 0.489 MJ/kg $FBW^{0.75}$ and for growth (MEg) 0.0231 MJ/g ADG. From requirement tables (NRC 2007), a range of body weights has been grouped from where an expected ADG can be found to match the ME requirement. For example, a Boer goat weighing 20 kg, expecting to gain weight at the rate of 100 g/d was found to require ME 6.6 MJ/d (NRC 2007).

These two data presentations from the NRC (2007) are useful in research and farm circumstances. Since the standard values were generated from meta data analysis (Luo *et al.,* 2004*b*), it should represent a wide range of meat goat production systems. However, the values of MEm (0.489 MJ/kg $FBW^{0.75}$) and MEg (0.0231 MJ/g ADG) by NRC (2007) contradict reports from tropical regions. Abate (1989) reported the MEm and MEg of goats in Kenya to be 0.556 MJ/kg $BW^{0.75}$ and 0.0279 MJ/g ADG. Salah *et al.,* (2014) reported a consistently high ME requirement for goats in the tropics as 0.542 MJ/kg $BW^{0.75}$ for MEm and 0.0243 MJ/g ADG for MEg. Factors accounting for these high requirements are presumably activity, acclimatisation, and efficiency of metabolism (NRC 2007). Consequently, validation of the ME requirement for goats in the tropics is required through a productive experiment or feeding trial.

Feeding strategy to increase ME and MP

Carcass yield of weaned meat goats finished on pastures should be at the optimum dressing percentage; 56% for Boer goats (Webb 2014) and 47% for Kacang goats (Adiwinarty *et al.,* 2016). The grazing meat goats should also grow at the optimum rate; 194 g/d for Boer goats (Van Niekerk and Casey 1988) and 40 g/d for Kacang goats (Djajanegara and Chaniago 1988). The NRC (2007), however, proposed variable ADG ranging from 25 to 150 g depending on the supply of dry matter, energy and protein (Table 2). This suggestion implies that live weight gain and carcass yield can be controlled from the amount and quality of pasture or diet offered to the goats.

Deficit quantity of forage or nutritive quality especially CP, MP and ME of forages on pasture were more likely causes for slow growth and light carcass weight. Therefore, a feeding strategy was required to ensure the difference of nutrients available on pasture (Table 1) and the goat requirements (Table 2) were minimised. These feeding strategies depend on whether energy, protein or energy and protein were the limiting factors. The two main strategies cover pasture quality improvement and the use of feed supplement.

In a limited size, pasture quality can be improved in several ways to provide sufficient energy and protein for the goats. Jensen *et al.,* (2003) enhanced crude protein and digestible neutral detergent fibre concentration in orchard grass (*Dactylis glomerata* L.) and perennial ryegrass (*Lolium perenne* L.) by irrigation and application of nitrogen fertilizer. The ADG of Boer x Spanish kids were increased as the animals were raised on nitrogen-fertilised pasture and the stocking rate was adjusted (Muir 2006). A higher ADG and cold carcass weight of Boer goats was recorded when the goats were finished on red clover and birdsfoot trefoil pastures as compared with that on Chicory pasture (Turner *et al.,* 2015). This suggests the importance of species sown on pasture. Mixing grasses and legumes on pasture (Cadisch *et al.,* 1994) brought about more benefits because total biomass production was increased, the grazing goats received protein from legumes and soil had nitrogen inputs. Gardiner (2016) suggested the establishment of legume such as Progardes^{TM} *Desmanthus* should be well adapted to the climate and soil type of the pasture.

Dietary energy should be provided to the goats in the forms of total digestible nutrients (TDN) and metabolisable energy (ME) (NRC 2007). Because digestible energy (CSIRO 2007) and TDN (NRC 2007) reflect ME, feeding strategy to increase ME of goats is to increase digestibility of forage or diet. Hall and Eastridge (2014) emphasised that energy was generated from carbohydrate fermentation by rumen microbes and carbohydrate digestion in the small intestine, where cell wall components were digested in different extents; lignin was indigestible while hemicelluloses and cellulose were digestible. Varga and Kolver (1997) argued that digestibility of fibrous diet depended on structure of the grass, density population of the fibrolytic rumen microbes, promoting factors for rumen microbes to adhere and hydrolyse ingesta and animal effect such as mastication. Ramos *et al.,* (2011) found that low forage (alfalfa or grass) and high concentrate in diet enhanced NDF digestibility but the highest total VFA was recorded for high alfalfa and low concentrate diet. This study implied that generating energy from rumen fermentation using legumes with low concentrate was more effective than generating the energy from increasing fibre digestibility using grass with high concentrate. If economic efficiency was considered, the mixture between grass and legumes on tropical pasture would be an ideal diet for meat goats.

Since components of cell contents: mono-and disaccharides, starch and oligosaccharides are digestible (Hall and Eastridge 2014), ingredients such as maize and molasses powder (Brand *et al.,* 2017), rice bran and cassava (Restitrisnani *et al.,* 2013), grain (Nogueira *et al.,* 2016) were included to enhance dietary ME. Results of these studies showed that live weight gain of housed Boer goats was exhibited a curvilinear, where it peaks at 12 MJ ME but the highest carcass percentage was recorded for the goats on 12.7 MJ ME (Brand *et al.,* 2017). The highest ADG on the low- and medium-energy diets would be due to mass of digestive tract content as the consequence of the higher DM intake, but the lowest FCR on the high-energy goats (Brand *et al.,* 2017) revealed that increasing ME caused more efficient usage of diet. Restitrisnani *et al.,* (2013) reported that housed Kacang goats had a linear ADG with dietary energy at 8.2, 8.8, or 9.8 MJ ME/kg DM, despite the highest DM intake was recorded for the goats on 8.8 MJ ME/kg DM. This finding clearly shows that DM intake was not a good predictor for meat goat productivity as compared to ME intake. Nogueira *et al.,* (2016) reported improved productive performances of goats in general but it was not simply associated with the effect of supplement since that data was from a perspective of goat producers.

Protein requirement for meat goats proposed by the NRC (2007) was in the forms of crude protein (CP), metabolisable protein (MP) and degradable intake protein (DIP). Protein supplementation, therefore, should be based on the degradability characteristics of protein feedstuff in the rumen and its ability to metabolise in the body.

Tree legumes are common in the tropical regions and some studies have reported their positive effect as protein sources on goats' productivity. Fuah and Pattie (2013) doubled live weight gain of grazing Kacang goats on native pasture (17 vs. 36 g/d) by offering them *Acacia villosa* at night. Leucaena (*Leucaena leucocephala*) contains CP 290 g/kg DM and rumen degradable protein 420 g/kg DM (Garcia *et al.,* 1996) was increased DM intake of Jamnapari goats (Srivastava and Sharma 1998). Gliricidia (*Gliricidia sepium*) and its mixture with maize increased ADG and rumen NH_3-N of goats on Rhodes grass (*Chloris gayana*) hay basal diet (Ondiek *et al.,* 1999). Desmanthus (*Desmanthus bicornutus*) increased feed intake and ADG of Boer x Spanish wethers on Sudan grass basal diet (Kanani *et al.,* 2006).

Tree legumes even gave better effect on goat's performances when mixed with starch. For example, live weight gain of Kacang goats even increased higher to 43 g/d when *Acacia villosa* was mixed with *Corypha gebanga* (Fuah and Pattie 2013) as an energy source. Ondiek *et al.,* (1999) also found better results when Gliricidia was mixed with maize. These two studies confirmed the fact that yields of microbial crude protein depended on the availability of metabolisable energy (AFRC 1993; CSIRO 2007; NRC 2007). Some studies even reported negative effects of legumes to goats. Jamnapari goats lose weight as the dried leaves of Leucaena increased that possibly as a result of higher mimosine content (Srivastava and Sharma 1998) or because of the higher rumen degradable protein (Garcia *et al.,* 1996) that lead to nitrogen losses through urine and faeces (Haque *et al.,* 2008). Leucaena, as compared with Desmanthus, gave a better performance to goats, which could be explained by tannin concentration (Kanani *et al.,* 2006). Mimosine and tannin are the secondary compounds that seem to limit the function of legumes in goats but their comprehensive processes are not discussed in this review.

Types of protein supplements offered to goats in New South Wales and Queensland, Australia (Nogueira *et al.,* 2016) are comprised of urea, whole cottonseed, copra meal and soybean meal. Fish meal and soybean meal for Kacang goats in Indonesia (Adiwinarty *et al.,* 2016; Kustantinah *et al.,* 2017) have been reported. The usage of these protein sources seems to be based on economic reasons, for they are abundantly available in the surrounding farms. Some studies have reported nutrient quality and the effect of these supplements to meat goats' productivity.

Cottonseed meal (CSM) is a protein and energy source as it contains 480 g CP/kg DM, 336 g MP/kg DM and 11.72 MJ ME/kg DM (NRC 2007). About 202 g/kg crude protein intake was undegraded in the rumen (NRC 2007) and so its protein was considered as very low degraded (Wang *et al.,* 2012), highly undegraded (Mishra and Rai 1996) and slowly degraded in the rumen of sheep (Walker 1997). The very low degraded protein in the rumen benefits the animals because more protein is available to be absorbed in the small intestine. In addition, slowly degraded ingested protein caused a continuous and constant protein supply to the cellulolytic rumen bacteria to digest fibre (Ben Salem and Smith 2008) providing more energy. Yinnesu and Nurfeta (2012) modified feed intake and digestibility of Sidama goats fed native grass hay with CSM supplement and reported that the supplemented goats grew five times faster and yielded heavier hot carcass (5.7 vs. 8.8 kg) as compared with the grass hay goats.

Fish meal contains 660 g CP/kg DM, 462 g MP/kg DM and 11.29 MJ ME/kg DM (NRC 2007). From consumed crude protein, about 396 g/kg DM protein was not degraded in the rumen (NRC 2007). Soybean meal contains 490 g CP/kg DM, 343 g MP/kg DM and 12.55 MJ ME/kg DM (NRC 2007). Undegraded intake protein of soybean meal amount to 172 g/kg DM (NRC 2007). Adiwinarty *et al.,* (2016) and Kustantinah *et al.,* (2017) reported that fish meal and soybean meal enhanced productivity of Kacang goats as compared with the grazing goats on native pasture. However, despite the dietary CP were almost similar between fish meal and soybean meal diets (153 vs. 156 g/kg DM), the soybean meal Kacang goats grew faster (92 g/d) and had the heavier carcass weight (11.9 kg) as compared to the fish meal goats (Adiwinarty *et al.,* 2016; Kustantinah *et al.,* 2017). The lower undegraded intake protein on soybean as compared with fish meal could explain this finding.

Urea is not a protein source of feedstuff, it is a non-protein nitrogen, but because urea contains 2880 g CP/kg DM and 2070 g MP/kg DM (NRC 2007), urea had been used as a protein supplement source for goats. Urea is a high rumen degradable protein (RDP) (Brun-Bellut *et al.,* 1990) while the NRC (2007) described that the intake protein from urea is completely and rapidly degraded in the rumen. If the dietary RDP exceeds the requirements for ruminal microorganisms, then CP is degraded into NH_3-N, absorbed, metabolised to urea in the liver, then excreted through urine (Bach *et al.,* 2005). These processes require energy and so if urea inclusion was not coupled with a sufficient dietary energy, the animals were likely to lose weight as shown by a study on German Alpine x Small East African bucks (Wambui *et al.,* 2006). A method to prevent this weight loss was to determine an appropriate composition between urea and energy-source feedstuff. For example, Uza *et al.,* (2005) demonstrated that 4 g urea/kg cassava peels promoted the goats to grow at the rate of 62 g/d.

In pasture conditions, grazing goats are exposed to gastro-intestinal nematode infection, therefore Kioumarsi *et al.,* (2012) suggested including urea in molasses, minerals and medicated blocks. The study by Kioumarsi *et al.,* (2012) revealed that growing Boer goats fed with urea molasses mineral block (UMMB) plus medicated UMMB (MUMMB) had the highest ADG (216 g/d) and hot carcass weight (19 kg). This study was more comprehensive as it supplied not only almost all of the required nutrients but also the drug to combat the parasites. Molasses seems to be a readily fermentable carbohydrate that is well matched with urea as a rapid RDP (Galina *et al.,* 2004; Kioumarsi *et al.,* 2012). A rapid degradable urea and a slow fermentation of fibrous grasses were not an ideal mixture. Therefore, Galina *et al.,* (2004) recommended formulating urea with other ingredients as a way to allow the goats to eat it slowly for 8 to 10 h, so that it would be available during the period for rumen microorganisms.

Mixing rumen degradable protein (RDP) such as urea with rumen undegradable protein (RUP) such as cottonseed meal would be a better alternative because RDP provides nitrogen for the rumen microorganism, while RUP escapes the rumen microorganism degradation and is available directly for the animals. The AFRC (1993) has emphasised that metabolisable protein is the sum of microbial crude protein (MCP) and digestible undegraded intake protein. The usage of urea to optimise the yield of MCP should consider the availability of dietary metabolisable energy (ME) because there is an association between these two factors. There is about 8.25 g MCP/MJ ME (CSIRO 2007) or 9 to 11 g MCP/MJ of fermentable ME (AFRC 1993). When energy is limited, the NRC (2007) predicts MCP as 0.13 TDN. Since MCP is a component of MP and its production depended on ME, a strategy to increase meat goats' productivity on the tropical pastures was to supply sufficient metabolisable protein and metabolisable energy.

Summary

Meat goats' productivity is very dependent on the biomass production and quality from pastures. Tropical pastures in New South Wales and Queensland, Australia lie on very large sizes of land as compared to the pasture sizes in Indonesia, where meat goat production was part of mixed farming systems. The grasses' qualities were typically similar: hay grasses in dry months contain low ME and MP, which would not meet the goats' requirement for energy and protein leading to slow growth and low carcass yield. Monitoring feed intake of grazing meat goats, predicting intakes of ME and MP and then comparing them with the recommended requirements should be exercised to ensure growth and carcass yield are optimum. The ME and MP concentration of forages reported from some studies might differ because of different methods of determination. Similarly, goats' requirement for ME and MP found in published books may be different for grazing animal on tropical pasture. These goats have a higher energy and protein requirement than penned goats in temperate regions. Therefore, ME and MP concentration of tropical forages should be validated. Similarly, ME and MP requirement for goats on tropical diets should also be validated. Finally, feeding strategy to increase ME and MP of meat goats would be based on a gap between ME and MP concentrations on pasture with those required by meat goats.

Conflict of interest

There is no conflict of interest between the authors and any institution that affect the content of this paper.

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Appendix 2: Growth and eye muscle area of cross-bred Boer goats fed Desmanthus cultivar JCU 1 hay

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Rhodes grass (*Chloris gayana*) hay (RGH) is an improved tropical pasture species used for livestock production in the Australian tropics and sub-tropics, however, RGH contains low crude protein, low metabolisable energy and high neutral detergent fibre relative to improved temperate pasture species and tropical legumes leading to low productivity of goats unless supplemented with a source of crude protein. Supplementation tropical grasses with urea (Uza *et al.,* 2005), cottonseed meal (CSM) (Solomon *et al.,* 2008) or the tropical legume species *Desmanthus* (Ngo 2012) is reported to increase dry matter intake and liveweight gain of goats and sheep. The objective of the present study was to compare rate of liveweight gain and accretion of eye muscle determined at the 12th rib of twenty female Boer goats (19.84±2.21 kg) fed RGH supplemented with either urea, urea + CSM, CSM or only fed Desmanthus (cultivar JCU 1) hay over 138 days. Total crude protein concentration in the diets was 185 to 195 g/kg DM. Each diet (Urea, Urea + CSM, CSM and Desmanthus) provided 144, 130, 139 and 112 g/kg DM of rumen degradable protein (RDP) and 42, 56, 59 and 83 g/kg DM of undegraded dietary protein (UDP), respectively. The urea and CSM in the Urea + CSM diet supplied equivalent amounts of crude protein. All animals received a complete mineral supplement (Rumevite® Fermafos). The diets were offered in equal amounts twice a day at 08:00 h and 16:00 h. Eye muscle area was estimated by counting the number of 1 x 1 mm squares marked on a clear plastic grid that covered a transverse section of the longissimus dorsi muscle (including fascia) on the caudal side of the 12th rib.

All diets supplied sufficient crude protein, RDP and minerals to maintain normal rumen function at high levels of DMI (NRC 2007). The Desmanthus diet resulted in the highest total dry matter intake (DMI), crude protein intake (CPI) and metabolisable energy intake (MEI) while the diet supplemented with urea produced the lowest total DMI, CPI and MEI (Table 1). The diets supplemented with urea + CSM or CSM showed intermediate values for total DMI, CPI and MEI. The rates of liveweight gain across all diets were consistent with those predicted by NRC (2007) based on metabolisable energy intake for a 20-kg Boer goat.

This intake pattern can be explained by both palatability and the amount of UDP supplied by the diets. In particular, the high palatability and UDP supplied by the legume likely promoted intake and liveweight gain while the low palatability (Tadele and Amha, 2015) and lower UDP supplied by the diets containing urea likely limited intake and liveweight gain. Importantly, once requirements of the rumen for RDP (and minerals) are met, diets with the most UDP in dry matter (CSM and Desmanthus) supported the highest dry matter intakes, rates of liveweight gain and eye muscle area. Supplementation strategies for diets based on tropical grasses must provide sufficient UDP to support high levels of intake and growth.

Appendix Table 3 Intake of dry matter, crude protein, and metabolisable energy as well as live weight gain and eye muscle area of supplemented growing Boer goats

Item	Dietary treatments				sem
	Urea	Urea-CSM	CSM	Desmanthus	
DMI total (g/d)	443^{a}	573^{b}	636^{b}	1027^{c}	43.10
CPI (g/d)	98^{a}	125^{b}	151^{c}	206^{d}	8.46
MEI (MJ/d)	3.8^{a}	4.5^{a}	5.9^{b}	10.1^{c}	0.46
Average LW gain (kg)	0.7^{a}	5.6^{b}	6.7^{b}	9.6^{c}	0.64
Eye muscle area (cm^2)	2.4^{a}	3.5^{ab}	3.9^{b}	5.5^{c}	0.25
Hot carcass weight (kg)	6.5^{a}	8.2^{b}	10.1^{c}	12.6^{d}	0.50

Different letters in the same row differ significantly; $P < 0.05$.

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Appendix 3: Poster - Growth and eye muscle of cross-bred Boer goats fed Progardes^{TM} Desmanthus cultivar JCU 1 hay

Growth and eye muscle area of cross-bred Boer goats fed Progardes Desmanthus cultivar JCU 1 hay

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Introduction

Finishing weaner goats on pasture sown with *Desmanthus* sp. has the potential to produce high value carcasses over shorter timeframes than currently available to producers in the rangelands of western Queensland and West Timor, Indonesia.

Objective

To compare the productive responses of Boer goats on rhodes grass hay (RGH) supplemented with cottonseed meal (CSM) and/or urea with Boer goats fed Progardes Desmanthus cultivar JCU 1 hay.

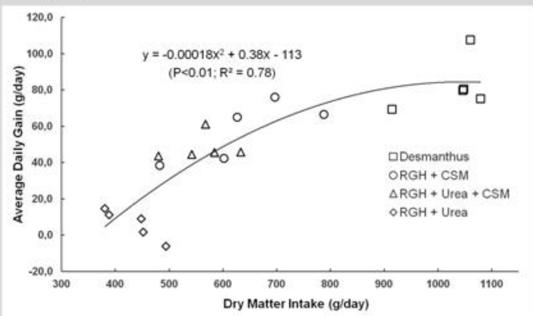
Materials & methods

Twenty female Boer goats (20.2 ±2.16 kg Lwt) were kept in individual pens in an animal house at James Cook University, Townsville, Australia from June to October 2016. The study had approval by the Animal Ethics Committee of James Cook University (A2122).

The goats were divided into four groups of five animals allocated to one of four dietary treatments: 1) Desmanthus hay, 2) RGH + CSM, 3) RGH + Urea or 4) RGH + Urea + CSM (Fig. 1). All diets were formulated to provide 160 g CP/kg DM and different amounts of true and non-protein nitrogen. All animals had *ad libitum* access to a complete mineral mix and drinking water.

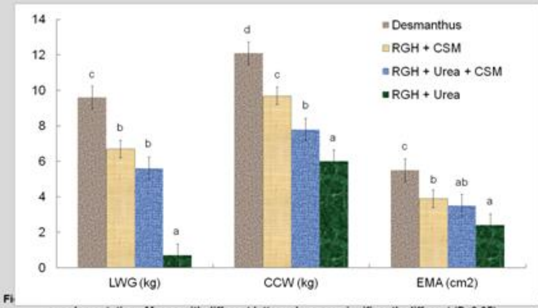
Results & Discussion

Weaner goats fed Progardes Desmanthus cultivar JCU 1 hay (plus minerals) ate more DM and CP and gained liveweight 32% faster (83 v. 58 g/day; P<0.05) compared with goats fed RGH and supplemented with CSM (Fig. 2).



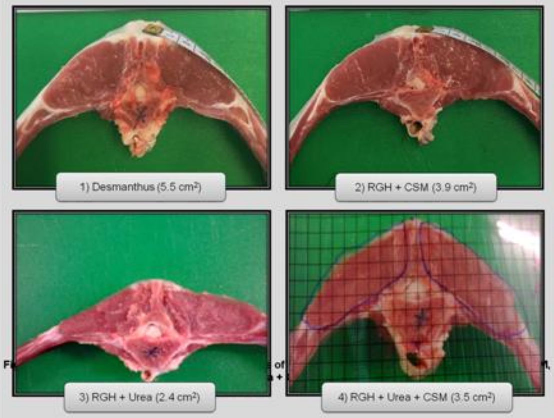
Liveweight gain (LWG), cold carcass weight (CCW), eye muscle area (EMA) and fat thickness were increased by feeding Desmanthus hay as compared with all other diets (P<0.05) (Fig's 3 and 4). Animals fed the urea diet failed to gain weight.

The higher total DMI of Desmanthus could be explained by high palatability and digestibility of the legume (Ngo, 2012).



supplementation. Means with different letter values are significantly different (P<0.05).

The increases in live weight gain, cold carcass weight and eye muscle area with animals fed the Desmanthus diet indicates that intakes of metabolisable energy and metabolisable protein were higher for that diet compared with all other treatments.



Conclusions

- Progardes Desmanthus cultivar JCU 1 hay increased LWG, CCW and EMA of growing Boer goats as compared with goats fed RGH and supplemented with cottonseed meal and/or urea.
- These responses were directly related to DMI, CPI and MEI.
- Urea supplementation did not produce a carcass that meets any category of Australian MLA standards.
- Desmanthus has the potential to enhance goat meat production in the clay soil regions of the subtropics and tropical areas of Australia, Indonesia and other similar land types.

Reference

Ngo, T. 2012. *The effects of diet preference on feed intake, digestibility and nitrogen balance of sheep given Flinders grass (Iseilema spp) hay and/or Desmanthus leptophyllus ad libitum* Masters, James Cook University, Townsville, Qld, Australia.

- Poster prepared for presentation at the Australian Rangeland Society 19th Biennial Conference

Appendix 4: Sugarbush™ – A break-crop for sustaining sugarcane productivity

Sugarbush™ - A break-crop for sustaining sugarcane productivity

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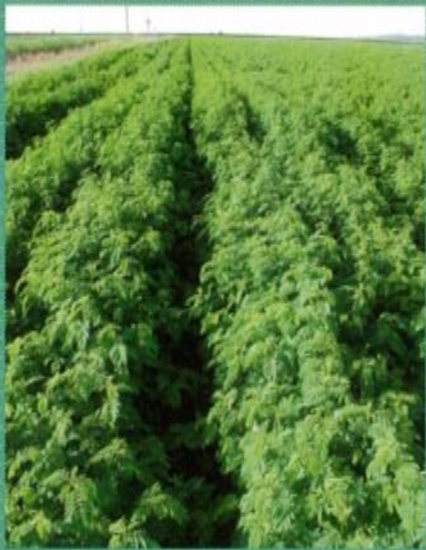
Many crops fail to achieve their biological maximum yield despite ideal growing conditions and surplus agronomic inputs. It is an ongoing issue in sugarcane in North Queensland, for which break crops are recommended to improve yield and correct poor soil condition.

In recent years, we have grown seed crops of Sugarbush™, selected genotypes of the legume *Desmanthus spp.*, during the plough-out period between sugarcane crops in the Burdekin River and Mareeba regions. *Desmanthus* is well-adapted to the extensive grazing regions of Queensland where it benefits animal production and the edaphic environment. Sugarbush hay recently analysed had 133g/kg DM crude protein compared to Rhodes grass hay at 82g/kg/DM and young goats had liveweight gains of over 100g/head/day on the hay diet.

Our observations suggest that SugarBush™, grown as a break-crop and with the crop residues returned to the soil, will increase both sugarcane yield and the crop nitrogen use, and may lessen off-site nitrate pollution from sugarcane farming. We submit the following technical rationale:

- The vegetative growing period of the selected *Desmanthus* genotypes is well-suited to summer break-crop conditions
- *Desmanthus* is a legume so will fix atmospheric N
- The plant has a large, woody, deep taproot system which: may recover N that has been leached below the roots of the sugarcane plant; form resilient root pathways and improve soil structure; and contribute to soil C
- The crop produces a large above-ground biomass (more than 12 t DM/ha) and contribute labile C to the soil

The bulky residues of *Sugarbush* are a preferred mix of low C:N leaf (similar to soybean and rapidly mineralised) and high C:N stem that will slow the rate of C and N mineralisation in the soil.



agrimix

SugarBush

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