final report

Project code: B.LSM.0039

Prepared by: Emma Babiszewski
Janelle Hocking Edwards

South Australian Research and Development Institute

Date published: March 2013

ISBN: 9781741919844

PUBLISHED BY
Meat & Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

Potential Industry Impact: Management of non-Merino ewes

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

The full potential of non-Merino ewes as prime lamb dams is an untapped resource which provides an opportunity to make transformational changes to the productivity of the prime lamb industry. This project provides the foundations to develop next generation, genotype specific guidelines for the management of non-Merino ewes.

A search for datasets containing both Merino and non-Merino genotypes was undertaken in order to determine the magnitude of difference in efficiency of nutrient utilisation. Few suitable datasets exist, with the Information Nucleus Flock providing the only new source of information. This dataset and an extensive literature search provide evidence that models for assessing nutritional requirements do not take into account breed differences and do not account for changes in the genetics of the ewe base of the prime lamb industry over the past two decades in Australia.

Non-Merino ewes outperform Merino ewes for key lamb production traits when managed under identical conditions. This review concludes that non-Merino ewes have a lower feed requirement per kg bodyweight than Merino ewes. Matching inputs to the actual needs of non-Merino ewes has the potential to increase stocking rates or decrease supplementary feeding costs by 14%, increase reproductive efficiency and increase turn-off rates thereby reducing cost of production.

Executive Summary

The full potential of non-Merino ewes as prime lamb dams is an untapped resource which provides an opportunity to make transformational changes to the productivity of the prime lamb industry. Management changes tailored to the Merino ewe have made transformational changes in the wool industry and have a significant impact on enterprise productivity. For example, participants in the Lifetime Ewe Management program increased stocking rate, increased lamb marking percentages and decreased ewe mortality by adopting best practice management of their ewes (Trompf *et al.* 2011). It is therefore expected that adoption of genotype specific management guidelines for reproduction in non-Merino ewes will improve pasture utilisation, increase weaning rates and reduce feed costs per kg of meat produced in the prime lamb industry. Approximately 21% of lambs slaughtered in 2010 were produced from non-Merino mothers. This maternal population consists predominantly of Border Leicester x Merino (BLM) ewes with an increasing contribution from SAMM, Dohne, Dorper (and other “cleanskin” breeds), Corriedale, Coopworth, East Friesian and composite breeds. Merino ewes have different pathways for nutrient partitioning between wool, meat and reproduction compared to non-Merino ewes and the biology behind this is poorly understood. Current feed requirements and guidelines for management of breeding ewes have been pre-dominantly derived from research on Merinos or breeds not common in Australia and are based on ewe liveweight and condition score but do not account for the difference in partitioning/utilisation of nutrients. Thus, the Merino based guidelines may not adequately describe the requirements for efficient reproduction in non-Merino ewes. This project provides the foundations to develop next generation, genotype specific guidelines for the management of non-Merino ewes.

A search for datasets containing both Merino and non-Merino genotypes was undertaken in order to determine the magnitude of difference in efficiency of nutrient utilisation. Few suitable datasets exist, with the Information Nucleus Flock providing the only new source of information. This dataset and an extensive literature search provide evidence that models for assessing nutritional requirements do not take into account breed differences, do not account for changes in the genetics of the ewe base of the prime lamb industry over the past two decades and do not accurately reflect the range of production systems present in Australia.

Non-Merino ewes outperform Merino ewes for key lamb production traits when managed under identical conditions. This review concludes that non-Merino ewes have a lower feed requirement per kg body weight than Merino ewes. Matching inputs to the actual needs of non-Merino ewes has the potential to increase stocking rates, decrease supplementary feeding costs, increase reproductive efficiency and increase turn-off rates thereby reducing cost of production. For example, supplementary feed requirements of non-pregnant adult non-Merino ewes can potentially be reduced by 14%, or stocking rates increased by 14%, compared to management guidelines recommended for Merino ewe management.

The development of genotype specific management guidelines will enable non-Merino ewes to be managed more efficiently, without compromising ewe and lamb welfare, resulting in increased farm income and efficiency through increased stocking rates, decreased supplementary feed and increased feed utilisation.

Table of Contents

1. Background

The full potential of non-Merino ewes as prime lamb dams is an untapped resource which provides an opportunity to make transformational changes to the productivity of the prime lamb industry. This project will provide the foundations to develop next generation, genotype specific guidelines for the management of non-Merino ewes - from lambs to the old girls.

The performance of non-Merino ewes is potentially being hindered by following Merino derived management guidelines. There is some evidence to suggest that management recommendations that have been developed for Merino ewes may be over estimating the needs of non-Merino ewes. Furthermore, many ram breeders (particularly breeders of composite and ‘non-traditional’ maternal sheep such as Dohnes, Corriedales, Coopworths and cleanskin breeds) are marketing their sheep as “more efficient users of feed”, although these claims are unsubstantiated. However, if the current Merino-derived management guidelines are used, then this efficiency will not be realised and the incorrect ewe management guidelines will reduce efficiency of feed utilisation and productivity.

A search for datasets of systems containing both Merino and non-Merino genotypes, for example the Information Nucleus Flock (INF) and prime lamb breeders (through PIRDS), was undertaken. This analysis will determine the magnitude of difference in efficiency of nutrient utilisation between Merino and non-Merino genotypes and the potential industry impact.

2. Project Objectives

1. To determine the magnitude of difference in efficiency of nutrient utilisation between Merino and non-Merino ewe genotypes

2. To determine the potential industry impact of differences in adult ewe feed efficiencies on prime lamb production systems

3. Introduction

Small ruminants (sheep and goats) play an essential role in production of food and fibre worldwide, and account for over 50% of all domesticated ruminants (Tedeschi *et al.* 2010). Since 2001, the world sheep flock has steadily increased; although the Australian sheep flock has declined during this period (ABS 2010). With less land and natural resources available, small ruminant production systems need to become more efficient if they are to remain viable. As such, the Australian Wool Innovation commissioned a project ‘lifetimewool’, with a large proportion of resources focussed on efficient ewe management. The Lifetime Ewe Management (LTEM) course was created to extend the outcomes of ‘lifetimewool’, and integrates new and existing knowledge about nutrition and its impact on the ewe, production and whole-farm profitability. The LTEM course is a 2 year ‘hands-on’ education program for sheep producers which was designed to address the low marking-rate in Australian flocks. It aims to increase reproductive efficiency through educating producers on i) the impact of ewe nutrition on ewe and progeny performance; and ii) accurate assessment of pasture quality and quantity. With the adoption of new management practices, farmers who participated in the LTEM course increased stocking rate by 14%, increased marking numbers by 11% and 13% (Merino and cross-bred respectively) and decreased annual ewe mortality by 43% (Trompf *et al.* 2011). The management practices outlined in the LTEM course are recommended for all breeds of ewe and, in the absence of better information, LTEM recommendations are still the best guidelines currently available to Australian sheep producers.

An integral part of increasing efficiency is the ability to accurately predict the energy and nutrients required to sustain systems (inputs), and to minimise wastage of these resources. The use of mathematical models formulated to predict animal requirements throughout their life is a tool that utilises scientific knowledge and can be used to aid management decisions for the improved efficiency of animal production (Tedeschi *et al.* 2010). In Australia, the most relevant and widely used model for estimating energy requirements of sheep was developed by the CSIRO and is now incorporated into GRAZPLAN® as part of the GrazFeed® decision support tool. Many of the variables used in the sheep estimations are based on research of Merinos and are generalised within the model and scaled according to mature ewe weight and condition score. GrazFeed® modelling is used to support LTEM guidelines.

There is extensive literature stating that breeds of cattle vary considerably in terms of energy requirements (Chizzotti *et al.* 2008; Prendiville *et al.* 2011; Oliveira de Souza *et al.* 2012). In contrast, there is limited literature available on the differences in nutrient and energy requirements between sheep breeds, and what is available was generally published more than 30 years ago. It is thought that by taking into account mature body weight and condition score, many breed effects are accounted for, however Galvani *et al.* (2008) showed that the energy and net protein requirements of growing Texel cross lambs were less than those reported in most nutritional standards (Galvani *et al.* 2009). This is also reflected in several studies of non-wool breeds of sheep such as Santa Ines (Regadas *et al.* 2011), Bergamacia (Santos *et al.* 2002), Balochi (Kamalzadeh & Shabani 2007), Awassi (Jassim *et al.* 1996) and Dorper (Elliott & O'Donovan 1969). Freetly *et al.* (2002) concluded that breed differences are a function of differences in maturation rates, implying slower maturing breeds will have a higher metabolic rate at a similar age to more rapid maturing breeds such as those being selected for in the modern Australian prime lamb industry. Extremely limited literature is available on common breeds in Australian production systems. However, there is considerable anecdotal evidence from the farming community that there are significant breed differences in feed requirements. In fact, many ram breeders (particularly breeders of composite and ‘non-traditional’ maternal sheep such as Dohnes, Corriedales, Coopworths and cleanskin breeds) market their sheep as “more efficient users of feed”, although these claims are unsubstantiated.

In addition to the hypothesis that breeds of sheep have different requirements of metabolisable energy for maintenance ME(m), it is known that there are vast differences in gastrointestinal tract morphology between breeds, which may allow some breeds to extract more nutrients from feed than other breeds (Kennedy 1982). This may have arisen as a result of adaptation to a wide variety of environments. Several studies have shown significant differences in the digestive capacity (the ability to extract nutrients from feed) between breeds of sheep; Lopez *et al.* (2001) showed that Merinos are less able to extract nutrients from fibrous diets than are Churra sheep, and Wilkes *et al.* (2012) established that Damaras have a greater ability to digest diets with increased cell-wall content than Merinos, however when offered a good quality diet, there were no breed differences.

This disparity in nutrient requirement and utilisation between breeds of sheep may be causing inefficiencies in production, especially when producers running non-Merino ewes are following feeding and management guidelines developed based on literature using primarily Merino sheep, as is the case with LTEM guidelines, and GrazFeed® management tool. This report will demonstrate that the efficiency of non-Merino ewes is potentially being hindered by following Merino derived management guidelines. Differences in energy requirements between breeds and differences in efficiency of feed utilisation between Merino and non-Merino genotypes will be described and the potential industry impact will be outlined.

4. Difference in efficiency of nutrient utilisation between Merino and non-Merino ewe genotypes

Differences in several parameters between Merinos and non-Merinos when managed together on the same nutrition are outlined in Table 1. During gestation and lactation, the Merino ewe is between 13 – 34% more efficient than the Border-Leicester x Merino (BLM) ewe at wool growth (Kleemann *et al.* 1984) while the BLM ewe produces 36% more milk than the Merino ewe during lactation (Kleeman & Dolling 1978). In the same study, the BLM x Poll Dorset lambs were weaned at higher weights, grew more quickly and ate less organic matter to reach slaughter weight than did Merino x Poll Dorset lambs (Kleemann *et al.* 1982). In the above studies, Kleemann *et al.* (1984) found no difference in dry matter intake (DMI) between Merino and BLM ewes per unit liveweight. As the BLM ewes were heavier and therefore ate more dry matter, they concluded that the Merino ewe-lamb unit is more efficient. However, this study was conducted on only eight BLM ewes and 13 Merinos. In addition, the twin bearing BLM ewes were removed from the study and the consequent fecundity of BLM ewes was not considered. In contrast, Ponnampalam *et al.* (2012) showed no difference in DMI when comparing BLM x Poll Dorset lambs to Merinos, and lower DMI in BLM x Poll Dorset lambs when expressed per kg BW compared to Merinos. While it is particularly evident that exotic breeds such as the Damara and Dorper perform very differently from the Merino, the distinction between the Merino and other British breeds is not clear; both due to a lack of data and also because of conflicting results.

Table 1. Difference in production factors (Diff) and level of significance (Prob) between Merinos and non-Merino breeds of sheep when managed together (ADG-Average daily weight gain; OMI-Organic matter intake; DMI-Dry matter intake; BW-body weight; CS-condition score)

Author	Comparison breed	Measurement	Non-Merino	Merino	Diff.	Prob
Kleeman and Dolling (1978)	Border Leicester x Merino	**Late Pregnancy**				
		ADG (kg)	0.43	0.39	0.04	ns*
		OMI (kg/day)	2.09	1.77	0.32	ns
		OMI (g/kg BW/day)	32.3	34.5	2.2	ns
		Lactation				
		ADG (kg)	0.12	0.11	0.01	ns
		OMI (kg/day)	3.08	2.56	0.52	P<0.001
		OMI (g/kg BW/day)	45.1	48.6	3.5	P<0.05
Kleemann *et al.* (1984)	Border Leicester x Merino	**Late Pregnancy**				
		OMI (g/day)	67.8	61.1	6.7	ns
		OMI (g/kg BW/day)	59.2	62.6	3.4	ns
		Lactation				
		OMI (kg/day)	239	204	35	P<0.05
		OMI (g/kg BW/day)	121.5	117.9	3.6	ns
Ponnampalam *et al.* (2012)	BLM x PD lambs	DMI (kg/day)	1.1	1.1	0	ns
		ADG (g/day)	38	3	35	P=0.1
		DMI (%BW)	2.08	2.32	0.24	P<0.0001
Engels *et al.* (1974)	SAMM	DMI/kg BW	66.0	71.7	5.7	ns
	Dorper	DMI/kg BW	57.2	71.7	14.5	P<0.05
Wilkes *et al.* (2012)	Damara	**Low Quality Diet**				
		ADG (g/day)	37.5	-28.1	65.6	P<0.05
		DMI (kg/day)	1.49	1.46	0.03	P<0.05
		High Quality Diet				
		ADG (g/day)	246.3	88.7	57.6	P<0.05
		DMI (kg/day)	1.99	1.74	0.25	P<0.05
Holst *et al* (2002)	BLM	**1994**				
		Joining CS	4.1	2.5	1.6	nr#
		1996				
		Joining CS	3.8	2.7	1.1	nr
Kilminster and Greeff (2011)	Damara	**2005**				
		Joining CS	2.3	1.8	0.5	P<0.05
		Conception (%)	98	22	76	nr
		2006				
		Joining CS	2.8	2.8	0	ns
		Conception (%)	50	128	78	nr
		2007				
		Joining CS	2.8	2.5	0.3	P<0.05
		Conception rate	80	145	65	nr
	Dorper	**2005**				
		Joining CS	2.4	1.8	0.6	P<0.05
		Conception (%)	100	22	78	nr
		2006				
		Joining CS	3.3	2.8	0.5	P<0.05
		Conception (%)	155	128	17	nr
		2007				
		Joining CS	2.8	2.5	0.3	P<0.05
		Conception (%)	159	145	14	nr

ns* - No significant difference (P>0.05); nr# - Not reported

When Merino and BLM ewes were managed together on the same pasture, 43% of Merino ewes had a fat score (FS) less than 3, 52% of the Merino ewes had FS=3 and 5% of the Merino ewes had FS>3. This is in contrast to only 2% of the BLM having a FS<3, 27% had a FS=3 and 71% of the BLM ewes have FS>3 (calculated from data of (Holst *et al.* 2002)). This increase in fatness of the BLM ewes was also implicated in decreased lamb survival due to injury during birth and increased mal-presentations (Holst *et al.* 2002). More recently, in the demonstration trial at Elmore, Vic., BLM ewes had an average CS of 4.0 and Merino ewes had an average CS of 3.1 at weaning, despite the BLM ewes weaning a greater weight of lambs (www.elmorefielddays.com.au).

Kilminster and Greeff (2011) specifically managed Merinos, Damaras and Dorpers together under LTEM guidelines, with the Damaras and Dorpers consistently having higher CS than the Merinos. The Damaras in particular had the propensity to become ‘over-fat’, resulting in decreased conception rates. While the management practices outlined in the LTEM course are recommended for all breeds of ewe, there is no evidence to suggest a positive relationship between fat level and reproductive success in non-Merino genotypes (as there is for Merinos). In fact, preliminary analysis of the Sheep CRC Information Nucleus Flock (INF) indicates that there is no relationship between liveweight and reproductive success in non-Merino ewes, nor is there a relationship between YFAT ASBVs and reproduction in non-Merino ewes (Paganoni 2012; Sheep CRC Discussion Paper “Maternal efficiency of Merino and Xbred ewes and genetic effects of ASBVs on efficiency” v1). CS of the INF has not been analysed to date.

The INF Merino and maternal (non-Merino) follower ewes were managed together as single mobs under LTEM guidelines across six sites over two years. The maternal ewes in this study include breeds common in Australian systems such as Border Leicester, Coopworth, Suffolk and Corriedale as well as Dohne and SAMM. In all environments, the maternal ewes were consistently heavier (Figure 1; Paganoni 2012; Sheep CRC Discussion Paper “Maternal efficiency of Merino and Xbred ewes and genetic effects of ASBVs on efficiency” v1). Fertility, fecundity and maternal efficiency were all higher in the non-Merino ewes compared to the Merino ewes. Non-Merino ewes were 10% more fertile, 20% more fecund and weaned 20% more lambs than the Merino ewes when managed under the same conditions. The dry non-Merino ewes were significantly heavier than the dry Merino ewes prior to joining, and were able to maintain this increased weight when run together with Merino ewes on the same nutrition.

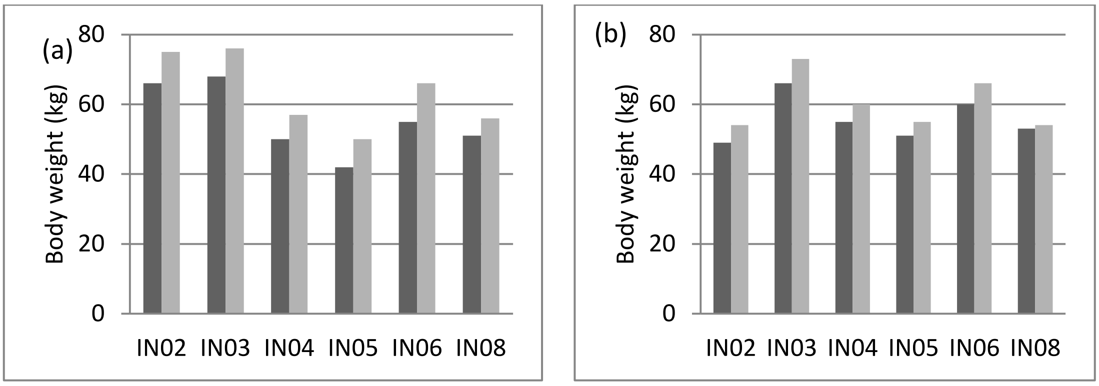

Figure 1: A comparison of liveweights between Merino (dark bars) and maternal (light bars) ewes mated at 18 and 30 months (Merinos) and 18 months (maternals), that were run together for at least 2 months prior to joining in (a) 2010 and (b) 2011.

The Maternal Central Progeny Test compared production efficiency of progeny by sires of numerous breeds. However there were very few Merino or wool specialist sires included, therefore it is not possible to use this dataset to describe the magnitude of difference in efficiency of nutrient utilisation between Merinos and non-Merinos.

The project "Influence of Merino genes on prime lamb production" (MLA project SHGEN.027) produced Merino and BLM ewes, however, ewes of similar ages were not managed together as a single mob and were mated at different times (Merinos in January and BLM in March), therefore it is not possible to use this dataset to describe the magnitude of difference in efficiency of nutrient utilisation between Merinos and non-Merinos.

A thorough search of MLA funded projects and PIRDs was undertaken, as well as discussions with state government staff. Surprisingly, there were no additional trials that investigated differences in production of Merino and non-Merinos ewes managed under the same conditions. Thus it was not possible to determine the magnitude of difference in efficiency of nutrient utilisation between Merinos and non-Merinos. Therefore, to determine the magnitude of difference in efficiency we have undertaken a thorough analysis of published literature.

In the case studies presented above, it is often not possible to attribute the cause of the difference in production and it is certainly not possible to rule out that the differences are simply due to increased intake in the non-Merino ewes. However, these data indicate that under identical production conditions, non-Merino ewes have improved production outcomes. The following sections describe the mechanisms that may be contributing to differences in production outcomes and the contribution that this may make to differences in efficiency of nutrient utilisation.

5. Energy

The energy requirement for maintenance is defined as the ME intake per day at which the animal is in zero energy balance. The energy available for maintenance use within an organism is energy obtained from feed minus what is lost in faeces (indigestible energy), urine, methane emissions and heat, leaving net energy (NE), which is the total amount of energy available for maintenance and production requirements (Rattray *et al.* 1973a).

Most of the work measuring the energy requirements of sheep has been conducted on growing lambs (Table 2), and provides a good basis for comparison between the breeds represented. Growing male lambs from the meat breed Bergamacia require 56% less ME than growing male lambs of the wool breed German Merino. Other growing meat lambs have lower ME requirements than the growing wool lambs (11-35% 2X Suffolk; 27% Texel x Ill de France; 15% Dorper) The range across trials is similar to the range reported across breeds in a single study (Shinde & Karim 2007). Across the range of lambs, the average ME is 428 kJ/kgBW$^{0.75}$/day and across the dry wethers, the average is 420 kJ/kgBW$^{0.75}$/day. In fact, the average value of all the studies in Table 2 is 425.6kJ/kgBW$^{0.75}$/day ± 97, which is not dissimilar to the estimate used in the Lifetimewool system (approximately 448 kJ/kgBW$^{0.75}$/day) for a mature, dry ewe at CS 3. However, a mature dry Dorper ewe has an ME of only 373 kJ/kgBW$^{0.75}$/day (Elliott & O'Donovan 1969) and mature Merino wethers require 90 kJ/kgBW$^{0.75}$/day more ME than other breeds of mature wethers (Table 2). In an Iranian study of 12 month old ram lambs, there was no significant difference in ME requirements between the small body sized Sangsari and the large body sized Afshari (Kamalzadeh & Aouladrabiei 2009). These sheep are both breeds of fat-tailed sheep, so it is likely that they would have similar nutrient partitioning.

Table 2: Maintenance energy requirements (ME; kJ/kgBW$^{0.75}$/day) in several breeds of sheep, at various stages of development.

Reference	Breed	Age	Status	ME
Early *et al.* (2001)	Omani	Lambs	Growing	526
Bellof and Pallauf (2004)	German Merino Landsheep	Lambs	Growing	520
Rattray *et al.* (1973b)	Mixed; Targhee and Finn and their crosses	Lambs	Growing	502
Jassim *et al.* (1996)	Awassi	Lambs	Growing	466
Ferrell *et al.* (1979)	2X Suffolk	Lambs	Growing	463
Elliott & O'Donovan (1969)	Dorper	Lambs	Growing	444
Galvani *et al.* (2008)	Texel x Ile de France	Lambs	Growing	381
Thomson *et al.* (1979)	2X Suffolk	Lambs	Growing	339
Santos *et al.* (2002)	Bergamacia	Lambs	Growing	229
Kamalzadeh and Shabani (2007)	Baluchi	Hoggets	Wethers	294
Duarte-Vera *et al.* (2012)	Pelibuey	Hoggets	Wethers	444
Young and Corbett (1968)	Merino	Mature	Wethers	552*
Dawson and Steen (1998)	Blackface, Suffolk and Texel x Blackface	Mature	Wethers	460
Liu *et al.* (1991)	Hu	Mature	Wethers	310 - 402
Olthoff *et al.* (1989)	Columbia x Hampshire x Suffolk	Mature	Dry ewe	708
Olthoff *et al.* (1989)	Finn x Suffolk x Targhee	Mature	Dry ewe	581
Elliott & O'Donovan (1969)	Dorper	Mature	Dry ewe	373*
Ball *et al.* (1998)	Coopworth	Mature	Dry ewe	290
Average (± SD) across all ME values		425.6*kJ/kgBW$^{0.75}$/day ± 97*		

* Used for simulation modelling (Figure 2)

The use of energy for maintenance can be broadly divided into two categories: service functions such as circulation, respiration and maintenance of homeostasis; and functions associated with cell maintenance such as ion transport, and protein and lipid turnover (Pond *et al.* 1995). Any energy that is obtained from feed, and surplus to the maintenance requirements is called retained energy (RE) and is stored either as protein or fat (Pond *et al.* 1995). There is conflicting evidence as to whether storage of energy as fat or protein is more- or less- efficient than energy use for maintenance; and the point at which animals begin storing energy. Sanz Sampelayo *et al.* (1995) showed that growing lambs store fat more efficiently than protein and begin energy storage as soon as maintenance requirements are met, while Canton *et al.* (2009a) showed that some breeds of sheep are more efficient than others at either using ME(m) and/or converting excess energy to either fat or muscle (feed conversion ratio), yet found no breed effect in a later study (Canton *et al.* 2009b). Cannas *et al.* (2004) stated that differences in efficiency between breeds are negligible however, Richardson *et al.* (2003) found that both diet type and feed synchronicity affected feed utilisation efficiency. If farmers are to be able to maximise the efficiency of their systems, the feed utilisation efficiency differences between Merino and non-Merino genotypes need to be established in order to reduce wastage and increase production.

The partitioning of ingested energy to various functions is controlled by a complex set of interactions that determine the flow of available nutrients (Adams & Liu 2003). Muscle and adipose tissue metabolism are regulated by homeostatic (acute) and homeorhetic (chronic) mechanisms. The homeostatic mechanisms are controlled by the hypothalamic-pituitary-adrenocortical axis (HPA) and the sympathetic nervous system, which mediates plasma metabolite levels including insulin, glucose, cortisol and non-esterified fatty acids (NEFA) (Miller & O'Callaghan 2002). Homeostatic responses include behavioural and neuroendocrine changes that occur as a result of stress and can result in changes to eating behaviour, energy expenditure, hormone secretion, lipolysis and glycolysis, and are influenced by an animal's genotype, age, sex, season, climatic conditions, plane of nutrition and body size (Pond *et al.* 1995; Mormede *et al.* 2002; Ponnampalam *et al.* 2012). Fatter sheep have lower ME requirements than lean sheep of the same liveweight due to higher metabolic activity of lean tissue. However, even if selection alters body composition, energy requirement per unit of fat (or carcase lean) is similar (Ball *et al.* 1995). Because there are so many factors (both genetic and environmental) that influence energy partitioning, it can be difficult to quantify differences between breeds and indeed between animals of the same breed (Friggens & Newbold 2007). Differences between breeds may have arisen due to adaptation to harsh environments, in which animals are required to become more efficient at conserving and utilising fat reserves (Ponnampalam *et al.* 2012).

Several studies have shown significant differences in hormone-stimulated metabolic activity between sheep selected for muscle accretion or leanness compared with those bred primarily for wool or milk production. Pituitary growth hormone (GH) is the principle hormone involved in growth stimulation in most species (Elsaesser *et al.* 2002), and plasma cortisol concentration mediates growth rate and feed conversion efficiency (Mormede & Terenina 2012). A strong, negative correlation between plasma cortisol levels and leanness exists in four breeds of pig, with significant differences in both cortisol and muscle tissue between each breed (Foury *et al.* 2007). In sheep, second cross (BLMxPD) lambs have significantly higher levels of basal plasma glucose, cortisol and NEFA than Merino lambs, which is consistent with their higher proportion of body fat (Ponnampalam *et al.* 2012). Selection for leanness resulted in decreased plasma lactate, glucose and NEFA concentrations in first-cross and Merino sheep compared with their control (non-selected) counterparts (Martin *et al.* 2011), while a comparison between Suffolk (meat production) and Targhee (wool) ewes show lower basal plasma glucose concentrations in the Targhee ewes (Hatfield *et al.* 1999). Likewise, SNP frequencies of the β-3 adrenergic receptor (ADRB3) – a main mediator of energy metabolism and lipolysis – increased in breeds selected for meat production (Texel, Dorper) and dual purpose for meat and wool production (Poll Dorset, German Mutton Merino, South African Mutton Merino) compared to those bred for wool production (Wu *et al.* 2012). These studies show intrinsic breed differences in basal and hormone mediated metabolites which may be related to the fundamental differences in physiology associated with breeds selected for meat and wool production, and may also affect the efficiency with which certain breeds use and store energy.

Indeed, differences in efficiency of energy usage between and within breeds genetically selected for a particular purpose have long been identified. Li et al. (2008) found there was no 'trade-off' in energy partitioning between wool growth and body reserves in Merino rams with high wool growth ASBVs, and rationalised this by stating 'fleece plus' rams were more efficient than 'fleece minus' rams at utilising nutrients. Bedo *et al.* (1996) showed that sheep selected for milk production were *c.*35% more efficient than non-selected breeds at producing milk during lactation, and also used dietary ME and crude protein (CP) more efficiently. Merino ewes selected for high weaning weight ate 24% more to maintain weight than Merino ewes selected for low weaning weight (Herd *et al.* 1993) and there were no differences in the net efficiency of feed use for weight gain. However, the high weaning weight ewes required only 22% more dry feed to maintain their heavier liveweight and produced less wool per kg liveweight for the same intake.

Luo *et al.* (2004) states that breed differences in ME(m) requirements are more likely to occur as a result of different requirements for NE(m) rather than in efficiency (k(m)). It is also apparent that breeds respond differently to climatic stress (Symington 1960), because of their inherent differences in fleece characteristics, but also due to behavioural and physiological differences (Blaxter *et al.* 1966; Moneva *et al.* 2008). Climatic stress has been shown to affect efficiency of energy utilisation through disturbances to blood metabolite levels and rumen environment (Marai *et al.* 2007) and is significantly different between breeds (Khalil *et al.* 1990; Marai *et al.* 2007).

In summary, breeds vary both in the requirement and use of energy, however the degree, and likely economic impact of variation – particularly among breeds common to Australian production systems – is not known. While the evidence presented above would indicate that certain breeds may have lower energy requirements and be more efficient than others at using energy, a definitive study needs to be undertaken to determine the magnitude of variation between breeds common in Australia.

6. Digestion

The morphology of the entire gastrointestinal tract (GIT) influences digestibility. Feed intake is limited by room in the rumen and as such, the quicker feed passes through the rumen, the more an animal can eat. However, rumen retention time (RRT) is positively correlated with digestibility (Faichney & Gherardi 1986), therefore breeds with larger GITs have the ability to extract more nutrients from feed than breeds with smaller GITs. Duarte-Vera *et al.* (2012) hypothesise that the lowered energy requirement of

Pelibuey ewes when compared with nutritional standards is the result of their higher GIT fill when compared to wool breeds, in conjunction with its higher bone:body tissue ratio which provides a smaller amount of metabolically active tissue. Similarly, in a robust study by Mann *et al.* (1987), Blackbelly and Dorset rams and their crosses were compared for voluntary feed intake (VFI), rate of passage, digestibility of feed and weight gain; and showed significantly greater GIT fill, slower passage rates and longer retention times in the tropical Blackbelly than in the Dorset or the cross bred. The Dorset rams had a higher passage rate, shorter retention time and digested the least CP and organic matter (OM). These results are consistent with studies in cattle that show higher apparent digestibility coefficients for tropical breeds than for temperate European breeds (Ashton 1962; Howes *et al.* 1963).

It has been well documented that different breeds of sheep are likely to select different feedstuffs (Botha *et al.* 1983; Zeeman *et al.* 1983; Brand 2000), and that the characteristics of ingested species alter the rumen environment and the microbial population of the GIT, which is pivotal in determining the array of nutrients extracted from feed (Hegarty 2004). As such, it is thought that differences in the population of micro-organisms present in the rumen between breeds (Ranilla *et al.* 1998) are likely to be the result of diet selection, rumen kinetics and rate of ingestion, rather than genotype (Hegarty 2004), but nonetheless, do cause differences between breeds in the digestibility of feeds. There was no difference in the site or extent of digestibility of high quality feeds between Anglo-Nubian cross kids and Dorset x Coopworth lambs (Alam *et al.* (1987). However, rumen digestion of low quality feed in cattle was influenced by both the characteristics of the feed and the breed, with Brahmans (*Bos indicus*) able to digest significantly more than Herefords (*Bos Taurus*) (Hunter & Siebert 1985). They hypothesised that this could be due to the ability of Brahmans to maintain higher rumen ammonia concentrations, and also suggest that the longer RRT of Brahman cattle may increase digestibility. These results are reflected in a study by Kennedy (1982) who showed that the ability of Brahman-cross steers to maintain weight at a fixed level of feed intake when compared to Hereford steers which lost weight, was correlated to longer RRT in Brahman-cross steers and the resulting ability to digest greater proportions of OM, and an increased efficiency in protein synthesis. Likewise in sheep, Ranilla *et al.* (1997) found significant increases in rumen digestion in the Churra compared to Merino, with differences more pronounced as feed quality decreased. It is hypothesised that this may be due to the larger rumen volume of the Churra, and the resulting ability to increase RRT. Aitchison *et al.* (1986) showed that there is no difference in RRT when comparing good and poor quality feeds; however this study does not describe the breed, sex or age of the sheep used, so data may not be reflective of all breeds. Givens and Moss (1994)The digestibility of DM, OM and digestible organic matter was significantly higher in Cheviot than Suffolk cross wethers (Givens & Moss 1994) and there was a higher digestibility of CP but no difference in VFI in Blackbelly x Dorset rams compared to either Blackbelly or Dorset rams (Mann *et al.* 1987). Lourenco *et al.* (2000) conclusively show that Ile-de-France sheep had lower OMI/kg LW ($P<0.001$), higher average daily gain (ADG), and higher organic matter digestibilities than the Churra da Terra Quente sheep. In contrast, there was no difference in total retention time, fractional rates of passage or total tract digestibility of OM, DM or neutral detergent fibre (NDF) between the Manchega and Lacaune breeds of dairy sheep (Molina *et al.* (2001). However, this study was conducted on two breeds of sheep originating from similar geographic environments, with common ancestors, and selected for the same purpose (milk production) which may explain the lack of differences observed.

Because of the difference in mature size of many breeds of sheep commonly used in Australian production systems, it can be hypothesised that difference in entire GIT size will alter VFI, RRT, clearance rates and the resulting digestion of OM and extraction of nutrients; particularly with lower quality feeds. The GrazFeed® decision support tool has standardised feed energy values and does not take into account possible differences between breeds in their ability to extract nutrients from feed. In addition, none of the models used to predict sheep energy requirements take into account feeding level, or slowly degraded feed fractions; both of which have significant breed interactions and can alter nutrient availability (Cannas & Atzori 2005), and are accounted for in the CNCPS-c model (see below).

7. Computer modelling to predict livestock production

Several computer models have been developed to predict ruminant feed requirements. The Small Ruminant Nutrition System (SRNS), formerly the Cornell Net Carbohydrate and Protein System (CNCPS-s), is one such model used in formulating energy requirements for small ruminants (Fox *et al.* 2004). The CNCPS has models for use in dairy, beef, and dual-purpose cattle; while the SRNS covers goats and sheep. Similar models have been developed by the CSIRO (GrazFeed®), NRC and AFRC. The set of equations used in each of the models were formulated based on averaging the ME(m) reported in publications from 1970 – 1990 representing a range of breeds, environments and feed types (Cannas *et al.* 2004; Tedeschi *et al.* 2010). Each model is comprised of a complex set of equations that take into account body weight, age, sex, wool production (for sheep), reproductive status, climatic conditions, plane of nutrition and condition score among many others.

Breeds of cattle vary considerably in terms of energy requirements (Chizzotti *et al.* 2008; Prendiville *et al.* 2011; Oliveira de Souza *et al.* 2012) and it is recognised that the inter-breed variation cannot be accounted for by scaling to mature body weight and/or condition score because of significant differences in birth weight, peak milk yield, milk composition, weight at first conception (Fox *et al.* 2004), heat tolerance, methane production and body composition (Dove 1996). The CNCPS-c is able to include breed differences because the extensive literature available describing the energy requirements of different breeds means the model is robust enough to accommodate breed differences, and indeed differences between temperate and tropical environments. The equations used to predict the ME(m) in cattle (both beef and dairy) incorporate five multipliers that are known to vary between breeds (with known values listed for 34 breeds of cattle). Goat predictions are made using one of two divergent genotypes: meat or dairy goats, based on evidence that there are significant differences between these two broad genotypes. Fernandes *et al.* (2007) showed that some goats have a feed utilisation efficiency lower than the standard reported by the AFRC.

The models used to predict ME(m) for sheep assume no difference between breeds. In the SRNS model, efficiency of conversion from ME to NE is assumed to be constant at 0.644 for all breeds of sheep at all times (Cannas *et al.* 2004). The NRC recently updated the ME(m) requirements of sheep to consider higher levels of productivity by larger and improved genotypes, however still produced one set of equations to calculate energy requirements for all breeds of sheep, despite evidence suggesting the differences in morphology and genetic merit between breeds of sheep are comparable to differences between breeds of cattle (Cannas *et al.* 2004). Likewise, CSIRO recently updated the nutrient requirements of ruminants (Freer *et al.* 2007) and despite major changes to some sections of the report, the original equation to estimate ME(m) was unchanged and is adjusted for breed by accounting for liveweight.

The GrazFeed® model is designed to be of general application to any genotype of sheep or cattle grazing pasture or on supplementary feeding/ feedlot situations (but not applicable to animals grazing shrub-dominant arid areas). Many of the variables used in the sheep estimations are based on research on Merinos and are generalised within the model and scaled according to mature ewe weight and CS. However, unlike the SRNS model, the energy partitioned to wool growth incorporates variables for photoperiod known to differ between breeds for nine major breed types in Australia, grouped into five main groups (Merino; Southdown and Ryeland; Corriedale and Romney; Dorset, Suffolk and Border Leicester; Border Leicester x Merino) (Freer *et al.* 1997). These breed groups are combined based on mature size and production characteristics (for example, prime lamb vs wool sheep). In comparison to the SRNS model, there are limited reviews or critiques of the GrazFeed® model in published literature, however Dove (1996) identifies the lack of available information on diet selection and the need for this factor to be incorporated into the model.

In contrast to the SRNS model, there seems to be no literature that evaluates the precision and/or accuracy with which GrazFeed® can predict DMI or ADG. Therefore, to determine the accuracy of the models in predicting actual production levels, a comparison of published ADG and DMI compared to the GrazFeed® model and the SRNS model for predicted DMI and ADG is presented in Tables 3a and 3b. Efforts were made to accurately match published feed values for dry matter (DM, %), dry matter digestibility (DMD), CP and ME as required by GrazFeed®; and to accurately identify feed composition as required by SRNS, however the SRNS requires characterisation of feeds that is not often published in enough detail. Where this information was missing from publications, the estimated values for specific feed types as stored in the GrazFeed® and SRNS libraries were used. Based on the nutritional information given, there was good agreement between actual and predicted ADG and DMI, particularly in Merinos. However, it was difficult to find published data with sufficient information to predict adult non-Merino DMI and ADG using GrazFeed® and compare it with actual performance.

Table 3a: Comparisons between actual DMI & ADG to those predicted by GrazFeed® for a range of breeds and sexes (M & F) and the probability (Prob) that they are the same

Reference	**Sheep** (breed, age, sex, weight)	**Diet** (MJ ME/kg DM)	**DMI** (kg/day) **Actual**	**Predicted**	**ADG** (g) **Actual**	**Predicted**
Ferrell *et al.* (1979)	Suffolk-cross; mixed sex weaners (3 months); 17kg shorn weight	Low concentrate	1.35	M: 0.95 F: 0.85	180	M: 180 F: 130
		Medium concentrate	1.32	M: 0.99 F: 0.98	230	M: 230 F: 191
		High concentrate	1.17	M: 0.88 F: 0.98	250	M: 250 F: 238
		Prob (Act/Pred)	M: Different F: Different		M: Same – P=1.00 F: Different	
Mahgoub *et al.* (2000)	Omani; ram weaners, 17.3kg	Low energy (8.67 MJ)	0.648	0.740	84	75
		Medium energy (9.95 MJ)	0.680	0.740	123	123
		High energy (11.22 MJ)	0.696	0.650	143	143
		Prob (Act/Pred)	Same P=0.99		Different	
Galvani *et al.* (2009)	Texel cross; ram weaners; 17.3kg	Ad. lib	0.562	0.850	245	245
		70% ad lib.	0.377	0.470	91	91
		55% ad lib.	0.287	0.330	27	27
		Prob (Act/Pred)	Similar P=0.94		Same P=1.00	
(Herd *et al.* 1993)	Merino ewes, 6 years, dry, 39kg	Pelleted lucerne & wheat (10.4MJ)	0.509	0.510	0	0
	Merino ewes, 6 years, dry, 35kg		0.459	0.470	0	0
	Merino ewes, 6 years, dry, 30kg		0.410	0.420	0	0
		Prob (Act/Pred)	Same P=1.00		Same P=1.00	

Table 3b: Comparisons between known dry matter intake (DMI) and average daily gain (ADG) to those predicted by SRNS for a range of breeds.

Author	**Sheep** (breed, age, sex, weight)	**Diet**	**DMI** (kg/day) **Actual**	**Predicted**	**ADG** (g) **Actual**	**Predicted**
Ferrell *et al.* (1979)	Suffolk-cross; mixed sex weaners (3 months); 17kg shorn weight	Low concentrate	1.35	0.91	180	283
		Medium concentrate	1.32	0.96	230	314
		High concentrate	1.17	0.96	250	315
		Prob (Act/Pred)	Different		Different	
(Herd *et al.* 1993)	Merino ewes, av. 6 years, dry, 35kg	Lucerne & wheat pellet (10.4MJ)	0.459	0.83	0	3

8. Potential industry impact of differences in adult ewe feed efficiencies on prime lamb production

The evidence presented above shows that sheep breeds do differ in their energy requirements for maintenance - for a number of reasons - and that these differences are not accounted for when calculating energy requirements and their impact on ewe management systems.

Small differences in ME(m) requirements and utilisation between breeds can have a significant effect on production parameters such as cost of supplementary feeding and stocking densities. Being able to accurately predict input requirements will significantly increase production efficiency, and reduce wastage of resources. As an example, if the Merino requirements are the average from Table 2 (425 kJ/kgBW$^{0.75}$/day) a 55kg dry ewe will require 8.60MJ/day for maintenance. If a non-Merino ewe has lower requirements (Table 2 average - standard deviation = 328 kJ/kgBW$^{0.75}$/day), a 65kg dry ewe will require 7.52MJ/day for maintenance. On supplementary feeding of 100% barley (~12.3MJ/ kg DM), the Merino ewe will require 699g/day for maintenance while the cross-bred ewe will require 611g/day for maintenance (difference of 88g/day). If a farmer was supplementary feeding non-Merino ewes at the recommended rates (as employed by the CSIRO model and GrazFeed®), each non-Merino ewe would receive 14.3% above their requirements. Therefore, supplementary feeding over eight weeks of January and February when paddock feed is scarce, equates to an additional $1.30/ewe; this is significant when feeding large mobs.

If the extremes of the ranges of measured ME requirements from Table 2 are simulated (Figure 2), there is a difference of $4.40/hd for feed costs over an eight week period. The upper limits of published Merino requirements are very similar to the 'upper limit' of requirements (Figure 2). To further add to the expense is the possibility that lower reproductive performance will result from over fat ewes (Kilminster and Greeff (2011).

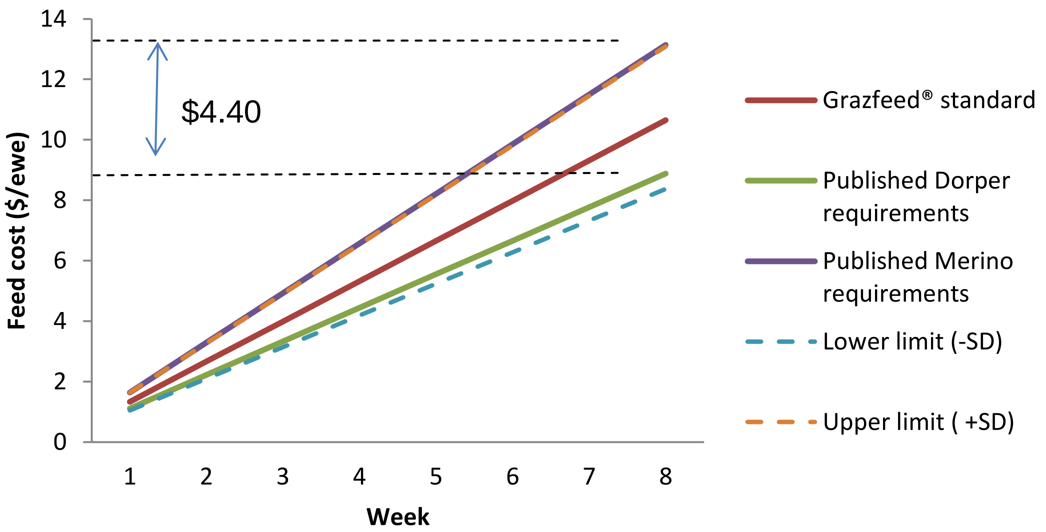

Figure 2: Simulated cost per ewe of supplementary feeding to published breed requirements (Dorper & Merino) compared to standard reference (Grazfeed®), for mature, dry animals of CS 3. Costs are representative of average costs for feed barley in Southern Australia.

Another scenario is where ewes graze a paddock of 1000kg DM/ha FOO of improved pastures at 12MJ/kg DM. Based on the equations above, the Merinos (who require 8.6MJ/d) will last for a month on the pasture at 46.5 ewes/ha, while the non-Merino ewes (who require 7.5MJ/day) will last for a month on the pasture at 53.2 ewes/ha; an extra six-seven ewes per ha. So, 500 Merinos would require 10.75ha, while the non-Merino would require 9.39ha; or 20ha will support 930 Merinos or 1064 non-Merinos. This a potential 14% increase in stocking rate for non-Merino ewes.

9. Conclusion

There is limited literature available on the energy requirements of sheep, and differences between breeds, and what is available generally has either limited relevance to Australian production systems and/or is more than 25 years old. It is not surprising then that models for assessing nutritional requirements do not take into account breed differences, do not account for changes in the genetics of the ewe base of the prime lamb industry over the past two decades and may not accurately reflect the range of production systems present in Australia.

The energy requirements recommended for Lifetime Ewe Management were developed using the GrazFeed® decision support tool, which is based largely on Merinos, and while there are many conflicting reports of maintenance energy requirements for sheep in the literature, there is strong evidence to suggest the maintenance energy requirements of Merino sheep may not accurately reflect that of non-Merino sheep currently in use in the Australian sheep industry. There is a considerable gap in the literature when comparing maintenance energy requirements for different sheep breeds, particularly common maternal breeds and those increasing in popularity in Australia such as the Border Leicester, Composite, Coopworth, Dohne, SAMM and Dorper. However based on the data presented in this review, it can be hypothesised that non-Merino ewes have a lower feed requirement than Merino ewes, which may arise from one - or a combination - of the factors outlined that influence energy use.

While it is known that breeds of sheep differ in their energy requirements, efficiency of utilisation of energy and digestive capacity, none of these breed differences are considered in the models used to predict energy requirements. It is likely that these factors are not considered because of the limited literature available, as well as the rationalisation that many breed differences in sheep may be accounted for by allowing for changes in mature body size and condition score. However, the intrinsic physiological and biological differences in sheep selected for different purposes – such as prime lamb, wool and milk production – mean they fundamentally use energy for different purposes and possibly via different pathways. Understanding these differences and the degree with which breeds common to Australian systems differ will be paramount in increasing efficiency of our systems into the future; increasing output (wool, lamb etc), decreasing inputs (supplementary feeding) and using our land more efficiently (increasing stocking densities).

The implication of this is that management recommendations that have been developed for Merino ewes may be over estimating the needs of non-Merino ewes. Matching inputs to the actual needs of non-Merino ewes has the potential to increase stocking rates by 14%, decrease supplementary feeding costs by 14%, increase reproductive efficiency and increase turn-off rates thereby reducing cost of production.

The development of genotype specific nutritional guidelines will enable non-Merino ewes to be managed more efficiently, without compromising ewe and lamb welfare, resulting in increased farm income and efficiency.

10. References

ABS (2010) Principle Agricultural Commodoties 2009-10. (ed. by Statistics ABo), Canberra.

Adams N.R. & Liu S.M. (2003) Principles of nutrient partitioning for wool, growth and reproduction: implications for nematode parasitism. *Australian Journal of Experimental Agriculture* **43**, 1399-407.

Aitchison E., Gill M., France J. & Dhanoa M.S. (1986) Comparison of methods to describe the kinetics of digestion and passage of fiber in sheep. *Journal of the Science of Food and Agriculture* **37**, 1065-72.

Ashton G.C. (1962) Comparative nitrogen digestibility in Brahman, Brahman x Shorthorn, Africander x Hereford, and Hereford steers. *Journal of Agricultural Science* **58**, 333-&.

Ball A.J., Thompson J.M., Alston C.L., Blakely A.R. & Hinch G.N. (1998) Changes in maintenance energy requirements of mature sheep fed at different levels of feed intake at maintenance, during weight loss and realimentation. *Livestock Production Science* **53**, 191-204.

Ball A.J., Thompson J.M., Hinch G.N., Fennessy P.F. & Blakely A.R. (1995) Feed requirements for maintenance of mature rams and ewes from lines selected for differences in body composition. . In: *Proc. New Zealand Society Animal Production* pp. 312-5.

Bedo S., Barcsak-Toth G. & Poti P. (1996) Feed intake and feed utilisation for milk production by ewes of various genotype. *Bulletin of the University of Agricultural Sciences, Godollo* **2**, 159-66.

Bellof G. & Pallauf J. (2004) Utilization of energy for growth in lambs of the breed German Merino Landsheep. *Archives of Animal Nutrition* **58**, 495-505.

Blaxter K.L., Clapperton J.L. & Wainman F.W. (1966) The extent of differences between six British breeds of sheep in their metabolism, feed intake and utilization, and resistance to climatic stress. *British Journal of Nutrition* **20**, 283 - 94.

Botha P., Blom C.D., Sykes E. & Barnhoorn A.S.J. (1983) A comparison between the diets of small and large stock on mixed karoo veld. *Proceedings of the Annual Congresses of the Grassland Society of Southern Africa* **18**, 101 - 5.

Brand T.S. (2000) Grazing behaviour and diet selection by Dorper sheep. *Small Ruminant Research* **36**, 147-58.

Cannas A. & Atzori A.S. (2005) Development and evaluation of a model to predict sheep nutrient requirements and feed utilisation. *Italian Journal of Animal Science* **4**, 15 - 33.

Cannas A., Tedeschi L.O., Fox D.G., Pell A.N. & Van Soest P.J. (2004) A mechanistic model for predicting the nutrient requirements and feed biological values for sheep. *Journal of Animal Science* **82**, 149-69.

Canton G.C.J., Bores Q.R., Baeza R.J., Quintal F.J., Santos R.R. & Sandoval C.C. (2009a) Energy Retention of F1 Pelibuey Lambs Crossed with Breeds for Meat Production. *Journal of Animal and Veterinary Advances* **8**, 2655-61.

Canton G.J., Bores Q.R., Baeza R.J., Quintal F.J., Santos R.R. & Sandoval C.C. (2009b) Growth and Feed Efficiency of Pure and F1 Pelibuey Lambs Crossbred with Specialized Breeds for Production of Meat. *Journal of Animal and Veterinary Advances* **8**, 26-32.

Chizzotti M.L., Tedeschi L.O. & Valadares Filho S.C. (2008) A meta-analysis of energy and protein requirements for maintenance and growth of Nellore cattle. *Journal of Animal Science* **86**, 1588 - 97.

Dawson L.E.R. & Steen R.W.J. (1998) Estimation of maintenance energy requiremetns of beef cattle and sheep. *Journal of Agricultural Science* **131**, 477 - 85.

Dove H. (1996) Constraints to the modelling of diet selection and intake in the grazing ruminant. *Australian Journal of Agricultural Research* **47**, 257-75.

Duarte-Vera F., Sandoval-Castro C.A., Sarmiento-Franco L.A., Tedeschi L.O. & Santos-Ricalde R.H. (2012) Energy and protein requirements of growing pelibuey sheep under tropical conditions estimated from a literature database analyses. *Tropical and Subtropical Agroecosystems* **15**, 97-103.

Early R.J., Mahgoub O. & Lu C.D. (2001) Energy and protein utilization for maintenance and growth in Omani ram lambs in hot climates. I. Estimates of energy requirements and efficiency. *Journal of Agricultural Science* **136**, 451-9.

Elliott R.C. & O'Donovan W.M. (1969) The dietary energy requirements of Dorper sheep. 1. The maintenance energy requirements of lambs and mature ewes. *Rhodesiar J. Agric. Res.* **7**, 89-96.

Elsaesser F., Pfaffl M.W., Meyer H.H., Serpek B. & Sauerwein H. (2002) Differences in somatotrophic axis, in blood cortisol, insulin and thyroid hormone concentrations between two pig genotypes with markedly divergent growth rates and the effects of growth hormone treatment. *Animal Science* **74**, 423 - 30.

Engels E.A.N., Malan A. & Baard M.A. (1974) The voluntary feed intake of three breeds of sheep on natural pasture. *South African Journal of Animal Science* **4**, 27-9.

Faichney G.J. & Gherardi S.G. (1986) Relationships between organic matter digestibility, dry matter intake and solute mean retention times in sheep given a ground and pelleted diet. *The Journal of Agricultural Science* **106**, 219 - 22.

Fernandes M., Resende K.T., Tedeschi L.O., Fernandes J.S., Silva H.M., Carstens G.E., Berchielli T.T., Teixeira I. & Akinaga L. (2007) Energy and protein requirements for maintenance and growth of Boer crossbred kids. *Journal of Animal Science* **85**, 1014-23.

Ferrell C.L., Crouse J.D., Field R.A. & Chant J.L. (1979) Effects of sex, diet and stage of growth upon energy-utilization by lambs. *Journal of Animal Science* **49**, 790-801.

Foury A., Geverink N.A., Gil M., Gispert M., Hortos M., Furnols M.F.I., Carrion D., Blott S.C., Plastow G.S. & Mormede P. (2007) Stress neuroendocrine profiles in five pig breeding lines and the relationship with carcass composition. *Animal* **1**, 973-82.

Fox D.G., Tedeschi L.O., Tylutki T.P., Russell J.B., Van Amburgh M.E., Chase L.E., Pell A.N. & Overton T.R. (2004) The Cornell Net Carbohydrate and Protein System model for evaluating herd nutrition and nutrient excretion. *Animal Food Science and Technology* **112**, 29 - 78.

Freer M., Dove H. & Nolan J.V. (2007) *Nutrient Requirements of Domesticated Ruminants*. CSIRO Publishing.

Freer M., Moore A.D. & Donnelly J.R. (1997) GRAZPLAN: Decision support systems for Australian grazing enterprises .2. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. *Agricultural Systems* **54**, 77-126.

Freetly H.C., Nienaber J.A. & Brown-Brandl T. (2002) Relationships among heat production, body weight, and age in Finnsheep and Rambouillet ewes. *Journal of Animal Science* **80**, 825-32.

Friggens N.C. & Newbold J.R. (2007) Towards a biological basis for predicting nutrient partitioning: the dairy cow as an example. *Animal* **1**, 87-97.

Galvani D.B., Pires C.C., Kozloski G.V. & Sanchez L.M.B. (2009) Protein requirements of Texel crossbred lambs. *Small Ruminant Research* **81**, 55-62.

Galvani D.B., Pires C.C., Kozloski G.V. & Wommer T.P. (2008) Energy requirements of Texel crossbred lambs`. *Journal of Animal Science* **86**, 3480 - 90.

Givens D.I. & Moss A.R. (1994) Effect of breed, age and bodyweight of sheep on the measurement of apparent digestibility of dried grass. *Animal Feed Science and Technology* **46**, 155-62.

Hatfield P.G., Head W.A., Fitzgerald J.A. & Hallford D.M. (1999) Effects of level of energy intake and energy demand on growth hormone, insulin, and metabolites in Targhee and Suffolk ewes. *Journal of Animal Science* **77**, 2757-65.

Hegarty R.S. (2004) Genotype differences and their impact on digestive tract function of ruminants: a review. *Australian Journal of Experimental Agriculture* **44**, 458-67.

Herd R., Oddy V. & Lee G. (1993) Effect of divergent selection for weaning weight on liveweight and wool growth responses to feed intake in Merino ewes. *Australian Journal of Experimental Agriculture* **33**, 699-705.

Holst P.J., Fogarty N.M. & Stanley D.F. (2002) Birth weights, meningeal lesions, and survival of diverse genotypes of lambs from Merino and crossbred ewes *Australian Journal of Agricultural Research* **53**, 175-81.

Howes J.R., Davis G.K. & Hentges J.F. (1963) Comparative digestive powers of Hereford and Brahman cattle. *Journal of Animal Science* **22**, 22-&.

Hunter R.A. & Siebert S.D. (1985) Utilization of low-quality roughage by Bos taurus and Bos indicus cattle. *British Journal of Nutrition* **53**, 637 -48.

Jassim R.A.M.A., Hassan S.A. & Al-Ani A.N. (1996) Metabolizable energy requirements for maintenance and growth of Awassi lambs. *Small Ruminant Research* **20**, 239-45.

Kamalzadeh A. & Aouladrabiei M.R. (2009) Effects of Restricted Feeding on Intake, Digestion, Nitrogen Balance and Metabolizable Energy in Small and Large Body Sized Sheep Breeds *Asian-Aust. J. Anim. Sci* **22**, 667-73.

Kamalzadeh A. & Shabani A. (2007) Maintenance and growth requirements for energy and nitrogen of Baluchi sheep. *International Journal of Agriculture and Biology* **9**, 535-9.

Kennedy P.M. (1982) Ruminal and intestinal digestion in Brahman crossbred and Hereford cattle fed alfalfa or tropical pasture hay. *Journal of Animal Science* **55**, 1190-9.

Khalil M.H., El-Gabbas H.M., Khalifa H.H. & Abdel-Fattah M.S. (1990) Effect of exposure to solar radiation on some physiological and haematological parameters in local and crossbred sheep. *Egyptian Journal of Animal Production* **27**, 47-60.

Kilminster T.F. & Greeff J.C. (2011) A note on the reproductive performance of Damara, Dorper and Merino sheep under optimum management and nutrition for Merino ewes in the eastern wheatbelt of Western Australia. *Tropical Animal Health and Production* **43**, 1459-64.

Kleeman D.O. & Dolling C.H.S. (1978) Relative efficiency of Merino and Border Leicester x Merino ewes. *Australian Journal of Agricultural Research* **29**, 605-13.

Kleemann D.O., Dolling C.H.S. & Ponzoni R.W. (1982) Effect of breed of dam and lamb, and of lamb sex on efficiency of conversion of food to lamb and wool in Merino and 1st-cross Merino ewes. *Australian Journal of Agricultural Research* **33**, 293-302.

Kleemann D.O., Dolling C.H.S. & Ponzoni R.W. (1984) Effect of breed of dam, type of birth and sex of lamb on efficiency of conversion of food to lamb and wool in Merino, Poll Dorset x Merino and Border Leicester x Merino ewes. *Australian Journal of Agricultural Research* **35**, 579-94.

Li L., Oddy V.H. & Nolan J.V. (2008) Whole-body protein metabolism and energy expenditure in sheep selected for divergent wool production when fed above or below maintenance. *Australian Journal of Experimental Agriculture* **48**, 657-65.

Liu S.M., Kou Y.C., Pan L.Y., Zhang L. & Zai W.Z. (1991) Efficiency of energy utilization by Hu-sheep during sucking, growing, pregnant and lactating periods and the energy requirement for maintenance of the sheep. *World Review of Animal Production* **26**, 85-9, 7.

Lopez S., Frutos P., Mantecon A.R. & Giraldez F.J. (2001) Comparative digestion of herbage by two breeds of sheep: effects of grass maturity stage and level of intake. *Animal Science* **73**, 513-22.

Lourenco A.L.G., Dias-da-Silva A.A., Fonseca A.J.M. & Azevedo J.T. (2000) Effects of live weight, maturity and genotype of sheep fed a hay-based diet, on intake, digestion and live weight gain. *Livestock Production Science* **63**, 291-6.

Luo J., Goetsch A.L., Nsahlai I.V., Johnson Z.B., Sahlu T., Moore J.E., Ferrell S.L., Galyean M.L. & Owens F.N. (2004) Maintenance energy requirements of goats: predictions based on observations of heat and recovered energy. *Small Ruminant Research* **53**, 221-30.

Mahgoub O., Lu C.D. & Early R.J. (2000) Effects of dietary energy density on feed intake, body weight gain and carcass chemical composition of Omani growing lambs. *Small Ruminant Research* **37**, 35 - 42.

Mann D.L., Goode L. & Pond K.R. (1987) Voluntary intake, gain, digestibility, rate of passage and gastrointestinal-tract fill in tropical and temperate breeds of sheep. *Journal of Animal Science* **64**, 880-6.

Marai I.F.M., El-Darawany A.A., Fadiel A. & Abdel-Hafez M.A.M. (2007) Physiological traits as affected by heat stress in sheep - A review. *Small Ruminant Research* **71**, 1-12.

Martin K.M., McGilchrist P., Thompson J.M. & Gardner G.E. (2011) Progeny of high muscling sires have reduced muscle response to adrenaline in sheep. *Animal* **5**, 1060-70.

Miller D.B. & O'Callaghan J.P. (2002) Neuroendocrine aspects of the response to stress. *Metabolism-Clinical and Experimental* **51**, 5-10.

Molina E., Ferret A., Caja G., Calsamiglia S., Such X. & Gasa J. (2001) Comparison of voluntary food intake, apparent digestibility, digesta kinetics and digestive tract content in Manchega and Lacaune dairy sheep in late pregnancy and early and mid lactation. *Animal Science* **72**, 209-21.

Moneva P., Gudev D., Popova-Ralcheva S. & Alexiev Y. (2008) Thermotolerance in the three breeds of sheep in Bulgaria. *Zhivotnov'dni Nauki* **45**, 147-52.

Mormede P., Courvoisier H., Ramos A., Marissal-Arvy N., Ousova O., Desautes C., Duclos M., Chaouloff F. & Moisan M.P. (2002) Molecular genetic approaches to investigate individual variations in behavioral and neuroendocrine stress responses. *Psychoneuroendocrinology* **27**, 563-83.

Mormede P. & Terenina E. (2012) Molecular genetics of the adrenocortical axis and breeding for robustness. *Domestic Animal Endocrinology* **43**, 116 - 31.

Oliveira de Souza E.J., Valadares Filho S.d.C., Guim A., Diniz Valadares R.F., Marcondes M.I., Chaves Veras A.S., Amaral P.d.M. & Santos T.R. (2012) Energy nutritional requirements for females of Nellore, Nellore x Angus and Nellore x Simmental fed on two forage: concentrate ratios. *Revista Brasileira De Zootecnia-Brazilian Journal of Animal Science* **41**, 753-61.

Olthoff J.C., Dickerson G.E. & Nienaber J.A. (1989) Energy Utilization in Mature Ewes from Seven Breeds with Diverse Production Potentials. *Journal of Animal Science* **67**, 2550-64.

Pond W.G., Church D.C. & Pond K.R. (1995) *Basic Animal Nutrition and Feeding*. John Wiley & Sons, New York.

Ponnampalam E.N., Warner R.D. & Dunshea F.R. (2012) Basal and hormone-stimulated metabolism in lambs varies with breed and diet quality. *Domestic Animal Endocrinology* **42**, 94-102.

Prendiville R., Pierce K.M., Delaby L. & Buckley F. (2011) Animal performance and production efficiencies of Holstein-Friesian, Jersey and Jersey x Holstein-Friesien cows throughout lactation. *Livestock Science* **138**, 25 - 33.

Ranilla M.J., Carro M.D., Valdes C., Giraldez F.J. & Lopez S. (1997) A comparative study of ruminal activity in Churra and Merino sheep offered alfalfa hay. *Animal Science* **65**, 121-8.

Ranilla M.J., Lopez S., Giraldez F.J., Valdes C. & Carro M.D. (1998) Comparative digestibility and digesta flow kinetics in two breeds of sheep. *Animal Science* **66**, 389-96.

Rattray P.V., Garrett W.N., East N.E. & Hinman N. (1973a) Net energy requirements of ewe lambs for maintenance, gain and pregnancy and net energy values of feedstuffs for lambs. *Journal of Animal Science* **37**, 853-7.

Rattray P.V., Garrett W.N., Meyer H.H., Bradford G.E., Hinman N. & East N.E. (1973b) Net energy-requirements for growth of lambs age 3 to 5 months. *Journal of Animal Science* **37**, 1386-9.

Regadas J.G.L., Pereira E.S., Villarroel A.B.S., Pimentel P.G., de Medeiros A.N., Fontenele R.M. & Maia I.S.G. (2011) Body composition and net protein requirements for growing Santa Ines sheep. *Revista Brasileira De Zootecnia-Brazilian Journal of Animal Science* **40**, 1339-46.

Richardson J.M., Wilkinson R.G. & Sinclair L.A. (2003) Synchrony of nutrient supply to the rumen and dietary energy source and their effects on the growth and metabolism of lambs. *Journal of Animal Science* **81**, 1332-47.

Santos Y.C.d.C., Perez J.R.O., Geraseev L.C., Teixeira J.C. & Bonagurio S. (2002) Requirement of net energy for maintenance of Bergamacia lambs

Exigencia de energia liquida para mantenca de cordeiros Bergamacia dos 35 aos 45 kg de peso vivo. *Ciencia e Agrotecnologia* **26**, 182-7.

Sanz Sampelayo M.R., Lara L., Gil Extremera F. & Boza J. (1995) Energy utilization for maintenance and growth in preruminant kid goats and lambs. *Small Ruminant Research* **17**, 25-30.

Shinde A.K. & Karim S.A. (2007) Energy expenditure of sheep and goats at pasture - a review. *Indian Journal of Small Ruminants* **13**, 1-18.

Symington R.B. (1960) Studies on the adaptability of three breeds of sheep to a tropical environment modified by altitude. I. The annual fluctuation in body temperature and body temperature increase between 6.30 a.m. and 12.30 p.m. *Journal of Agricultural Science* **55**, 287-94.

Tedeschi L.O., Cannas A. & Fox D.G. (2010) A nutrition methematical model to account for dietary supply and requirements of energy and other nutrients for domesticated small ruminants: The development and evaluation of the Small Ruminant Nutrition System. *Small Ruminant Research* **89**, 174 - 84.

Thomson D.J., Fenlon J.S. & Cammell S.B. (1979) Estimates of maintenance requirement of growing lambs. *British Journal of Nutrition* **41**, 223-9.

Trompf J.P., Gordon D.J., Behrendt R., Curnow M., Kildey L.C. & Thompson A.N. (2011) Participation in Lifetime Ewe Management results in changes in stocking rate, ewe management and reproductive performance on commercial farms. *Animal Production Science* **51**, 866-72.

Wilkes M.J., Hynd P.I. & Pitchford W.S. (2012) Damara sheep have higher digestible energy intake than Merino sheep when fed low-quality or high-quality feed. *Animal Production Science* **52**, 30-4.

Wu J.L., Qiao L.Y., Liu J.H., Yuan Y.N. & Liu W.Z. (2012) SNP variation in ADRB3 gene reflects the breed difference of sheep populations. *Molecular Biology Reports* **39**, 8395-403.

Young B.A. & Corbett J.L. (1968) Energy requirement for maintenance of grazing sheep measured by calorimetric techniques. *Proceedings of the Australian Society of Animal Production* **7**, 327-34.

Zeeman P.J.L., Marais P.G. & Coetsee M.J. (1983) Nutrient selection by cattle, goats and sheep on natural Karoo pasture 1. Digestibility of organic matter. *South African Journal of Animal Science* **13**, 236 - 9.