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Best practice for production feeding of lambs: A review of the literature

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Executive Summary

Interest in production feeding lambs has intensified in Australia in recent years. However, there has been a scarcity of evidenced-based guidelines available to producers or their advisors. As a result, the intensive lamb finishing industry has developed a culture of "learning by their mistakes" or passing on practices from one to the next, such that particular practices have become recommendations and guidelines.

Because research has not kept pace with the demands of industry, many of the current guidelines have been gained from the internet, anecdotes or from scant and often unrelated, fragments of research. Despite this, the majority of feedlotters in Australia have managed to develop an industry that is basically sound and competitive.

Concurrently, returns to intensive lamb finishers have been volatile which has resulted in all but a small percentage of the industry continuing to operate on an "opportunity" basis; this in itself, has not driven interest or investment in either lamb feedlot or finishing system research which has, to a large extent dictated the current industry position.

Growth rate is the main determinant of profitability within a finishing system. Yet growth rates of lambs in Australian finishing systems are well below expected industry standards and the reasons for this have not been readily explained.

The purpose of this review was to thoroughly investigate all factors relating specifically to lamb growth with the objective of reducing the need for producers to continue to 'learn by their mistakes', to provide evidence with which to counteract or support 'industry myths', and to provide a strategic and soundly-based direction for research.

This review has provided confirmation that the guidelines for the nutrient requirements of fast growing lambs vary widely and that there remains a diversity of opinion as to which is the correct source of information and this is yet to be resolved. The genetic value of Australian lambs is not being fully realised with growth rates well below potential, and although there is considerable variation between individual lambs in their nutritional response, it appears certain that their nutritional requirements remain unclear.

Contrary to recent advice provided to lamb feedlotters, there appears to be clear evidence supporting the retention of roughage in the diet of lambs, and other than the inclusion of a source of calcium and salt added to the ration, the remaining minerals should be formulated to counteract known deficiencies.

Although not standard industry practice there is clear evidence of the benefits of imprinting lambs to unfamiliar feedstuffs before weaning, both in growth rate and adaptation to a change in environment, while gradual introduction to cereal grains will alleviate the risk of acidosis during the adaptation period.

Clearly, there are many lambs that do not successfully adapt to a feedlot environment either due to restricted intake of nutrients at a critical phase in their development or for reasons of failed socialisation. Although there are plethoras of feed additives that are available for addition to a feedlot diet, it is clear that many of these products add unnecessary cost to many finishing rations. Rations that utilise feeds of medium degradability minimise the requirement for feed additives.

No strong relationship was found between ration design and lamb growth, such that the choice of ration design should be determined by cost-efficiency alone. In addition, for the choice of feeding method, either on an *ad libitum* basis or by daily allocation, there was insufficient evidence found to support restriction of feed intake, however this is an area worthy of further investigation, and is a concept encouraged by some feedlotters. Choice feeding, however, appears to have the potential to improve lamb growth rates, although the practicalities of commercial scale adoption of this system may preclude further research investment in this area.

As the design of lamb feedlots varies so widely and research in this area appears scarce, it was impossible to find any association between many aspects of feedlot design and lamb performance. It appears that there is a relationship between lamb growth rate and stocking density, but the exact nature of this relationship remains unclear. The benefits of feedlotting over paddock finishing have not been clarified, nor has the choice of feed and/or watering systems. The existing guidelines for feed and water access space vary significantly and can be considered unreliable.

In studies where the welfare of intensively finished lambs were considered, it appeared that there was a positive impact on lamb growth rates. Shy feeders have a significant impact on average feedlot performance, and hence profitability, although the way in which they are managed varies widely. Strong evidence in favour of providing shade and shelter and a scarcity of evidence in support of shearing, other than to optimise skin value, may help to dispel some current industry myths.

The breeding and selection of lambs with above average growth potential is still being under-utilised by a large proportion of the sheep industry. Although there are still not sufficient large lean lambs being marketed specifically into feedlot finishing systems, those feeding their own lambs could make greater use of performance recording and selection systems such as Lambplan (now Sheep Genetics Australia).

With the industry experiencing lamb growth rates below potential, spending on electronic performance recording equipment may not be justifiable at this stage. However, sub optimal growth rates do strengthen the case for intensive lamb finishers to more thoroughly scrutinise their budget position than is currently practiced.

Recommendations for best practice management have been provided at the end of each section, however, many areas were identified during this review that require further clarification before they can be recommended as best practice.

This review has confirmed the hypothesis that the current lamb finishing industry has developed from a base of ‘trial and error’, in combination with anecdotal information supported by a small amount of fragmented research. To grow as a sustainable and profitable industry, a strategic plan of investment will be required in areas of research specific to optimising lamb growth and feed conversion efficiency. Clarification of the influencing factors that combine to optimise lamb growth and hence profitability will result in the production of a ‘Best Practice’ manual for intensively finishing lambs and ultimately, increased production of Australian lamb.

Recommended further research

At the conclusion of each topic, recommendations have been made for further research. These recommendations are summarised below:

Section 1: Nutrition

1.1 Dry matter intake

- Restriction of intake to improve carcase quality as for beef cattle; effect of an 80% restriction in dry matter intake on feed conversion efficiency and proportion of gain (H. Oddy 2006 pers comm. 12 September)

1.2 Protein and energy requirements of fast growing lambs

- Two sets of nutrient recommendations (NRC 1985; Oddy 2006) should be tested with common genotypes under indoor and outdoor conditions in Australia to determine growth and carcase responses, before a comprehensive set of guidelines can be recommended that will be acceptable to the whole of industry.
- Determine if different genotypes (Merino, fat tails and British breed crosses) differ significantly in their nutrient requirements.

1.3 Fibre requirement of fast growing lambs

- The effect of silage chop length on dry matter intake and growth rates of lambs
- Roughage presentation and hay delivery design

1.4 Mineral and vitamin requirements of fast growing lambs

- No further research appears to be required in this area

1.5 Water requirements of fast growing lambs

- Water pressure and trough refill time to optimise water intake
- Self-cleaning troughs
- Trough design
- Aeration of water supply

1.6 Managing dietary change

- Determine the effect high quality hay and legume hay has on rapid adaptation to feed and dry matter intake

1.7 Factors influencing growth and feed conversion ratio in fast growing lambs

- Determine the optimum stage of growth to achieve optimum efficiency
- Determine the true value in manipulation of growth in lambs; is it the same as for cattle?
- Clarify the effect of growth rate prior to weaning and its affect on subsequent growth rate and fatness

1.8 Nutritional restriction during pregnancy

- Investigation of the effects of nutritional restrictions at early, mid and late pregnancy on growth rate, weaning weight and post weaning weight to 12 months of age
- Investigation of the effects of nutritional restrictions at early, mid and late pregnancy on carcase quality of the progeny at industry-relevant slaughter weights

1.9 Feed Additives

- Determine the effect of magnesium in feed rations on the alleviation of stress of fast growing lambs under intensive conditions (H. Oddy 2006 pers comm.. 13 September)
- Determine the effect of chromium supplementation in the diets of fast growing lambs

1.10 Ration design

- Are the components of a ration more or less important than the end formulation?

1.11 Feeding methods

- Determine the effect of restricted feeding on feed efficiency
- Determine if the intensive lamb finishing industry would adopt a choice feeding system
- Determine the cost-efficiency of choice feeding on a commercial scale

Section 2: Feedlot Design

2.1 Feeding equipment

- See 2.3

2.2 Watering equipment

- See 2.3

2.3 Guidelines for feed and water access

- Determine optimum feeding space allowance for self feeders
- Determine the number of feeders required per pen
- Determine the role of "lick feeders" in controlling acidosis and optimising lamb growth
- Identify the effects of feeder design on growth and performance
- Development of a hay delivery system that minimises waste
- Identify any effects of water trough space and design on lamb growth rate
- Identify the effects of water pressure (return rate) on growth rates

2.4 Feedlot Design

- Determine the relationship between the number of lambs per pen and growth rate
- Determine the optimum pen size and shape
- Determine the optimum feedlot layout
- Determine the optimum feedlot slope

2.5 Stocking density

- Determine the optimum stocking density for outdoor feedlots during hot, cold and or wet conditions
- Compare performance of lambs held in:
  10 acre paddocks *vs* paddock supplemented *vs* feedlots (G. Martin)
- Are economically 'optimum' stocking rates acceptable in terms of animal welfare?

2.6 Paddock supplementation versus feedlot finishing

- Determine the difference in growth rate between paddock and feedlot finishing

Section 3: Animal Welfare

3.1 Animal behaviour

- Mixing of unfamiliar mobs of lambs
- Effect of socialisation on ease of introduction and the associative effects on pH decline and sheep meat eating quality
- The effect of temperament on lamb growth
- The effect of pen enrichment on the growth rate of confined lambs

3.2 Shy feeders

- Investigate the causes of shy feeding and the cost to the intensive lamb finishing industry
- Determine the difference in the incidence of shy feeding between Merino lambs and crossbred lambs
- GPS or CCTV study of feeding behaviour and time spent in shade

3.3 Shearing

- No further research appears to be required in this area

3.4 Heat Stress

- Determine the amount of shade required to optimise the performance of intensively finished lambs
- Determine the cost-efficiency of shearing to optimise skin value vs not shearing to optimise performance during hot weather

3.5 Cold stress

- No research appears to be required in this area

3.6 Shade and shelter

- See 3.4

3.7 Disease prevention and animal health

- Determine the predisposing factors leading to pleurisy and pneumonia in paddock and feedlot finished lambs

Section 4: Management

4.1 Breeding and selection

- Determine the influence of genes on the rate of adaptation of lambs to an intensive finishing environment
- Investigate the cause of underutilisation of estimated breeding values in finishing systems

4.2 Performance monitoring and recording

- Determine the reasons for success or failure of supply chains
- Investigate the cost-efficiency of automatic weighing and drafting systems

4.3 Marketing and budgeting

- There does not appear to be a requirement for further research in this area, other than that currently being undertaken

Introduction

The practice of intensive finishing of lambs has been carried out on-farm for many years on an opportunistic basis, but as lamb prices and the export demand for Australian lamb has increased, producers have invested in more permanent infrastructure to support a full-time lamb finishing business.

Intensive finishing of lambs is a high-turnover, low-margin business and is therefore high-risk, which requires excellent business management skills and an accurate supply of information.

Unfortunately research has not kept pace with industry expansion which has resulted in many operators learning by their mistakes, which many continue to do, despite there now being a plethora of guidelines and general information relating to successful lamb finishing available via a range of publications. However, some of the information which has found its way from anecdotal into the reliable advice category, has resulted in the establishment of infrastructure and beliefs which appear to support only average daily rates of growth and profitability in most instances.

As there is a wide range of information available to producers, advisors and researchers, all of these sources have been given equal weighting in this review. These include scientific literature, general publications and fact sheets, personal comments and the World Wide Web. Although the use of the internet as an information source is often discounted as suspect, at least 16% of intensive lamb finishers have nominated this as a major information provider (Giason & Wallace, 2006); therefore, it cannot be discounted or ignored.

It is the intention of this report to thoroughly review all aspects of the intensive lamb finishing industry under the terms of reference that specifically relate to growth, as this is the main profit driver in an intensive finishing system. Although it may appear that some critical factors relating to the lamb feedlot industry have not been included in this review, those factors that do not directly influence growth, will have been omitted as per the original terms of reference.

The terms of reference for this review have been addressed within four main sections which include nutrition, feedlot design, animal welfare and management.

This report is not intended to represent a best practice production feeding manual for intensively finished lambs, but is more a review of what *is* current practice, why is it current practice (that is, what is it based on?), is there any scientific basis for the current practice and therefore, can it be recommended as best practice? Recommendations for further research can then be made and a best practice manual can be developed.

It is likely that there are excellent practices within this rapidly growing industry that may have escaped the attention of the reviewer; however, in an attempt to avoid this being the case, a reference group consisting of feedlotters, researchers, advisors and MLA program managers was formed and consulted throughout the review. Many of this group have contributed unpublished work which may otherwise not have been available and the efforts of particular individuals have added significant value to this review.

For the intensive lamb finishing industry to grow and prosper, it is essential that producers have access to information that is reliable and soundly-based. This will facilitate correct decision making in relation to nutrition, feedlot design, management strategies and animal welfare practices that optimise lamb growth and business profitability, so that lamb supply can be increased and sustained into the future.

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1 Nutrition

There is wide variation in the literature for nutrient requirements of fast growing lambs, which can be confusing for advisers and producers alike. Examination of a large number of studies has failed to determine a clear link between growth rate and crude protein and metabolisable energy level in formulated diets due to a large number of confounding factors in the trials reviewed. Although, if factors such as breed, age, live weight and ration formulation are ignored, a strong relationship does exist between crude protein and growth, but no relationship was found between the energy content of the diet and growth response.

It is unclear how the current recommendations in the literature relate to the modern Australian genotype. From the number of studies reviewed, the responses are highly variable and methodologies inconsistent. There may be an opportunity to further reduce the current level of feed conversion efficiency, which appears to be higher in Australia than reported in many overseas studies, particularly via control of dry matter intake; this requires further investigation. It is clear that long fibre is required in the diet of fast growing lambs to optimise adaptation to feed and rumen pH; although, the ideal chop length has yet to be determined.

There appears to be no reason to question the current recommendations for mineral and vitamin supplementation, other than on an individual basis in addressing specific deficiencies. The provision of cool, clean water, low in soluble salts, is associated with optimum intakes, although trough design requires further investigation. There are many factors that influence the successful adaptation of lambs to a change in diet, but careful management and an awareness of animal behaviour generally results in an uneventful transition. The many factors that influence growth and the efficiency of conversion of feed to live weight gain, make it difficult to determine the optimum level of growth and efficiency that the industry should strive to achieve. It is evident, however, that breeding values are being underutilised which may account in part for the poor rates of growth that are currently the industry averages. The nutrition of the ewe during pregnancy and the potential effect on productivity of the progeny requires further investigation for lambs aged between three and twelve months.

There is a range of feed additives available to the lamb finishing industry, and while limestone and salt are considered as essential feed ingredients, the value and benefits of others have not been established.

Ration designs are generally based on the most readily available feedstuffs more so than by their cost-efficiency, and range from simple to highly complex. The relationship between the design of the ration or the method by which it was delivered and lamb performance was not immediately obvious. Although there are a range of ration formulation programs commercially available to producers and advisors, they do not appear to be widely utilised; pelleted formulations negate the need to understand ration formulation. There is widespread industry disagreement and uncertainty about the nutrient levels required to optimise productivity of intensively finished lambs, and working toward resolution via strategic research is likely to benefit the whole industry in the long term.

Most producers are aware of the value of either breeding or sourcing lambs with the potential for rapid, lean growth in order to optimise productivity and turnover. However, few appear to have more than a basic understanding of nutrition or the nutrient requirements of lambs. Ruminant nutrition is a complex science in which, in an attempt to devise ‘simple solutions’, a great deal of accuracy, and hence productivity, may be lost. This may explain to some degree, why an industry with lambs able to potentially grow at 400-500grams per head per day, continue to average only 250 grams.

This section of the report will review the following terms of reference:

- Dry matter intake
- Protein and energy requirements of fast growing lambs
- Fibre requirement of fast growing lambs
- Mineral and vitamin requirement of fast growing lambs
- Water requirements requirement of fast growing lambs
- Managing dietary change
- Factors influencing growth and feed conversion ratio in fast growing lambs
- The effect of nutritional restriction during pregnancy
- Feed additives
- Ration design and formulation
- Feeding methods

The specific nutrient requirements for fast growing, lean modern Australian genotypes, under Australian conditions are not clear, and despite numerous publications offering recommendations, there is no consensus across the industry.

The guidelines for the nutrient requirements of fast growing lambs vary between authors and publications. Some of these recommendations are so detailed that it would be beyond the resources of most producers or their advisors to formulate a ration to this level of complexity. It is unclear if a high level of ration complexity is required to facilitate expression of growth potential.

Most European studies are formulated to follow the guidelines of National Research Council (NRC) (1985) although Australian researchers do not agree, and prefer a different set of guidelines.

It is important that the nutrient requirements of fast growing lambs are clearly determined as feed costs amount to between 25% (paddock finished) to 60% (feedlot finished) of the total cost of finishing lambs.

Although breeds are frequently included in the published data within feeding trials, there is seldom any evidence linking the estimated breeding value (EBV) of the parents and its relationship with the performance of the progeny under specified nutritional regimes. There is also a tendency for researchers to refer to ‘high’ and ‘low’ planes of nutrition, which fails to provide the reader with a clear picture of the ration formulation and therefore effectively analyse the results and draw conclusions.

It is virtually impossible to compare many of the published studies and develop a clear set of guidelines due to the number of confounding factors involved such as breed, age, live weight, ration formulation and environment.

This section will review the current recommendations which are readily available to researchers, and to a lesser extent, advisors and are of limited value to producers.

1.1 Dry matter intake

Dry matter intake is the main determinant of growth rate, but is seldom determined on a commercial scale under intensive feeding conditions due to the difficulty in accurately measuring feed wastage. This is of particular relevance where hay and/or grain is provided on an *ad libitum* basis either in a paddock or feedlot.

Dry matter intake can be calculated by measuring the quantity of total feed intake per lamb per day on a moisture-free basis (Jones and Stewart 1995). Many factors influence dry matter intake and include; palatability and digestibility of the ration or individual feeds, the rate at which the feed is degraded, rumen outflow rate, protein content (Manso *et al*. 1998), water content of the feed (Black *et al.* 1987), mineral levels in the diet (Beede *et al.*1984), the pH level of the rumen fluid (Phy and Provenza 1998) , weight and age of lambs.

Additional factors include trough space and access, feeder positioning relative to traffic areas (P. Gunner, pers comm. 14 July 2006), environmental temperature (Dixon *et al*. 1999; Brink 1975), photoperiod (NRC 1987; Abbas *et al.* 2002), neophobia relating to feed and equipment (Chapple and Lynch 1986), and time of the day that lambs are fed (S. Chapman, pers comm. 13 September 2006).

The majority of intensive finishers either provide lambs with high quality pasture, plus or minus grain supplementation, or provide self-feeders to facilitate *ad libitum* access, thereby avoiding the need to calculate feed requirements. The majority of lamb finishers supply feed on an *ad libitum* basis (Gaison and Wallace 2006) via self feeders for increased labour efficiency with less than 40% feeding out in open troughs. As this is the preferred feeding method, feed intake is often calculated on the amount of feed mixed or purchased retrospectively.

Some allowance is currently made for wastage, and estimates can be as high as 20% for *ad libitum* hay and as low as 2% for grain supplied in a self feeder.

Prediction of dry matter intake is not an exact science and can be subject to considerable variation. As the amount of feed a lamb will consume during the finishing period amounts to approximately 58% of the total cost of finishing, prediction of intake is important for feed and financial budgeting purposes. For feed budgeting, purposes, feed intake is calculated on an ‘as-fed’ basis. However, rations are formulated and calculated on a dry matter basis, as nutrients are predominantly contained within the dry matter portion of the diet.

Estimation of dry matter intake can be completed more accurately where lambs have access to a pelleted diet in a shedded facility, or in a controlled environment, such as a research facility. Those producers feeding a controlled amount of the diet once or twice a day in troughs are able to calculate intake with a higher degree of accuracy.

Intensive lamb finishers who do feed out controlled amounts daily in troughs, report greater intakes and growth responses if lambs are fed mid afternoon (G Campbell 2006 pers. comm., 13 September). There is significant evidence within the cattle feedlot literature that restricted or controlled feeding regimes can increase feed efficiency and carcase quality. This will be discussed in Part 1.10.

Daily dry matter intake of fast growing lambs can vary between 3.8-4.2% of live weight (NRC 1985) which has been confirmed by Knee (2005) in indoor feeding trials in south-western Victoria, when feeding lambs a pelleted diet.

In studies conducted on haired sheep, Rocha *et al.* (2004), Morais *et al.* (1999) and Susin *et al*. (2000), confirmed the recommendations of NRC (1985) which are detailed in Table 1 and concurs with intake rates of between 3.2-4.2% measured by Fluharty *et al.* (2001) feeding maize-based pellets.

Table 1 Daily dry matter intake requirements of early weaned lambs with rapid growth potential (NRC 1985)

LW	Growth rate	DMI kg	DMI % of LW
10	250	0.6	6.0
20	300	1.2	6.0
30	325	1.4	4.7
40	400	1.5	3.8
50	425	1.7	3.4
60	350	1.7	2.8

When the formulation of the ration is below the nutrient requirements of the animal, there is a reliance on increasing intake to compensate for the low nutrient density of the diet. However, if the rate at which the diet is degraded in the rumen is too low, secondary to the fibre content, only limited compensation can occur. Although the relationship between intake and milk production is clear in dairy cattle (Jones and Stewart 1995), Savage et al, (2006) was unable to confirm this during observations of feeding behaviour of fine wool Merino lambs under feedlot conditions (Figure 1).

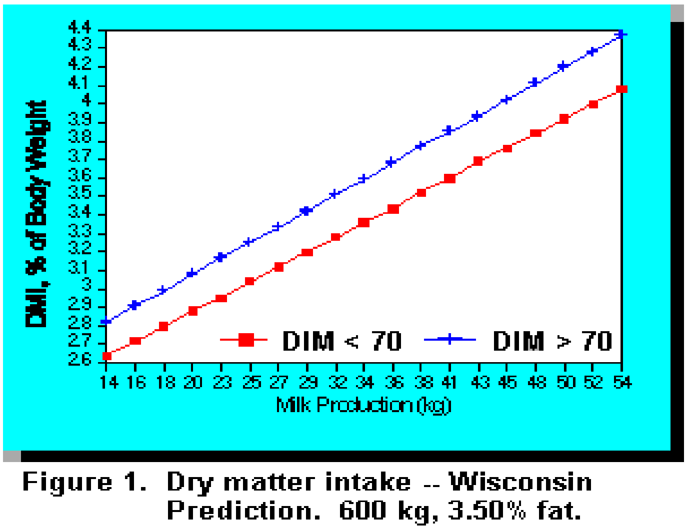


Figure 1 Relationship between dry matter intake and milk production in dairy cows (www.weds.afns.ualberta.ca)

Daily dry matter intake of housed wethers, recommended by AFRC (1995) and detailed in Table 2, is possibly limited in its relevance, as it does not include lambs growing at rates greater than 200 grams per head per day, which, in Australia in 2006, is not an economically viable rate of growth for intensively finished lambs. The AFRC (1993) recommendations are used as guidelines for ration formulation by some researchers in Australia (Wiese *et al*. 2003).

Table *2* Daily dry matter intake requirements of housed, castrated lambs for maintenance and live weight gain, (AFRC 1993)

LW kg	Growth rate g/day	DMI kg	DMI % of LW
20	50	0.5	3.0
20	100	0.6	3.0
20	150	0.8	4.0
20	200	1.0	5.0
30	50	0.6	2.0
30	100	0.8	3.0
30	150	1.0	3.0
30	200	1.3	4.0
40	50	0.8	2.0
40	100	1.0	3.0
40	150	1.3	3.0
40	200	1.6	4.0
50	50	0.9	2.0
50	100	1.2	2.0
50	150	1.5	3.0
50	200	1.9	4.0

- According to Professor Hutton Oddy (2007 pers comm. 31 January) “the SCA system would suggest that intake to match energy requirements to achieve 200,30 and 400g/d gain is 1.52, 1.99 and 2.48 kg DM/day at an ME density of 11 and 1.39, 1.83 and 2.27 kg DM /day at an ME density of 12 . These translate to a dry matter intake rate as a percentage of body weight of 3.8, 5 and 6.2% and 3.5, 4.6 and 5.7% for 11 and 12 ME respectively” These recommendations relate to a 40 kg lamb, standard reference weight 60 kg at 250 days of age.

Conclusion
The daily dry matter intake requirements of fast growing lambs can be calculated on a percentage of live weight basis to provide an estimate of intake for feed budgeting purposes. Where manipulation of carcase quality is to be achieved by restricted feeding regimes, assistance with more accurate assessment of intake may be required. NRC (1985) provide the most clear and concise recommendations of dry matter intake for growth rates more relevant to Australian conditions with which the scientific literature and experience of producers agrees.

Best Practice
- Budget on 3.8-4.2% of live weight

- Adjust according to live weight as per NRC (1985) for controlled or restricted feeding regimes
- Remove spoiled feed from troughs or self-feeders on a daily basis
- Minimise the water content of the feed (target 90% dry matter)
- Provide adequate trough or self-feeder space (Refer Section 2)
- Position feeders away from traffic areas
- Familiarise lambs with feeding equipment

Recommended further research

- Restriction of intake to improve carcase quality as for beef cattle; effect of an 80% restriction in dry matter intake on feed conversion efficiency and proportion of gain (H. Oddy 2006 pers comm. 12 September)

1.2 Protein and energy requirements of fast growing lambs

The energy content of a diet relates to the amount of energy produced as a result of the fermentation of the constituent feedstuffs rather than to an inherent 'energy value' of those feeds.

The metabolisable energy content of the diet contributes substantially to the cost and therefore, it is essential to develop some clarity in the guidelines for fast growing lambs. Currently there exists considerable variation between authors and publications in their guidelines for the energy requirements of fast growing lambs.

Although energy metabolism of the ruminant animal is a complex science, the lamb finishing industry may benefit from the development of a 'best-bet' set of guidelines for the energy requirements of fast growing lambs, rather than a complex set of scientific calculations.

NRC (1985) has published a clear set of guidelines that have yet to be tested under Australian conditions with genotypes more commonly found in southern Australian finishing systems.

In formulating rations, the most important consideration is the nutrient requirements of the rumen micro-organisms such that the flow of microbial protein to the small intestine is optimised, and that rumen outflow rate is optimised to facilitate further intake of nutrients.

Although Jones *et al*. (2004) state that "no single figure can adequately describe the percentage of crude protein that lambs require in their diet", there are a plethora of guidelines to be found both in the literature and available to lamb finishers online. It is important to determine which of these if any, is both soundly based and able to be confidently recommended to intensive lamb finishers in Australia.

The purpose of ration formulation is to produce a diet, either total or complementary, on a least cost basis that will optimise the growth rate of lambs. As a 2% reduction in the crude protein content of the diet can increase the profit margin by $1 per head, it is important to accurately determine requirements.

When trial rations are formulated, little account is taken in the formulation of *ad libitum* access to alternative feeds such as hay (Ryan and McIntyre 2006), silage or pasture and the effect of that additional feed, on the final formulation. The nutritive value of *ad libitum* feeds is seldom published making it impossible to assess the impact of the total formulation on the result achieved.

Many popular sources of information such as, state Departments of Agriculture and online publications, seldom reference the sources of their guidelines, therefore the reliability and origins of their recommendations remain unclear. However, a substantial proportion of intensive lamb finishers obtain their advice from the state departments; 50% of medium sized operators, 48% of small operators and 33% of large finishers (Giason and Wallace 2006).

The crude protein level in the ration depends on the energy density of the diet and the age and weight of the animal (H. Oddy. pers comm. 13 September 2006). This presents some difficulty in making specific recommendations as ‘best practice’ if age is not known. The role of accurately completed National Vendor Declarations in clearly defining the age of feeder lambs cannot be understated in the success of the best practice guidelines.
Up to 50% of lamb finishers source lambs from saleyards (Giason and Wallace 2006) where age is frequently unknown, therefore guidelines for dietary levels of crude protein and energy to optimise the growth of these lambs remains difficult to determine.

Anecdotally, industry advisers recommend between 10.5 to 11ME and 14% and 16% crude protein and most commercial pellet formulations (Milne Feeds, WA; Q-lamb, WA; Coprice Feeds, NSW; Laucke Mills, SA) are to be found within that range.

Some producers have been advised that a dietary crude protein level in excess of 14% is a ’waste’ of protein (T. Grant, pers comm. 8 August 2006) which is a view supported by Rocha *et al*. (2004) who found that plasma urea levels increased when the dietary crude protein level increased above 14%. Oddy (pers comm. 30 January 2007) suggests a minimum of 12 ME and 15-16% protein should optimise growth in lambs of unknown age.

AFRC (1993) includes guidelines of protein requirements on a metabolisable protein basis, but it is beyond the resources of most of the industry to formulate diets to this level of detail, and producers have indicated they require simple solutions (T. Grant pers comm. September 13 2006).

Table 3 Guidelines for the crude protein, metabolisable protein, metabolisable energy (ME), dry matter intake (DMI) requirements of fast growing lambs at specified daily rates of gain and live weights.

Source	LW kg	Growth rate g/day	DMI kg	DMI % of LW	ME per kg DM	Crude protein % of DM	MP g/day
NRC (1985)	20	300	1.2	6.0%	11.5	17%	
AFRC (1995)	20	50	0.5	2.5%	9.6		49
AFRC (1995)	20	100	0.6	3.0%	10.2		64
AFRC (1995)	20	150	0.8	4.0%	9.8		80
AFRC (1995)	20	200	1.0	5.0%	10.0		95
NRC (1985)	30	325	1.4	4.7%	12.0	15%	
SCARM (1990)	30 (Housed)	200	1.1	3.7%	11.0	10%	
SCARM (1990)	30 (Grazing)	200	1.3	4.3%	11.0	9%	
AFRC (1995)	30	50	0.6	2.0%	10.7		56
AFRC (1995)	30	100	0.8	2.7%	10.3		71
AFRC (1995)	30	150	1.0	3.3%	10.3		85
AFRC (1995)	30	200	1.3	4.3%	10.0		100
NRC (1985)	40	400	1.5	3.8%	11.4	16%	
AFRC (1995)	40	50	0.8	2.0%	10.0		63
AFRC (1995)	40	100	1.0	2.5%	10.1		77
AFRC (1995)	40	150	1.3	3.3%	9.8		91
AFRC (1995)	40	200	1.6	4.0%	9.9		105
NRC (1985)	50	425	1.7	3.4%	11.6	14%	
AFRC (1995)	50	50	0.9	1.8%	10.6		69
AFRC (1995)	50	100	1.2	2.4%	10.0		83
AFRC (1995)	50	150	1.5	3.0%	10.1		97
AFRC (1995)	50	200	1.9	3.8%	9.9		110
NRC (1985)	60	350	1.7	2.8%	11.6	14%	

Schroeder (1994) states that although there is a conversion equation from crude protein to metabolisable protein, there is little value in formulating rations to the level of metabolisable protein.

MP = (Crude protein x 0.908) – 3.77

If the level of crude protein and/or ME (MJ ME /kg DM) is too low in the diet, to some extent, lambs can compensate by increasing dry matter intake, but their capacity to do that will be limited by the rate at which the diet is degraded in the rumen and rumen outflow rate.

As there is a group of producers finishing haired sheep in western New South Wales, as part of a developing supply chain, the protein and energy requirements of haired or fat-tailed sheep have been investigated and Haddad *et al*. (2001) has indicated that a dietary level of 16% crude protein is optimal for Awassi sheep. Haddad has indicated, though, that it is largely unclear if different genotypes have different crude protein and/or ME requirements.

Computer programs such as Grazfeed™, Takeaway™, and Ready Rations™, are used to assist in ration formulation for growing lambs, however, due to program constraints, provide limited assistance where growth rates in excess of 250 grams per head per day are required. Under the market conditions operating in 2006, it is generally unprofitable to have lambs growing at less than 300 grams per head per day within an intensive, confined feedlot system.

Bell *et al*. (2003) recommend that rations be formulated based on the relationship between crude protein and metabolisable energy taken from Grazfeed™ (Table 4).

Table 4 Crude protein requirements of balanced rations for lambs (from Grazfeed cited in Bell et al. 2003)

Live weight (kg)	ME			
	10	11	12	13
20	12.8	14.5	16.5	18.2
30	11.8	13.5	15.8	17.5
40	9.2	11	13.8	16.8
50	8.6	10	12.6	15.5

However, these differ from those recommended by Jones *et al*. (2004) using the formula:

12 grams of crude protein per MJ ME (SCARM 1990)

These authors also provide a guide to the energy requirements of fast growing lambs that are summarised in Table 5, although this relationship is rarely observed or reported in practice (Appendix 1).

Table 5. Impact of ration energy content on lamb growth (Grazfeed™ cited in Bell et al. 2003)

Energy density of the ration (MJ ME / kg DM)	Growth response (grams per day)
13	320
12	290
11	220
10	150
9	80

The nutrient guidelines for fast growing lambs (NRC 1985) provide a clear set of recommendations that can be readily applied to ration formulation (Table 6), and are frequently used by the Australian Stockfeed industry in pellet formulations and quoted world-wide in scientific studies. However, these guidelines do not necessarily have the support of some Australian scientists working in the area of ruminant nutrition who believe that more recent research warrants investigation of the guidelines suggested by Oddy as outlined in Table 7.

Table 6. Daily metabolisable energy requirements of early weaned lambs with rapid growth potential (NRC 1985)

LW kg	Growth rate g/day	DMI kg	MJ ME per day	ME per kg DM
10	250	0.6	7.11	11.85
20	300	1.2	13.8	11.5
30	325	1.4	16.74	12
40	400	1.5	17.15	11.4
50	425	1.7	19.67	11.6
60	350	1.7	19.67	11.6

As knowledge of rumen function has increased since 1985, more recent guidelines for the crude protein and energy requirements of growing lambs are based on the formula:

12 grams of crude protein per MJ ME

This relationship should enable unrestricted microbial growth and ensure that the flow of microbial protein (MCP) into the small intestine is unrestricted (Jones *et al*. 2004). It is on this basis that the following ration formulation guidelines for crude protein and metabolisable energy (Table 7) have been proposed by Oddy (22 September 2006), but these have yet to be tested.

Table 7 Recommended energy density (M/D = MJ ME/kg DM) and crude protein (%) levels in the diet to ensure rumen MCP production is not limited by N availability (Oddy 2006 unpub.)

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

Diets that are formulated to 11 ME and 16% crude protein are commonly reported within the Australian feedlot industry, as highlighted in recent, as yet unpublished work (Scammell and Jolly 2006) described in Table 8. This supports the recommendations of Oddy (Table 7) provided the degradability of the diet is 60%, although he suggests the most appropriate formulations would be based on a diet degradability of 70%.

Table 8. Growth rate, feed conversion ratio (FCR) and feed intake of crossbred lambs fed a hay-based pelleted ration formulated to 11 ME and 16% crude protein (Scammell and Jolly 2006 unpub.)

Feeding Period	Days on Feed	Daily Lamb Intake (kg/head)	Average Daily Gain (g/day)	FCR	Number of Lambs on Feed
Day 1- 4	4	1.29	0.124	10.4	325
Day 5-15	11	1.76	0.383	4.6	324
Day 16-22	7	1.85	0.360	5.1	154
Day 23-29	7	1.62	0.348	4.7	105
Day 30-37	7	1.77	0.277	6.4	106

Although the inclusion of studies relating to early weaned lambs (Orskov 1971; Orskov *et al*. 1973; Fraser and Orskov 1974) may attract criticism, there are currently confidential trials in progress investigating the growth and cost-efficiency of production feeding of early weaned lambs with a view to early de-stocking of the pastoral zone and intensive finishing of young lambs. This data has been included in this review as it may be of future relevance.

Reviewing lamb feeding trials is not helped by the lack of comprehensive data such that Beauchemin *et al*. (1995) did not observe a difference in growth response to an increase in crude protein levels in the diet from 15-18%, but there were no details provided as to the formulation of ME in the diet. Machado *et al*. (2004) did not observe a significant effect on either daily gain or feed efficiency when dietary crude protein was increased from 14-20%, but once again there were no details provided relating to the formulation of ME in the diet. Some published feeding trials refer to ‘high’ and ‘low’ planes of nutrition which makes assessment of the results impossible and therefore those investigations have been eliminated from this review.

Some authors have reported a linear increase in the rate of gain in response to increasing levels of crude protein in the diet; McGregor and McLaughlin (1980) found the fastest and most efficient rate of gain in Merino weaners resulted from a dietary crude protein level of 20% with ME formulated at 12.4. In contrast, Zundt *et al*. (2002) found that 12% crude protein was the most cost efficient level of dietary crude protein when feeding third cross Texel Corriedale lambs (Appendix 1).

In a review of the nutritional requirements of growing lambs, Jones *et al*. (2004) indicated that slower grown older lambs were likely to have higher protein requirements due to the increase in tissue accretion during compensatory growth, although Rocha *et al*. (2004) indicated that the crude protein requirements recommended by SCARM were 20% lower that what is actually required.

Jones *et al*. (2004) reviewed the protein and energy (ME) requirements of growing lambs and stated that “the quantity and array of nutrients required by tissues is a function of the stage of growth of the animal, its nutritional history and its genetic capacity for growth”.

Intensive lamb finishing rations in selected trials were formulated to between 9.4ME (Francis 2002) and 13.5 ME (Bowen *et al*. 2006) and 11.5% crude protein (Ryan and McIntyre 2006) to 19% crude protein (Ahmad and Davies 1986; Francis 2002; Ryan and McIntyre 2006), although the basis for these formulations were not explained.
In order to drive tissue protein synthesis, energy supply is the major ‘nutrient’ of importance in the diet of fast growing lambs, and the higher the energy level in the diet ,the faster the growth rate and level of feed efficiency (Hack *et al*. 1997). Rocha *et al*. (2004) in a study feeding haired Santa Ines lambs, found that the effect of diet on performance was more related to ME content than to protein source or content but conceded that more work was required on the protein requirements of growing lambs. However, this finding was not supported by more recent work with first cross Poll Dorset/Merino lambs (Bowen *et al*. 2006) on sorghum-based diets where, despite an ME estimate of 13.5, growth rates of only 150-190 grams per head per day were recorded. The crude protein levels in these trials varied from 12.5 to 18%, however, the intake of *ad libitum* wheaten hay was not reported such that the end formulation of the total diet could have been considerably lower than 13.5 ME.

Lambs on diets formulated to an ME intake in excess of requirements, tend to increase fat deposition (Hegarty *et al.* 1999) and diets containing high levels of cereal grain have been associated with a softening of the fat (Duncan *et al.* 1972). There is an opportunity to explore the addition of grains that are more fully utilised in the small intestine such as sorghum (Pethick *et al*. 1995) to reduce fat softness.

The genotype of the Australian lamb has been becoming increasingly lean since the development and availability of estimated breeding values for genetic selection, and the question remains unanswered as to the nutritional requirements of this improved genotype. If more lean tissue is being deposited at an earlier age and/or at a more rapid rate, does this increase the protein and/or ME requirements of these animals?

Best Practice

- It is apparent from both the literature and anecdotally that it may be premature, although long overdue, to recommend specific guidelines for the metabolisable energy and crude protein content of diets for fast growing lambs of modern genotype (increased ratio of lean to fat) under Australian conditions.

- Use NRC (1985) guidelines until further research indicates otherwise.
- Vendor declarations to include date of birth and whether the animal has originated from a paddock or a feedlot

Recommended further research

- Two sets of nutrient recommendations (NRC 1985; Oddy 2006) should be tested with common genotypes under indoor and outdoor conditions in Australia to determine growth and carcase responses, before a comprehensive set of guidelines can be recommended that will be acceptable to the whole of industry.
- Determine if different genotypes (Merino, fat tails and British breed crosses) differ significantly in their nutrient requirements.

1.3 Fibre requirement of fast growing lambs

Ruminants require fibre in their diet to stimulate the growth and development of the rumen during the pre-weaning phase, and once weaned, to stimulate rumen motility (SCARM 1990) and saliva production to provide natural buffering (maintenance of rumen pH) of the rumen environment. Chewing is stimulated by particle length and particle size, the aim being to reduce the particle size to facilitate digestive processes. At a laboratory level, fibre is measured and reported as acid detergent fibre (ADF) for cereal grains or neutral detergent fibre (NDF) for roughages such as hay, straw, almond hulls or silage.

NDF consists of the slowly digested fibrous portion of the plant; the cellulose, hemicellulose and lignin which is most of the cell wall material. As total dietary NDF increases voluntary intake tends to decline (Robinson *et al*. 1998).

ADF is a sub-fraction of NDF and consists primarily of lignin and cellulose and has a strong negative relationship with digestibility (Dalton 2005).

Neither ADF nor NDF provide an accurate measure of the effectiveness of the fibre in the diet, and although NDF of long fibre can provide an indication, once that fibre is processed into pellet form, the usefulness of NDF as a predictive measure is negated.

In response to a recent survey of intensive lamb finishers across Australia (Giason and Wallace 2006) 60% of large and medium producers and 35% of small producers indicated that they provided ‘high quality’ roughage to lambs; however, between 25-45% of all finishers indicated that they provided low quality roughage. Fourteen percent of small feedlotters did not provide any roughage, but this may have indicated the use of pellets. The respondent’s judgement of quality was not defined in the survey.

The majority of medium and large operations provided greater than 50% roughage in the starter ration with a reduction of the roughage component in the finishing ration. Of the medium sized operations, 13% retained 13% roughage in the finisher ration, while 50% and 38% of the large and medium finishers respectively reduced the roughage component of the finishing ration to less than 10%.

Many lamb finishers in Western Australia use hay-based pellets to grow out lambs, in particular those producers belonging to supply chains either, Q Lamb or the Merino Lamb Alliance, where pellet finishing is a requirement. Grain-based pellets are more readily available in the eastern states and more competitively priced than hay-based pellets, but the rate of usage is currently unclear.

Roughage is a major component of the diet of fast growing lambs as over 75% of small, medium and large operations supply grain and hay (or a roughage source) on a *ad libitum* basis (Giason and Wallace 2006).

Despite some intensive lamb finishers being encouraged by a team of mineral concentrate salespeople to remove all effective fibre from their feedlot rations to increase feed conversion efficiency, and hence profitability, recent trials by the NSW Department of Agriculture have found no cost benefit from this practice (G. Duddy, pers comm. 13 September 2006). Instead, there is an increase in animal health problems (W. Hawkins, pers comm. 13 September 2006). As there is the potential for substantial amounts of wastage when feeding hay or straw on an *ad libitum* basis, producers are attracted by the recommendation of any feeding solution which may alleviate the need to provide a roughage source. Predominantly this is an issue of feed delivery design and is discussed in more detail in Section 2.

The rate at which the fibre is degraded in the rumen, chop length (R. Davidson, Pers comm. 13 September 2006) and the type of fibre used, are seen as the most important factors relating to the fibre requirement of the diet (H. Oddy, pers comm., 13 September 2006). Processed roughage provided in pelleted form, although reducing the rate of ruminal degradation, is limited in its effectiveness in stimulating chewing and hence, saliva production. However, the fall in rumen pH following fermentation of pelleted feed, can be reduced by the addition of a fibre source as opposed to grain-based pellets, which as a rule, are wheat based and therefore rapidly fermented.

Nutritionists tend to refer to the percentage of roughage (hay, straw, almond hulls or silage) in a diet to provide an indication of the proportion of effective fibre the diet is providing. Ideally, 20% roughage in the ration should be sufficient to maintain rumen pH (SCARM 1990; Weston 1974), and a minimum of 27-30% NDF (Firkins 1999).

Francis (2002) found a significant reduction ($P<0.001$) in dry matter intake in lambs with a low level of dietary NDF fed in conjunction with a rapidly available form of carbohydrate, and given the opportunity, lambs would select diets with a more slowly digested source of carbohydrates. In a further study comparing diets containing differing proportions of lucerne hay and wheat fed to lambs, the greatest level of feed efficiency was recorded with 25% lucerne hay in the diet (Stanton and Levally 2006).

Sheep and cattle appear to differ in their minimum fibre requirements, especially in terms of fatty acid production, meat quality (Pethick, pers comm. 13 September 2006) and it appears that sheep in particular require a minimum of 10% roughage in the diet. The quality of the roughage, if fed out on an *ad libitum* basis, is important to encourage appetite and intake during the introductory period to grain (Harpster 2004; Jordan *et al*. no date; O'Dempsey 2002).

Although hay appears to be the most commonly fed roughage source, many lambs are grown out on high quality pastures, or have silage included as a component of their ration. The growth response of lambs to chopped silage can relate directly to the quality of the silage (Kaiser *et al*. 2000); chopping lucerne silage can increase growth rates but also costs, therefore, the growth response to chopping requires further clarification.

Lucerne silage supplemented with barley and lupins produced higher growth rates in second cross lambs than supplemented oaten silage (Kaiser *et al*. 2000). Studies feeding grass silage to store lambs, found that the chop length has a greater effect on intake and performance than digestibility (Fitzgerald 1996); although, when Hong *et al*. (1986) fed shredded silage to lambs, shredding had no effect on dry matter intake or daily live weight gain.

Kaiser *et al* (2000) investigated the effect of lucerne silage chop length on growth rate and found a difference in growth rate with chop length that was significant ($P<0.05$) only in the absence of grain supplementation. They found a significant difference in growth rate between a chop length of 75cm and 1-3 cm with oaten silage, but the work was confounded by the poor quality of the silage, and they were unable to determine the importance of chop length with good quality silages.

This is further supported by Kenney *et al*. (1984) who investigated the difference in the intake rate of sheep offered kikuyu grass at different particle lengths and found a substantial difference in intake rate with the short chop length (Table 9).

Table 9. Effect of particle length and dry matter content on the potential intake rate of kikuyu grass (from Kenney et al. 1984)

Forage	Particle length (mm)	DM (%)	Intake rate (g/min) As fed basis	Intake rate (g/min) Dry matter basis
Undried kikuyu	10	17	52.7 ± 4.9	9.2 ± 0.95
Undried kikuyu	40	16	42.8 ± 3.8	6.9 ± 0.61
Dried kikuyu	10	96	16.7 ± 0.8	16.1 ± 0.71
Dried kikuyu	40	81	11.1 ± 0.8	9.0 ± 0.62

Although intensive feedlot rations for both beef cattle and lambs tend to be grain dominant, Ruttle and Sundt (1968) found lambs fed on a ‘low energy’ diet consisting of 70% lucerne hay and 30% concentrates had an increased daily rate of live weight gain, converted feed to gain more efficiently and had fewer digestive disturbances than those on a 70% concentrate ration.

Best practice

- Provide an effective source of fibre in the rations of intensively finished lambs, either in the form of high quality roughage on an *ad libitum* basis or in the form of increased particle size in hay-based pellets
- Minimum NDF of the ration should be 27-30%
- Roughage should be included in the diet at a minimum of 10% of total dietary DM

Recommended further research

- The effect of silage chop length on dry matter intake and growth rates of lambs
- Roughage presentation and hay delivery design

1.4 Mineral and vitamin requirements of fast growing lambs

The mineral status of lambs admitted to intensive finishing systems is often unclear due to lack of knowledge of their nutritional history; therefore, rather than have a specific deficiency impeding potential lamb performance, it is advisable to include a concentrated mineral mix in the ration formulation. However, there is considerable variation in the formulation of mineral concentrates, such that many producers are unable to determine the appropriate concentrate to use and the format of specifications on the containers make cost benefit comparison impractical.

Intensive lamb finishers are often advised to use a mineral supplement that has been ‘specifically formulated for their area’ or ‘specifically formulated for feedlot lambs’, or more frequently, containing ‘products that will improve growth rate and feed efficiency’ with little supporting evidence.

The average mineral concentrate adds a cost of $1 per head to the feed cost over a 50 day finishing period, although some preparations can increase that cost to $3.

Mineral and vitamin concentrates are available in pellet, powder or liquid form and can be provided as a stand-alone product with *ad libitum* access or mixed in with the ration. Liquid mineral drenches are also available for intermittent administration.

There are significant interactions between minerals and trace elements and differences in availability that can be unpredictable and therefore definitive recommendations for supplementation must be treated with caution. Guidelines found within the literature for growing lambs have been tabulated in Table 10.

Producers are encouraged to seek independent advice and to determine the mineral deficiencies in feed before purchasing mineral concentrates.

Anecdotally, a broad range of mineral supplements are commonly used in confined intensive finishing systems, with significant variation in formulations. These range from powders that are made available on an *ad libitum* basis or mixed in with the feed, to pelleted concentrates or one-off mineral drenches administered before commencing intensive feeding. Those producers, who do not use a proprietary formulation, tend to use lime as a calcium source at 1% of the ration and/or salt at the same rate of inclusion, or provide a combination of lime and salt on an *ad libitum* basis.

Neither lambs nor ration ingredients are routinely tested for mineral and trace element content, such that an appropriate mineral concentrate could be formulated to complement the diet. It was considered inappropriate to include the potential contribution of a range of feedstuffs to the mineral content of the diet in this review.

Lambs to be finished on pasture-based systems may have intra ruminal slow-release capsules inserted to avert known on-property deficiencies, or an *ad libitum* mineral concentrate to access in the paddock. In some instances, the paddock feed may be analysed for mineral content before grazing.

It appears to be almost routine practice to inject lambs with Vitamin B_{12} before the commencement of an intensive feeding regime. This may be due to a known or suspected deficiency and is thought to stimulate appetite.

In Western Australia, feedlot finishers routinely inject lambs with Vitamin E at induction. Others inject a combination of Vitamins A, D and E prior to commencement on grain based diets in the belief that it will increase growth rates and feed conversion efficiency. Routine injection of Vitamins A, D and E is also practiced if lambs are entering a finishing system from an unknown area, from stubbles or an area where there has been a prolonged dry period. This practice has been largely promoted by retailers servicing the feedlot industry, but is also a requirement of some supply chains (R Davidson, pers. comm., 13 September 2006). Davidson (pers comm. 13 September 2006) also states that if the lambs are deficient in Vitamin E at the commencement of an intensive feeding regime, the injectable form of vitamins A, D and E will not overcome the deficiency. This is supported in the literature by Larsen (1988, cited in Hungerford 1990) who indicated sheep on high grain diets and /or under stress, require 10-50 mg per day given orally, as the injectable form can be immobilised at the site of injection for long periods. Additionally, Vitamin E powder can be added to the water trough.

Macro minerals

Calcium and Phosphorus

Calcium is required in the diet of fast growing lambs for bone growth and development, muscle function and to reduce the incidence of urinary calculi. Calcium and phosphorus are required in the diet at a ratio of 2:1 to prevent calculi formation, and as high grain diets are inherently deficient in calcium and high in phosphorus, calcium supplementation is essential unless legume hay or silage is a major component of the diet.

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

Table 10. Daily mineral requirements of lambs

		NRC 1985	Underwood & Suttle 1999
Calcium	g/kg DM	4.2	3.4
Phosphorus	g/kg DM	2.1	2-2.8
Magnesium	g/kg DM	1.2	0.7-1.8
Sodium	g/kg DM	0.6	0.6
Potassium	g/kg DM	5.2	3.0
Sulphur	g/kg DM	2.2	
Manganese	mg/kg	20	13.0
Iron	mg/kg	30	30-50
Zinc	mg/kg	23	15.8
Copper	mg/kg	8-10	4-6
Molybdenum	mg/kg	0.5	
Cobalt	mg/kg	0.15	0.11
Selenium	mg/kg	0.12	0.03-0.05
Iodine	mg/kg	0.18-0.27	0.2-0.3
Vitamin A	iu/kg	1175	
Vitamin D3	iu/kg LW/day	6.66	
Vitamin E	iu/kg	15	

Sodium
As cereal grains are low in sodium, grain based finishing rations for lambs require additional sodium. Sodium can be provided as sodium chloride (salt), sodium bicarbonate or sodium bentonite at an addition rate of 1% of the total diet. A deficiency of salt in the diet of intensively finished lambs can result in a reduction in dry matter intake and hence, growth rate (Underwood and Suttle 1999). The inclusion of sodium in the diet of lambs on high grain diets, also provides a buffering effect against ruminal acidosis by increasing rumen outflow rate and hence the pH of rumen fluid.

Slattery (2006) recommends the addition of more than 1.5% salt to the diet of feedlot lambs, as less than this amount is insufficient to prevent the formation of urinary calculi.

Potassium
Diets containing urea as an additional source of nitrogen or lambs that have been backgrounded on potassium deficient pastures, such as can occur in coastal South Australia, may require supplementation with potassium. Sources of potassium include potassium chloride or potassium iodide, which is frequently used by stockfeed manufacturers as a supplemental source of iodine and potassium.

A deficiency of potassium can depress growth rate secondary to reduced dry matter intake (NRC 1985), although care should be taken with supplementation as dietary potassium in excess can reduce the absorption of magnesium.

Magnesium
Supplemental magnesium is seldom required in the diets of fast growing lambs unless pasture-finished during autumn around the ‘break of the season’, where on individual properties, magnesium deficiency can occur. Magnesium deficiency can also occur in response to high levels of rumen ammonia on high protein diets, which is more likely to occur on pasture-based finishing systems than in feedlots. Sources of magnesium include magnesium oxide (54% magnesium) or magnesium sulphate (10% magnesium).

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

Sulphur
Additional sulphur is required in the diet of fast growing lambs when urea is added as a source of non-protein nitrogen. The desired ratio of urea to sulphur lies between 10:1 and 13:1 to facilitate synthesis of microbial protein (O’Reagain and McMeniman 2002).

Micro minerals or trace elements or trace minerals

The most economically important trace minerals (also commonly referred to as trace elements) in the diet of intensively finished lambs, include selenium, cobalt, copper and zinc. Deficiencies of any, or all of these, will result in a depression in growth rate and dry matter intake (Lee *et al*. 2002).

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

Cereal grains are generally low in selenium, therefore supplementation is recommended when feeding lambs high grain diets, although care should be exercised if supplementing from additional sources such as inclusions in drenches and vaccinations. Many commonly grazed plant species in the pastoral areas of South Australia are known to be high in selenium and lambs grazing those species have been found to have high serum activity of glutathione peroxidase, an indicator of selenium status (Jolly 2003 unpub.).

Cobalt deficiency is common in lambs newly weaned from spring pastures in high rainfall areas in Australia, and grain based finishing rations are inherently deficient in cobalt. Cobalt is required by rumen micro-organisms for the synthesis of Vitamin B_{12} (SCARM 1990).

Lambs entering finishing systems from either the pastoral areas of southern Australia or the wheat-sheep zone, are at risk of zinc deficiency and may require additional zinc in their diet. Extensive analyses of pastures and shrubs from the pastoral zone (Jolly 2003 unpub.) has revealed widespread zinc and some patches of copper deficiency, and much of the cropping zone now is zinc deficient (P March, pers comm. September 13 2006), possibly related to long term use of chlorsulphuron herbicides in wheat crops (Osborne and Robson 1992).

Of lesser importance are the trace elements manganese, iron and iodine; however, lambs grazing *Brassica spp* such as rape can become deficient in iodine due to the ingestion of goitrogens (Underwood and Suttle 1999). Iron deficiency is uncommon in intensively finished lambs, and manganese deficiency, whilst inducing skeletal deformities, is rarely seen in Australia and abnormalities are usually evident at birth.

Vitamins

Vitamin A is essential for effective vision and immune cell function and deficiency symptoms include; night blindness, depression in growth rate and an increase in susceptibility to disease. Requirements for Vitamin A, increase with high grain diets, and in lambs that have had liver or intestinal damage from grazing toxic plants or internal parasite infestation. Lambs that have been grazing green pasture within 2 months of arriving into a feedlot, should have adequate liver stores, however lambs from drought affected areas may benefit from an injection of Vitamin A prior to induction into a feedlot (SCARM 1990).

Vitamin B1 or thiamine deficiency (polioencephalomalacia) has been reported randomly in pasture-based lambs and also in feedlot lambs, where a sudden change in feed has occurred. The sudden change of feed, stimulates production of thiaminases in the rumen. Feeding mouldy hay or silage can also precipitate the disease.

Lambs are generally found lying on their side with legs rigidly extended with nystagmus (rotating eyeballs) and aimlessly gazing about (Hungerford 1990). The condition can be avoided by a gradual change in feed, or by the addition of a prophylactic dose of thiamine added to the mineral concentrate, but this adds to the cost of the feed ration. Alternatively 750-1000mgs of thiamine hydrochloride powder for administration as a drench, can be kept on hand for emergency treatment if required (Hungerford 1990).

Vitamin B_{12} deficiency is caused by a lack of cobalt in the diet. Vitamin B_{12} plays an essential role in the conversion of sugars and starches into glucose (Hungerford 1990) and signs of a deficiency include poor growth, listlessness, scaly ears, inappetence, weight loss and anaemia. The B_{12} requirements of fast growing lambs are not well defined in the literature, however it can be assumed that if the cobalt requirements of the lambs are met, that resultant synthesis of Vitamin B_{12} should be adequate.

Vitamin D deficiency is rarely seen in Australian finishing systems due to their requirements being met by exposure to ultra-violet light rays from the sun, and ingestion of green and dried forages. Lambs backgrounded on pasture have sufficient stores of Vitamin D to last for 6-15 weeks (SCARM 1990), although supplementation with Vitamin D should be considered for lambs finished in indoor feedlots.

Vitamin E deficiency is generally observed in lambs that have been denied access to green pasture for extended periods, such as grazing cereal stubbles over the summer period; however, lambs that have had access to saltbush are unlikely to be Vitamin E deficient (Barrett-Lennard *et al*. 2005).

Vitamin E acts as an antioxidant removing free radicals and protecting the integrity of cell membranes in a complementary activity with selenium (SCARM 1990). Signs of Vitamin E deficiency include stiffness of gait, although bright and alert (Hungerford 1990), and myopathy or muscle wasting (SCARM 1990). Inclusion of Vitamin E in the mineral concentrate or injected prior to feedlot induction should prevent a deficiency for lambs considered at risk.

Best practice

- Provide a balanced, cost-effective mineral concentrate for fast growing lambs on grain-based diets
- Seek independent advice prior to purchase, if unsure of requirements
- Analyse pastures for mineral deficiencies prior to finishing lambs, to determine their mineral requirements
- Inject all lambs with Vitamin B12 to stimulate appetite and avoid unknown deficiency prior to intensive finishing
- Inject all lambs with Vitamin A, D and E before commencing on grain-based finishing rations
- Inject all lambs with Vitamin A, D and E if deprived of access to green pasture for more than 2 months prior to intensive finishing
- Drench lambs with Vitamin E powder or spray on hay for 2 weeks if known or suspected to be deficient in Vitamin E prior to intensive finishing

Recommended further research

- No further research appears to be required in this area

1.5 Water requirements of fast growing lambs

Total daily water intake by lambs is positively related to dry matter intake and hence productivity and requirements increase with the dry matter content of the diet. Water is critical to lamb survival as water can amount to as much as 50-80% of live weight (SCARM 1990), and the loss of more than 10% of body water can be fatal (Corbett and Ball 2002).

The amount of water lambs consume is influenced by ambient temperature, shearing (Markwick 2002), water quality and availability, salt content of the water, the temperature of the water, familiarity with water delivery devices, trough size, flow rate and genotype (SCARM 1990).

Intensive lamb finishers appear to be aware of the need to supply clean water and a recent survey revealed that at least 50% of all feedlotters clean out the water troughs once a week with a further 40% indicating they cleaned the troughs at least 2-3 times per week. Less than 15% of respondents cleaned water troughs once a fortnight (Giason and Wallace 2006). One specialist feedlotter has stated that troughs should be cleaned out on a daily basis, with more frequent cleaning required under dusty conditions (T. Grant pers comm. 13 September 2006) to avoid dehydration.

Intensive operations that are supplied with dam water report a decline in lamb performance into late autumn as water quality declines, although there is no clear evidence in the literature as to the degree of lost productivity.

Two producers have reported a significant loss in productivity as a result of plastic water troughs being located in full sun for most of the day and supplying shedded operations (S. Reid, pers comm. 16 March 2006; A. Boyle, pers comm., 4 February 2005) as warm water appears to be less palatable.

Although intake of 3-4 litres per head per day is generally accepted as the daily intake requirement of lambs (H. Oddy, pers comm. September 13 2006), there are wide range of recommendations to be found in the literature; these are listed in Tables 11 and 12.

To optimise dry matter intake, total soluble salts should not exceed 3500 ppm and magnesium levels should be less than 250 ppm (SCARM 1990). To encourage optimum intake for cattle the water should be cool (<15°C, ALFA 2001), although there are no such recommendations for lambs other than to ensure the pipes are buried to keep the water temperature as low as possible in hot conditions. Aeration of the water may be worth further consideration as it apparently increases water intake in pigs (J. Franklin-McEvoy 2006 pers comm. 15 November).

From field observations it has been reported that flow rate, and hence water pressure, are important factors in the amount of water that lambs drink on a daily basis, and although there is evidence supporting this for dairy cows there is no supporting evidence in the literature as to the required water pressure or flow rate for lambs. Lambs have been observed approaching the water trough and waiting to drink, however if the first group of lambs empty the trough, and the refill time is slow, the second group of lambs tend to wander away and not drink at that time.

Table 11 Recommendations for daily water requirements of fast growing lambs (litres per head)

Source	Cool weather	Hot weather
Davis 2003	4	9
SCARM 1990	2 litres/kg DM	3.5 litres/kg DM
SCARM 1990	4-6 litres/kg DM (16-25°C)	
WA Ag 2005		1.8 – 3.7
Rook 2003		
Croker and Watt 2001	4	
WA Ag guidelines 2003 Dept local Govt and regional development		6
Canadian Agri-food Research Council		2-3 times DMI + salt effects in water or diet
Hack *et al.* 1997	3	6
O'Dempsey 2002	4	Intake 2-4 times DMI
Harpster 2004		2.5 times DMI
Vigortone 2003		5-6
Provided In confidence (2006):		
NSW	4 litres; clean	
Victoria		Up to 9 litres
South Australia	3	6
Western Australia	3	6
Queensland		

Table 12 Total daily water allowances at various mean environmental temperatures for weaned sheep (SCARM 1990)

Environmental temperature	Water allowance (litres per kg DM)
< 15°C	2
20°C	2.5
25°C	3.5
30°C	5
35°C	7

Best practice

- Provide a clean source of cool water containing less that 3500ppm soluble salts
- Clean water troughs as frequently as required to maintain a clean water supply
- Where water is stored, provide at least 3 days supply in reserve plus an allowance for losses during trough cleaning

Recommended further research

- Water pressure and trough refill time to optimise water intake
- Self-cleaning troughs
- Trough design

- Aeration of water supply

1.6 Managing dietary change

Introduction to intensive feeding, either within a confined area or on high quality pastures, from post-weaning, backgrounding, maintenance feeding or fasting, can present significant difficulties for ruminant animals and requires careful management.

Issues of importance include physiological and social adaptation, to both the surroundings, and the diet. There is increasing awareness of the role of social behaviour in the adaptation of lambs to unfamiliar situations, and the degree of ‘stress management’ required by intensive finishers of lambs; this will be discussed in more depth in the section on Animal Welfare.

Rumen bacterial populations require a period of adaptation from a roughage dominant diet, to a grain based diet, to avoid a significant increase in lactic acid production, and hence, a fall in rumen pH as a result of rapid fermentation of carbohydrates.

The introductory period of lambs to a feed ration that will optimise productivity requires careful management to ensure rapid adaptation to the feed and new surroundings, as well as avoidance of acute onset of gastrointestinal disorders such as acidosis, enterotoxaemia and polioencephalomalacia. A fall in rumen pH can result in weight loss during the introductory period which can be the difference between profit and loss of that feeding cycle.

Up to 60% of intensive lamb finishers report, that up to 5% of the lambs they feed, exhibit signs of shy feeding and poor adaptation to their surroundings or acidosis (Giason and Wallace 2006); although some pellet manufacturers claim rapid introduction to hay based pellets without evidence of acidosis (J. Davis, pers comm. 13 September 2006).

As traded lambs may have been subjected to prolonged curfew and periods of stress prior to arriving at their destination, the first consideration is to encourage water and dry matter intake and to provide a quiet and relaxed environment, whereas, lambs bred on-property will benefit from prior introduction to a finishing ration. Some producers provide electrolytes in the water for lambs on arrival if the sheep have been transported for long distances, been off feed for more than two days or in hot, humid conditions and report better survival rates as a result (P. March. Pers comm., 13 September 2006).

Anecdotally, intensively finished lambs on the property of birth are introduced to grain in the paddock prior to entering a confined area, but an unknown number of these may not have been introduced to grain prior to weaning. Routine practice in the United States appears to be to introduce lambs to high quality legume hay for at least three days prior to commencing a grain or pellet-based diet; although, Bowen *et al* (2006) recommend feeding a high quality roughage source in conjunction with hay based pellets.

More than 50% of large and medium lamb finishers in Australia provide greater than 50% roughage in the starter ration and 33% of those with smaller operations, although little is known about the quality of roughage that is provided (Giason and Wallace 2006).

More than 23% of intensive lamb finishers feed a pelleted ration and many of these pelleted diets are hay-based, which greatly reduces the risk of acidosis occurring during the introductory period; however, the majority of lambs are finished on diets based on cereal grains.

A range of rumen buffers are commonly formulated into the diet to reduce the risk of acidosis, however the percentage of producers using antibiotics, such as virginiamycin, to control acidosis in the feed is currently unknown.

The level of awareness of producers about the potential to improve productivity during the period of introduction to an intensive finishing system, by providing a 'low stress' environment, remains unclear. A recent survey (Giason and Wallace 2006) revealed that between 14 and 25% of lamb finishers moved lambs in and out of groups at each weighing. This may be of concern since Winfield *et al*. (1981), in open field studies, found that lambs do not readily integrate into unfamiliar social groups. This may also have implications for the performance of confined lambs when mixed with other lambs under intensive conditions, but this has yet to be determined.

Important factors that influence rapid adaptation to feed, include prior experience (Juwarini *et al*. 1981; Lynch and Bell 1987) of, or familiarity with, the feed (Burritt and Provenza 1998), palatability of the feed (Vigortone 2003), familiarity with the feeding equipment (Chapple and Lynch 1986) and post-ingestive feedback responses (Provenza 1995).

There is evidence that dry matter intake is enhanced by the provision of familiar feeds (Hinch *et al*. 2004), which is not always possible when lambs are purchased from elsewhere, but, anecdotally it appears that palatable legume hay is likely to encourage lambs to eat.

Investigations into the 'failure to eat' syndrome, seen in adaptation feedlots prior to live sheep export, has demonstrated that long periods of fasting (96 hours) prior to feedlot entry resulted in 71% of sheep adapting to feed within 6 days, compared with 98% of sheep that fasted for 48 hours (McDonald *et al*. 1986).

Feedlot lambs that are purchased off-farm are likely to be subjected to shearing, vaccination and weighing within 24 hours of arrival to the finishing system. This amount of handling, following an extended period of fasting, maybe a significant contributing factor to the failure of some lambs to adapt to feedlots.

The literature contains many references that recommend the provision of 'high quality' hay for lambs upon arrival to an intensive feeding environment, although, the definition of high quality is not always quantified (O'Dempsey 2002; Bowen *et al*. 2006; Jordan *et al*. no date).

Prior adaptation to grain feeding increased intake of lambs by 13% (Juwarini *et al*. 1981); although, this effect was not observed by Savage *et al* (2006) when Merino lambs were offered 200 grams of pellets on two separate days prior to weaning.

The relationship between palatability, preference and intake has been clearly defined, although observations by Quaranta *et al* (2006) of behaviour of intensively reared Merino lambs, demonstrated the influence of feed composition and that preference is largely determined by positive or negative post-ingestive feedback.

Best practice

- Imprint lambs to grain or pellets before weaning
- Imprint lambs to feeding equipment before weaning where applicable
- Introduce new mobs to feed separately
- Provide high quality, legume dominant hay during the introductory period to grain
- Leave lambs to settle for 3 days prior to induction (vaccination, drench etc)

- Ensure lambs are vaccinated with 5:1 to reduce the incidence of enterotoxaemia
- Introduce lambs gradually to grain or pelleted diets under feedlot conditions unless otherwise instructed by the pellet manufacturer
- Use low starch diets during the adaptation period (i.e. oats and lupins)
- Provide access to clean, cool water

Recommended further research

- Determine the effect high quality hay and legume hay has on rapid adaptation to feed and dry matter intake
- Determine the effect of mixing unfamiliar social groups on lamb performance

1.7 Factors influencing growth and feed conversion ratio in fast growing lambs

Growth

Although the ability of an animal to efficiently convert feed to live weight gain is the most important factor determining profitability, the option to select lambs on that basis is not yet available to producers. Therefore, growth is currently the main profit driver within an intensive finishing system. Intensive lamb finishing is currently a high volume, high turnover, low margin enterprise and therefore high risk. In order to manage that risk and remain profitable, lambs confined within a feedlot system are generally required to grow in excess of 300 grams per day.

There appears to be the potential to improve the rate of growth currently experienced within feedlot systems in Australia, and although there has been substantial improvement in the growth potential of lambs since the inception of the Lambplan recording system, the industry unfortunately continues to under-utilise the valuable information that Lambplan provides (H Oddy 2006 pers. comm., 13 September).

Until producers gain an understanding of the nutrient requirements of fast growing lambs, and the nutritive value of either the paddock feed on offer or the feedlot ration, it is unlikely that much of the industry’s genetic gain will be realised on a commercial scale.

There are a plethora of published and on-farm trials that do not achieve these rates of growth (Appendix 1), but the different methodologies for those that do exceed 300 grams make many of these studies difficult to compare.

Profitable levels of growth consistently in excess of 300 grams per day were recorded in only a small percentage of the trials reviewed (Appendix 1), with the higher growth rates predominantly reported from early weaned lambs, or entire male lambs. Not all early weaned lambs achieve high rates of growth, as evidenced by Merino and first cross SAMM/Merino pastoral lambs who were lot fed a pelleted diet (20.9% CP and 12.6 ME) over a 9 week period and failed to achieve high rates of daily gain (Figure 2).

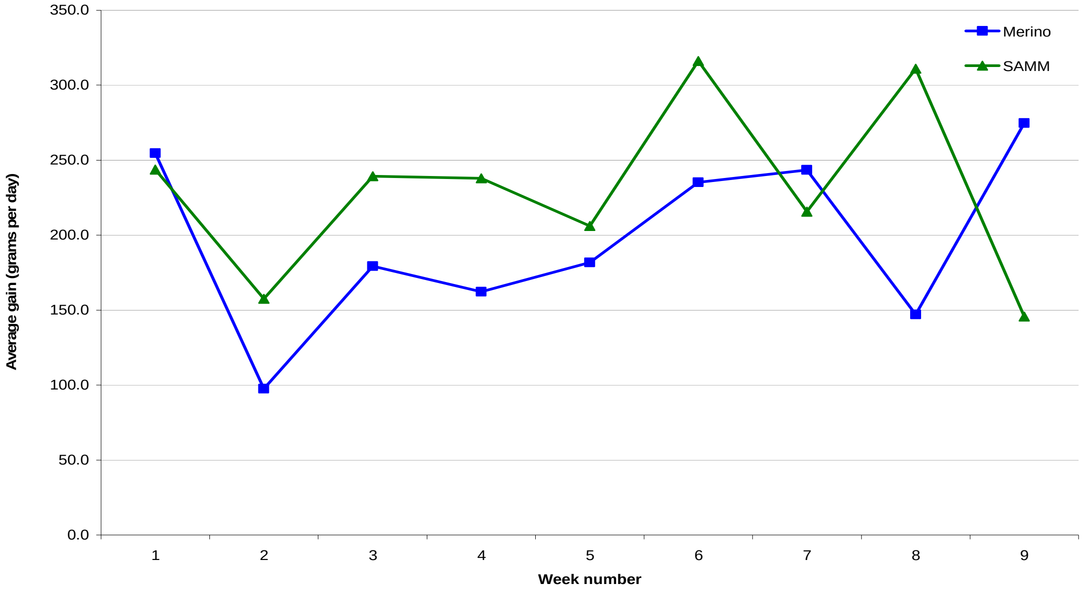


Figure 2 Growth rate of pellet finished, early weaned pastoral Merino and SAMM lambs (Scammell and Jolly 2006 unpub.)

Many published trials from reputable sources achieve growth rates less than the current industry average of 250 grams per head per day (Table 13) and therefore their contribution to this report has been limited. However, lamb feeding trials conducted in Western Australia, have demonstrated growth rates in excess of 300g per head per day (J. Davis 2005 pers comm., 13 September).

Table 13 Average growth targets recommended for feedlot finishing of lambs taken from Australian State Departments of Agriculture extension publications (adapted from Kirby and Beretta 2004)

Growth rate (g/head/day)	Breed	Comment	Author
130	Merino lambs	After 2-3 weeks adaptation to feedlot conditions	Hack *et al* 1997cited in Kirby and Beretta 2004
130-140	Merino lambs		Suiter 1990 cited in Kirby and Beretta 2004
140-160	Crossbred lambs		Suiter 1990 cited in Kirby and Beretta 2004
150-250	Merino lambs		Seymour 2000 cited in Kirby and Beretta 2004
150-300			Bell *et al* 1998 cited in Kirby and Beretta 2004
200	Crossbred lambs	After 2-3 weeks adaptation to feedlot conditions	Hack *et al* 1997cited in Kirby and Beretta 2004
200-320		Finishing lamb from 30-50 kgs	Bell *et al* 2003 cited in Kirby and Beretta 2004
220-320	Merino lambs		Milton 2001 cited in Kirby and Beretta 2004
250		Average 40 kg finishing lamb	Bell *et al* 2003 cited in Kirby and Beretta 2004
250-300	Crossbred lambs		Seymour 2000 cited in Kirby and Beretta 2004
250-350	Crossbred lambs		Milton 2001 cited in Kirby and Beretta 2004

Fat deposition increases in lambs from approximately 40kgs live weight (Jones *et al*. 2004) which reflects the weight at which lambs are typically introduced to finishing regimes. Figure 3 shows that as lambs mature, an increasing proportion of gain is deposited as fat, which these authors imply, is the basis for growth rates of 400 grams per head per day being rarely seen under feedlot conditions.

As lambs age, they deposit more fat, ie, weight gain becomes more energy dense and growth potential declines as illustrated by Oddy (2006) in Figure 3. However, field studies have clearly demonstrated the potential of older lambs to grow at a rate in excess of 400 grams per head per day (Scammell and Jolly 2006 unpub). The question remains, is the greater proportion of this weight gain always fat, especially in modern Australian genotypes? There is a strong economic case for regular weighing and fat scoring of intensively finished lambs, and removal of those that are depositing fat early in their growth path, as well as those that have low rates of daily gain.

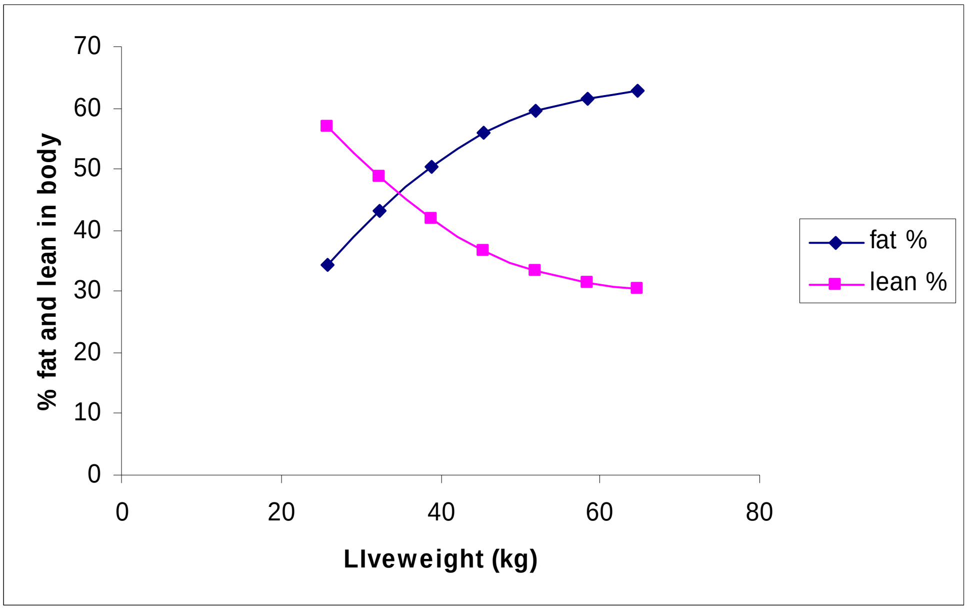


Figure 3 Gross efficiency of gain in feedlot lambs (Source: Oddy 2006)

Lambs purchased from the saleyard system from March to July 2006 of unknown genetic potential and history and fed a hay-based pellet diet (16% crude protein; 11 ME; 30% NDF) demonstrated growth rates in excess of 400 grams per day (Scammell and Jolly 2006 unpub) as summarised in Table 14. Unfortunately, the fastest growing lambs in this trial were removed for slaughter after 22 days, therefore it remains unclear for how long that level of growth might have been sustained.

Table 14 Crossbred feedlot lambs (entry weight 37 kg) intake, growth rate and FCR (Scammell and Jolly 2006 unpub.)

Feeding Period	Daily Lamb Intake (kg/head)	Average Daily Gain (kg/day)	Feed Conversion Ratio (FCR)	Number of Lambs on Feed
Day 1- 16	1.62	0.310	5.2	191
Day 17-22	1.95	0.421	4.6	191
Day 23-29	2.02	0.143	14.1	87

Many lambs within intensive production systems fail to achieve economically viable rates of growth, as evidenced in ***Table 15***. After removal of lambs that reached market specifications, the remaining lambs were growing at 66% the rate of the top performers and were still consuming substantial amounts of feed.

Table 15 Merino feedlot lambs intake, growth rate and FCR fed a pelleted diet (Scammell and Jolly 2006 unpub.)

Feeding Period	Daily Lamb Intake (kg/head)	Average Daily Gain (g/day)	Feed Conversion Ratio (FCR)	Number of Lambs on Feed
Day 1-26	1.83	109	16.8	450
Day 27-35	2.13	277	7.7	347
Day 36-44	2.24	312	7.2	248
Day 45-51	1.94	130	15	179

Merino lambs, although not traditionally selected for high rates of growth, have demonstrated the potential for rapid growth (Scammell and Jolly 2006 unpub; Milton 2001 cited in Kirby and Beretta 2004) under two feeding regimes (Table 15). The Sheep CRC Meat Eating Quality program has clearly shown that grain finished Merino lamb is indistinguishable from cross bred lamb in terms of eating quality, which provides an opportunity for the industry to intensively finish a higher percentage of Merino lambs.

Growth rates reported from intensive finishing systems (Appendix 1) vary widely due to a range of factors which include the age (Jones *et al* 2004) and sex of the lamb (Andrews and Orskov 1970), breed and genotype (Wiese *et al*. 2003), hybrid vigour (Holst *et al*. 1998), nutritional history (Hegarty *et al.* 1999), dry matter intake, type of feed (Oddy 1995; J. Davis pers comm., 13 September 2006; Whale *et al*. 2005) and the formulation of the ration. These factors will be discussed in more detail in later sections of this report.

Linden *et al.* (2006) investigated the weight gain or loss over the feeding period of lot fed lambs of varying age on entry, and found that the older lambs grew faster than young lambs as illustrated in **Error! Reference source not found.**. The trial used AI lambs all born within a one week period which were drafted in three intake groups at weaning; heavy, medium and light. The average LW of all three groups of lambs on entry to the feedlot was approximately 37 kgs; the LW of the heavy group entered the feedlot at 14 weeks of age, the medium weight mob entered the feedlot at 21 weeks of age and the third and final intake of lambs, had reached 37 kgs when they entered the feedlot at 28 weeks of age. All lambs were individually penned and fed for seven weeks and shy feeders were not removed. Feed intake was monitored on a daily basis with all lambs weighed on a weekly basis (Linden 2007, pers comm. 7 March 2007).

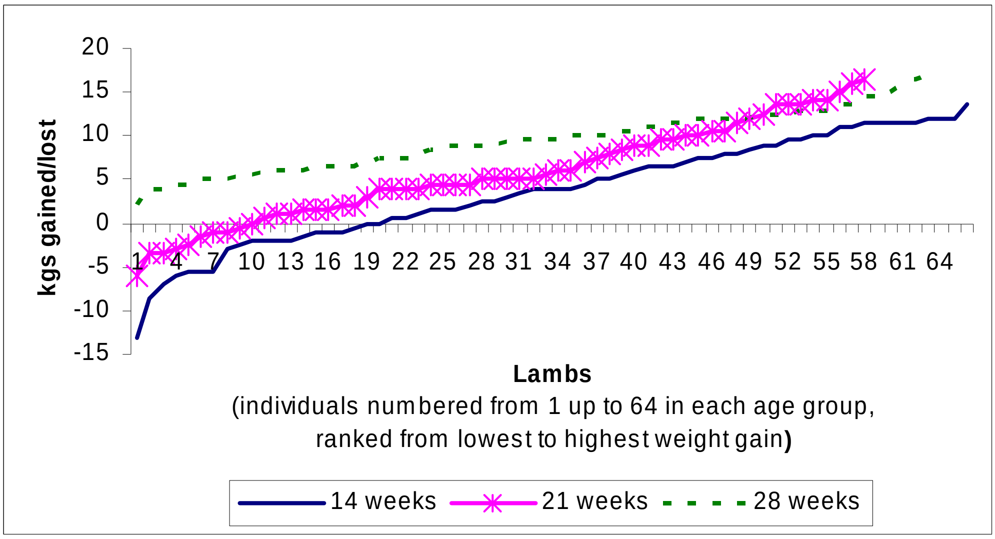


Figure 4 Impact of age on lamb performance (wt gain) (Linden et al. 2006)

Weaning weight is one of the best predictors of subsequent lamb growth (H. Oddy, pers comm., 7 April 2006) although not frequently recorded on a commercial scale. Pen enrichment has been shown to increase daily weight gains during the introductory period under feedlot conditions (Linden *et al*. 2006) and choice feeding of three pelleted diets (Whale *et al*. 2004), compared with access to a single formulation, resulted in a positive growth response during the introductory feeding period.

In addition, Bowen *et al* (2006) has highlighted the adaptation of lambs to grain and feeding systems, as well as social and physiological factors as being major contributors to growth under feedlot conditions.

Feed conversion ratio

The efficiency with which lambs convert feed to live weight gain is the major determinant of profitability in an intensive lamb finishing enterprise. However, it not yet possible to select sires based on their potential to sire progeny that will convert feed to live weight gain more efficiently, other than to select sires with high EBV's for growth. Research into gene and diagnostic markers for feed efficiency are currently in progress (Ball and Pethick 2006).

Feed conversion ratio (FCR) is the ratio of inputs to outputs, or costs vs returns, and is expressed as a ratio of the amount of feed eaten (on an 'as-fed' or 'as-is' basis) per kilogram of live weight gained.

$$\text{FCR} = \frac{\text{kgs fed}}{\text{Kgs LW gain}}$$

Producers generally have a poor understanding of the meaning of feed conversion or how to calculate it, although most appear to be aware of its importance.

In order to capitalise on the true commercial value of feed efficiency to an intensive lamb finisher, mobs of lambs require identification and traceability to facilitate the purchase of further drafts of lambs from those breeders whose lambs perform better than the average.

Feed conversion ratio is frequently reported on a 'dry matter' basis instead of an 'as-fed' basis, which can give a falsely favourable impression of efficiency. The main reason for feed efficiency calculations is to assess the cost-efficiency of feeding a group of lambs. As feed is purchased on an 'as-fed' basis, the cost is incurred from the ingested feed, not by the dry matter content of the feed.

In 50% of small and medium finishing enterprises, lambs are weighed on entry and exit, however all larger enterprises weigh lambs in and out (Giason and Wallace 2006). Furthermore, 50 – 55% of small and medium finishers weigh their lambs on a regular 2-4 week basis with only 17% weighing lambs in the larger businesses. As the entry weight is often an empty weight, and the exit weight may be a full weight, feed conversion ratio calculations are often inaccurate.

Respondents to a recent survey of intensive lamb finishers (Giason and Wallace 2006) indicated their average feed conversion ratio ranged between 5:1 and 6:1 with only 17% of small operations experiencing an FCR greater than 7:1. It is unclear how many producers were quoting actual measurements versus those who were citing industry averages or targets, as these figures are more impressive than many published studies (Table 16).

Many producers quote feed conversion ratios but it remains unclear as to how many calculate it as a measurement of profitability. Few producers manage their finishing enterprise to optimise feed conversion efficiency by restricted feed allocation and feeding at particular times

of day.
Many lambs will have been on a restricted growth path before entering an *ad libitum* feeding regime during summer and autumn in southern Australia, but it is unclear how many producers buying these lambs for finishing would be aware of the potential benefits of compensatory growth. Lambs that are weaned onto high quality pasture-based systems would not be exhibiting compensatory growth, however, the profit drivers in an intensive grazing system differ markedly from a feedlot or grain finishing system.

Table 16 FCR targets recommended for feedlot finishing of lambs taken from Australian State Departments of Agriculture extension publications (Kirby RM and Beretta V 2004)

FCR (X:1)	Breed	Comment	Author
5	Crossbred lambs		Suiter 1990 cited in Kirby and Beretta 2004
6	Merino lambs		Suiter 1990 cited in Kirby and Beretta 2004
6	Crossbred lambs	After 2-3 weeks adaptation to feedlot conditions	Hack *et al* 1997cited in Kirby and Beretta 2004
7	Merino lambs	After 2-3 weeks adaptation to feedlot conditions	Hack *et al* 1997cited in Kirby and Beretta 2004
8-5			Bell *et al* 1998 cited in Kirby and Beretta 2004
7-5	Crossbred lambs		Seymour 2000 cited in Kirby and Beretta 2004
8-6	Merino lambs		Seymour 2000 cited in Kirby and Beretta 2004
7-5.5	Crossbred lambs		Milton 2001cited in Kirby and Beretta 2004
7.5-6	Merino lambs		Milton 2001cited in Kirby and Beretta 2004
6.5		Average 40 kg finishing lamb	Bell *et al* 2003 cited in Kirby and Beretta 2004
10-5		Finishing lamb from 30-50 kgs	Bell *et al* 2003 cited in Kirby and Beretta 2004

Manipulation of feed conversion data can be used as a tool by resellers to market their products, with sometimes exaggerated claims about the effect of products on FCR, whilst producers do not fully understand the concept of FCR.

Factors that influence FCR include behavioural responses to an unfamiliar environment, season, age, sex, ambient temperature and activity (Terrill 1975). Photoperiod (day length) and thermal stress have been found to affect FCR in beef cattle (NRC 2000) and in lambs existing outside their thermo neutral zone of 5-30°C (Ames and Brink 1977) as illustrated in

Figure 5.

Figure 5 Effect of environmental temperature on feed efficiency (adapted from Ames and Brink 1977)

From the work of Ames and Brink (1977) it would appear that the ideal ambient temperature range for lambs lies between 5 and 20°C, as outside this range their ability to convert feed to live weight gain becomes progressively less efficient.

Early weaned pastoral Merino and SAMM lambs fed a pelleted diet (20.9% CP and 12.6 ME), converted feed to live weight gain with a high level of efficiency (Figure 5). Note, however, that there was a period of interruption during week eight where the lambs were subjected to 24 hours of sustained noise which included barking dogs, semi trailer arrivals and the movement of large numbers of sheep within the feedlot environment. The onset of this seemingly stressful event impacted negatively on weight gain and therefore feed conversion ratio as highlighted in Figure 5.

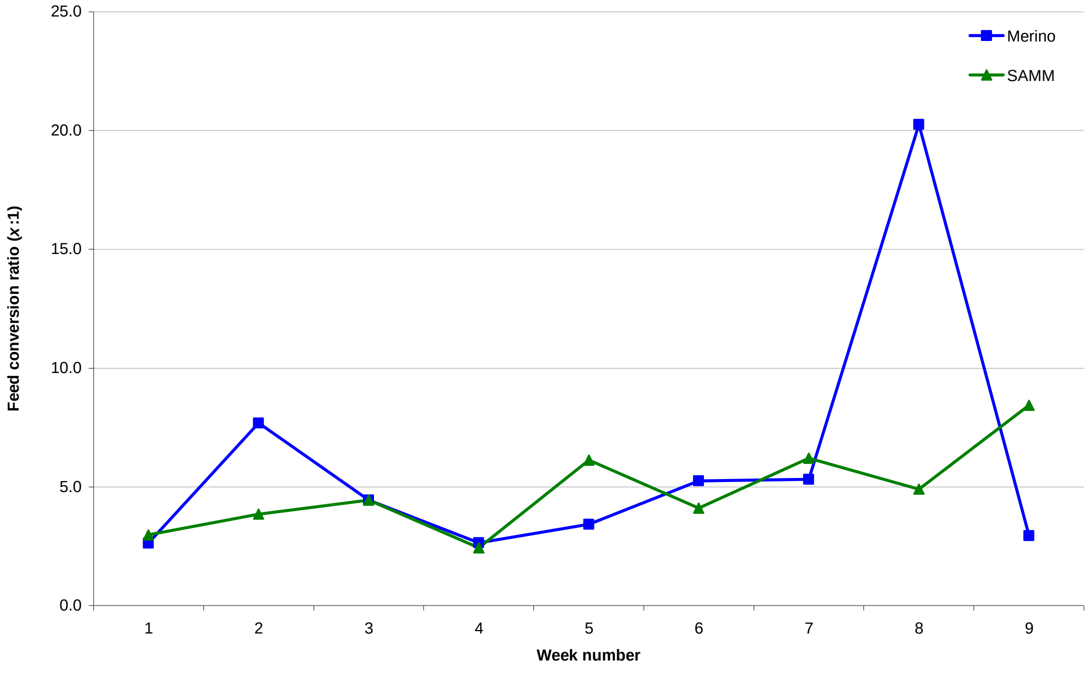


Figure 6 FCR of pellet finished, early weaned pastoral Merino and SAMM lambs (Scammell and Jolly, unpub.)

The predicted influence of age on feed conversion ratio is clearly illustrated by Oddy (2006) in Figure 7, although it is equally clear that there are lambs that defy this trend, which may provide the industry with a selection opportunity in terms of feed conversion.

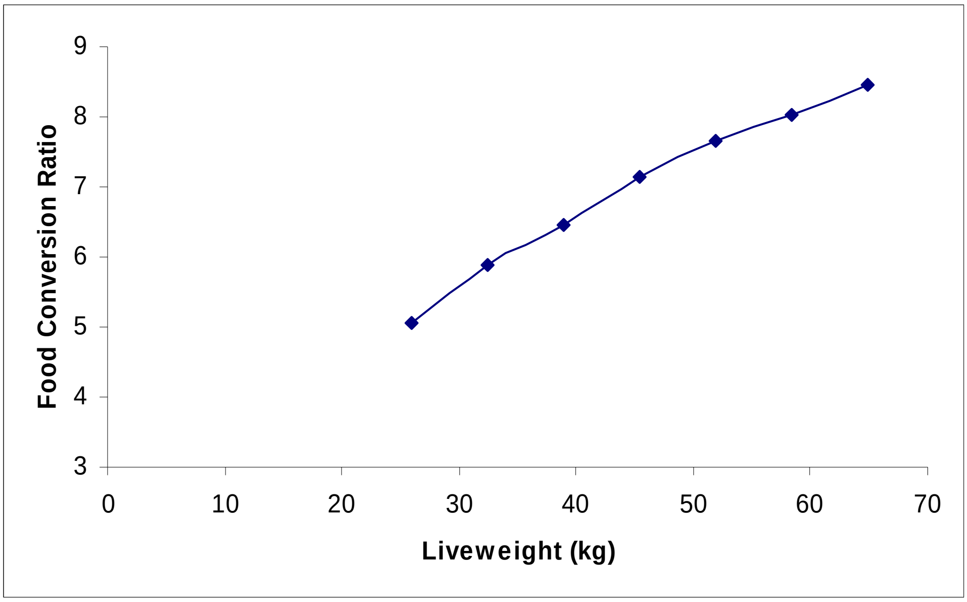


Figure 7 Predicted increase in FCR with increasing age of lambs (Source: Oddy 2006)

The variation in feed conversion ratio between lambs is considerable (Figure 8) making the current lamb industry practice of averaging misleading and costly. Intensive lamb feeding trials at Rutherglen, Victoria (Linden *et al.* 2006.) reported a range in FCR from 2.8:1 to 74:1.

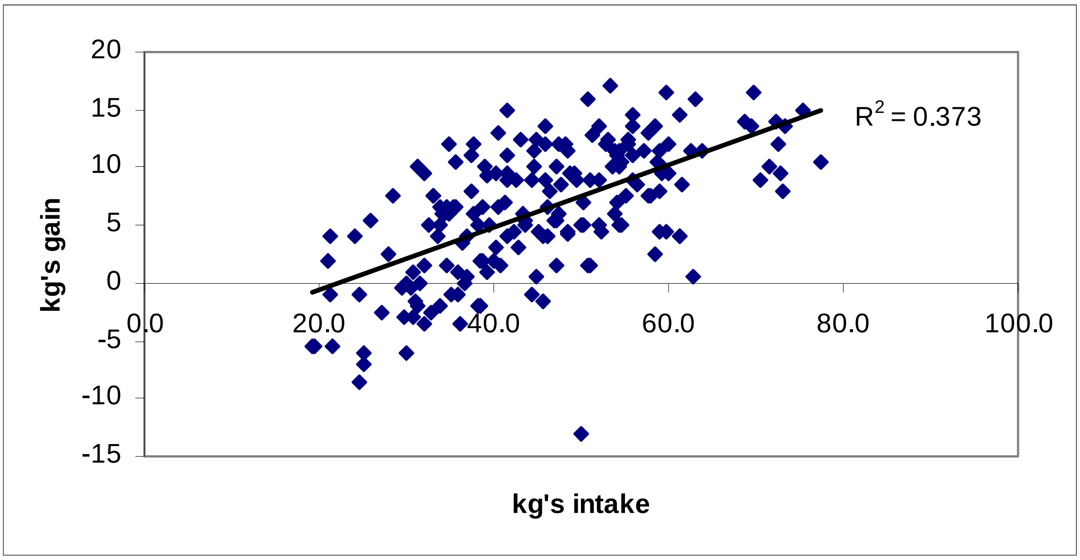


Figure 8 Variation in feed conversion of feedlot lambs (Linden et al. 2006.)

Recently completed trials in a large commercial lamb feedlot in South Australia (Table 17), have demonstrated the potential of older lambs (8-12 months) to convert feed to gain at a more efficient level than the current industry average of 6-7:1 quoted by Davis (2003).

As the more efficient lambs were removed from the trial for slaughter, it became evident that the average FCR was concealing a large number of inefficient lambs. These feedlot trials investigated the effect of a legume hay-based pellet on the health and performance of lambs following a rapid introductory period, and resulted in high levels of productivity and efficient conversion of feed to live weight gain.

The inclusion of legume hay may warrant further investigation, as similar trials by Stanton and Levalley (2006) across a range of ration formulations, found the most efficient ration contained 70% concentrate and 30% legume hay and resulted in a FCR of 4.24:1.

Table 17 Average daily gain (ADG), number of days on feed (DOF), feed conversion ratios (FCR), estimated dry matter intake (DMI) and lamb mortalities for crossbred feedlot lambs (Scammell and Jolly 2006)

DOF	Number of lambs	Lamb deaths	Mortality %	ADG (grams per day)	FCR	DMI (kg/day)
1-4 (4)	327	2	0.6%	124	10.4	1.29
5-15 (11)	324	1	0.3%	383	4.6	1.76
16-22 (7)	324	0	-	360	5.1	1.85
23-29 (7)	154	0	-	348	6.8	1.62
30-37 (7)	106	0	-	277	6.4	1.77
38-43 (7)	100	0	-	195	8.7	1.77
44-54 (11)	49	0	-	187	9.5	1.78
Total/weighted average		**3**	**0.9%**	**284**	7.3	**1.66**

In recent years, investigations into the efficiency with which sheep convert feed to live weight gain have had more emphasis on net feed efficiency rather than feed conversion.

Net feed intake (NFI) provides the cattle industry with a measure of those animals that are more feed efficient and grow faster (Priest 2006) and NFI has been shown in terminal sire rams (Knott *et al*. 2004) to be correlated with lean tissue mass (- 0.49; P<0.01), average daily gain (- 0.59; P<0.01) and gross FCR (0.59; P<0.01) and therefore warrants further investigation as a future selection tool for the lamb industry.

Murphy *et al*. (1994) found that Hampshire lambs fed at 100%, 85% or 70% *ad libitum* did not significantly increase their level of efficiency in converting feed to gain, however it did result in a 15 -30% reduction in the rate of daily live weight gain which was attributed to a reduction in fat accretion.

Time of feeding can affect feed conversion efficiency as demonstrated by Marshall *et al* (2003) who found that lambs fed in the afternoon gained significantly more weight and were more feed efficient than those fed in the morning.

McLeod (1994) examined the effect of shearing on feed conversion, and although lambs on a slatted floor converted 17.4% more efficiently than lambs in an open feedlot, there was an insignificant difference between those that were shorn and those that were woolly.

Feed conversion efficiency has been shown to improve in response to an increase in dietary protein and energy (Aktas 2001; Gorgulu and Ozturkan 1992; McClure *et al*. 1994) but only as a result of meeting, rather than exceeding, requirements as per NRC (1985) recommendations.

Some researchers (McIntyre and Ryan 2005; Ryan and McIntyre 2006) have included feed wastage when calculating feed conversion ratio. Although feed conversion is an indicator of cost and returns, and feed waste is a cost, including feed wastage in feed conversion ratio calculations is not truly representative of the relationship between feed intake and live weight gain.

Feed conversion ratio targets can be found online by groups such as Alliance Nutrition Inc, as illustrated in Table 18, although it is unclear as to whether these recommendations are on an 'as-fed' basis or a 'dry matter' basis.

Table 18 Target feed conversion ratios for feeder lambs (Alliance Nutrition Inc)

LW (Kgs)	Weaned @ 6-10 weeks	Weaned @ 5-7 months
18-27	3.5	
27-36	4.75	5
36-45	5.75	6.5
45-55	8	8.5
55+	9	10

Compensatory gain and FCR

Compensatory gain can be described as "greater than normal live weight gain observed in animals previously adapted to an extended period of nutritional restriction" (Choct, *et al*. 2003).

The extent to which compensatory gain is expressed can be influenced by the age at which the restriction occurs and the duration and severity of the restriction, as full compensation is unlikely to be observed in young animals.

Many studies focus on mature animals that are gaining condition, rather than lean gain, and the relevance of these findings to immature, growing lambs is unclear.

Oddy (pers comm. 24 April 2006) states that "providing the lambs were well grown out to weaning, a subsequent reduction in growth before finishing may be offset by compensation in the feedlot and this growth may be leaner and therefore more efficient". This view is supported by Ryan *et al*. (1993) who investigated compensatory growth responses in Merino wether lambs and Hereford weaner steers. This investigation found that the period of compensation was shorter in lambs than steers, and that at the end of the re-feeding period, the compensating animals remained lighter than the controls. Compensatory growth was found to be due to a greater efficiency of conversion of feed to live weight gain.

Restriction of intake may contribute to feed efficiency evidenced by Murray *et al* (1994), who found that when lambs were restricted to 1.5% of live weight before commencing *ad libitum* feeding, they were more efficient at converting feed to gain than those restricted to 2.2% of their live weight. In contrast, Knee (2005) found that restriction of intake prior to finishing lambs in a feedlot shed, did not result in a significant improvement in feed conversion.

The challenge for producers will be how to take advantage of this research in intensive finishing systems. Clear guidelines of how much to restrict intake, and the length of time of restriction, need to be developed for the industry to avoid negative animal welfare practices. *Ad libitum* feeding is commonly practised in Australian feedlots which negates the need to calculate the amount of feed lambs require on a daily basis, although total daily feed intake obviously contributes to operational costs.

Lambs that have experienced nutritional restriction at critical stages of early development may fail to respond to periods of feed restriction and re-feeding. Suiter and McDonald (1987) found that Merino lambs weighing 27 kg at 7 months had a poor response to re-feeding under feedlot conditions. Clearly, details of the previous plane of nutrition are required to optimise outcomes, as many of these lambs currently end up in feedlots.

Currently, many lambs are backgrounded on stubbles over summer before entering feedlots and it is likely that they have been subjected to a restriction in growth potential. Mullholland *et al*. (1976) investigated the growth rate of 10 month old crossbred lambs on oaten stubbles and reported a weight gain of 49g per day at low stocking density and weight loss of 43g per day at high stocking density which, in both cases would indicate a period of nutritional restriction.

Weaned lambs that were subjected to a period of nutritional restriction for 3 months grew significantly ($P<0.001$) faster and ate more ($P<0.001$) during re-alimentation than their unrestricted counterparts (Kamalzadeh 2004). Compensatory growth was related to a higher intake and greater ($P<0.001$) efficiency of ME intake. The maintenance requirement of the re-fed lambs was only lower during the initial stage of re-alimentation.
There is also an effect on carcase fat when lambs are either continuously fed or restricted to maintain a stable weight for a period of time after weaning and then re-fed; the restricted lambs being significantly leaner (Hodge and Star 1984).

It is evident that the period of restricted feeding should not take place before weaning as lambs will tend to be lighter and fatter (D. Pethick, pers comm. 13 September 2006). The recommended minimum weight for age after which lambs will compensate effectively is 20kg at 9 weeks or 30 kg at 14 weeks of age (Ball and Pethick 2006).

Best practice

- Monitor weight gains and fat score on a regular basis
- Remove poor performers and commence on an alternative feeding regime or sell

Recommended further research

- Determine the optimum stage of growth to achieve optimum efficiency
- Determine the true value in manipulation of growth in lambs; is it the same as for cattle?

1.8 Clarify the effect of growth rate prior to weaning and its affect on subsequent growth rate and fatnessNutritional restriction during pregnancy

As the rate of daily live weight gain is the main profit driver within an intensive finishing system, a detailed history of prior nutrition of lambs may be an important risk management tool.

Lambs that have been subjected to a period of nutritional restriction during foetal life exhibit suboptimal development of the small and large intestine (Trehair *et al*. 1997), deposit less bone, less muscle and more fat to weaning (Greenwood *et al*. 1998; Greenwood and Bell 2003), and may have a lifetime penalty in wool growth (Schinckel and Short 1961).

Approximately 33% of medium and large lamb finishing operators purchase all their lambs off-farm (Giason and Wallace 2006) with the remaining 66% of the larger operators relying on an even spread of purchased and home bred lambs.

Although lambs purchased off-farm are required to have a National Vendor Declaration accompany them, the paperwork seldom arrives with the lambs and does not include a history of nutrition and/or growth path, unless volunteered by the vendor.

The Lifetime Wool program is increasing producers' awareness of the value of body condition score in improving the reproductive success of the ewe flock. It seems, however, there is a low level of awareness of the effect of nutritional restriction at various stages of pregnancy on the potential outcome of lambs.

Hawkins *et al*. (2000) found that under-nutrition of ewes during the first half of pregnancy had no significant effect on the growth rate of lambs after birth, but caused relative hypertension in lambs at weaning age. Krausgrill *et al* (1999) also found no significant difference in the growth rate of first cross lambs from birth to slaughter; however, this was only investigated up to 35kg live weight. There is evidence that lambs of ewes that experience restricted supply of nutrients in early foetal life, may consume up to 20% more feed during early post natal life (Greenwood *et al*. 1998).

The effect of a period of nutritional restriction in pregnancy on bone growth and development appears to be more severe than the effect on lean tissue deposition although synthesis of muscle protein appears to be inhibited in the growth-retarded newborn (Greenwood *et al*. 1999). Lambs of higher birth weight tend to have reduced feed intake, reach market weight faster, have leaner carcases, and as a result are more efficient and profitable.

Merino wether lambs born to ewes maintained on a low plane of nutrition during pregnancy had significantly lower birth weights and weaning weights (Thompson *et al*. 2006) and significantly increased fat deposition. These lambs were not re-examined until 3 years of age, at which time they were found to be significantly fatter than their unrestricted counterparts.

Although there is clear evidence that a period of nutritional restriction during pregnancy can have significant implications for a range of outcomes in postnatal lambs, more research is required to investigate the effect on lambs of an age of more specific relevance (6-12 months) to the intensive finishing sector.

Best practice

- Avoid weight loss in ewes during pregnancy
- Maintain reproductive ewes at body condition score 3 all year round
- There was insufficient evidence available at the time of writing this report to recommend any specific practices other than to maintain ewes in condition score 3 during pregnancy and to increase that to 3.5 by the commencement of lambing.

Recommended further research

- Investigation of the effects of nutritional restrictions at early, mid and late pregnancy on growth rate, weaning weight and post weaning weight to 12 months of age
- Investigation of the effects of nutritional restrictions at early, mid and late pregnancy on carcase quality of the progeny at industry-relevant slaughter weights

1.9 Feed Additives

The majority of feed additives are used either to prevent acidosis, urinary calculi formation or as an additional protein source. However, some manufacturers claim that particular products also improve growth rates, feed conversion efficiency and negate the effects of particular toxins.

Although, effective avoidance of acidosis can be achieved by providing a source of palatable fibre in the diet, which stimulates rumination, mastication and therefore saliva production, many producers object to the wastage that can result from the provision of an *ad libitum* source of fibre.

There is a wide range of products that can be added to the diet of fast growing lambs, either as a single dose or in addition to a mineral premix or concentrate. These include

- Antibiotics
- Ionofores
- Sodium bicarbonate
- Sodium bentonite
- Limestone
- Acid Buf®
- Ammonium chloride/ammonium sulphate
- Urea
- Salt
- Electrolytes
- Zeolite
- Probiotics
- Chromium
- Caustic Soda

Antibiotics
Virginiamycin, an antibiotic, is registered for use in the diet of feedlot lambs to prevent the onset of lactic acidosis during the introductory period to grain feeding.

Virginiamycin is currently the antibiotic most frequently used in sheep and cattle diets as a prophylactic against acidosis, and is registered for that purpose (APVMA 2004). Virginiamycin selectively controls Gram positive, lactic acid producing bacteria and, as demonstrated by Godfrey *et al*. (1993) in Table 19, can be significantly effective in reducing mortality rates during the introductory period of ruminants to cereal grain diets.

Anecdotally, the addition of virginiamycin to the diets of dairy cattle has been less effective in reducing the symptoms of lactic acidosis when cows are ‘slug fed’ but more effective under feedlot conditions where access to feed is continuous. However, the response to virginiamycin in high grain diets has not been consistent.

Table 19 Effect of virginiamycin on ruminal pH and lactate production (Godfrey et al. 1995)

	Rumen pH	Lactate (mm/l)	Mortality rate (%)
Wheat	4.72	86.9	20
Wheat + virginiamycin	5.47	20.3	0
Significance	<0.05	<0.01	<0.01

An extensive review of non-ionophore antibiotics and their efficacy in controlling acidosis by Kirby *et al* (2004), indicated that virginiamycin was effective in reducing lactic acid production in the rumen during rapid introduction to high starch cereal grains, however public perception relating to antibiotic use in animal feed may rule out their use in the longer term.

Access to virginiamycin has been restricted to a veterinary prescription in recent years following a risk assessment by the Australian Pesticides and Veterinary Medicines Authority (APVMA) in 2004. This review clearly stated the risk associated with the use of virginiamycin in animal feeds:

> *"it is possible for virginiamycin resistance to be selected in a wide range of intestinal Gram-positive bacteria. The most important bacteria with respect to human health that are likely to be affected are those in which multi-resistance is already present, especially vancomycin-resistant E. faecium. QD is currently considered the drug of choice for vancomycin-resistant E. faecium infections in humans. Therefore, selection of virginiamycin resistance in vancomycin-resistant E. faecium and transmission of such strains through the food chain could represent a significant risk to humans."*

Antibiotics have been shown to improve weight gains (Godfrey *et al.* 1993b) and feed efficiency (Chiba 2005) with the greatest response demonstrated in lambs under stress, however the addition of virginiamycin to barley-based diets did not reduce the ruminal populations of lactic acid bacteria or prevent lactic acidosis in sheep (Al Jasim *et al*. 2003). During adaptation from low to high starch grains Bowen (2006) did not observe any improvement in rate of adaptation, growth rate or final carcase weight of mature Merino ewes with the inclusion of virginiamycin in the diet.

Ionophores

Ionophores can be defined as a group of antibiotic compounds that act by disrupting the flow of ions into and out of microbial cells (Choct 2003). Ionophores are commonly added to feed prepared by commercial stockfeed companies, however, anecdotally few producers add ionophores or antibiotics to rations produced on-farm.

Ionophores tend to be included in the diets of ruminants in an attempt to control or prevent coccidiosis and to provide the additional benefit of improving feed conversion efficiency, largely by suppressing intake (Goodrich *et al*. 1984). A review of the use of ionophores in ruminant diets by Kirby *et al* (2004) concluded that improvements in feed efficiency are more likely to be evident in cattle than sheep.

Ionophores available for use in sheep and cattle diets include monensin sodium (Rumensin®) and lasalocid sodium (Bovatec®).

Although monensin is more commonly used in cattle feedlot rations to improve feed conversion efficiency, responses can be inconsistent (Richardson 1976); however Nowakowski and Patkowska-Sokoa (1990) supplemented Merino weaner lambs with monensin and noted an average increase in weight gain of 13.3% and an average reduction in energy consumption of 12.4%.

More recent investigations of lambs supplemented with monensin demonstrated an increase in feed efficiency and a significant ($P<0.03$) effect on growth rate, although there were no significant improvements noted in the performance of young weaner lambs (Susin *et al*. 2004).

Calhoun *et al* (1979) supplemented 32 kg feedlot lambs with monensin sodium and found a decrease in ruminal acetate ($P<0.05$) and butyrate ($P< 0.01$), and an increase in propionate ($P<0.01$). A greater response with the low energy diet was noted, where a significant ($P<0.01$) interaction between monensin and energy level in the diet was reported. The long-term use of monensin may come into question following its ban in the United Kingdom (UK) from January 2006.

Lasalocid sodium is registered for inclusion in sheep and lamb diets to control coccidiosis, and has also been shown to improve feed efficiency by 10% (Umberger 1996), 4% (Harpster 2004) and 6% (Couvearas *et al*. 1980). Some reports also found improvements in live weight gain; 10% (Umberger 2001) and 6% (Harpster 2004).

Sodium bicarbonate

Sodium bicarbonate is included in finishing rations to neutralise the acid produced by carbohydrate fermentation. However, as each kilogram of feed produces approximately 7-12 moles of volatile fatty acids, the addition of sodium bicarbonate at 2% of the diet producing approximately 0.2 moles of bicarbonate is unlikely to have a significant effect on ruminal acidity (Choct *et al*. 2003).

The buffering effect of sodium bicarbonate is similar to that of sodium chloride and is thought to increase the osmotic pressure in the rumen, drawing in water and increasing the rumen outflow rate. This enhances the rate of dilution of rumen fluid and facilitates maintenance of rumen pH within the normal range (Hutjens 1991).

Responses to the addition of sodium bicarbonate in high concentrate diets consumed by ruminants vary widely and can even have a negative effect on animal health. From the literature it appears that the addition of sodium bicarbonate to the ration at 3% (Round 1983), 2% (Ha and Emerick 1984), or in combination with sodium bentonite also at 2% (Dunn *et al*. 1979), increases lamb growth and feed efficiency. However, it may also predispose lambs to urinary calculi formation (Saville *et al*. 1973; Dunn *et al*. 1979).

Anecdotal experience is that sodium bicarbonate cannot be relied upon to prevent ruminal acidosis especially in the presence of high starch diets, although there is some evidence in support of its efficacy. Ha *et al*. (1985) found a significant ($P<0.01$) improvement in starch digestibility with the inclusion of sodium bicarbonate in the ration, although Ha and Emerick (1984) found the addition of 2% sodium bicarbonate was unsuccessful in preventing the onset of acidosis when the diet was rapidly changed from high roughage to high concentrate.

However, there have been reports of positive effects on lamb growth by the addition of sodium bicarbonate to the grain ration. Cerci *et al* (1996) observed a 13.8% increase in live weight gain and a reduction in FCR from 6.6:1 to 5:1 following the addition of sodium bicarbonate to a concentrate ration at 2.5%. Although Chaturvedi *et al* (2003) recorded a 35% increase in growth rate when sodium bicarbonate was added to a 75% concentrate ration, they did not observe a decrease in feed conversion. In a similar study, Santra *et al* (2003) concluded that the addition of sodium bicarbonate to a 75% concentrate ration significantly ($P<0.05$) increased ruminal pH, increased cellulose digestibility, ciliate protozoal populations and total N concentration and therefore daily weight gain of lambs. Round (1998) noted an increase in dry matter intake by 23% following the addition of sodium bicarbonate to a wheat-based pellet at 3%.

Sodium bentonite
Sodium bentonite is a clay mineral that swells in the rumen, alters the rate of passage of rumen digesta, and adsorbs minerals and ammonia, and is commonly added to the diets of feedlot cattle to reduce the incidence of acidosis. Rowe and Atkinson (cited in McDonald *et al*. 1986) suggest that bentonite may alter patterns of rumen fermentation away from lactic acid production in favour of acetate production. However, Colling *et al* (1979) and Ha and Emerick (1984) found that bentonite had no effect on ruminal pH or lactate production when rapidly adapting lambs to a high concentrate diet.

The combination of sodium bentonite and sodium bicarbonate has been found to improve lamb performance following a rapid change from low to high concentrate diets. Dunn *et al.* (1979) reported a 19% increase in dry matter intake and 37% increase in average daily gain, compared with controls.

Bentonite improves the environment for rumen protozoa, leading to an increased flow of protozoal protein from the rumen to the intestines (Fenn and Leng 1990). This may partially explain the increase in weight gain, dry matter intake and feed efficiency ($P < 0.05$) noted by Walz *et al* (1998) in lambs fed high concentrate diets.

Bentonite has been found to improve faecal consistency (Waghorn *et al*. 1994) and significantly increase faecal dry matter percentage ($P<0.01$). Faecal consistency may be a good monitoring tool to determine the gut health status of lambs during the adaptation period to grain.

Faecal consistency can be estimated on a simple 1-5 scale, where hard pellets = 1, and fluid faeces = 5 (Bisset *et al*. 1994). A similar model to that used in dairy cows (Moran 2005) and outlined in Table 20 may be adapted to apply to intensively managed lambs. Linden (2006) used a pictorial descriptor (Figure 9) to clearly highlight the potential difference in faecal consistency between lambs when introduced to grain based rations.

Table 20 Faecal consistency score for dairy cattle (adapted from Moran 2005)

Score	
1	Very liquid manure; includes diarrhoea
2	Runny manure which does not form a distinct pile; splatters on impact and forms loose piles
3	Porridge-like consistency; forms a soft pile
4	Thick manure
5	Hard pellets

Figure 9 Faecal consistency assessment (Linden 2006)

Limestone

Fast growing lambs fed high concentrate diets require additional calcium in the ration to restore the calcium:phosphorus balance, to a ratio of approximately 2:1 (NRC 1985). Most sources of limestone available in Australia provide between 30-38% calcium.

Anecdotally, a high proportion of intensive lamb finishers add at least 1% ground limestone to the ration unless legume hay is available on an *ad libitum* basis. Limestone has an alkalinising effect in the rumen, but little effect on maintaining pH or buffering, as demonstrated by Ha and Emerick (1984) when rapidly changing lambs from a low to a high concentrate diet. They found that the addition of 2% limestone in the diet did not prevent the onset of ruminal acidosis.

Acid Buf®

Acid Buf® is a commercially available product, marketed as a rumen buffer derived from finely ground calcified seaweed rich in calcium (28%) and magnesium (4.4%). The manufacturers claim that Acid Buf® has a large surface area and a honeycomb like structure which enables it to absorb and neutralise acids, and has 2.5 times the buffering capacity of sodium bicarbonate.

Following the ban on the use of monensin in beef cattle diets in the UK from January 2006, Acid Buf® has been investigated as an alternative. Cattle were found to have a significant increase in daily live weight gain ($P<0.05$), less days to reach slaughter weight ($P<0.073$) and an improvement in FCR from 6.98 to 6.20 (Marsh and Reeve 2006).

Although Acid Buf® is currently added to several commercial stockfeed pellets, there is a lack of evidence in the published literature as to its efficacy in preventing lactic acidosis.

Ammonium chloride and ammonium sulphate

Ammonium chloride or ammonium sulphate may be added to the concentrate diets of fast growing lambs at 0.5% of the total diet to aid in the prevention of urinary calculi formation. Crookshank (1970, cited in NRC 1985) found that ammonium chloride was more effective than ammonium sulphate.

Ammonium chloride may reduce the palatability of a ration if not adequately concealed within a pellet or total mixed ration, which can therefore potentially reduce intake.

Ammonium chloride alone is not an adequate substitute for a balanced calcium phosphorus ratio in the diet of grain fed lambs as a preventative against calculi formation.

Urea

Urea is a product commercially from ammonia and carbon dioxide and is the most common source of non-protein nitrogen (NPN) included in feed rations.

Urea is added to the diet of fast growing lambs as a source of ammonia for the rumen bacteria to facilitate the synthesis of microbial protein. However, to avoid ammonia toxicity and/or a depression of feed intake (NRC 1985), a synchronous supply of readily fermentable carbohydrate, such as that supplied by grains or molasses, is required.

High grain diets provide a more than adequate supply of rumen fermentable carbohydrate to enable rumen bacteria to utilise non-protein nitrogen (NPN) as a cost-effective source of protein, when the availability of plant protein sources is limited.

Urea may be included in lamb diets when the price of plant protein sources increases or supply becomes constrained. Many producers may not be aware of the need to supply an additional source of sulphur in grain dominant rations, or the best and safest way to incorporate it into the diet whilst avoiding urea toxicity. For every nine units of urea, an additional one unit of ammonium sulphate is required to optimise microbial protein synthesis.

Urea can safely be added to commercial pelleted diets, total mixed rations on-farm, or to mineral concentrates but can pose a risk of urea toxicity if added to loose grain mixes.

A safe method of supplementation with urea is in the form of lick blocks, where substantial amounts of salt in the block limit the animal's ability to consume excessive amounts.

Supplementation with potassium, phosphorus and sulphur is required when urea is used as the main source of dietary protein, as wool contains a high percentage of sulphur amino acids.

Rumen development needs to be complete for lambs to be able to fully utilise urea (Ricketts 1999) and therefore it not a recommended addition to the diet of lambs weighing less than 22 kg (Bell 1997).

Used correctly, urea can provide a cost-effective source of rumen degradable nitrogen in the feed rations of fast growing lambs as described in Table 21.

Table 21 Intake, live weight gain, FCR, HSCW and cost-efficiency of four grain rations fed to lambs for 6 weeks (adapted from Davis 2003)

Experimental diets	Ration 1 Control	Ration 2 Urea	Ration 3 Canola	Ration 4 Sunflower
Initial LW, kg	35.3	35.6	35.3	36
Final LW, kg	46.5	46.5	45.3	46.8
ADG g/day	271	269	241	260
Intake, kg/day	1.7	1.61	1.71	1.57
Hay	0.25	0.26	0.24	0.24
FCR, g/g	7.32	6.72	8.04	6.07
HSCW, kg	20.2	20	19.9	20.3
Cost / kg LWG	$1.22	$1.07	$1.17	$1.46

The recommended inclusion rate of urea in the dietary dry matter of lambs varies between 1% (Seymour 2000; NRC 1985) which provides 3% crude protein equivalents (H. Oddy 2006 pers comm.13 September) to 1.5% (Hodge and Kat 1985; Chiba 2005). Further recommendations include a maximum contribution of urea to the total dietary protein of 33% (Chiba 2005) and 15-25% (Stanton and Levally 2006).

Sodium chloride

Salt is frequently added to lamb finishing diets to stimulate dry matter intake, to increase water intake in the prevention of urinary calculi formation and to overcome the sub-optimal levels of sodium to be found in cereal grains.

Producers may not be aware of the additional 'buffering' effect of sodium chloride in the rumen or that sodium chloride is a more cost efficient buffer than sodium bicarbonate or sodium bentonite.

The recommended rate of salt addition to the diet of fast growing lambs includes a maximum of 1% (NRC 1985), 1.2% salt on wheat based diets (O'Dempsey 2002) and *ad libitum* access to salt (Chiba 2005; Vigortone 2003). Pethick (2006, pers comm. 13 September) suggests the performance of lambs can be enhanced by the addition of up to 2% salt in the diet.

Salt is frequently used by stock-feed manufacturers as an "intake limiter" in concentrate feeds containing antibiotics or urea, which may also limit the intake of other desirable minerals and/or trace elements provided in the concentrate.

Electrolytes
Studies involving crossbred lambs subjected to restraint and isolation stress, showed no positive effects from the addition of electrolyte addition to their water trough (Apple *et al*. 1993). However Gardner *et al*. (2001) recommend the use of magnesium supplementation for reducing the stress effects of exercise prior to slaughter.

Tollersrud *et al*. (1971) investigated the effects of trucking and subsequent exercise on the serum magnesium levels of ewes with lambs at foot. They measured a significant fall in magnesium levels during trucking but a return to normal levels after movement, once unloaded.

It is difficult to compare these studies and draw any meaningful conclusions however, as the methodologies and dose rates were different.

Zeolite
Zeolite (clinoptilolite) is a naturally occurring mineral that has ammonia binding properties (Williams *et al*. 2002) and is reportedly used in lamb finishing rations in New South Wales (G. Duddy 2006 pers comm. 13 September).

Promoters of the use of Zeolite (Zeolite Australia) claim that "researchers suggest" that zeolite:

- improves rumen microbial activity
- reduces acidosis due to its cation exchange capacity (120meq/100g) which is superior to bentonite (40-80 meq/100g)
- reduces the risk of urea toxicity by binding with NPN and releasing it slowly over 4-6 hours
- increases binding of aflatoxins
- reduces manure odour
- reduces salt levels in manure

The addition of Zeolite to the diets of lambs had no effect on the prevention of acidosis (Bartko *et al*. (1983; Prosbova *et al*. 1983) and did not significantly affect acid-base balance, total buffering capacity, actual or standard bicarbonate (Prosbova *et al*. 1983). There was no significant effect on weight gain (Colpan *et al*. 1986; Nikolaev 1992; Tabbaa 1999) however ,Tabbaa (1999) did note an improvement in feed efficiency when feeding rations containing 3% zeolite. Pond (1989) found a significant increase in the daily gain of lambs fed a 14% crude protein ration but no effect when feeding a ration containing 9% crude protein.

Forouzani *et al*. (2004) concluded that zeolite did not appear to offer any significant benefits to the performance of intensively finished lambs in terms of growth rate or feed conversion efficiency. Studies on zeolite added to the diets of dairy cows failed to demonstrate an increase in dry matter intake (Williams *et al*. 2002), and did not alter rumen pH or ammonia concentrations (Bosi *et al*. 2002).

Probiotics
Probiotic bacteria have been promoted as feed additives to replace antibiotics due to their action in suppressing the activity of harmful bacteria and enhancing the activity of indigenous gut microflora, however their results to date have been inconsistent (Choct *et al*. 2003).

Probiotics such as ‘Protexin’ and ‘Bio-start’ claim to improve growth rate and feed efficiency by the suppression of pathogens and production of enzymes that support digestion and improve the immune response by increasing antibody levels (Choct *et al*. 2003).

Although neither of these products is yet to be commonly used in the rations of fast growing lambs and few studies have investigated their efficacy, Rao *et al* (2003) found that the addition of a range of probiotics to the diet of sheep significantly improved weight gains and feed efficiency. However earlier work by Birch *et al* (1994), did not report any significant improvement in either growth rate or feed efficiency when including probiotics in the diet of fine wool wether lambs.

Chromium
Chromium deficiency has been highlighted as a potential issue for animals under stress (Mowat 1997), although the degree of stress that lambs experience in intensive finishing systems has yet to be quantified. Newly weaned and transported lambs supplemented with inorganic chromium had lower ($P<0.05$) concentrations of serum cortisol on Day 3 after transport, and a trend toward lower levels on days 6 and 9, however there was no effect observed on glucose or lactate levels (Yanchev *et al*. 2003). Sano *et al* (2000) investigated the effect of chromium supplementation on heat stress (20-30°C for 5 days) in sheep and in terms of blood glucose and insulin parameters, no significant response was recorded.

An increase in the rate of lean tissue deposition may be an additional benefit (Tehrani *et al*. 2004) from the inclusion of chromium in the diet of fast growing lambs and Uyank (2001) has suggested that chromium may alter carbohydrate and lipid metabolism, such that lipid deposition may be reduced in supplemented lambs. Hayirli *et al* (2001) found an increase in dry matter intake and milk production in periparturient dairy cows supplemented with chromium methionine and their finding of improved glucose tolerance and insulin responsiveness may partly explain the findings of Uyank.

Chromium supplementation has been shown to decrease serum cortisol concentrations in weaner calves under stress (Chang and Mowat 1992) however further studies by Kegley and Spears (1995) failed to corroborate these findings.

Kitchalong *et al*. (1995) concluded that the metabolic measures that chromium appears to influence may affect the performance of growing lambs although Gentry *et al*. (1999) found that chromium supplementation had minimal and inconsistent effects on lamb production. In 2004, the Kojonup Sheep Group, investigated the effect of elemental chromium on conception rates in sheep. Their investigation failed to show any improvement.

In an online review of supplemental chromium for beef and dairy cattle, Mowat (1997) states that studies at the University of Guelph have shown that chromium supplementation can:

- increase weight gain in feeder cattle by an average of 21% and up to 173%
- reduce morbidity in cattle feedlots from bovine respiratory disease by 32%
- increase weight gains at similar levels to antibiotic supplementation

Caustic soda (sodium hydroxide)
Alkali treatment of grain prior to feeding with caustic soda to prevent acidosis is part of a feeding system promoted in Australia by a company for use within a mixed feed ration. The alkalinisation process maintains stable rumen pH, and avoids the fall in pH often associated with the introduction and feeding of high starch cereal grains such as wheat, triticale, barley or maize and acidic silages.
Although the benefits to livestock are obvious, there are substantial occupational health and safety hazards in the handling of caustic soda, and inefficiencies in the process, for example, it is recommended that the treated grain be removed from the mixer and left to stand for at least 5 hours before feeding to livestock.

Supplements that improve feed conversion efficiency and weight gains often have a greater effect in livestock that are fed low quality diets; therefore the cost-efficiency of supplementation vs improving diet quality requires consideration prior to the addition of “performance enhancing” products.

Best Practice

- Individual feed additives may be required in addition to a grain based ration, but need to be assessed in the context of the total ration on an individual basis

Recommended further research

- Determine the effect of magnesium in feed rations on the alleviation of stress of fast growing lambs under intensive conditions (H. Oddy 2006 pers comm.. 13 September)
- Determine the effect of chromium supplementation in the diets of fast growing lambs

1.10 Ration design

It is not the intention of this review to examine individual grains and their positive or negative effect on lamb performance, as there is considerable variation within and between grains in their physical and chemical characteristics, as reviewed extensively by Kirby and Beretta (2004). Accordingly, any relationship between individual ingredients and lamb growth is too difficult to determine.

Worthy of note however, is the apparent low rumen digestibility of whole sorghum grain (Bowen *et al*. 2006), which results in the production of high levels of faecal starch and poor faecal consistency (D. Pethick 2006 pers comm.13 September). This grain is readily available in northern New South Wales and Queensland as a cost effective source of carbohydrate.

In a summary of a series of studies undertaken by the Sheep CRC (Bowen *et al*. 2006), no significant difference in lamb performance was reported between sorghum-based diets, pelleted diets or those based on winter cereal grains; however, growth rates across all treatment groups were sub-optimal by current industry standards, and averaged only 176 grams per day. The highest daily gains were achieved by lambs fed diets consisting of whole sorghum and cottonseed (190g/day) and whole sorghum plus cottonseed meal (190g/day), however all the trial lambs had access to *ad libitum* wheaten hay of unknown quality, and daily intakes were not reported.

The two most important factors relating to ration design are the cost efficiency of the ration and the effect of the ration on the health status of the animal.

Production rations for fast growing lambs can include:

- high quality pasture base
- complementary feeding on dry pasture or stubbles
- feedlot rations

The form of the ration can include:

- loose grain mixes or single grains with *ad libitum* access to pasture or hay
- grain-based pelleted diets plus *ad libitum* hay
- hay-based pelleted diets
- total mixed rations

Finishing lambs on a pasture-based system is generally the most cost-efficient system, unless the pasture base is lucerne that can be unpredictable in its nutritive value. Optimum growth potential is seldom realised on a pasture-based system, unless the pasture is analysed for nutritive value on a frequent basis, and a complementary grain mix, adjusted to meet the nutrient requirement of the lambs, is provided.

Dry pastures and stubbles are utilised more for backgrounding lambs prior to entering a finishing system, rather than for production feeding, as growth rates tend to be sub-optimal under these conditions (Arnold *et al*. 1976; Rowe *et al*. 1989; Gardner *et al*. 1993, cited in Ryan *et al*. 2004).

Feedlot ration design

Factors influencing the cost-efficiency of an intensive finishing ration include:

- minimisation of mortalities during the feeding period
- actual ration cost
- purchase price or value of the lambs at commencement of the feeding period
- sale price
- skin value
- time spent on feed
- daily intake } feed conversion ratio
- growth rate } feed conversion ratio

Producers tend to prefer to utilise feedstuffs produced on-farm rather than buy in feeds that may be more cost-effective (G. Duddy 2006 pers comm. 13 September) due to the risk of importation of weeds, and for convenience.

Feed wastage is sometimes a hidden cost associated with ration design and two studies (McIntyre and Ryan 2005.; Ryan and McIntyre 2006) have highlighted the effect that wasted feed can have on 'feed conversion efficiency' and therefore profitability. Although it is not strictly correct to include feed wastage in feed conversion ratio calculations, it does highlight the effect on cost efficiency.

Hay wastage, with estimates as high as 40% (Bowen *et al*. 2006) have been identified as a major problem that warrants further research (G. Duddy 2006 pers comm. 13 September); as well, the scooping out of pellets and sorting of grains from *ad libitum* self-feeders can contribute to waste. The amount of waste can be difficult to estimate.

The most important components of a well-designed ration include stimulation of initial intake with high quality roughage, low starch grains (oats and lupins) and a gradual period of introduction to ensure a safe adaptation to grain. There has been much written about rapid adaptation of lambs to high grain diets, and feed additives to assist in this process, but gradual adaptation appears to be the most cost-effective method.

Feeding whole grain is preferable to processed grain to avoid the production of soft fat associated with high levels of propionic acid (Webster and Povey 1990); although processing of large and unfamiliar grains, such as lupins or beans, can assist the introductory process. Grain does not require processing for fast growing lambs (O'Dempsey 2002; Holst and White 2003; Wand 2003) and responses to either the physical form or mode of presentation of the ration appear inconsistent (Ryan and McIntyre 2006).

Processing grain incurs an added expense. Feeding trials with cast-for-age Merino ewes (Beretta *et al* 2004) were unable to demonstrate a significant difference in daily live weight gain, or feed conversion, in response to steam flaking sorghum.

There is considerable variation in trial responses to different combinations of ration ingredients (Umberger *et al*. 1998, Flanagan 1999) and in some cases comparisons have been impossible due to the different nutritive values of the diets being compared (Wiese *et al*. 2003).

In many instances, comparison of trials set up to determine differences in ration design have been difficult to interpret due to poor trial design.

It is important for producers and researchers to appreciate the effect the nutritive value of the total ration has on productivity, more so than the individual ration ingredients, or the manner in which the ingredients are processed and/or presented to the sheep or lambs.

Merino and crossbred lambs fed a total mixed ration (TMR), a pelleted diet or a loose grain mix and *ad libitum* hay (McIntyre and Ryan 2005) were compared so as to measure the effect of feeding systems on growth rate and carcase characteristics. No significant difference was reported in the growth rates achieved on the TMR or the loose grain mix plus *ad libitum* hay, but the lambs on the pelleted diet grew significantly faster. However, the consumption rate of the pelleted diet was 7.6% higher than the TMR and 10% higher than the loose mix and *ad libitum* hay that may have contributed to an increase in growth rate. Unfortunately, the consumption rate and nutritive value of the hay was unknown, making it impossible to assess the impact of the nutritive value of the total diet on performance.

There has been some encouragement for producers to remove the roughage content from the diet of fast growing lambs in recent years (ELMS 2006), to attempt to improve growth rates to greater than 400 grams per head per day and the feed conversion ratio to less than 4:1. Although this claim has the support of Umberger (1996) and Landa *et al* (2001), when feeding either whole barley or maize, there is still sufficient evidence to support the retention of roughage in a ration for fast growing lambs, as outlined in Section 3.

Lambs fed whole wheat plus 20% roughage gained significantly more weight than a whole wheat di*et al*one (Davis *et al*. 1976). Neary (1998) recommends a minimum of 10% roughage to prevent acidosis. Ha *et al* (1985) found that the addition of 10% hay to the diet of lambs, changing from a roughage dominant to a grain dominant diet, reduced the mortality rate by 41%.

In recently completed unpublished trials, crossbred lambs fed a hay based pellet *ad libitum*, following a three day introductory period on legume hay, achieved growth rates in excess of 400 grams per head per day and FCR of 4.6:1. Under the same trial conditions Merino lambs achieved growth rates in excess of 300 grams per day and converted feed to live weight gain at a ratio of 7.2:1 (Scammell and Jolly 2006).

It would appear sensible to provide high quality hay or silage in an *ad libitum* feeding system to encourage sufficient intake of roughage, without significantly diluting the NV of the ration

The majority of ration designs, within a myriad of trial data, are too variable for meaningful comparison, such that the specifics of ration design may be unimportant, providing:

- the nutritive requirements of fast growing lambs are met (NRC 1985)
- the ration is introduced to the lambs gradually to allow adaptation of the rumen microflora
- the ration is palatable to encourage dry matter intake
- there is sufficient buffering effect, provided by the addition of roughage and/or sodium chloride, to prevent a significant decline in ruminal pH

Ration formulation

A high degree of knowledge and understanding of nutrition is required for producers or their advisors to be able to formulate a ration that will optimise profitability.

The nutrient requirements of fast growing lambs must be known, the nutritive value of the available feedstuffs must be obtained on an actual analysis, and not from a 'book estimate', the mineral requirements of the lambs must be assessed or estimated, and there should be an awareness of the hazards and daily intake limitations of certain feed additives and by-products. All of these factors must be considered and combined to formulate a least cost ration; however the lowest cost ration is not always the most cost-effective.

Ration formulation programs currently on the market are either expensive and complex (Feedmania; Agridata), or are limited by growth potential (Takeaway; Ready Rations), or reach questionable conclusions (Grazfeed; Dixon *et al*. 1993). Therefore the onus is currently on producers to estimate requirements, or to seek independent expert assistance, which is not readily available.

There are few operators in the lamb feedlot industry who currently possess this capability, and this may be the greatest limitation to lamb growth that is evident in many of the reviewed studies (Appendix 1).

Simple solutions such as the Pearson Square (Choct *et al*. 2003) are available to assist in ration formulation and can suffice if the ration contains only two or three ingredients, but calculations are limited, and do not cover a broad spectrum of nutrients (Figure 10).

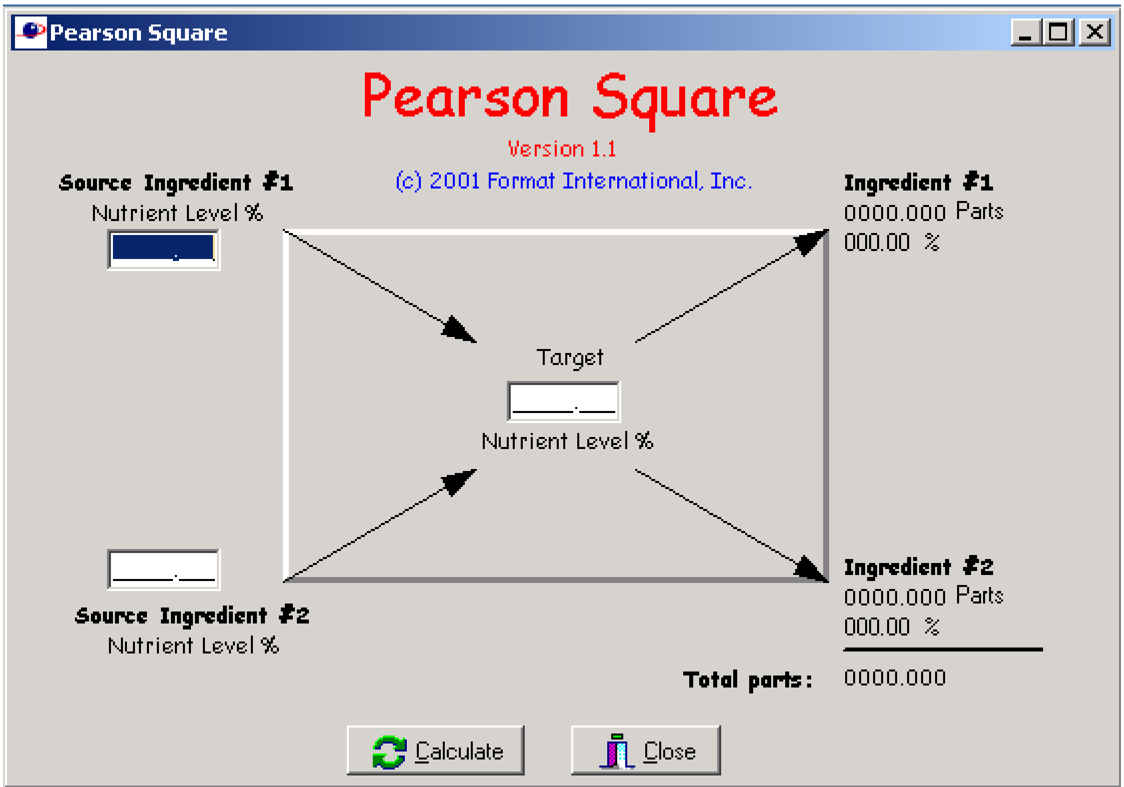


Figure 10 Pearson Square (http://www.format-international.com)

To download: www.format-international.com/software/Screens/psquare_PC_screen.htm
For instructions and simple formulation examples, see also:
www.ext.vt.edu/pubs/sheep/410853/square.html

Different feedstuffs need to be compared on a dry matter (DM) basis and selected on the cost per unit of energy and protein, rather than the cost per tonne. However, selecting grain purely on a cost per nutrient basis, ignores the potential cost of sub-clinical acidosis and mortality associated with grains of high nutrient density such as wheat, or the additional cost of antibiotics and rumen buffers designed to counteract the effects of high starch grains.

The Sheep CRC Feedlot Calculator: Version 3 (Duddy *et al*. 2006) will hopefully address many of these issues, as it is further developed and refined, to provide the lamb feedlot industry with a useful ration formulation tool (Figure 11).

Basic Feedlot Calculator

INPUTS

Initial Liveweight	(kg LWT)	28
Final Liveweight	(kg LWT)	48
Carcase Dressing %	%	46
Carcase Sale Price	($kg/kg)	3.80
Skin Sale Price	($/hd)	10.00
Target Daily Growth Rate	(g/h/d)	230
Level of feeding (DM)	%LWT	3.5
Fleece price	$/kg	2.00
Deaths	(%)	2
Draft 1 lambs	(%)	80
Shy Feeders	(%)	5
Draft 2 lambs	(%)	13
Draft 2 Selling Price HCWT	% price	100
Purchase Price/lamb	($/lamb)	30.00
Interest Cost on Purchased Lambs	(%)	10
Running Costs		
Shearing	$/hd	2.80
Crutching	$/hd	
Drench	$/hd	0.25
Fly Control	$/hd	
Lice Control	$/hd	0.25
Vaccine (Vitamin A,D,E or B12)	$/hd	0.25
Vaccine (5 or 6 in 1)	$/hd	0.25
Transport - In	$/hd	
Transport - Out	$/hd	3.00
Killing Costs/Slaughter Levy	$/hd	1.83
Commission - Buy	$/hd	0.00
Fixed Costs/lamb	$/hd	0.50
Selling Commission	%	5.0
Feeding Costs		
Labour Cost	c/l/d	5
Ration Cost (as fed)	$/tonne	277
Feedout Costs (as fed)	$/tonne	10
Ration DM	% DM	89

IF you are costing the ration from the ingredients put the average Cost and DM% to the feeding costs above

OUTPUTS

Production		
Daily Intake	kg/h/day DM	1.33
Feed Conversion	kg/feed/kgLWT	5.8
Liveweight Change	kg	20.0
Days on feed	days	87
Daily Feed (as fed)	kg/day/lamb	1.49
Total feed (as fed)	kg/lamb	130
Average HCWT	HCWT (kg)	22.1

Income/lamb ($/lamb)	
Draft1	93.90
Draft2	93.90
Shy Feeders	45.80
Wool	2.00
AVERAGE PRICE	91.62

Costs/lamb ($/lamb)	
Purchase	30.00
Running costs	14.33
Labour cost	4.35
Ration Cost	37.29
TOTAL COSTS	85.97
PROFIT ($/lamb)	5.65
Value Added Ration %	15

Ration Costing (if required) AS FED

Ingredient	$/tonne (as fed)	% fed	DM%
Barley	250	62	90
Lupins	400	10	90
Bentonite	260	1	100
Lime	165	1	100
Salt	300	1	100
Hay	300	25	84
Ration Average	277	100.0	89

Figure 11 Sheep CRC Feedlot calculator (Duddy et al. 2006) (http://www.sheepcrc.org.au/images/pdfs/FEEDCALCULATORV3.xls)

By-products are promoted by resellers when grain and hay prices are high, however their contribution to the ration can often be minimal, even though their comparatively low purchase price per tonne may appear attractive. By-products such as potatoes, brewer's grains and orange peel are all high in water content, and therefore low in DM, so that when the nutrient contribution is calculated on a DM basis, they can prove comparatively expensive to grain or hay. When sourcing by-products, additional freight costs can result from their high water content. In addition, a TMR feeding system may be required for mixing and delivery.

Specific by-products have inclusion restrictions, for example, whole cottonseed is not recommended to be included at greater than 20% of the ration (Ensminger *et al*. 1990), which is information that may not be readily available or easily found. Some by-products contain toxic levels of individual nutrients, therefore, an understanding of how each of these products can add value to a ration is essential prior to their use.

There is also evidence that the water content and water holding capacity of feed can depress intake (Kenney *et al*. 1984; McBurney, *et al*. 1985; John and Ulyatt 1987; Orr *et al*. 1997) which may detract from the addition of wet by-products or silage to the ration of fast growing lambs. It appears that lambs fed silage improve growth rate and dry matter intake when silage is supplemented with a feedstuff that is higher in dry matter content, such as dry grass (Fitzgerald 1987; Petit and Castonguay 1994).

Although it may appear that pelleted diets provide the highest growth rates comparatively (Ryan and McIntyre 2006), they are generally the most expensive feed source as pelleting companies require an operating margin when value-adding feedstuffs. As the increased performance on pelleted diets is often secondary to an increase in dry matter intake (Ryan and McIntyre 2006), the growth response measured may not always be the most cost-efficient, although this is rarely reported or measured. Flanagan (1999), reported greater feed conversion efficiency feeding lambs a loose mix (FCR =3.3:1) than a pelleted ration (FCR = 3.7:1).

In a recent survey of intensive lamb finishers (Giason and Wallace 2006), less than 34% of respondents indicated they fed a pelleted diet to finish lambs.

Best Practice

- Cost efficient ration design
- Ration formulation to meet the nutrient requirements of the lambs

Recommended further research

- Are the components of a ration more or less important than the end formulation?

1.11 Feeding methods

A review of confinement feeding undertaken by the Sheep CRC (Bowen *et al*. 2006) found no significant difference between lamb or sheep performance between three diet forms; pellets, *ad libitum* hay and grain, or total mixed rations.

The most important consideration for feedlot operators, or those supplementing in the paddock, is labour efficiency, which can be the main determinant of the feeding method.

This section reviews the effect of the method of access to feed on the growth rate of intensively finished lambs, and includes:

- *Ad libitum* access (self-feeders or troughs)
- Restricted intake (trough feeding)
- Choice feeding

Ad libitum access

A recent survey of feedlotters found that grain, grain mixes or pellets were provided on an *ad libitum* basis for fast growing lambs in 100% of feedlots containing more than 15,000 lambs; 75% of medium sized feedlots and 82% of small operations (Giason and Wallace 2006).

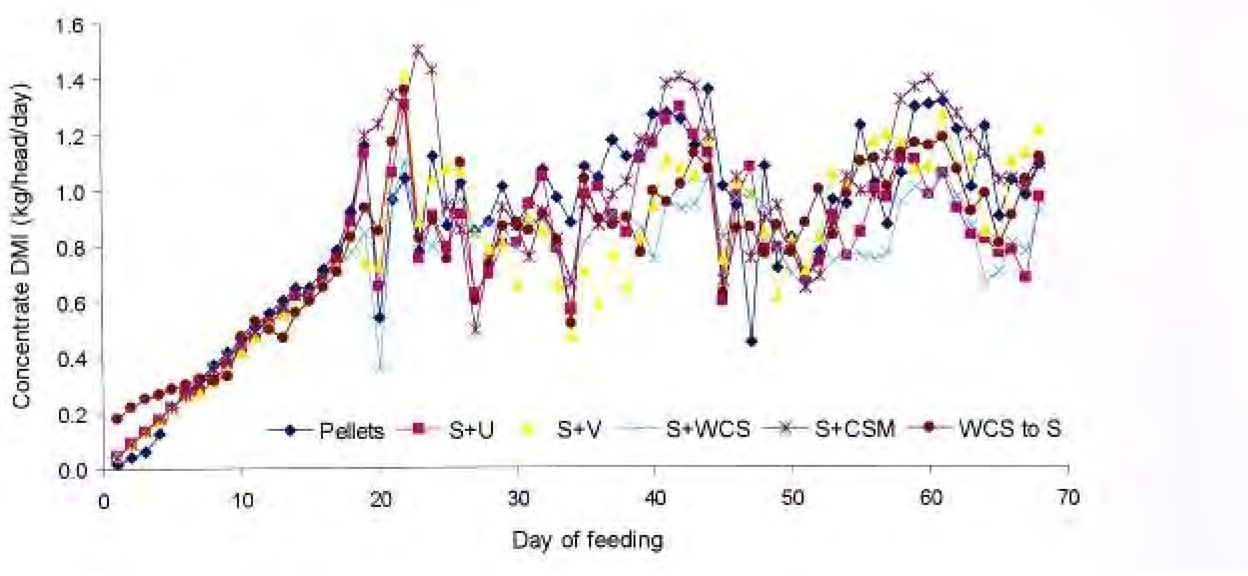


Figure 12 Concentrate dry matter intake fluctuations by sheep over the feeding period (Bowen et al. 2006 unpub.)

Self-fed lambs have a greater variation in daily dry matter intake compared with trough fed lambs (Bowman & Sowell 1997; Bowen *et al* 2006) however Hack *et al.* (cited in Ashton and Morbey 1997) claim that *ad libitum* feeding increases growth rates and feed efficiency which is further supported by Stanton and Levalley (2006). On the other hand, Fluharty *et al* (2001) found no difference in daily gain or feed efficiency attributable to feed access, and Hampshire cross lambs fed *ad libitum*, 85% or 70% of *ad libitum* had similar levels of feed efficiency (Murphy *et al*. 1994) as illustrated in Table 22.

Table 22 Effects of intake level on lamb performance (Murphy et al. 1994)

	Intake level, % of *ad libitum*			SEM
	100	85	70	
Initial LW(kg)	**25.8**	**25.8**	**25.7**	**0.2**
Days 0-28				
ADG (g/day)	420	323	253	10.8
DMI(g/day)	1250	1020	850	14.9
FCR (DM basis)	3.0	3.2	3.4	1.4
Days 29- slaughter				
ADG (g/day)	387	363	317	10.5
DMI(g/day)	1447	1273	1097	31.1
FCR	3.7	3.5	3.5	3.0
Final LW (kg)	**49.1**	**48.5**	**47.9**	**0.2**
Days on feed	58	66	76	1.1
Total ADG (g/day)	407	347	293	10.5
Total DMI (g/day)	1350	1167	1007	21.0
FCR (DM basis)	3.3	3.4	3.4	2.0

Restricted intake

When restricting access of lambs to feed, the feedlot operator has to be aware of the daily requirements of fast growing lambs. This may not be the case for many operators who feed on an *ad libitum* basis. However, some producers are currently restricting intake successfully in terms of supplying a leaner, higher value product (S. Chapman 2006 pers comm. 13 September).

Restriction of feed intake has improved feed efficiency in cattle (Murphy *et al*. 1994). Hicks *et al*. (1987) found in a review of several studies, that restricting feed intake by 8.7% below *ad libitum,* reduced daily gain by 5.2% and increased feed efficiency by 3.2%.

Glimp *et al*. (1989) found a 20% improvement in feed efficiency when lambs were restricted to 92.5% of *ad libitum* intake. Most of the efficiency gain was due to an increase in growth rate; as intake reduced by a further 7.5%, the rate of daily gain reduced by 7% but feed conversion efficiency increased by 7%. In contrast, Fluharty and McClure (1997) found that restricting intake of early-weaned lambs to 85% of *ad libitum* did not improve feed efficiency.

Although 20-38% of intensive lamb finishers currently feed in troughs (Giason and Wallace 2006), it is not known what percentage of these producers restrict daily feed allocation.

Restricted feeding is clearly an area of intensive lamb finishing that requires further investigation in order to establish the feeding method that results in the most cost efficient response.

Choice feeding

In an attempt to optimise growth rates of intensively reared lambs, there has been a degree of interest shown by the scientific community at least in providing lambs with a range of diet options; the theory being that if they can select their own diet and presumably overcome dietary imbalances, growth rates will markedly improve. Some studies have confirmed this finding, although the methodologies between each study reviewed have been too variable to justify a comparison.

Provenza *et al*. (1996) proposed that free choice feeding systems could be a way of determining actual nutrient requirements, rather than predicted, as is the current system. Atwood *et al*. (2001) also suggested that calves would be better able to meet their own nutritional requirements when offered a choice of feeds. This hypothesis assumes that most rations are formulated to meet the requirements of the average rather than the individual animal.

Further work by Tolkamp *et al*. (1998), suggests that reliance on the animals' selection of feeds could be misleading, as dairy cows given a choice of two feeds were found to select for feed characteristics rather than for or against metabolisable protein content. In the same experiment, the addition of urea had a depressant effect on diet choice. However, James *et al*. (2001) found that although sheep increased intake when urea was added to feeds deficient in effective rumen degradable protein, across all choice treatments they demonstrated a significant ($P<0.01$) preference for feeds containing urea, unless the urea levels in the diet were excessive (Kyriazakis and Oldham, 1993). These researchers found that given a choice, sheep avoided an excess of protein intake and selected against an excess of urea.

Kyriazakis and Oldham (1993) offered lambs a choice of a high and a low protein diet and noted that self regulation resulted in similar growth rates to that of a 16% crude protein ration. In more recent work (Kyriazakis and Oldham 1997) proposed that diet selection may have been affected by the synchrony of energy and protein supply to the rumen. Lambs offered a choice of diets that varied in energy density, selected both and grew at similar rates of gain to those offered only a single diet high in energy density (Cooper *et al*. 1995).

Provenza *et al*. (1996) proposed that offering lambs a choice of different foods of similar nutritional value, or the same foods differently flavoured, were methods that resulted in increased preference and intake.

There is evidence that dairy cows will select feeds that attenuate the effects of subclinical acidosis, either by selecting a roughage source (Keunan *et al*. 2002), or by selecting a diet supplemented with sodium bicarbonate (Cooper *et al*. 1996).

Neutral detergent fibre (NDF) content and rate of carbohydrate degradability have been found to contribute to the diet selection of lambs (Francis 2002), as sheep appear to prefer a diet that is slowly degraded. Lambs offered a choice between pelleted diets of low, medium or high rumen degradability convert feed to gain most efficiently when ingesting the pellets of medium and high degradability, but without a choice, efficiency was optimised by feeding pellets of medium ruminal degradability. Both carbohydrate degradability and NDF content were found to contribute to selection as summarised in Table 23.

Table 23 Effect of diet choice on total intake and live weight gain (adapted from Francis 2002)

		H	M	L	H/M	H/L	M/L	sed	P
DMI	g/day	1725	1648	2174	1879	2144	2201	191.1	*
CPI	g/day	319	314	401	356	396	415	35.9	*
MEI	MJ/day	17.4	16.2	20.4	18.6	20.6	21.3	1.86	ns
NDFI	g/day	581	641	905	713	832	876	75.3	***
LWG	g/day	186	232	352	348	368	395	54.4	**
FCR		10.6:1	6.17:1	7.09:1	6.19:1	6.69:1	6.4:1		

DMI (dry matter intake); CPI (crude protein intake); MEI (ME intake); NDFI (NDF intake); LWG (live weight gain); FCR (feed conversion ratio)
Sed (standard error of difference); * (P<0.05); ** (P<0.01); *** (P<0.001)
H (high rate of degradability); M (medium rate of degradability); L (low rate of degradability)

Lambs offered a choice of a range of feedstuffs including barley, maize, beet pulp, soybean meal, grape pomace, and wheat straw ate more, converted feed to gain more efficiently and cost less per unit of gain (P<0.05) than lambs offered a single diet which included 70% cereal grain (Atwood *et al*. 2006). Awassi lambs at 12 weeks of age were offered a choice of feeds that included barley, wheat bran, cotton seed meal and lucerne hay and were compared with lambs fed a single diet of 10ME and 17% crude protein (Gorgulu *et al*. 1996). The choice fed group consistently had higher weight gains (346 vs 299g/day; P< 0.01) and converted feed to gain more efficiently (5.1 vs 5.7; P<0.05); however, there was no difference (P<0.05) in intake between the two groups.

When Atwood et al (2006) offered lambs a choice of feedstuffs to enable them to select their own diet, there were considerable differences noted between individual lambs in their selection. No two animals selected the same ingredients and none selected a diet similar in nutritive value to the single mixed ration.

Two groups of choice fed goats, offered a range of feeds (Fedele *et al*.1996), selected different feeds which resulted in a diet consisting of similar nutritional composition in terms of NDF (39.9-41.7%) and crude protein (12.5–13%). What remains unclear is whether animals that are allowed to select their diet, optimise their potential productivity or perform to the average.

Feedlot lambs offered a choice of pellets during the introductory period had a lower rate of scouring and faster rate of weight gain than those fed single pelleted diets (Whale *et al*. 2005). However, this effect did not continue into the finishing period after *ad libitum* hay was removed from the diet (Figure 13).

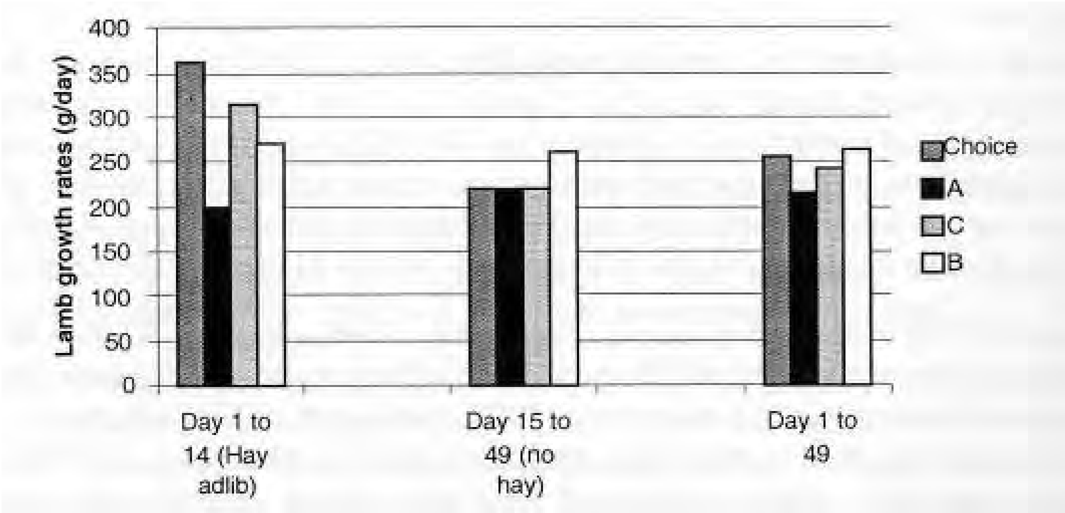


Figure 13 Mean lamb growth rates for feedlot introductory phase, following finishing phase and overall feedlot time (Whale et al. 2005)

Choice feeding may provide a means whereby growth rate can be optimised, although at this stage it is unclear if this research can be used to any practical advantage on-farm, but further investigation of this feeding method on a commercial scale appears warranted.

Best Practice

- There is currently insufficient evidence to justify the recommendation of one feeding method over another, depending on the type of feedstuffs available

Recommended further research

- Determine the effect of restricted feeding on feed efficiency
- Determine if the intensive lamb finishing industry would adopt a choice feeding system
- Determine the cost-efficiency of choice feeding on a commercial scale

2 Feedlot Design

The current guidelines for feedlot design vary widely and no relationship has been established either anecdotally or within the literature, between design and performance. The choice of feeding equipment appears based on cost and personal preference, and although the relationship between water and feed intake is strong, the effect of water supply, delivery systems, flow rate and positioning remain unclear.

It is likely that access to feed and water will significantly impact on lamb growth and performance, although the exact nature of this relationship has yet to be determined.

Although the relationship between stocking density and performance has been investigated with pigs, beef and dairy cattle, there is limited evidence to support the current guidelines for stocking densities in outdoor lamb feedlots.

Despite a range of recommendations, the relationship between stocking density (both indoors and outdoors), and growth has not been determined and the evidence-based recommendations for indoor stocking rate may not be acceptable in terms of animal welfare.

Limited research has failed to resolve the benefits of feedlotting over paddock finishing, in terms of lamb growth, therefore this area requires further investigation. The relationship between feed trough space, water trough space and lamb growth has not been determined.

The majority of lamb feedlots have been established on an opportunity basis and as such, there is a wide variation in existing designs to be found; anecdotally, most of these designs function quite effectively.

While there are two large, purpose-built indoor feedlots currently in operation, clear guidelines as to their construction requirements are not readily available. However, there is considerable interest from lamb finishers in building highly efficient, shedded facilities.
Although there are many publications clearly describing the construction requirements for cattle feedlots, and there has been a considerable amount of research in this area, the relationship between these designs and the design requirements of feedlot lambs remain unclear.

Design faults of existing outdoor lamb feedlots include, insufficient slope to facilitate drainage, lack of shade and shelter, inappropriate positioning of, and access to, feeders and water troughs within pens.

This section will review the following terms of reference:

- Feeding equipment
- Watering equipment
- Guidelines for feed and water access
- Guidelines for trough space
- Feedlot design
- Stocking density
- Paddock supplementation versus feedlot finishing

2.1 Feeding equipment

While there is a wide range of feeding equipment available for use in lamb feedlots, the majority of lamb finishers provide *ad libitum* access to feed via self-feeders (Giason and Wallace 2006). Although monitoring both intake and shy feeding can be less accurate and more difficult when using self-feeders (Morrical no date), Fluharty *et al*. (2001) found no difference in feed efficiency due to the feeding system employed.

Variation in individual intake was noted when lambs were given access to self-feeders, as reported by Bowman and Sowell (1997) who also found that variation increased if excessive trough space was provided when feeding in open troughs. However, they also observed a reduction in dry matter intake with restricted trough space. Earlier work by McDonald et al (1986) reported that an increase in trough length resulted in an increase in the percentage of regular feeders (Table 24).

Table 24 Trough length and percent regular feeders (McDonald et al. 1986)

Trough length (cm/head)	0.5	1.0	2.0	4.0	8.0
Regular feeders	37%	47%	74%	79%	81%

Feeding lambs on the ground removes the cost issues related to providing adequate trough space, and a recent study found that there was no difference in the growth rate of Merino lambs when fed on the ground compared to in a trough (Savage *et al*. 2005). However, none of the current lamb finishers surveyed by Giason and Wallace (2006) fed lambs on the ground.

Figure 14 Self-feeders designed to deliver grain based rations.
[Previous]: self-feeder in operation (Source: Productive Nutrition Pty Ltd)
[Above] : semi-expanded view of a typical self-feeder (Source: Magnus Australia)

Optimising growth rate and feed conversion efficiency are the main profit drivers within an intensive finishing system, and therefore, encouraging dry matter intake during the introductory phase should be a priority. Neophobia, caused by a fear of unfamiliar equipment (Chapple and Lynch 1986) and the positioning of the feeders (McDonald *et al.* 1986, cited in McDonald *et al*. 1986; P. Gunner 2006 pers comm. 10 July), has been noted as a contributing factor to

depressed intake and growth rate.
Anecdotally, feeders positioned too close to a busy traffic area or laneway can cause a substantial intake reduction. This contrasts with current practice where many feeders are situated within the pens along a central laneway for ease of access for feed delivery and to avoid injury to lambs.

Unpublished data, cited in McDonald *et al* (1986), indicated that when feed troughs were located in the centre of feedlot pens, 79% of Merino wethers satisfactorily adapted to feed over a 7-day introductory period, compared with 67% when feed troughs were located on boundary fences.

Self feeders are considered to be the most cost-efficient feeding option due to reduced labour costs, although some specialist feedlotters who mix feed as a total mixed ration (TMR), find it easier to deliver the feed into an open trough.

Many self-feeders are designed to handle grain based rations only (Figures 14 and 15) and due to their narrow outlet, can cause flow difficulties for total mixed rations. In this case, some operators prefer to use self feeders designed for cattle, although as the feed tray is generally larger, lambs can climb into the tray reducing feed access for other lambs and causing feed spoilage.

Figure 15 Self-feeder designed to deliver grain based rations (Source: Productive Nutrition P/L)

A Western Australian lamb finisher (C. White) has designed a simple and cost-effective feed trough made out of shade cloth and assembled with a portable sowing machine. This system is suitable for silage based rations as excess moisture can drain out of the feed as illustrated in Figure 16.

Figure 16 Shade cloth trough feeding system (Source: C. White Nepowie Feedlot, WA)

Round feeders have the potential advantage of no corners where sheep may suffocate (I. McFarland 2007, pers comm., 28 February via B Hancock, 7 March), however some producers have had to install gates at right angles to round feeders to prevent dominant lambs from chasing shy feeders around the feeders and away from feed.

Approximately 20% of the larger outdoor feedlots use automatic feeding systems (Gaison and Wallace 2006) although indoor feedlot sheds have more substantial systems in place (Figure 17).

Figure 17 Automated indoor pellet delivery system, WA (Source: Productive Nutrition P/L)

Figure 18 demonstrates a simple but effective system operating in an outdoor feedlot that provides automated feeding.

Figure 18 Automated outdoor pellet delivery system, WA (Source: Productive Nutrition Pty Ltd)

The majority of intensive lamb finishers feed hay and grain on an *ad libitum* basis and many report dissatisfaction with the equipment currently available for self-feeding of hay (G. Duddy

2006 pers comm. 13 September). Providing hay on the ground can result in a large amount of wastage, although it is unclear if the level of wastage is due to the quality of the hay.

If medic hay is provided in self feeders, it can increase the risk of wool contamination and therefore downgrade skin value due to an increase in the vegetable matter deposited around the neck of the lamb. Poorly designed hay feeders allow lambs to become trapped within the feeder and others do not prevent the lambs climbing in. Clearly, more work is required in this area to develop hay feeders that are both safe and reduce spoilage, and superficially, this would appear to be a relatively simple engineering task (Figures 19, 20, 21).

Figure 19 Hay rack suitable for rectangular bales

Figure 20 Round bale feeder for hay or silage

Figure 21 Hay rack for large or medium square bales

An alternative to providing hay *ad libitum* is feeding a total mixed ration (TMR). While this alleviates the problem of wastage by mixing hay in combination with grain and additives, it may not be a cost-effective option for the opportunity finisher due to the need for specialised machinery.

Access to grain during the introductory period can be controlled so as to reduce the risk of acidosis by the use of 'lick feeders' (Figure 22) where the rate of flow of grain can be effectively limited.

Figure 22 Lick feeder

Importantly, lambs may need prior education as to how to extract grain from these feeders and it is unclear how many feeders would be required to facilitate access by every lamb. As illustrated in Figure 23, sheep feeding from a self-feeder are presented with feed in a somewhat different manner to when they are grazing.

Figure 23 Self-feeder containing a total mixed ration (TMR) (Source: T. Grant)

Figure 24 Lambs feeding at open trough (Source: Productive Nutrition Pty Ltd)

2.2 Watering equipment

Anecdotally, there does not appear to be any strong reasons for choice of any particular water delivery system. Therefore, the choice of watering system, and the reasons for the use of that system, can vary widely. Apart from traditional circular, rectangular concrete and plastic troughs (Figure 25), some producers have been quite innovative in reducing establishment costs and wastage (Figure 26), while others have chosen rather simple solutions as illustrated in Figure 27 and 28.

Figure 25 Water delivery trough with underset drainage system (Source: T. Grant)

Figure 26 Externally mounted moulded water troughs (Source: Productive Nutrition P/L)

Figure 27 Water trough sited for ease of drainage (Source: Productive Nutrition Pty Ltd)

Figure 28 PVC water trough (Source: Productive Nutrition P/L)

2.3 Guidelines for feed and water access

There are a range of feeding space recommendations and guidelines, found both online and in state Department of Agriculture publications, but supporting evidence is scarce. The recommendations are presented in Table 25, and highlight the range of feeding space allowances found in the literature.

Table 25 Guidelines for feeding space recommendations (cm per lamb) for intensively fed lambs

Note	Open trough space allowance (cm)	Self feeder space allowance (cm)	Reference
C	2		WA Dept Ag 2003
A	5		Bell & Shands in McLeod 1994
A	5-10		Ridley Agriproducts
	6.5		Fabo 1986
A	10		ADAS 1987 cited in Wathes & Charles 1994
		10	Davis 2003
A	10		Slade and Stubbings 1994
		10	Wand 2003
AS	12.4		Knee 2005
D	15		O'Dempsey 2002
	17		Jordan 2002
	25		Seymour 2000
	25		Umberger 1997
	22-30	7.6–10	Alliance Nutrition Inc no date
	30		Chiba 2005
	30	7-10	Curtis 1983
	30		Neary 1998
R	15-24	38	Morrical no date
R	20		WA Dept Ag 2003
R	22.5-30	25–50	Vigortone 2003
R	30		ADAS 1987 cited in Wathes & Charles 1994
R	45		DEFRA 1995
Notes relating to open trough space allowance:			
A	*Ad libitum* or continuous access		
AS	*Ad libitum* in shed		
C	Continuous supply for 15 hours		
D	Double sided trough, 60 cm wide		
R	Restricted or limit fed		
Blank	Feeding method not provided		

In a shedded environment, growth rates were maximised by providing a feeding space allowance of 12.4 cm per lamb (Knee 2005), while Fabo (1986) recommends 6.5 cm per lamb. For an intensive lamb finisher with 500 lambs per pen, this is the difference between 32.5m or 62m of feeding space.

Restricted feeding requires greater trough space as all animals are likely to approach the feed trough at once, whereas self feeder space requirements are lower as animals have access to feed at all times. However, the number of feeders or troughs per pen to facilitate optimum growth rates has yet to be determined.

The live export trade has investigated the cause of the “failure to eat” syndrome exhibited by mature Merino wethers destined for live export and held in adaptation feedlots prior to departure. Hodge *et al* (1991) found a higher incidence of wethers with *ad libitum* access to feed that failed to eat with a trough space of 5cm per head, than those that had a trough space allowance of 38 cm per head. Conversely, when feed availability was restricted, a higher percentage of sheep failed to eat from the longer troughs as opposed to the shorter troughs.

As 30 cm of trough space allowance is the recommended limit for fed cattle, it would seem a similar amount of trough space for lambs would be excessive. However, the extent of this is yet to be determined. It is evident that limited trough space and high stocking density combine to reduce animal performance, due at least in part to poorer animal health and welfare.

Table 26 Guidelines for water trough space allowance for intensively fed lambs

Water trough space allowance	Reference
0.09 M² per 40 lambs	Wand 2003
0.75 M²	Croker and Watt 2001
0.8 cm	O'Dempsey 2002
1 cm	Rook 2003
1.5 cm per sheep	WA Dept Ag (2003)
Min length 30 cm + 1.5 cm per sheep for 500 sheep	Department of Primary Industries Victoria
Min length 30 cm + 1.5 cm per sheep for 500 sheep	Department of Primary Industries New South Wales
2.2 cm on straw	Slade and Stubbings 1994

Table 26 lists recommendations of water trough space for intensively fed lambs and illustrates the variety of recommendations that feedlotters may find when searching for information. As the benefits of water quality are highlighted in many publications, the amount of water trough space that lambs have access to would also seem to be of critical importance.

Best practice:

- No recommendations for best practice feedlot design specific to lambs can be made

Further research

- Determine optimum feeding space allowance for self feeders
- Determine the number of feeders required per pen
- Determine the role of “lick feeders” in controlling acidosis and optimising lamb growth
- Identify the effects of feeder design on growth and performance
- Development of a hay delivery system that minimises waste
- Identify any effects of water trough space and design on lamb growth rate
- Identify the effects of water pressure (return rate) on growth rates

2.4 Feedlot Design

According to the Queensland Department of Primary Industries and Fisheries, the important components of feedlot design for cattle include the feeding and watering systems, as well as effluent and manure management systems and the staff facilities.

It is not the intention of this review to consider the principles of cattle feedlot design or to assess their effectiveness in terms of lamb feedlots but to consider the current lamb feedlot designs, their relationship with growth and performance and document any supporting evidence. However, design principles are clearly set out for cattle feedlots in terms of slope, stocking density, feed trough space allowance, watering systems, pen orientation and drainage systems.

Following an extensive review of the literature, there are no similar guidelines for the intensive feeding of lambs other than for creep-fed, or experimental early weaned lambs, to be found within the published literature or online documents.

There are many and varied designs available for both indoor and outdoor feedlots, but Tennesen (1989) suggests that the “ability of animals to adapt behaviourally, emotionally and physiologically to the circumstances of confinement is central to their wellbeing”. He also raises the issue of adaptation to new surroundings as not being a fait accompli, which requires consideration when designing a confinement feeding system. The relationship between design and lamb performance may be of great significance.

As the environment can affect animal performance, a balance is required between animal comfort, wellbeing, cleanliness and economic efficiency (Fluharty *et al*. 1999).

There is a scarcity of published literature relating to the design requirements of lamb feedlots, but a plethora of information for cattle feedlot design. However, the practicality of modifying cattle feedlot design principles to optimise the performance of confined lambs, remains unclear. Figure 29 illustrates a feedlot specifically designed for lambs but based on cattle principles (T. Clark 2001 unpublished), but this design has yet to be been constructed or tested.

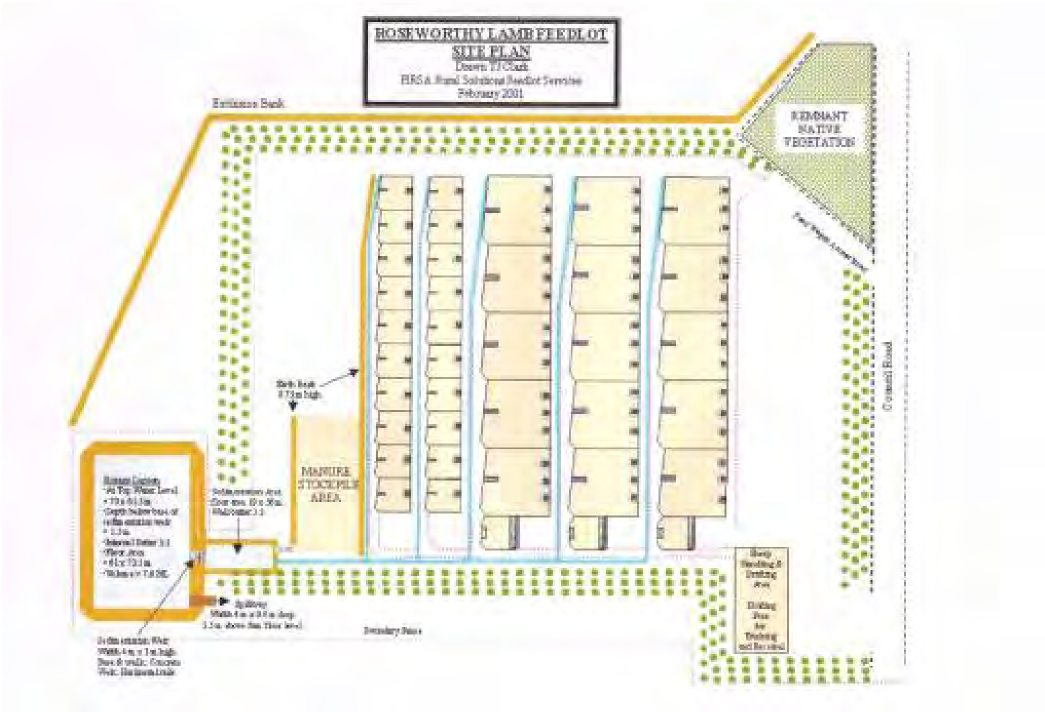


Figure 29 Lamb feedlot design based on cattle design principles (Courtesy T. Clark, PIRSA 2001)

Outdoor feedlots are currently of a simple design (Figure 27 and Figure 38). They incorporate either a central laneway for feed delivery into self-feeders and for ease of stock movement (Figure 33), or a feeding area at one end of an adjacent line of pens leading from the feeding area (Figure 32) where the lambs are fed in a continuous trough.

Some lamb feedlots have an open trough design at the end of the pens, as is commonly seen in cattle feedlots (Figure 30), while others employ a controlled feeding system (Figure 32).

Figure 30 Open trough design (Source

http://www.omafra.gov.on.ca/english/livestock/beef/facts/04-093.htm#2)

Figure 31 Restricted or controlled feeding system (Source: Productive Nutrition P/L)

The advantage of the controlled feeding system is that restricted feeding methods can be implemented, and injury to stock during feeding, avoided. On the other hand, labour inefficiency can be a major disadvantage. Where self-feeders or feed troughs are located within the feedlot pens, the potential risk of injury to lambs during feeding is high (Figure 38), unless other feeders are located elsewhere such that they can be filled prior to entering the pens.

The controlled feeding system design allows for one pen of lambs to be fed at one time after their daily feed allocation is placed in a trough located in a separate feeding area. When one pen of lambs has finished their allocated ration, they return to their pen after which time the feed trough is refilled and the next pen admitted to the feeding area.

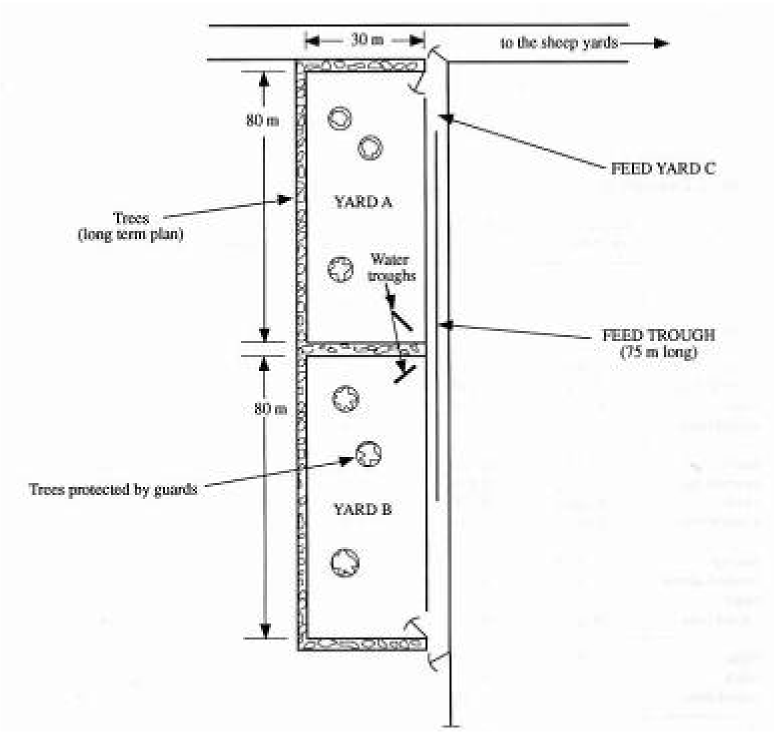


Figure 32 Restricted or controlled feeding system design (Source: Ashton and Morbey 1997)

Outdoor feedlots with a centrally constructed laneway and pens either side, with either open troughs or self feeders, increases labour efficiency and prevents the need to enter the pens when feeding. As stated previously however, daily feed consumption of lambs may be depressed in feedlots using this design due to disruption of passing traffic.

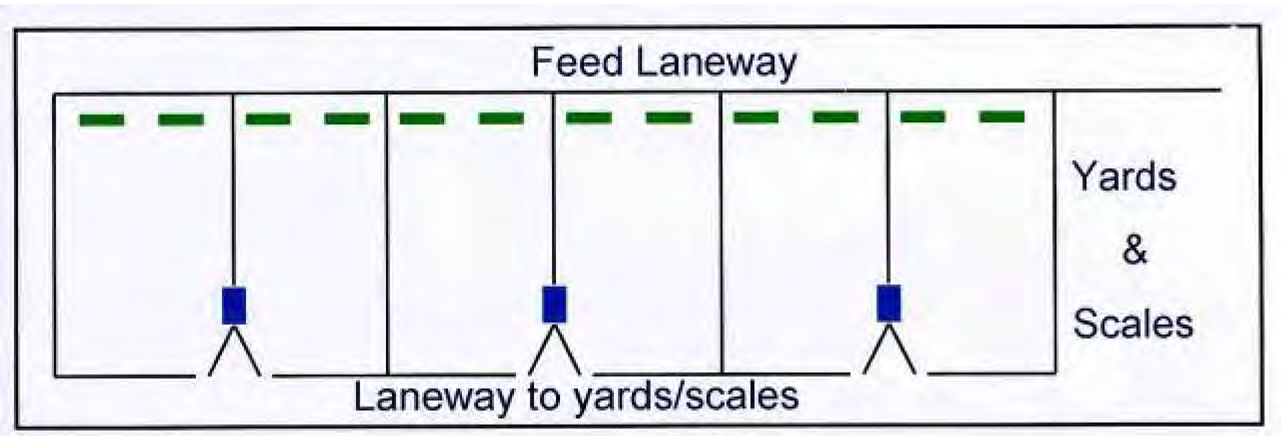


Figure 33 Double laneway system design (Source: T Grant and M Stanley 2006)

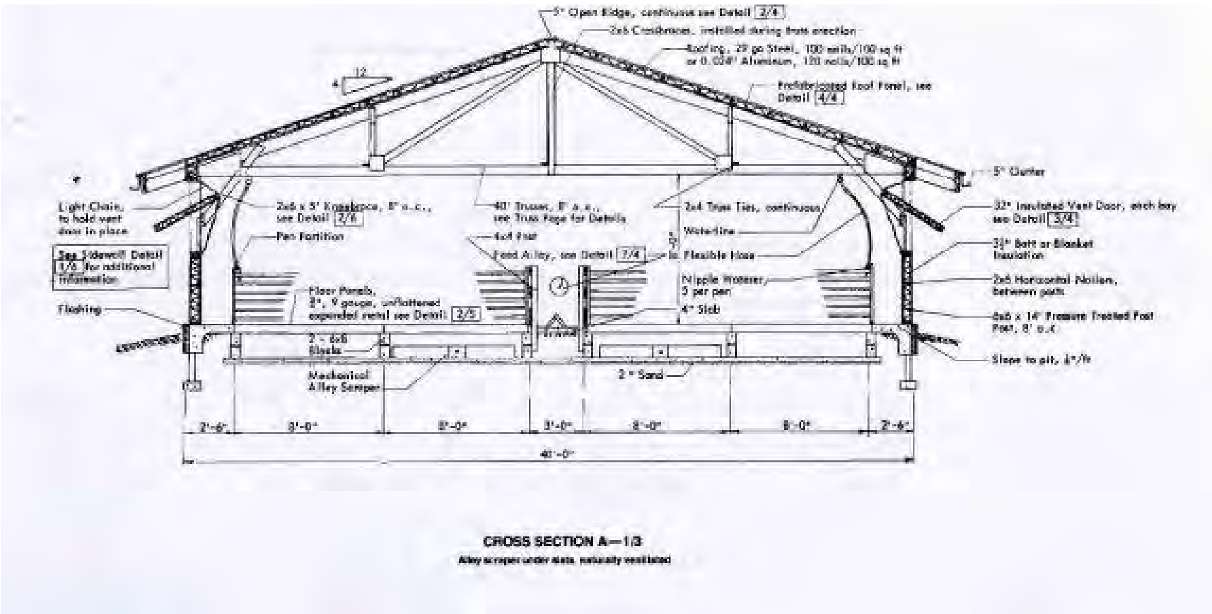


Figure 34 Feeder lamb confinement barn design (Midwest Plan Service, no date)

However, eco-shelters have been adopted extensively by the pork industry in the last five years and are increasingly being incorporated into some outdoor lamb feedlots as a more cost-efficient and less permanent option (Figure 35 and Figure 36).

Figure 35 “Eco-shelter” (Source: R. Shepherd)

Figure 36 Semi-permanent lamb feeding shelter or double "eco-shelter design (Source: VP structures)

As shown in Figure 34, the internal construction of an indoor feedlot is highly complex and requires specialised fit-out compared to any other type of shed. While indoor facilities for livestock are common in Europe and parts of the United States of America, the expertise to build these structures is limited in Australia and the economics questionable. Hence, Eco-shelters are currently a more cost-efficient option due to their lower establishment cost and greater flexibility for on-going modifications and mobility.

Pen floor type

Pen flooring in Australian indoor feedlot sheds can include expanded metal mesh (Figure 37), wooden slats or straw, while the flooring of outdoor feedlots includes compacted soil, limestone outcrops or ridges (Figure 38) or a compressed rubble base.

The type of pen floor can affect dry matter intake (Fluharty *et al.* 1999) and growth rate, and in the case of indoor feedlots the specifications of mesh flooring can have a significant effect on animal welfare and comfort (T. Boyle 2004 pers comm. February). The data of Fluharty *et al.* (1999) shows that lambs housed on straw had higher feed intake to those on expanded metal or mesh, leading to faster growth rates, and these lambs were heavier at sale (Table 27).

Figure 37 Mesh flooring in elevated shed (Courtesy T. Boyle 2004)

Figure 38 Outdoor feedlot with natural loam and limestone base (Source: Productive Nutrition P/L)

Table 27 Effects of Pen Characteristics on Lamb Performance (adapted from Fluharty et al 1999)

Item	Expanded Metal	Straw	SEM[a]
No of lambs	23	23	
Initial weight (kgs)	35.2	35.3	0.2
DMI[a], (kgs per day)	1.23[b]	1.28[c]	0.01
Gain (kgs per day)	0.26[d]	0.29[e]	0.01
Feed conversion ratio (DM basis)	4.7:1	4.4:1	0.005
Days on feed	85.5	83.2	2
Total DMI (kgs)	104.8	105.9	6.6
Final weight (kgs)	57.3	59.1	1.1

[a] Dry-matter intake and SEM = standard error of mean.
[b,c] Means within a row with different superscripts differ significantly ($P<0.01$)
[d,e] Means within a row with different superscripts differ significantly ($P<0.05$)

Before constructing an outdoor feedlot, the soil properties must be assessed for their engineering capabilities in terms of water runoff and infiltration, to avoid faecal nutrients leaching and contaminating groundwater, and also, to reduce the risk of water and wind erosion.

Slope of the land for outdoor lamb feedlots

The guidelines for slope of the land in lamb feedlots to facilitate drainage and minimise erosion are 2 to 6% (Ridley AgriProducts 2006) with 3% considered optimal for cattle feedlots (Skerman 2003). Some slope is required for drainage (especially during rainfall), while excessive slope presents logistical limitations and may result in run-off being too rapid, risking erosion. Obviously water troughs should be located at the bottom of the slope which is diagrammatically represented by Figure 39.

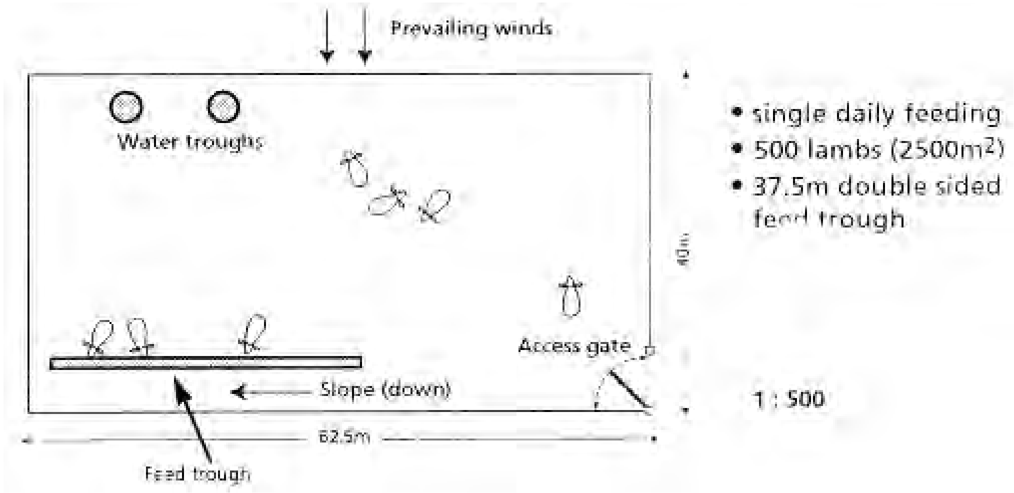


Figure 39 Feedlot design for confinement feeding of 500 lambs (Kondinin Group 1998). Note the yard is sloping to the left of the diagram.

Pen size

The relationship between pen or paddock size and performance of lambs is not clear. Indoor studies of early weaned or creep-fed lambs show that as pen size is reduced, live weight gain and feed efficiency are also reduced (Horton *et al*. 1991), although the implications of this to feeder lamb production systems remains unclear.

Intensive lamb finishers anecdotally believe that a stocking density of 5m² per head with a pen size sufficient to hold 300 lambs, at that density, produces the optimum lamb performance. The influence of pen shape on the behaviour or performance of lambs has not been investigated, although, Boe *et al* (2005) found that pen shape had no effect on the lying and standing behaviour of ewes housed indoors. Investigations into the effect of grazing behaviour in sheep (Sevi *et al.* 2001) found that square paddocks resulted in improved pasture utilisation, although the relevance of this finding to the shape of feedlot pens is questionable.

There are lambs being finished in larger areas with many self-feeders available per pen (P. March 2006 pers comm. September 12), therefore it is not clear if pen size, or the number of feeding points, has the greater influence on lamb growth. T

Within the published literature, there is considerable interaction in comparisons between pen size, stocking density and animal performance, making it difficult to draw conclusions, although indoor studies with lambs indicate a correlation between pen size and performance. Steers demonstrated a reduction in dry matter intake and feed conversion with a reduction in pen size, but live weight gain was unaffected (Prawl, *et al.* 1998). However, pen size was confounded with shelter.

The Queensland Department of Primary Industries suggest that pen sizes for cattle vary according to the individual operators' management practices, which implies that pen size and number of cattle per pen may not be important to growth rate, feed conversion or profitability.

It is clear that, although there are many feedlot design options available to producers, that the relationship between design and performance has yet to be determined.

The cost advantage offered by a shedded environment in terms of profitability was outside the terms of reference of this review however, as skin price has such a significant impact on profitability it would appear that a controlled environment would offer some benefits to those producers finishing lambs during winter.

Guidelines for feed and water access remain unclear as does the relationship between stocking density and lamb performance.

As the provision of an intensive feeding environment is associated with substantial costs, the option to optimise profitability in terms of paddock finishing requires further investigation. This is particularly pertinent for smaller operators and opportunity lamb finishers.

Best practice

- No recommendations for best practice for lamb feedlot design can yet be made

Recommended further research

- Determine the relationship between the number of lambs per pen and growth rate
- Determine the optimum pen size and shape
- Determine the optimum feedlot layout
- Determine the optimum feedlot slope

2.5 Stocking density

There is an abundance of published studies determining the relationship between stocking density and the performance of pigs and poultry, but a scarcity of publications investigating the effect of stocking density and the daily weight gain of intensively finished lambs. Due to the physiological and nutritional differences between these species, it is impossible to attempt to transfer this information between sheep and pigs.

A reduction in stocking density, from 0.32m² per head to 0.48 m² per head, increased weight gain by 10% over an 8-week period in pigs (Gonyou *et al*. 1985). A similar effect was observed in shedded lambs; optimal weight gains (350-450g/day) were found at a stocking density of 0.5m² per head, and a reduction in the rate of gain was experienced when the stocking rate was increased to 0.3m² per head (Knee 2005). In cattle, Morrison *et al*. (1970) observed cattle stocked at 11m² per head, converted feed to gain at a ration of 6.8:1 and at a stocking density of 1.85m² per head, the rate of feed conversion increased to 8.4:1.

Investigations into the effect of stocking density and the performance of feedlot cattle (Arp *et al*. 1983), found that variation in stocking density from 1.95–6.5 m² per head, had no significant effect on weight gain; similar findings were reported by Nienaber et al (1974) when observing Nebraskan cattle stocked at either 9.5 or 18.5 m² per head.

However, pigs have clearly demonstrated a significant response to stocking density and work by Harper and Kornegay (1983) clearly showed a decline in weight gain, feed intake and feed efficiency with decreasing floor space allowance.

Lambs stocked at 0.33m² per head lost significantly more weight than those stocked at 1.5 m² per head (Hodge *et al* 1991), regardless of whether they were managed indoors or outdoors. High stocking density reduced feed intake and feed efficiency, however, it is unlikely that stocking densities of this level would be commonplace in Australian outdoor lamb feedlots. A recent survey revealed the majority of outdoor intensive lamb finishers have a stocking density of between 2 and 5m² per head, however 29% of small operators and more than 43% of medium and large feedlotters provide in excess of 5m² per head (Giason and Wallace 2006). A decrease in stocking density to 10 m² has reportedly reduced the soiling of lambs when intensively feeding during wet conditions (T. Grant 2006 pers comm. 8 August).

When finishing lambs between 20kg and 50kg live weight, the optimum indoor space allowance recommended by Horton *et al.* (1991) is 0.99m² per head in a group size of 3 lambs per pen, as they found that when stocking density was increased to 0.62 m² per head, intake was reduced by 11%, and daily gain by 14%.

Stocking density guidelines for outdoor finishing of confined lambs , vary from 5 to 10m² per head, which appears to have been derived more from experience and anecdotal observations of performance than any research (G. Duddy 2006 pers comm. 12 September).

Linden (2006) found a stocking density of 5m² per head resulted in a greater percentage of lambs achieving market specification than those stocked at 3 m² per head in either the feedlot or the paddock (Figure 40) which was the only study found to have investigated this relationship.

Kondinin Group recommends 2.5 m² per head for lambs, although the growth rate of goats stocked at between 1 to 3.3m² per head was not significantly different (Flint and Murray 2001). This is similar to the findings of Ruiz de la Torre and Manteca (1999) who found that a difference in stocking density between 1 and 3.3m² had no effect on aggressive behaviour of 20 kg lambs. Flint and Murray (2001), however, reported a significant reduction in aggressive behaviour of lot-fed goats at lower pen densities. These results probably reflect the different feeding behaviour and social structure of goats compared to sheep.

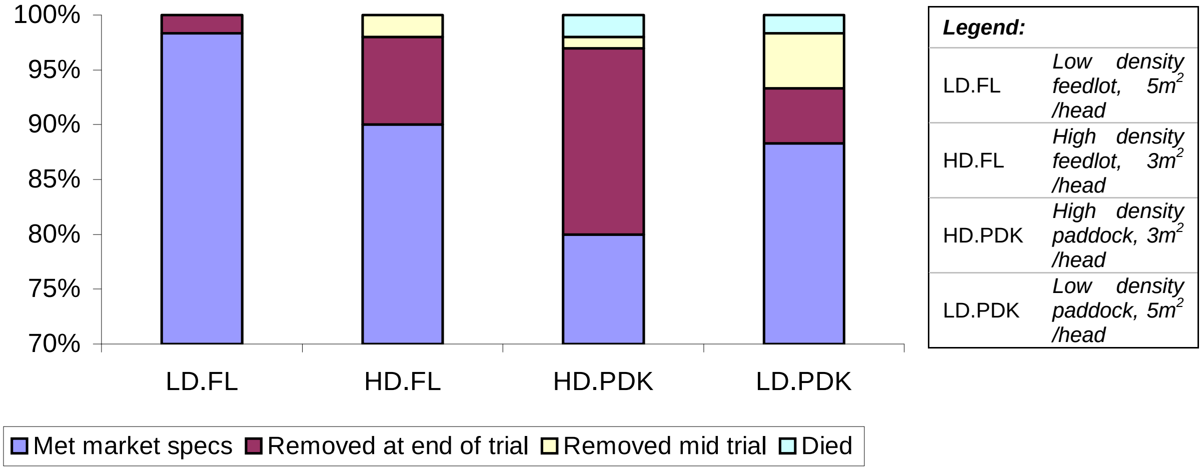


Figure 40 Variation in lamb performance associated with pen density or stocking rate (Linden 2006)

A report by the New South Wales Department of Agriculture (Bell *et al*. 2003) recommended 5m² per head, but suggested that between 10 and 20m² per head may reduce social stress and shy feeding, although supporting evidence is purely anecdotal. However, this is probably related to the findings of (McDonald *et al*. 1986) who found that the average number of visits of Merino wethers to the feed trough was significantly ($P<0.001$) associated with stocking density. They found that 75% were regular feeders at stocking rates of 3.38 and 7.56m² per head, compared with 59% at a stocking density of 0.62 m² per head. This suggests that high stocking density reduces feed intake due to added competition between animals for feeding space.

Studies of early-weaned lambs fed from 15 to 29kg live weight (Fabo 1985), found that indoor weight gain was optimised at a stocking density of 0.2m² per lamb. Fabo (1985) also found that lambing ewes in pens resulted in the highest lambing rate at 2m² per ewe, but that the size of the pen or the group did not affect the daily weight gain of their lambs.

Whilst acknowledging that little research has been published, delegates at a workshop held by the Animal Welfare Science Centre of Monash University (2005) agreed that the stocking density for individually penned sheep should be 1 to 1.5m² per head (SCARM 2002; Report 29) or 1.2 m² per head (ANZCCART 1995).

Anecdotally, outdoor feedlots aim for a stocking density of between 3-10 m² per head, with most online information implying that US lamb feedlots stock at 3 m^2 per head. The stocking density of indoor feedlots varies between 0.5-1 m^2 per head. This means that a 1,000-lamb feedlot would require 0.05 to 0.1ha if indoors, or 0.3 to 1ha if outdoors. Obviously, space is more expensive in an indoor feedlot, with shed infrastructure being a major capital cost that will depreciate with time.

It is unclear at this stage if stocking rates determined optimal by research findings will be acceptable to animal welfare scientists.

Further research

- Determine the optimum stocking density for outdoor feedlots during hot, cold and or wet conditions
- Compare performance of lambs held in:
  10 acre paddocks *versus* paddock supplemented *versus* feedlots (G. Martin)
- Are economically ‘optimum’ stocking rates acceptable in terms of animal welfare?

2.6 Paddock supplementation versus feedlot finishing

Ali *et al*. (2005) studied post-weaning growth of early weaned lambs (70 to 94 days of age) that were fed until they reached 58.5kg live weight and observed a significantly greater ($P<0.01$; $P<0.05$) rate of daily gain and feed conversion efficiency for the feedlot finished lambs (333g/day; 4.4:1) than the paddock finished lambs (244g/day; 5.1:1).

A more recent study (Davidson and Peacock 2006), comparing the performance of Merino lambs finished on alternative pelleted diets (formulations commercial-in-confidence), in either a 10 acre paddock or in a feedlot (Table 28), demonstrated an increased rate of gain in the feedlot of 154 grams per day over the paddock. The rate of gain in the paddock was 212g per day, compared to the feedlot which was 366g per day; a 42% increase on Pellet 1. The differential rate of gain for the lambs fed Pellet 2, however, was only 30 grams per day (292g vs 262g or 10%). The reason for this discrepancy is unclear, although the paddock finished lambs only had 2 days *ad libitum* access to hay before induction to pellets, whereas the feedlot lambs commenced the pelleted diet after 4 days access to *ad libitum* cereal hay and a loose grain mix.

The relevance of these results to the broader lamb finishing industry is uncertain as the trial of Ali *et al*. (2005) was investigating the performance of early weaned lambs, and the trial of Davidson and Peacock (2006) was a short term feeding trial of 13-16 days.

Table 28 Growth rate, feed intake, feed conversion ratio (FCR) and cost per kg live weight gain of Merino lambs fed two pelleted rations within a feedlot or paddock environment (adapted from Davidson and Peacock 2006)

	Growth rate (gm/day)		Feed intake (kg/day) and intake as a % of LW (as fed)		FCR (*x*:1)		Cost per kg LW gain	
Study	**Pellet 1**	**Pellet 2**	**Pellet 1**	**Pellet 2**	**Pellet 1**	**Pellet 2**	**Pellet 1**	**Pellet 2**
Paddock finished	212	262	1.67 (3.75%)	1.85 (4.1%)	7.85	7.00	$1.88	$1.51
Feedlot finished	366	292	2.27 (4.8%)	2.21 (4.7%)	6.15	7.76	$1.48	$1.65

From December 1979 to September 1980, Suiter and McDonald (1987) observed similar live weight gains in feedlot weaner lambs compared to paddock supplemented lambs. Although it appeared that acidosis was an issue during the first 34 days in the feedlot, they concluded that the location of feeding (paddock or feedlot) may not be an important factor influencing weaner growth.

Savage (2006) investigated the production potential of fine wool Merinos in either a feedlot, supplemented while grazing high performance pastures, or grazing alone, and did not observe a significant difference in growth rate between each of the systems. However, daily gains were by current industry standards poor at 131g/day. Savage observed the greatest variation in performance in the feedlot system, and this will be reviewed in Section 3 on animal welfare and shy feeding.

These findings require further investigation to determine if 35-55 kg LW lambs differ significantly in their performance and profitability when paddock supplemented or feedlot finished.

Recommended further research

- Determine the difference in growth rate between paddock and feedlot finishing

3 Animal Welfare

Consideration of animal welfare and behaviour in terms of optimising production responses in unfamiliar environments should be a priority for intensive lamb finishers, however further research is required into the effects of interrupted socialisation either by other lambs or groups of lambs.

The current management of shy feeders varies widely, and although cause and effect may differ, further investigation into the optimum management practice to reduce the negative impact of these animals on the profitability of finishing enterprises appears warranted.

Although the lamb industry appears convinced of the positive relationship between shearing and growth rate, the supporting evidence is scarce. From this review, there seems little doubt as to the need to shade intensively finished lambs, however, the relationship between shelter and productivity is not so clearly defined.

Current management practices to avoid ill health during the finishing phase, should be well known to the sheep industry at large, therefore full adoption of these practices, such as vaccination and careful introduction to feed, should be encouraged.

There is increasing scrutiny of intensive animal industries from animal welfare activists, such that any expansion of the intensive lamb finishing industry would ignore the opinions of sensible animal welfare advocates at their peril. There is a plethora of evidence clearly demonstrating the benefits of consideration of animal comfort that will be highlighted in this section.

Lambs that are provided with an environment that satisfies the 5 freedoms of animal welfare (FAWC 2006) would be expected to thrive and fully express their genetic potential for growth, however, this is often not the case.

The 5 freedoms include, freedom from:

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

Because profit margins from intensive finishing of lambs can be small on a per head basis, the performance of each lamb can be critical to the operation's success or failure. All lambs that are intensively finished have with access to feed and water within a safe, disease-free environment however, this alone does not appear to eliminate fear and distress in some lambs.

This section of the report will address the following terms of reference:

- Animal behaviour
- Shy feeding
- Shearing
- Heat stress
- Cold stress
- Shade and shelter
- Disease prevention and animal health

3.1 Animal behaviour

A recent survey of intensive lamb finishers (Giason and Wallace 2006) revealed that approximately 33% of medium and large operators sourced all of their lambs off-farm with the remaining 66% of the large operations sourcing at least half their lambs off-farm. In total, 36% of lambs brought into intensive finishing systems in Australia are purchased from saleyards, therefore it is likely that within larger operations, that some of these mobs are mixed at or after arrival.

Lambs that have been bred on the property on which they are to be finished are more likely to remain as one or two groups from weaning to slaughter (Giason and Wallace 2006). However, some producers draft lambs into sexed mobs, or heavy and light groups, at or soon after weaning as recommended by Vigortone (2003).

There is some indication that different groups of lambs do not readily integrate into one mob, especially in an open grazing situation (Winfield *et al*. 1981) although there is no specific evidence of this behaviour relating to lambs in confinement. Blackshaw (2003) implies that some lambs form such strong social bonds that they become mutually dependant and suggests that a socially integrated mob may adjust to environmental change more readily than a socially unstable flock (Stolba *et al*. 1990). Price and Tennesen (1981) noted a depletion in pre-slaughter glycogen levels in cattle, and attributed this effect to the addition of strange bulls during transport, although this finding could simply be due to stress in response to transport.

It is also worth noting that when animals are re-grouped, the move often includes an additional change in diet and surroundings, which may compound the effect of the adjustment process (Grant and Albright 2001).

However, during observations of the behavioural effects of social mixing of lambs, Ruiz de la Torre and Manteca (1999) demonstrated that while flock mates associated preferentially with each other, they were more likely to demonstrate aggressive behaviour toward one another than with unfamiliar lambs, although they concluded that social mixing of lambs was unlikely to be a welfare issue.

It has been suggested that lambs within feedlot environments may be under stress or bored and therefore could benefit from enrichment of the environment (Flint and Murray 2001) such as is the case with intensively reared pigs. Although goats were found to significantly increase live weight gain (P<0.04) in response to an environment enriched with tyres, railway sleepers, pipes and containers, the provision of rubber tyre mounds for feedlot lambs increased growth rate by only 21 grams per day over a ten week feeding period which was not significant. (Linden *et al*. 2006). However, it has been reported (S. Green 2006 pers comm. October 12) that rubber tyres used to cover kangaroo holes in fence lines in New South Wales have been effective in securing sheep within paddocks as it appears that they do not like to pass through the tyres. Despite this, Linden and co workers (2006) noted a significant increase in growth rate (221 g/d–253g/d) in response to pen enrichment during the first three weeks of their study.

Sheep in open paddocks increase their range of behaviours in response to the addition of logs mounds and trees (Stolba et al, 1990). When confined to deep litter pens, sheep have been observed playing with plastic drums and balls, presumably to overcome boredom (Hinch & Lynch, no date), These observations are further supported by anecdotal evidence that lambs are frequently observed “playing” on logs, rock heaps and hay bales.

The individual effects of animal responses when confined, separated from social groups and/or isolated may confound feeding trials performed within individual pens. Savage (2006) concluded that low correlations between estimated breeding values (EBV) in fine-wool Merino hoggets within an intensive finishing system, was attributable to feeding behaviour responses.

Best practice

- Avoid trials on isolated animals
- Consider animal behaviour within all aspects of intensive finishing systems management

Recommended further research

- Mixing of unfamiliar mobs of lambs
- Effect of socialisation on ease of introduction and the associative effects on pH decline and sheep meat eating quality
- The effect of temperament on lamb growth
- The effect of pen enrichment on the growth rate of confined lambs

3.2 Shy feeders

A recent survey of lamb finishers revealed approximately 5% of intensively finished lambs may be classified as shy feeders (Giason and Wallace 2006) although the reasons for this were not clear. Further reports of the percentages of shy feeding include:

- 1% (Stewart 2006)
- 3-8% (Seymour 2006)
- 5-10% (Fawcett 2004)
- 11% (Holst *et al.* 1997)
- 15% (Tomes and Dymond 1976)
- 16% (Woods 2005)
- 15-20% (Savage *et al*. 2006)

Obviously there are a range of factors that influence the level of shy feeding, including the experimental method, which explains the range in the above observations. There are many factors that determine the reasons for and numbers of shy feeders within an intensive finishing system. These may include:

- unpalatable or unfamiliar feed
- feed formulation
- acidosis
- toxins within the feed (negative feedback)
- trial methodology (paint, rubber, penned alone)
- familiarity with personnel, feeding equipment, other lambs
- social hierarchy and or dominance
- trough space
- nutritional history of the lamb

Shy feeders are presently removed from the feedlot and sold on hoof or over hooks, or removed from the feedlot and returned later, or retained in feedlot.

Broadly, industry recommendations favour the removal of shy feeders from the finishing system within the first 2 weeks to avoid financial losses that may be incurred as a result of either poor performance or death.

There is a possibility that many shy feeders have just been the subordinate lambs in the social hierarchy and the experience of some operators (P March 2006 pers. comm., September 12) is, that if removed and returned at a later date, these lambs generally perform to the level of the average.

Lambs are often subjected to a range of 'stressors' at weaning that may include shearing in addition to a change in feed; if the feed is unfamiliar to them, as can be the case when transferring lambs from a pasture based system to a feedlot or more intensive grazing system, the adaptation process can be prolonged. If lambs are being introduced to either forage rape, lupins or beans, the adaptation process will be enhanced by prior familiarisation to these feedstuffs.

Stockman (2004) defines shy feeding as 'persistently refusing to eat' as relating to some or all of the feedstuffs on offer. She investigated the relationship between shy feeding, breed and feed type and found that during the first two weeks of feeding an unfamiliar ration, 21% of crossbred lambs (Figure 42) in comparison with 14% of Merino lambs (Figure 41,) were shy feeders. Ten percent of all lambs remained shy feeders for the duration of the trial; as many as 70% were shy feeders during the introductory period. This extraordinary level of shy feeding may, however, be linked to the experimental design, in which paint soaked sponge rubber was used to detect shy feeding. This may have negatively affected the feeding enthusiasm of these lambs and confounded the trial results.

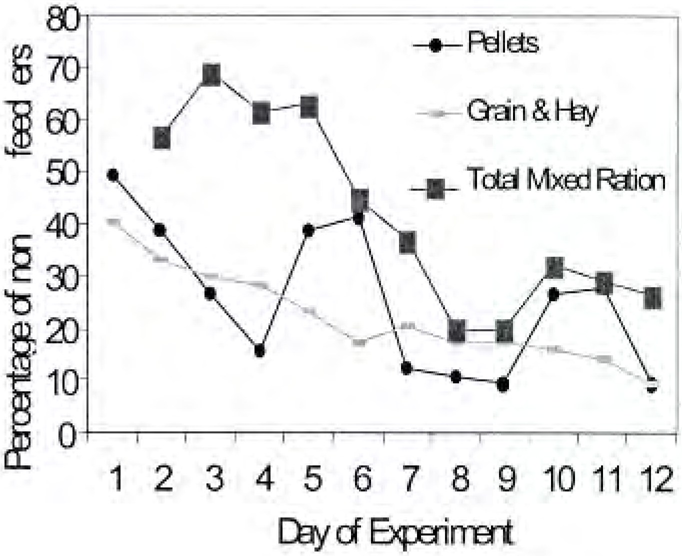


Figure 41 The effect of diet on non-feeding Merino lambs (Stockman 2004)

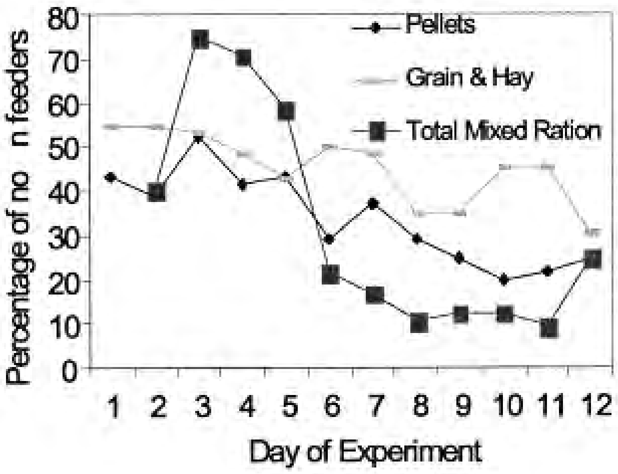


Figure 42 The effect of diet on non-feeding crossbred lambs (Stockman 2004)

In grazing sheep adaptation to different forage diets appears to be enhanced if the forage is either sweet or sour, with rejection of plants that are bitter (Krueger *et al*. 1974). Work, yet to be published, on preference and palatability of a range of hays fed to dairy cows (Pain and Revell 2006), has demonstrated that smell has a more important role to play than taste in feed adaptation and selection.

A possible explanation for those lambs that fail to adapt to a intensive finishing system may be provided by McBride and Craig (1985) who ascribe the condition of “learned helplessness” to those animals, who when subjected to repeated aversive events, fail to adjust. Further, Tennessen (1989) proposes that animals which have evolved in a grazing system may not be “genetically adapted” to a confined environment.

Burritt and Provenza (1998) investigated the effect of an unfamiliar location and the consumption of familiar and unfamiliar feeds by sheep and found that fear of novel feeds is greater at an unfamiliar location and recommended that lambs should be provided with familiar feeds in novel environments to reduce intake depression. These findings and those of Lynch and Bell (1987) have support, both anecdotally and in a further study by Juwarini et al (1981) who reported a 13% increase in grain intake by sheep that had prior experience of grain feeding, and that inexperienced sheep did not consume the ration until two weeks after intensive feeding commenced.

Unpublished feedlot trials conducted by Scammell and Jolly (2006) involving saleyard sourced lambs, reported rapid adaptation to feed by lot fed lambs when legume hay was supplied *ad libitum* for 4 days before and/or during the introduction of pellets, and that adaptation to hay based pellets was equally rapid with refusals consistently less than 0.6%.

Initial intake during the first 10 minutes of feeding was found to be significantly higher (P<0.01) in lambs that had been exposed to pelleted diets pre weaning than those that had not (Savage *et al*. 2005, unpublished) and this effect was most pronounced during the first two days of the trial. Younger or lighter lambs appeared to take the longest to adapt to feed. However, this was not the case when 6-8 week old pastoral Merino lambs entered a semi-enclosed, straw-based intensive finishing system (Scammell and Jolly 2006) and rapidly adapted to unfamiliar pelleted diets.

Variation in stocking density, trough space or level of feeding did not prevent some sheep from refusing to eat pellets (Hodge *et al*. 1990) which they attributed to the failure of the sheep to recognise pellets as feed. On the other hand, Scammell and Jolly (2006, unpublished) found that sheep rapidly adapted to a hay-based pellet, following 3-5 days *ad libitum* access to legume hay.

Positioning of the feed source close or adjacent to laneways especially in relation to self feeders has been reported to reduce dry matter intake by up to 50% (P. Gunner 2006 pers comm.) although, repositioning of feeders to a central location within the pen may increase the risk of injury to lambs when feeders are being re-filled. Vieren and Bouissou (2003) studied the responses of weaned lambs in fear eliciting situations and found that the most common responses to fear were an inhibition of feeding. This provides some support for the removal of feeders from within close proximity to heavy traffic areas.

Unpublished trials (Scammell and Jolly 2006) with early weaned Merino and crossbred lambs clearly show the effect of ‘traffic’ on lamb productivity when new loads of sheep were being transported in and unloaded with dogs in the morning prior to weight recording (Figure 6).

Lambs within feedlots appear to prefer to feed at sunrise and sunset, at which time there can be considerable competition for self-feeder space (Shreffler and Hohenboken 2003) and Squires and Daws (1975) observed that dominance only became a significant factor when access to a “valuable resource” was restricted.

Producers acknowledge the presence of shy feeders in feedlots although some report that it is likely that they are not eating (Fawcett 2004) and therefore are not contributing significantly to the cost to warrant their removal. It may be erroneous to assume that animals classed as shy feeders are not eating as, Table 14 (Scammell and Jolly 2006) clearly shows that when the better performing lambs are removed for slaughter, the remainder, although performing poorly, are still consuming feed.

There has been a widely held view for many years promoted by some sectors of the lamb finishing industry that lambs will lose weight during the first 2 weeks of adaptation to a new feed however little research effort appears to have been employed in this important area. It is the experience of others within the industry that lambs can adapt and grow from Day 1 if correct adaptation procedures are implemented.

Social adaptation to a new environment and to different groups can increase or decrease the proportion or risk of shy feeders resulting in competition for feed. Much has been written about the space requirements for lambs but there is no supporting evidence in the literature about the required number of feeding or watering points to enable lambs to avoid the dominance of older or larger lambs within their group. Squires and Daws (1975 cited in Blackshaw 2003) assessed the dominance order of Merinos and Border Leicesters and found that Merinos had a rigid hierarchical structure which was less so in Border Leicesters when competing for feed access. When feeding lambs controlled amounts of feed in troughs, the allocation of insufficient space to reduce competition has been proposed as a cause for shy feeding (Seymour 2006) although, within the literature, the recommendations for space requirements vary widely as highlighted earlier.

Producers are mostly aware of the need to introduce lambs to grain prior to weaning, although it is not clear how many implement this procedure as standard practice. It is unlikely that lambs are routinely introduced to feeding equipment, feed or machinery prior to entering an intensive finishing system, however, it would seem that there is sufficient evidence to recommend this practice as standard procedure to reduce the percentage of shy feeders.

Best practice

- Imprint lambs to feed type, equipment, people and surroundings prior to finishing
- Position feeders away from heavy traffic areas
- Reduce competition for feed
- Alter management practices of lambs that have failed to adapt to an intensive finishing system after 2 weeks

Recommended further research

- Investigate the causes of shy feeding and the cost to the intensive lamb finishing industry
- Determine the difference in the incidence of shy feeding between Merino lambs and crossbred lambs
- GPS or CCTV study of feeding behaviour and time spent in shade

3.3 Shearing

Unshorn sheep have very wide thermo neutral zones as demonstrated by Klemm (1962) who found that environmental temperatures of between 15 and 35°C had no effect on heat production.

Shearing lambs before finishing is common industry practice as identified in a recent survey of intensive lamb finishers (Giason and Wallace 2006). Sixty eight percent of small operators shear lambs prior to feedlot entry, whereas only 38% and 33% of medium and large operators shear all lambs prior to finishing.

The main reasons for shearing are to optimise skin value at the point of sale and to improve the growth rate of lambs.

Anecdotally, shearing lambs increases growth rate, although there is a considerable amount of evidence to the contrary (Tucker 1964; Roberts 1968; Bath 1970; Hawker, *et al*. 1985; Lane and Kemp 1990; Vipond *et al*. 1992; Marshall *et al*. 2003). Investigations across 11 New Zealand farms with 150 lambs per farm, found a growth response to shearing on only one farm (Summer 1984).

Ferguson (1968) noted an increase in growth rate following shearing however in some studies (Wheeler *et al*. 1963) it can be difficult to isolate the effects of environmental temperature from shearing effect.

The use of snow or cover combs, although not widely practiced, reduced the mortality rates of off-shears Merino sheep (Hutchinson *et al*. 1960). 12.5% of sheep shorn with snow combs were removed from their study due to cold stress, whereas 87% of the conventionally shorn sheep required removal from the study. The positive effects of shearing with snow combs and leaving a small amount of residual wool cover appears to be less in a dry year (Gaden and Hoad 2004), but significant in wet and cold conditions (Dabiri *et al*. 1995).

Appetite (Bell *et al*. 2003) and dry matter intake increase in response to shearing (Wheeler *et al*. 1963; McLeod 1994; Rook 2003), although the increase in intake can be delayed (Farrell and Corbett 1970; Faichney *et al*. 1976).

As skin price is a major contributor to the profitability of an intensive lamb finishing operation, in the Eastern states of Australia optimising wool length at the point of sale is an essential part of management practices and requires some forward planning. Approximately 14-42 days are required to optimise wool length (T. Grant 2006 pers comm., September 12) although this does not concur with the wool growth rates reported by Holst *et al* (1997). Rendell (2006) recommends shearing six weeks before feedlot entry in order to optimise wool length which concurs with Scobie (2006, pers comm. November 2) who suggest a wool length growth rate of 0.5mm per day is about the average for strong wool sheep.

Wool growth rate is significantly different between breeds (Holst *et al*. 1997) and individual animals, therefore the appropriate time to shear in order to optimise skin price remains unclear (Table 29). The market for skins varies across the country with ideal wool length in Western Australia being 5 cm and in the eastern states 3-4 cm with financial penalties for wool length outside that range. Bare shorn lambs presented for sale in WA incur a $2 per skin penalty to the grower (D. Pethick 2006 pers comm., September 12).

Table 29 Wool length and growth rate per day at 20 weeks post shearing in 6 genotypes (adapted from Holst et al. 1997)

Breed	Wool length (cm)	Wool growth rate (cm/day)
Texel x BLM	64.0 ± 2.0	0.457
Poll Dorset x BLM	55.0 ± 2.2	0.393
Texel x Merino	53.0 ± 1.6	0.379
Poll Dorset x Merino	48.3 ± 1.8	0.345
BL x Merino	74.1 ± 1.8	0.529
Merino x Merino	57.6 ± 2.1	0.411
s.e.d.	2.73	
Significance	*** (P<0.001)	

Heat stress depresses wool growth rate, particularly during pregnancy, principally due to a reduction in length growth rate rather than a reduction in fibre diameter, as sustained high temperatures can result in an elevation of serum prolactin concentration, which may influence growth rate (Kendall *et al*. 2006). The effect of photoperiod or day length on prolactin concentration and depression of wool growth was noted in short-wool sheep (Kendall 1999 cited in Kendall 2006), although Merino sheep did not appear to exhibit the same responses in wool growth to day length.

While shearing increases the risk of arthritis and cheesy gland (Rendell 2006), it can dramatically improve the physical appearance of the lamb, although in extreme weather, growth rate and feed conversion efficiency are likely to be reduced.

Shearing reduces the lambs' resistance to heat and cold stress and increases maintenance requirements in response to the increased demand for dissipation of heat or thermal energy. Shearing increases the energy requirement of lambs by as much as 98-150% (Faichney *et al*. 1976) in temperatures of 0 - 16°C and as dry matter intake only increases gradually after shearing, an increase in the energy density of the ration in advance should be recommended (Rook 2003). Farrell and Corbett (1970) found that an increase in feed intake failed to occur in Merino wethers until 10 - 15 days after shearing during which time maintenance requirements increased by 2.2 times (Rook 2003). The ideal ambient temperature at which to optimise growth potential of lambs is 13°C (Curtis 1983).

The respiratory rates of shorn sheep during summer were found to be more than twice those of unshorn sheep when standing in the sun (Macfarlane *et al*.1958). Prolonged increased respiratory rates may cause respiratory alkalosis, as has been observed in Bos taurus cattle (Beatty *et al*. 2006). In earlier work, Macfarlane *et al* (1959) reported an inverse relationship between wool length and respiratory rate of Merino sheep standing in the sun.

The process of shearing lambs has a significant stress effect (Hargraves and Hutson 1990) which may result in a depression of appetite for at least two days following the procedure (Donnelly *et al*. 1974) and a fall in critical temperature by as much as 10°C following fleece removal.

Bioclip® is a relatively new biological wool harvesting technique that has been developed as an alternative to shearing whereby the lamb is injected with a wool growth inhibitor that induces a break in the wool fibre allowing the wool to be removed by hand after approximately 10 days (St Vincent Welch *et al*. 1993). Although the stress effect is minimised, up to four weeks of wool regrowth is required to restore insulation against heat and cold stress. A small number of intensive lamb finishers are utilising Bioclip® technology, widespread adoption is unlikely until it becomes a more cost effective procedure.

Best practice recommendations:
- Shear only to optimise skin value
- Use snow or cover combs to reduce exposure to heat or cold stress
- Use Bioclip® where suitable or when cost-efficiency improves

Further research:
- No further research appears to be required in this area

3.4 Heat Stress

Both heat and cold stress increase maintenance energy requirements, leaving less available for production.

Although there are clear benefits from the provision of shade and shelter and the majority of feedlot finished lambs have access to it, 18%, 25% and 33% of small, medium and large lamb finishing operations respectively do not provide lambs with protection from the weather (Giason and Wallace 2006).

Sheep rely on panting to reduce heat load and dissipate heat as at 38°C, only 30% of water loss is from the skin (Hofmeyr *et al*. 1969). The energy cost of panting is low and efficiency of heat dissipation, high (Alexander and Williams 1989), furthermore sheep can breathe up to 300 respirations per minute with minimal evidence of respiratory alkalosis. Under conditions of extreme heat load respirations can slow and deepen resulting in severe alkalosis (Hales and Webster 1967).

Heat stress induces panting which leads to respiratory alkalosis to compensate for metabolic acidosis. Brown-Brandl (2005) observed that respiratory rate was the most reliable, simple and cost-effective indicator of heat stress in cattle, and several authors have reported an increased respiration rate in response to induced heat stress in sheep (Riek *et al*. 1950; Bhattacharya & Hussain 1974; Dixon *et al*. 1999; Stockman *et al*. 2006).

Silankove (1987) found that sheep in a Mediterranean environment in summer had respiratory rates that averaged 125 per minute and that provision of shade reduced the rate by 56% to 80 per minute. Further research found that respiratory rate increased from a resting rate of approximately 25-30 respirations per minute in resting sheep up to > 40 per minute.

There is clear evidence that animals subjected to prolonged periods heat stress significantly reduce their dry matter intake (Thwaites 1967; Abdel-Samee *et al*. 1998; Holst and Stanley 2000; Beatty *et al*. 2006), and that a reduction in dry matter intake generally results in a fall in performance.

Intake depression can be exacerbated by the consumption of diets containing a high percentage of roughage (Brink 1975; Dixon *et al*. 1999), although Stockman *et al* (2006) reported an increase in the pellet intake of Merino wethers subjected to high heat load conditions in a controlled environment. Under thermo neutral conditions feed intake increases with increasing roughage intake from 25-75% roughage, although under hot conditions, Bhattacharya and Hussain (1974) found that intake was negatively correlated with the proportion of roughage.

The growth rate of lambs in ambient temperatures greater than 30°C is known to be depressed (Dixon *et al*. 1999) as Awassi lambs in Saudi Arabia grew 19% faster and converted feed to gain with greater efficiency (16%) when provided with shade (Pritchard and Ruxton 1977). Earlier work with Awassi lambs (Bhattacharya and Hussain 1974) found that respiratory rate, pulse rate and rectal temperature significantly increased at high temperatures and that the effect was most pronounced when lambs were consuming diets consisting of a high proportion of roughage. Investigations into the effect of environmental temperature on daily gain (Figure 43) and feed efficiency (Table 30) identified a clear link between live weight gain, feed conversion ratio and environmental temperature (Ames and Brink 1977).

Table 30 Effect of environmental temperature on feed conversion ratio (adapted from Ames and Brink 1977)

Air temp (°C)	FCR
-5°C	25 : 1
0°C	12.5 : 1
5°C	9 : 1
10°C	6.7 : 1
15°C	7 : 1
20°C	7.7 : 1
30°C	12.5 : 1
35°C	25 : 1

Figure 43 The effect of temperature on lamb performance (Ames and Brink 1977)

Although lambs intensively finished in shedded environments at least have continual shade, Razzaque and Ibnoaf (1990) found that micromist cooling resulted in a significant improvement in weight gain in young wethers.
Holst (2000) hypothesised that shaded water may reduce the heat load on feedlot lambs based on the findings of Ittner and Kelly (1951) who noted a reduction in water temperature from 18°C to 1°C, improved the performance of feedlot cattle. This finding is supported by

Blackshaw and Blackshaw (1994) who observed that when temperature of water available to cattle was cooled to 18°C, live weight gain increased 18% above the level of those cattle with access to water at 30°C.

Investigations into the effect of shade on the performance of feedlot cattle have identified the importance of the correct engineering of shaded structures, and that poorly designed structures can increase humidity by reduction of air movement and airflow (ALFA 2001). The Australian Lot Feeders Association, the representative body of the cattle feedlot industry, also suggests that shade may increase the humidity of the microclimate by between 4 and 9%.

Measures recommended to alleviate the effects of heat stress (Mader *et al*. 2000) in feedlot cattle include:

- Feeding during the evening
- Feed delivery 2-4 hours after the peak daily temperature
- Reducing the ME level of the diet to reduce metabolic heat load
- Improve air flow in pens
- Provide shade at 1.85 – 3.7 m² per head
- Shade height to be 2.4 – 4.2 metres to facilitate air flow

How appropriate the above recommendation is for feedlot lambs remains unclear and requires investigation.

Sheep can maintain “thermostability” despite heat stress at maintenance levels of feeding (Silanikove 1992), however highly productive animals tend to increase body temperature faster due to the interaction between dehydration and high internal heat load.

Restricting feed intake during periods of high diurnal temperature can alter body temperature patterns, reduce peak metabolic heat load (Shirlow 2005) and feeding duration without adversely affecting productivity (Mader and Davis 2004).

The thermo neutral zone for sheep refers to the temperature range within which they are most comfortable or likely to optimise productivity and is ideally between 10-20°C as reported by Ames and Brink (1977). However, Parker (cited in Butler 2006) proposes a thermo neutral range of between 2 and 20°C for Australian sheep. The critical temperature refers to the temperature at which heat production is minimised (McCGraham 1964), and according to Armstrong *et al*. (1959) for shorn sheep is 27°C at moderate levels of feeding (Table 31).

Table 31 Critical temperatures for sheep in calm conditions (adapted from Armstrong et al. 1959)

Fleece length (cm)	Critical temperature (°C)	Feeding level
Shorn	38	Low
Shorn	27	Moderate
Shorn	24	High
2.5	13	Moderate
4.4	8	Moderate
10	5	Moderate

Wool length of greater than 3 cm protects sheep from radiant energy; Macfarlane *et al* (1958) observed that the respiratory rates of summer shorn sheep were twice as fast as those of unshorn sheep when standing in the sun. Respiratory rate can be used as an indicator of heat stress as sheep appear to maintain thermal equilibrium by increasing evaporation rate via the respiratory tract (Klemm 1961).

The greater the body condition the more heat tolerant the sheep (Butler 2006) and shorn sheep appear to have improved tolerance of hot-humid conditions, although Silanikove (2000) suggest that it is essential to provide shade for sheep where the summer ambient temperature exceeds 24°C. Stockman (undated) observed that ewes appeared to be less affected by heat stress than wethers and, although they consumed more water, tended to spend less time in the shade. The small sample size of this experiment may have influenced the validity of the findings.

At temperatures in excess of 33°C, the dietary energy available for productive purposes declines (Armstrong *et al*. 1959) therefore it is considered important to avoid an excess formulation of dietary crude protein due to the increased energy demand for conversion. Protein requirements are generally unaffected by heat stress (Curtis 1983), therefore, more protein can be available than surplus energy can efficiently utilise which can result in unnecessary waste and expense; to enhance protein efficiency, dietary crude protein may need adjustment during periods of thermal stress. Ames and Brink (1977) observed an increase in urinary N outside the temperature range of 15-30°C, suggesting this could be the optimum tolerance range, and outside of this range protein may be used for energy production.

The UK Department of Environment Food and Rural Affairs (DEFRA) recommend the following protocol for transport of livestock during periods of high heat load:

- load at cooler times of the day
- do not overstock
- ensure adequate head room to facilitate air flow
- park in the shade
- keep vehicle moving as much as possible

Best practice

- Provide shade at all times when feeding outdoors
- Shade water troughs, but not the surrounding area
- Reduce the ME content of the ration during periods of high heat load
- Micromist cooling in shedded environments
- If feeding in troughs, provide feed during the cooler part of the day
- Avoid transporting lambs during hot weather

Recommended further research

- Determine the amount of shade required to optimise the performance of intensively finished lambs
- Determine the cost-efficiency of shearing to optimise skin value vs not shearing to optimise performance during hot weather

3.5 Cold stress

As market indicators in Australia traditionally favour intensive finishing of lambs over the summer, autumn and into early winter, cold stress can be a factor in determining productivity as well as heat stress.
Dry matter and N digestibility can fall by 0.14% for each degree fall in temperature (Ames and Brink 1977) or by as much as 0.31% per degree fall in temperature below 18°C (Christopherson 1978). Although wool is an effective insulator, its effectiveness declines as it gets wet, especially under windy conditions.

Many producers provide shelter from the wind via straw bales (Figure 44) and or galvanised iron sheeting bolted to fence lines (Figure 45), although no comparative studies have been found to support the efficacy of such structures.

Figure 44 Straw bale wind break (Source: Productive Nutrition Pty Ltd)

Figure 45 Galvanised iron as a feedlot wind break (Source: Productive Nutrition Pty Ltd)

Stocking density of lambs intensively managed in sheds should be decreased during periods of extreme cold to facilitate movement, which can alleviate the effects of cold stress (Sutherland 1967). Lambs in outdoor feedlots during winter do not appear to like standing in mud (W Hawkins 2006 pers comm. 12 September), therefore, the provision of mounds or shelter or the slope of the pen (2-3%), may be essential to maintain growth, productivity and well-being.

“Eco-shelters” (Figure 46) have become a popular form of windbreak as they also provide protection from the rain. They are effective in facilitating finishing lambs through winter in high rainfall areas by substantially reducing mortalities from cold stress (R. Davidson 2006 pers comm. September 12).

Figure 46 Eco-shelter protection for production feeding of lambs in WA (Courtesy R Davidson)

Indoor sheds provide the most controlled environment for finishing lambs, but although they remain cost-prohibitive for many opportunity finishers, there is some interest from specialist feedlotters in establishing sheds (S. Jolly 2006 pers comm.).

Best practice

- Provide shelter during cold weather for shorn lambs in outdoor finishing systems

Recommended further research

- No research appears to be required in this area

3.6 Shade and shelter

Johnson (1981) observed that shaded Merino ewes ate 24% more feed and drank 33% more water at both 20°C and 50°C. The Australian Lot Feeders Association (ALFA 2001) suggests that shade can reduce feedlot surface temperature by up to 14°C.

Feedlot lambs seek shade from the flanks or between the hind legs of adjacent lambs and appear to be deliberately seeking shade for their heads (Schreffler and Hohenboken 1980).

Grazing Merino sheep provided with shade overcame the symptoms of heat stress two hours after seeking shade (Harszti and Nagy 1972), although Sherwin and Johnson (1989) noted significant differences between individual sheep and their selection of shade, whilst grazing irrigated pastures. They further commented that the extent of shade selection appeared to be unrelated to heat load as measured by rectal temperature, but noted that the sheep in this study were insulated by 2 cm of wool. Sheep appear to increase utilisation of shade when on dry paddocks to a greater extent than when grazing irrigated pastures.

Both the beef and dairy cattle industries have extensively investigated the effects of shade on various performance indicators and several authors have noted the importance of the temperature humidity index (THI) and the compounding effect of humidity on heat stress (Shirlow 2005). Shorn sheep appear better able to tolerate hot and wet conditions (Klemm 1961) whereas unshorn sheep react less to hot and dry conditions.

Merino sheep in hot and humid environments increase water available for evaporative cooling by drinking up to 12 times their daily winter intake and reducing their urine output (MacFarlane *et al* 1956).

Figure 47 Fenced off treed areas in a Western Australian confinement feeding area (Source: Productive Nutrition Pty Ltd)

A member of the project reference group (T. Grant 2006 pers comm. 12 September) has suggested that shade should not be provided above the feed or watering points as it appears to encourage lambs to camp there. Social behaviour may then limit all lambs' access to both feed and water. This recommendation is in contrast to Davis (2003), who suggests that a shaded water trough is essential during the period of introduction to the feedlot.

Treed areas provide the most common shelter for intensively finished lambs retained outdoors (Figure 47), although they may be short lived if not fenced off. Trees require protection from rubbing and eventual ring-barking, and possibly from the effects of high levels of urea being deposited around the base of the trees (T. Grant 2006 pers comm. 12 September). Compaction and soil acidification may contribute to the early demise of shade and shelter belts (J. Franklin-McEvoy 2006 pers comm.13 November).

3.7 Disease prevention and animal health

Common diseases of intensively finished lambs

Anecdotally it would appear that acidosis and enterotoxaemia are the most important feedlot diseases and major contributors to mortality and poor performance, although within a recent survey of lamb finishers (Giason and Wallace 2006) the reported rate was less than 5%. Producers sourcing lambs from saleyards are at increased risk of importing lambs with incubating infectious diseases, cheesy gland or grass seed infestation.

Acidosis
Acidosis is caused by accumulation of large amounts of ruminal lactic acid resulting from ingestion of diets that are high in fermentable carbohydrate or low in effective fibre. The symptoms that occur relate to the rate and extent of lactic acid production, utilisation and absorption (Nocek 1997). Lactic acid accumulates in the rumen when those bacteria that produce lactic acid outnumber the populations of bacteria that utilise lactic acid. Lactic acidosis has been defined as a rumen pH less than 5.2 and a rumen lactic acid concentration of greater than 20mm/L (Murray *et al*. 1992)

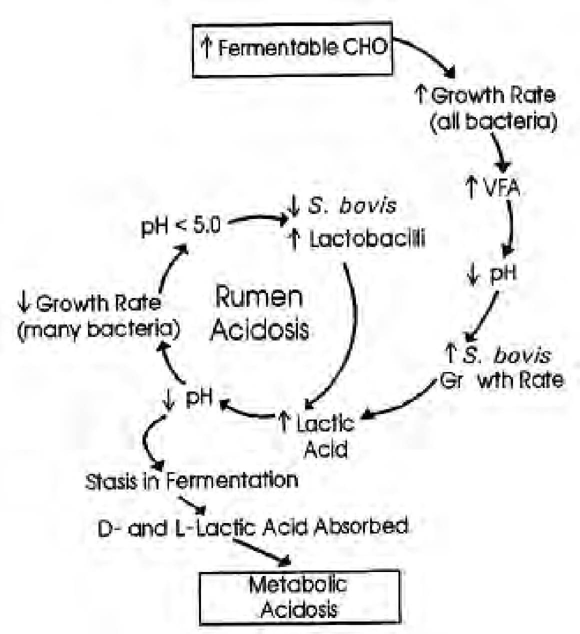


Figure 48 Sequence of events associated with the induction of lactic acidosis (Nocek 1997)

Although acidosis can occur whilst ruminants are grazing lush pastures containing sub-optimal levels of effective fibre, acidosis occurs most commonly in grain fed animals. Total mixed ration systems can assist in the prevention of acidosis by providing a balanced ration whereby hay and grain are mixed together to reduce the rate of fermentation of feed and rate of passage through the gut. Antibiotics such as virginiamycin and rumen buffers such as sodium bicarbonate can be incorporated into the feed (see Feed Additive section) as a prophylactic measure.

However the most effective method of prevention of acidosis is by gradual introduction of lambs to high starch cereal grains and peas to allow proliferation of lactic acid digesting bacteria in the rumen and hence maintenance of a stable rumen pH.

Enterotoxaemia
This is an acute, usually fatal and infectious disease caused by the bacterial toxin produced by *Clostridium perfringens* type D (Hungerford 1990). The organism is normally found within the intestine in population numbers insufficient to cause disease, however, a rapid change in feed can cause the bacteria to suddenly grow and cause acute disease.

The most effective preventative measures currently available include vaccination and avoidance of sudden changes in feed, although the current recommended vaccination program for marking and weaning appears to be relatively ineffective in protecting fast growing lambs within an intensive finishing system. On this basis, Rendell (2006) recommends vaccination on a three monthly basis.

A recent industry survey (Giason and Wallace 2006) revealed that up to 33% of all intensive lamb finishers vaccinate at induction although the question that was asked only related to Weaner Guard® and not '6-in-1' with which a broader range of producers would be familiar.

Urolithiasis

Urinary calculi or bladder stones block the outlet from the bladder in castrated or male lambs due to the narrow diameter of the urethra; the eventual outcome is rupture of the bladder causing peritonitis and death. The main cause is thought to be an imbalance of calcium in relation to phosphorus and is therefore commonly seen in lambs grazing cereal stubbles or fed a predominantly cereal based diet. Predisposing factors may include vitamin A deficiency and excess dietary rumen degradable protein (Hungerford 1990). Two percent of lambs within a feedlot in New South Wales fed a commercially prepared pellet developed calculi that resulted in a large number of deaths. The pellet appeared to be correctly formulated, with balanced calcium and phosphorus, however, poor quality water was thought to be the main predisposing factor (Slattery 2006).

Lambs with access to bore water with a high pH are susceptible to calculi and dilution of bore water with a pH greater than 8 is recommended. Urolithiasis is also thought to be more common in lambs fed sorghum based diets (Slattery 2006) although the reasons for this remain unclear.

Effective prevention is generally provided by calcium supplementation to achieve a ratio of calcium to phosphorus at 2:1, although this does not alleviate the incidence of the condition under all circumstances. Acidification of the diet by either the addition of ammonium chloride (NRC 1985) or apple cider vinegar (J. Franklin-McEvoy 2006 pers comm. 10 May) has been reported to reduce the incidence of calculi formation, but not in all cases where lambs are consuming grain based pelleted and therefore highly processed rations.

Inclusion of sodium chloride at 1 - 3% of the dietary dry matter, fed as a loose lick or block, may encourage an increase in water intake and thereby reduce the incidence of calculi formation in the bladder; anecdotally, apple cider vinegar has been seen to be effective.

Scabby mouth

A highly infectious viral disease caused by a strain of the *Parapoxvirus* family (Hungerford 1990). The disease takes three weeks to run its course and is characterised by pustules predominantly located on the lips plus or minus ulceration on the lips and inside the mouth. Eating appears to be painful and therefore intake is reduced significantly during this time, although affected lambs can usually consume smooth grains such as lupins. The lesions are susceptible to fly strike or secondary infection. Although the disease can severely check lamb growth, outbreaks are not common and vaccination is expensive (Rendell 2006).

Vaccination at marking is effective in preventing outbreaks of the disease, but not once an outbreak has occurred (Hungerford 1990). Topical antiseptic preparations are usually not practical treatments within an intensive finishing system, although application of sump oil and kerosene has been reported as a successful treatment (T. Grant 2006 pers comm. 12 September). The scabby mouth virus survives for many years in soil and on infrastructure and, once an outbreak has occurred, vaccination is the most effective mode of prevention.

Foot rot

Foot rot is defined by Hungerford (1990) as “an infectious, non suppurative disease of the feet of sheep showing progressive necrosis of the deeper layers of the epidermis, with underrunning of the horn, inflammation of the sensitive laminae of the hoof and severe lameness”. Lesions are caused by the bacterium *Bacterioides nodosus* and appear to be painful and debilitating. It is unlikely that lambs with foot rot would enter an intensive finishing system although the disease does impair the productivity of lambs being finished in high rainfall areas on improved pastures.

Prevention and management of the disease involves property management planning and is outside the terms of reference of this review.

Cheesy gland

Caseous lymphadenitis is a chronic disease of sheep characterised by abscess formation within the lymph nodes. Although there is little effect on health or productivity the downgrading of carcases at the point of sale can have a significant effect on profitability.

Prevention requires vaccination at marking as once lambs have been exposed to the disease and abscesses have developed, vaccination is no longer useful or effective.

Internal Parasites

Although worm infestation can have a significant effect on the productivity of intensively finished lambs, especially within a pasture-based system, monitoring is the most effective diagnostic tool available to producers to ensure drenching programs are targeted, specific and cost-effective. However, a recent survey of intensive lamb finishers revealed that 100% of small and large lamb finishers drench their lambs prior to commencing on a feeding program and 75% of medium sized operations routinely administer drench (Giason & Wallace, 2006).

As an outbreak of internal parasites can be potentially lethal and have a significant effect on productivity and profitability drenching is recommended but due to the high incidence of drench resistance in Australia, and the potential cost of ineffective treatment drenching programs should be planned on an individual basis.

The National Vendor Declaration could increase their importance by providing more detail about the vaccination and parasite history of lambs.

Pink eye

Outbreaks of pink eye or infectious keratoconjunctivitis are common in lamb feedlots caused by Chlamydia psittaci or *Rickettsia* and appear to be predominantly due to either Vitamin A deficiency or irritation secondary to dusty conditions or grass seed infestation. Other than removal of grass seeds from the eye treatment with Tetracycline spray, ointment (Rendell 2006) or powder remains controversial, as unless the condition is severe and results in ulceration of the cornea, most lambs recover with or without treatment.

Growth rate depression occurs due to increased difficulty of the lamb to find feed and water and the appearance of photophobia. Although some authors recommend separation of affected lambs, it is likely that once an outbreak occurs that more lambs may be affected than is immediately obvious therefore, little may be gained from drafting lambs from their social groups.

Pleurisy and pneumonia

Pleurisy or pneumonia are reportedly common diseases in intensively finished lambs, especially within feedlots (G. Duddy 2006 September 13). Pleuropneumonia is common in flocks of British breed sheep (Hungerford 1990) and the causative organisms can include *Pasteurella* spp., *Actinomyces* spp., *C. pseudotuberculosis, Mannheimia haemolytica, Mycoplasma* or other mixed infections.

In Western Australia, 1.3% of feedlot lambs died from bacterial pneumonia and pleurisy over a 3- week period and similar mortality rates had been reported within grazing systems (Buckman 2006).

A survey of the incidence of pleurisy in slaughter age lambs raised on a pasture-based system in New Zealand (Hathaway and McKenzie 1987) revealed a relatively high incidence of the disease as summarised in Table 32.

Table 32 Incidence of pleurisy detected in slaughter age lambs in New Zealand in 1985

	North Island	South Island
July	24.4%	11.1%
August	27.7%	9.0%
September	27.2%	
November	1.5%	6.0%
December	2.5%	0.8%

An earlier survey in New Zealand (McGowan *et al*. 1978) of all lambs slaughtered during July 1974 detected 11% of lambs with the disease.

Rumenitis

Within a group of mixed age feedlot lambs fed a ration of lupins, oats and cereal hay some lambs were found to have rumenitis which Buckman (2006) attributed to a rapid introductory period; in a similar age group grazing a failed oats crop and similarly supplemented, 2.5% had rumenitis. However, the incidence of this disease and its effect on productivity remains unclear.

Coccidiosis

Coccidial infection is a mild intestinal infection due to protozoan parasites (Alpharma 2002) and causing transient diarrhoea and a reduction in feed intake, however severe outbreaks can result in profuse blood stained diarrhoea, loss of appetite and weight. Coccidiosis occurs more commonly in sheep up to 2 years of age and is prevalent where lambs are heavily concentrated. Infection can be acquired from contaminated water, feed, and pasture or by licking the wool of infected animals.

Lasalocid (Bovatec) is registered for use in sheep and lambs and is commonly added to commercial feed additives and or mineral preparations as a prophylactic measure.

Parakeratosis

Parakeratosis is a common finding in feedlot cattle fed high concentrate diets, particularly where the feed has been pelleted, although there are no direct symptoms of the disease to be observed.

As this disease causes thickening and enlargement of the rumen papillae, it is likely it reduces the efficiency at which feed is converted to live weight gain. Stanton and Levalley (2006) commented that pelleting of high concentrate rations results in an increased incidence of ruminal parakeratosis. Monensin has been shown to significantly reduce the incidence of the disease by a 50% reduction in the butyrate level in the rumen (Kutas *et al*. 1983). Butyrate stimulates keratinisation of ruminal epithelial cells.

Zinc deficiency or calcium-induced zinc deficiency is thought to be a predisposing cause to this disease when diagnosed in pigs (Hungerford 1990). Early weaned lambs at 15 kg live weight offered whole barley and a protein supplement on a free choice basis were found to have hyper parakeratosis and ulceration of the rumen wall however the effect was significantly reduced by the addition of barley straw to the diet (Askar *et al*. 2006).

Best practice

- Provide a 14 day introductory period to cereal grains
- Control access to grain during the introductory period
- Provide palatable roughage source during introduction to grain
- Balance a grain-based ration with calcium
- Vaccinate lambs against Scabby Mouth at marking in high risk areas
- Vaccinate lambs against Cheesy Gland at marking
- Vaccinate lambs with a minimum of “3-in-1” before a change in diet
- Investigate the worm history of lambs prior to entering an intensive finishing system
- Inject lambs with Vitamins A, D and E if they have had no access to “green feed” for 8 weeks prior to finishing
- Add lasalocid sodium to the rations of lambs considered at risk of coccidiosis infection

Recommended further research

- Determine the predisposing factors leading to pleurisy and pneumonia in paddock and feedlot finished lambs

4 Management

Although the genetic potential of the lamb is critical in determining not only its growth rate but also its growth path, lamb breeders do not always convey genetic history or Australian Sheep Breeding Values (ASBVs) when selling stock. This prevents lamb finishers preferentially purchasing lambs with higher growth potential.

In order to avoid fat penalties, fat scoring of lambs on a regular basis is recommended. While, the cost-efficiency of automatic drafting and weighing systems has yet to be determined, there is clear evidence that regular weighing of lambs during the growing period is essential.

Marketing and budgeting are of critical importance and this has been recognised by MLA in their continued support of the Sheep CRC's development of the feedlot calculator. Anecdotally, despite a recent survey to the contrary, there are substantial numbers of producers intensively finishing lambs with no idea of their budget position.

The role of the manager in the success or failure of an intensive lamb finishing system cannot be understated. Many opportunity feedlots in operation anecdotally produce a consistently high quality product from a very simple system.

This section will briefly address those issues that are largely under the control of the manager, and that can greatly influence the profitability of the enterprise. These include:

breeding and/or selection of lambs that have the potential for above average growth

performance monitoring and recording

marketing and budgeting

4.1 Breeding and selection

Genetic gain in the lamb industry has been increasing at an average of 4% (Pethick *et al*. 2006) for just under 10 years and although this has resulted in the production of larger, leaner lambs it does not appear to have translated into sustained higher growth rates within commercial finishing systems.

Genetic adaptation to a confined or feedlot environment (Tennessen 1989) may be a predisposing factor to the relatively high and costly incidence of shy feeding and as the intensive finishing industry continues to grow may justify the development of an Australian Sheep Breeding Value (ASBV, previously known as Estimated Breeding Value or EBV)) for intensive adaptation or for grain finished lambs.

Section 1 of this report has included considerable evidence of the value of growth potential to an intensive finishing system, and that it appears that the genetic information generated by members of SGS and Lambplan is currently being underutilised by the sheep industry (H. Oddy 2006 pers comm. 13 September). The reasons for this are not entirely clear, although it seems that despite efforts to provide educational sessions to the broader farming community in terms of selection of more profitable sires via ASBVs, there remains a poor level of understanding of the system. The Meat and Livestock Australia web site provides clear and concise information about the value of using performance recorded sires and this can be sourced in easily understood language (http://www.mla.com.au/TopicHierarchy/InformationCentre/TipsandTools/Default.htm).

Clearly sires with above average ASBVs for growth, produce progeny with above average growth potential (Gaunt and Harris 1996), and the feeding and finishing of those progeny should be more profitable. Pethick (2006) states that for each increase of five units of post weaning weight (PWWT) ASBV, live weight increases by 11 grams per day.

Many of the feeding experiments outlined in Section 1 demonstrate below average growth rates, and, if an economic assessment of these studies was reported, many of them would not have been profitable.

Greenwood *et al*. (1998) showed the advantages of selecting higher birth weight lambs included reduced total feed intake, reached market weight sooner and were leaner and therefore more efficient.

The advantages of using sires with high growth and leanness potential may be reduced if nutrition is limiting and lamb growth restricted (Hall *et al*. 2002; Gardner *et al*. 2006). Previous studies (Hall *et al*. 1994) revealed a 13-15% increase in the percentage of large lean lambs produced from high growth sires. The expected growth advantage in progeny of sires elected for high growth potential (PWWT ASBVs) may not be evident until three months of age (Stanley *et al*. 2006), which is ideally suited to the intensive lamb finishing industry.

However, it has been suggested that there is insufficient commercial data available from progeny of sires and dams with known ASBVs (G. Gaunt 2006 pers comm. 13 September) to convince the industry of the true merit of performance recording as a management tool.

The Australian sheep industry is still characterised by breed preferences rather than individual animal performance although there is no evidence to support preferential breed selection. Early work by Reid (1971 cited in Terrill 1975) suggested breed differences in feed efficiency appeared to be due in part to differences in fat content at specific weights.

Some breeds have more growth potential than others (Neary 1998) although Johnston *et al*. (2001) found daily weight gain to be highly variable between and within breeds, with little difference in feed conversion ratio. Merino lambs tend to have less growth potential than crossbred lambs (Bowen *et al*. 2006), although Merino rams have not traditionally been selected for their high growth potential.
Notter et al (2004) failed to find significant differences in post weaning weight gain between lambs sired by either Dorper or Dorset rams out of composite ewes. Composite ewe breeding appears to be delivering a wide combination of genotypes to intensive lamb finishing operations, posing significant challenges in formulating rations for even finishing.

Frame size appears anecdotally to be an important prerequisite for lambs entering finishing systems, with the industry perspective being that lambs with larger frames have faster growth potential and leaner product. Nichols et al. (1993) and Tatum *et al*. (1998) support this view. Tatum *et al*. (1998) found daily gain was greater for large framed lambs across a range of diets, except for those lambs fed a high protein diet, where rate of gain was similar (220g/day). There was no sex effect and every 10 kg increase in live weight gain was associated with a 0.22cm increase in fat depth.

Hybrid vigour clearly has a positive effect on lamb growth as Holst *et al*. (1998) found that second cross lambs grew significantly faster ($P<0.05$) than first cross lambs, although Hopkins et al (1996) in earlier work, noted that first cross lambs were leaner at heavier weights.

Recent investigations into a genetic selection tool for feed efficiency (Knott *et al*. 2003; Knott *et al*. 2004) have shown that in seven month old ram lambs, net feed intake (predicted intake minus actual intake) is significantly correlated with lean tissue mass (-0.34), fat tissue mass (-0.37), average daily gain (-0.59), FCR (0.59) and lean tissue gain (-0.67), and that it is moderately heritable.

Best practice

- Breed lambs for intensive finishing systems from sires with post weaning weight ASBVs of +6 or greater
- Income, expenses and profitability to be reported on all feeding and performance trials

Further research

- Determine the influence of genes on the rate of adaptation of lambs to an intensive finishing environment
- Investigate the cause of underutilisation of estimated breeding values in finishing systems

4.2 Performance monitoring and recording

The cattle feedlot industry places great importance on performance recording and feedback to breeders that supply weaners to their finishing systems; although supply chains are an integral part of the Western Australian lamb finishing industry, they are not so evident elsewhere. Although alliances with processors are likely to result in higher returns for producers (McLeod 2003), mutual loyalty has been the greatest limiting factor to the success of these supply chains.

The current structure of the lamb industry does not encourage two-way information flow, which impedes the ability of intensive lamb finishers to make progress, and to purchase lambs into their systems with a genetic history of rapid growth and efficient conversion of feed to live weight gain.

A high percentage of feedlot-finished lambs are purchased off-farm with little history supplied, allowing little opportunity to provide feedback on their performance to the breeder of the lambs. This places limitations on the incentive of the breeder to improve the lambs they are breeding for this industry sector.

Individual animal performance can severely influence the profitability of a finishing system and therefore consideration should be given to the opportunity cost of not individually identifying and weighing lambs. Atwood *et al*. (2006) suggests, “productivity may be adversely affected if animals differing from the mean are fed a uniform food formulated to meet the needs of the average individual”.

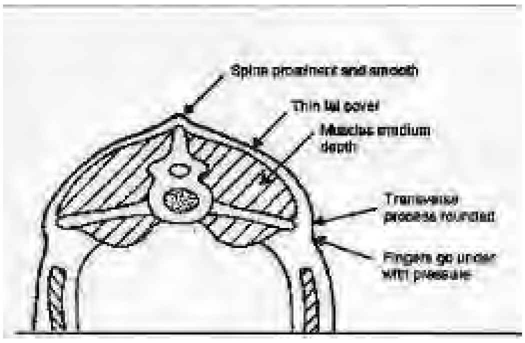
When lambs are considered as groups rather than individuals, many high performing lambs are hidden in the averages as are the poor performers, and the effect of individual lambs tends to be greater than any treatments applied (Ryan and McIntyre 2006; Linden *et al*. 2006 unpub.).

Intensive lamb finishers managing large operations weigh all lambs on entry and exit (Giason and Wallace 2006) with lambs weighed after two weeks by only half of the small and medium sized operators.

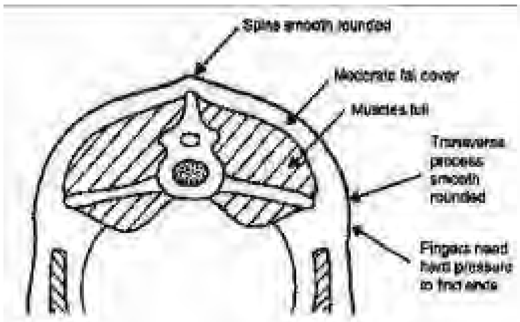
Regular weighing and fat scoring of lambs during the growing period facilitates culling out of those lambs that, for whatever reason, have failed to adapt to their environment. It is a fallacy to assume that all of those lambs have not been consuming feed, even if at a below average rate of consumption. Producers currently manage these lambs in a range of ways including, returning them to the paddock from the feedlot environment and bringing them back on feed at a later date, sending them for slaughter, or restarting them on feed in a different environment.

There is a range of efficient auto-drafting systems now commercially available, one of which is illustrated in Figure 49. These machines can weigh and draft up to 700 lambs per hour, which saves on labour and makes drafting relatively simple and efficient. Most auto-drafting systems have the option of data download for record keeping. Many producers are not keen to monitor weight gains as they are of the opinion that weight gains are reduced by the disruption. In reality, it is more likely to be that their weighing facilities are inefficient and that regular weighing is too time-consuming.
Simplistic and efficient methods of fat scoring include running the flat part of the operator's fingers along the rib cage of the lambs when they are in the drafting race and proficiency can be rapidly developed. When marketing over the hooks there can be substantial penalties for over fat lambs, and as well as this additional weight being both inefficient and costly, it reduces the carcase value and potentially can remove the profit margin from fat individuals. One producer has indicated that lambs greater than fat score 2 (Figure 50) do not enter the feedlot as in his experience, they will become over fat by the time they reach saleable weight (T. Grant 2006 pers comm. 13 September).

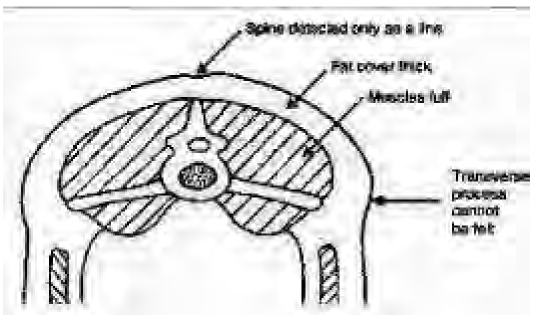
Figure 49 Automatic drafting and weighing system for sheep and lambs (Source: Productive Nutrition Pty Ltd)

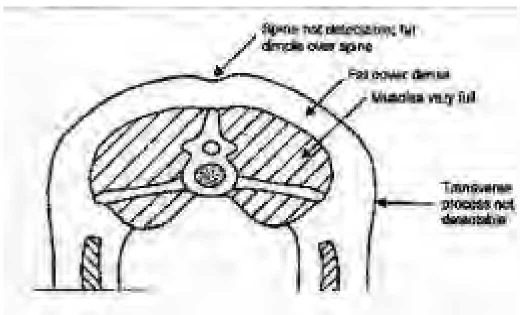


Fat score 2 (GR tissue depth: 6-10mm)



Fat score 3 (GR tissue depth: 11-15mm)





Fat score 4 (GR tissue depth: 16-20mm) Fat score 5 (GR tissue depth: >20mm)

Figure 50 Tissue depth at the GR site as determined by fat scoring (Thompson and Meyer, no date)

The Sheep CRC is currently working on an electronic “walk-through” weighing system which is successfully operating in a Western Australian feedlot where lambs are identified with electronic ear tags as illustrated in Figure 51. The advantage of this system is that lambs can pass through the system each time they access the water trough, such that data is constantly available on individual lamb performance, with minimal labour input. Weights are recorded instantly and can be accessed from a central database. The efficiency of these systems is enhanced by the use of electronic ear tags which are currently part of the Sheep CRC research program.

Figure 51 Walk through automatic weighing and drafting system (Courtesy: R. Shepherd Sheep CRC)

Some intensive lamb finishers do not regularly weigh lambs, as there is a perception that the lambs become "stressed" and refuse to eat for a considerable time after weighing. However weighing is critical to determine the point of sale for lambs (McLeod 2003) and there is evidence that frequent weighing does not adversely affect the performance of pigs (Wolter *et al*. 2002) or significantly increase plasma cortisol levels of young lambs (Lester *et al*. 1991).

Lambs travelling through unfamiliar equipment for the first time can be difficult to handle because of apparent fear of their surroundings, although most producers state that the second time, they have settled well and do not appear to be affected by the procedure.

The quality of the handling equipment may be an influencing factor in the lambs' reaction to regular weighing. Inferior facilities, plus or minus dogs (Figure 52), people being excessively noisy, and/or the use of manual handling systems, all negatively effect lambs.

Figure 52 Feedlot lambs being weighed and drafted under noisy and stressful conditions (Source: Productive Nutrition Pty Ltd)

Although the exact figure remains unclear it appears that relatively few opportunity and medium sized operations have efficient stock handling systems, as they are often seen as too expensive.

Best practice

- Record weaning weights on all lambs intended for intensive finishing systems
- Provide feedback on performance outcomes to lamb breeders
- Regular weighing and fat scoring
- Identify and remove lambs that are not growing
- Consider the value of automatic weighing and monitoring systems
- Supply chain management systems

Further research

- Determine the reasons for the success of supply chains in Western Australia and their failure elsewhere

- Investigate the cost-efficiency of automatic weighing and drafting systems

4.3 Marketing and budgeting

It is not the intention of this review to examine this topic in depth as those researchers who are developing the Sheep CRC Feedlot Calculator are completing those investigations. However as marketing and budgeting are the most important factors to be considered when feeding lambs, it was considered essential to include some reference to this topic in this section.

The importance of securing forward contracts and completing a simple gross margin budget when intensively finishing lambs cannot be understated although between 25-33% of respondents to a recent survey (Giason and Wallace 2006) indicated they do not complete gross margin budgets. Intensive lamb finishing operations can be highly profitable, however, margins in feedlotting are currently very narrow and accordingly it is imperative that feedlotters monitor their position before commencement of a feeding cycle.

As the value of the lamb, and many of the variables in the following budget examples change on a daily basis, the importance of maintaining a regular budget position should be clear.

Skin value has a significant impact on profitability as shown in Table 33, which demonstrates a breakeven scenario as at November 2006.

The Sheep CRC Feedlot Calculator (http://www.sheepcrc.com.au/feedlotcalculator) provides producers with an online budgeting format. Alternatively, Tables 33 and 34 indicate an effective method of examining the current and potential profit or loss position and can either be set up on an Excel® spreadsheet or calculated by hand.

Feedlot budgets, commonly referred to as gross margin budgets, need to include the following:

Initial value
The current value of the lamb, prior to entering a feedlot, has a profound effect on the gross margin. As illustrated in Table 34, if all other variable costs remain unchanged, a $6 increase in the initial value, or potential sale price on that day, results in a loss of $5.87 per head. To breakeven at this higher initial value, if all other parameters remain the same, an increase in the end contract price of $0.33, to $3.63 per kilogram carcase weight on a hot standard carcase weight (HSCW) basis would be required to at least break even.

Transport to property
An additional cost, to those listed in these gross margin examples, incurred for lambs purchased off-farm.

Animal health treatments at induction
Prior to commencing on a grain-finishing ration or introduction to a high quality pasture, the following animal health treatments are required:

- Drench
- Vaccination 6:1
- Vitamin A, D and E
- Additional treatments on an individual basis

Crutching
At some stage prior to sale, the lambs will require a keyhole crutch to remove stained and/or soiled wool from the breech area

Shearing
In terms of optimising skin value, shearing may be required during the period of time the lambs are in the finishing phase.

Feed cost per tonne
Feedstuffs grown on farm should be valued at the price for which they could be sold on that day (i.e. current market value) as a true indicator of feed cost or the opportunity cost of not selling that feed. Feed costs vary widely, depending on the ingredients used that make up the ration, and on average, pelleted feeds cost approximately $100 per tonne more than home mixes. However, in the gross margin examples included in this report, there is no additional allowance for the cost of mixing feed such as in a mixer wagon.

Fuel, oil repairs
When feeding lambs on a daily basis there can be significant use of fuel and oil and machinery frequently requires repairs. This should be allowed for in the budget and adjusted on an individual basis to reflect true costs, if known.

Water
Water costs can vary widely depending on the water source and any additional pumping associated with supply.

Transport to market
All lambs will require transportation at the end of the feeding cycle and once again the costs vary with distance to markets, shared loads and are also affected by whether or not the lambs were purchased live on farm (on hoof) or over the hooks at the processing end.

Agent's commission on sale
The role of stock agents in an intensive finishing system remains unclear as, in many instances, the agents commission on the sale of lambs is greater than the margin made by the producer. At an industry level this situation warrants further discussion.

Slaughter levy
All animals sold for slaughter attract a slaughter levy which is reinvested in industry research, development and marketing to benefit the producer in the longer term.

Labour and administration
In larger finishing systems, labour can be a substantial additional cost that is seldom accounted for in a gross margin budget. Costs will vary across enterprises, but if labour is employed to run the finishing system then the cost must be included in the budget. A figure of $0.04 to $0.05 per head per day has been put forward from an intensive lamb finisher in New South Wales (T. Grant 2006 pers comm. 13 September) for use in these gross margin examples.

Dressing percentage
Dressing percentage (McLeod 2003) can be influenced by many factors that include:

- fat score
- fasting period
- wool and skin weight
- sex
- breed
- weaned or unweaned
- extent of carcase trim
- feeding regime

Details of the extent to which these factors influence dressing percentage can be found at http://www.agric.nsw.gov.au/reader/sheep-meat and following the link to “Comparing Lamb Marketing Methods”. When marketing lambs directly to processors and therefore selling over the hooks, payment received is on a dressed weight basis, therefore it is important for producers to fully understand, and where possible manage, the factors that affect their final payment.

Skin price
Skin price has a substantial effect on the profitability of an intensive finishing operation therefore it is important to plan the time of shearing in relation to expected date of sale, to ensure required market specifications are met. Avoidance of factors that negatively impact on skin quality, such as contamination by medic burr or mud, is an important consideration when providing hay in racks or when feeding in confined, unsheltered areas during winter.

Failed lambs
In every finishing system, there are “failed lambs’ that do not meet market specifications and will negatively impact on the average profitability of the enterprise. Although it is likely that in most years these lambs will still generate some financial return, it will be less than for those lambs that meet specifications. Some account needs to be taken of these lambs in terms of those sold off early as shy feeders, and those that fail to achieve finishing weights and/or fat score, as they will have contributed to the overall feed cost.

Total returns per head
There are opportunistic lamb finishers and or lamb breeders who are reluctant to sell lambs at lighter weights or for seemingly low returns, when they either anticipate higher prices in the future or are aware that other producers with heavier weight lambs are receiving a higher return.

Estimating profitability from the sale price can be very misleading as illustrated in Figure 53. In this example, which is indicative of the situation as at November 2006, the sale price of a 30kg lamb may be $36 at the time when a decision has to be made to either sell or feed. Although after 66 days on feed the lamb is worth $74.22, due to the costs involved in the finishing process, the producer has made a loss of $4.05 per head. This illustrates the importance of budgeting in a high-volume, low-margin, high-risk business.

Figure 53 Breakeven analysis for grain-finished, Merino lambs and crossbred lambs as at November 2006

The breakeven analysis for Merino and crossbred lambs as at November 2006 clearly demonstrates the potential risk involved in finishing lambs at that time. Contract prices for January 2007 delivery of a 20kg crossbred lamb (HSCW) were $3.20kg however Figure 53 illustrates a financial loss incurred at a price less than either $3.20 or $3.60 at an initial value of $1.00 per kg live weight or $1.20 per kg live weight respectively.

Forward contract prices for Merino lamb ranged from $2.60 up to $3.00 which, although their initial value would be lower, finishing at those prices is still clearly unprofitable.

Table 33 Example of a simple gross margin budget, at breakeven point ($1.00 per kg LW initial price) (Jolly 2006 unpub.)

Ration consisting of barley, lupins, cereal hay and a mineral concentrate	Crossbred lambs				Costs[1]	Costs[2]
Purchase price	Average live weight (kgs):	30	@	$1.00	$30.00	
Transport to property	per lamb:	$0.00			$0.00	
Drench: Cydectin		$0.21			$0.21	$0.21
Vaccination + B12		$0.24			$0.24	$0.24
Crutching and shearing		$2.70			$2.70	$2.70
Enter total days fed, cost per tonne	Total days @250g/day:	66	$ / t	$303.58		

& kgs fed per day	kgs per day:	1.53	$ / head	**$30.66**	**$30.66**	**$30.66**
Fuel, oil, repairs	cost per lamb:	$0.05			$0.05	$0.05
Water	cost per lamb:	$0.01			$0.01	$0.01
Transport to market	cost per lamb:	$1.20			$1.20	$1.20
Commission on sale (%)		5.00%			$3.30	$3.30
Slaughter levy	cost per lamb:	$0.50			$0.50	$0.50
Labour and administration	cost per lamb:	$3.30			$3.30	$3.30
Total costs per head					**$72.17**	**$42.17**
Returns per head						**72.70%**
	Average carcase weight (kgs):	20	@	**$3.30**	$66.04	
Dressing percentage		45%				
Skin price		$7.00			$7.00	
Less out of spec. lambs (%)		2%			$1.46	
plus lambs sold off early	@ cost price per lamb:	2%			$0.60	
Total returns per head					**$72.18**	
Breakeven point					**$0.01**	

[1] Costs per head

[2] Costs per head excluding purchase and transport

Table 34 Example of a simple gross margin budget, at a loss position ($1.20 per kg LW initial price) (Jolly 2006 unpub.)

Ration consisting of barley, lupins, cereal hay and a mineral concentrate	Crossbred lambs				Costs[1]	Costs[2]
Purchase price	Average live weight (kgs):	30	@	$1.20	$36.00	
Transport to property	per lamb:	$0.00			$0.00	
Drench: Cydectin		$0.21			$0.21	$0.21
Vaccination + B12		$0.24			$0.24	$0.24
Crutching & shearing		$2.70			$2.70	$2.70
Enter total days fed, cost per tonne	Total days @250g/day:	66	$ / t	$303.58		
& kgs fed per day	kgs per day:	1.53	$ / head	**$30.66**	**$30.66**	**$30.66**
Fuel, oil, repairs	cost per lamb:	$0.05			$0.05	$0.05
Water	cost per lamb:	$0.01			$0.01	$0.01
Transport to market	cost per lamb:	$1.20			$1.20	$1.20
Commission on sale (%)		5.00%			$3.30	$3.30
Slaughter levy	cost per lamb:	$0.50			$0.50	$0.50
Labour & administration	cost per lamb:	$3.30			$3.30	$3.30
Total costs per head					**$78.17**	**$42.17**
Returns per head						**72.70%**
	Av. carcase weight (kgs):	20	@	**$3.30**	$66.04	
Dressing percentage		45%				
Skin price		$7.00			$7.00	
Less out of spec. lambs (%)		2%			$1.46	
plus lambs sold off early	@ cost price per lamb:	2%			$0.72	
Total returns per head					**$72.30**	
Profit / loss per head					**-$5.87**	

[1] Costs per head

[2] Costs per head excluding purchase and transport

Best practice

- Determine the budget position before committing to intensively finish lambs

Further research

- There does not appear to be a requirement for further research in this area, other than that currently being undertaken

5 Appendices

Appendix 1 Summary of feeding trials reviewed, listed by growth rate

LW (Kgs)	ME[1]	Protein (%)	FCR	Growth rate[2]	Period (days)	Breed	Comment	Author
	13.3	N/A	2.84	409			Early weaned male lambs; whole barley	Fraser & Orskov 1974
			6.4	395			Pellets; Choice: M/L	Francis 2002 PhD thesis
Fed to 50 kg	13.5	15.1	4.06	381		¼ Finn		Notter *et al.* 1991
			6.69	368			Pellets; Choice: H/L	Francis 2002 PhD thesis
		14.6		368		95% conc Romanov's		Beauchemin *et al.* 1995
	12.7	N/A	3.1	360			Early weaned male lambs; rolled barley pellets	Fraser & Orskov 1974
40.5-48.4	10.8	16%	5.4	359		SAMM x Mo	Pellets	Davidson *et al.* 2000
	9.4	18.5	7.09	352			Pellets; Low degradability	Francis 2002 PhD thesis
Fed to 50 kg	13.5	15.1	4.82	351		Rambouillet Suffolk		Notter *et al.* 1991
			7-5.5	250-350		Crossbred lambs	Average prodn targets for feedlot finishing of lambs	Milton 2001 cited in Kirby and Beretta 2004 p. 57
	11.8	15		349	43	PDBM, 6 months	Lot fed	Hopkins *et al.* 1996
			6.19	348			Pellets; Choice: H/M	Francis 2002 PhD thesis
40.5-47.9	10.8	16%	6	336		BL x Mo	Pellets	Davidson *et al.* 2000
to 45		16%	3.1	335			Pelleted diet; Early weaned to 45kg LW	Flanagan 1999
to 45		16%	3.2	332			Loose mix; Early weaned to 45kg LW	Flanagan 1999
30 - 55	N/A	19.4	highest	330			Early weaned male lambs	Orskov *et al.* (1971)
	n/a		3.13 - 3.9	277 - 326	25, 33 or 41		Early weaned	Orskov, Fraser & Gill (1973)
to 45		16%	3.7	325			Pelleted diet; Early weaned to 45kg LW	Flanagan 1999
			7.5-6	220-320		Merino lambs	Average prodn targets for feedlot finishing of lambs	Milton 2001 cited in Kirby and Beretta 2004 p. 57
30-50			10-5	200-320			Average prodn targets for feedlot finishing of lambs	Bell *et al.* 2003 cited in Kirby and Beretta 2004 p. 57
42.4-49.4	10.8	16%	6.1	318		PD x Mo	Pellets	Davidson *et al.* 2000
30 - 55	N/A	19.4	highest	301			Early weaned female lambs	Orskov *et al.* (1971)

LW (Kgs)	ME[1]	Protein (%)	FCR	Growth rate[2]	Period (days)	Breed	Comment	Author
	11.8	15		301	43	TBM, 6 months	Lot fed	Hopkins *et al.* 1996
			7-5	250-300		Crossbred lambs	Average prodn targets for feedlot finishing of lambs	Seymour 2000 cited in Kirby and Beretta 2004 p. 57
			8-5	150-300			Average prodn targets for feedlot finishing of lambs	Bell *et al.* 1998 cited in Kirby and Beretta 2004 p. 57
23	12.42		4.58	299		Konya Merino		Aktas *et al.* 2001
23	11.5		4.33	296		Konya Merino		Aktas *et al.* 2001
	11	15	5.1	296			Feedlot, pellets	Wiese *et al.* 2003
41.9-48.4	10.8	16%	6.4	295		EF x Mo	Pellets	Davidson *et al.* 2000
to 45		16%	3.3	291			Loose mix; Early weaned to 45kg LW	Flanagan 1999
23 - 40	**10.7**	**16**	**4.4**	**287**		Awassi	Graph data	Haddad *et al.* 2001
38.9-45.2	10.8	16%	6.1	286		Merino	Pellets	Davidson *et al.* 2000
	10.2	11.5		286		10 mo PD x Mo	**Intro** pellet	Ryan & McIntyre 2006 CRC
26.7	13	13.9	4.56	281		Targhee	1983	McClure *et al.* 1994
23	10.58		4.4	278		Konya Merino		Aktas *et al.* 2001
	11.8	15		278	43	PDM, cryptorchids	Lot fed	Hopkins *et al.* 1996
		12.8		276	84	Suffolk wether lambs	Added Cr	Gentry *et al.* 1999
		14.4		275		100% conc Awassi		Mulwala *et al.* 1994
	10.5	14.4	6.2	272			Feedlot, pellets	Wiese *et al.* 2003
	10.5	14.4	6.2	272			Feedlot, pellets	Wiese *et al.* 2000
	13.09	N/A	3.55	270			Early weaned female lambs; whole barley pellets	Fraser & Orskov 1974
30 - 55	N/A	15.7		270			Early weaned male lambs	Orskov *et al.* (1971)
		9		266	84	Suffolk wether lambs		Gentry *et al.* 1999
	13.44	N/A	3.33	264			Early weaned female lambs; unprocessed barley	Fraser & Orskov 1974
	13.4	N/A	3.55	260			Early weaned female lambs; rolled barley pellets	Fraser & Orskov 1974
23 - 40	10.7	18	4.6	259		Awassi	Graph data	Haddad *et al.* 2001
		12.1		257	84	Suffolk wether lambs		Gentry *et al.* 1999

LW (Kgs)	ME[1]	Protein (%)	FCR	Growth rate[2]	Period (days)	Breed	Comment	Author
	11.8	15		256	43	TM	Lot fed	Hopkins *et al.* 1996
22.7	13	13.9	4.85	253		Targhee	1985	McClure *et al.* 1994
40			6.5	250			Average prodn targets for feedlot finishing of lambs	Bell *et al.* 2003 cited in Kirby and Beretta 2004 p. 57
			8-6	150-250		Merino lambs	Average prodn targets for feedlot finishing of lambs	Seymour 2000 cited in Kirby and Beretta 2004 p. 57
		14.4		250	84	Suffolk wether lambs	Added Cr	Gentry *et al.* 1999
20-35	11.4	14.7	3.5	243		Crossbred lambs	barley, oaten straw, lupins	Tomes & Dymond 1976 cited in Kirby and Beretta 2004 p. 59
24	N/A	13 (lup)	3.54	243		BL x Mo	Preconditioned to ration	Tomes & Dymond (1976)
	11	15%	6.1	243		Merino		Wiese *et al.* 2003
20-35	11.9	18.9	4	242		Crossbred lambs	barley, oaten straw, lupins	Tomes & Dymond 1976 cited in Kirby and Beretta 2004 p. 59
24	N/A	16 (lup)	4.05	242		BL x Mo	Preconditioned to ration	Tomes & Dymond (1976)
	10.5	14.4	6.8	242			Feedlot, pellets	Wiese *et al.* 2000
20-35	12.3	17.2	4.5	240		Crossbred lambs	wheat, lucerne hay, meat meal	Davis *et al.* 1976 cited in Kirby and Beretta 2004 p. 59
23	13	13.9	4.22	237		Suffolk composite	1984	McClure *et al.* 1994
	10.6	18.9		235		10 mo PD x Mo	Grain / hay	Ryan & McIntyre 2006
	10.6	14.3	7.1	233			Feedlot, pellets	Wiese *et al.* 2003
	9.8	19	6.17	232			Pellets; Med degradability	Francis 2002 PhD thesis
18 - 31	10.99	20	4.93	231		Santa Ines ram lambs (haired)	80% barley; 20% sugarcane bagasse	Rocha *et al.* 2004
18 - 31	10.99	18	4.83	230		Santa Ines ram lambs (haired)	80% barley; 20% sugarcane bagasse	Rocha *et al.* 2004
18 - 31	10.99	14	4.65	228		Santa Ines ram lambs (haired)	80% barley; 20% sugarcane bagasse	Rocha *et al.* 2004
23 - 40	10.7	12	4.5	227		Awassi	Graph data	Haddad *et al.* 2001
30 - 55	N/A	15.7		225			Early weaned female lambs	Orskov *et al.* (1971)
23 - 40	10.7	14	4.6	223		Awassi	Graph data	Haddad *et al.* 2001
18 - 31	10.99	16	4.75	220		Santa Ines ram lambs (haired)	80% barley; 20% sugarcane bagasse	Rocha *et al.* 2004
	10.5	14.4	7	220			Feedlot, pellets	Wiese *et al.* 2000

LW (Kgs)	ME[1]	Protein (%)	FCR	Growth rate[2]	Period (days)	Breed	Comment	Author
20-35	12.6	19.5	5.4	205		Merino lambs	triticale, pasture hay, lupins	Roberts *et al.* 1984 cited in Kirby and Beretta 2004 p. 59
				204		2nd cross	Lucerne silage + 74% barley, 26% lupins	Kaiser *et al.* 2000
35	11.3	19.31	5.3	200		BLxMo		Ahmad & Davies 1986
			6	200		Crossbred lambs	After 2-3 weeks adaptation to feedlot conditions; Average prodn targets for feedlot finishing of lambs	Hack *et al.* 1997 cited in Kirby and Beretta 2004 p. 57
	11.3	16.3		197		10 mo PD x Mo	virginiamycin	Ryan & McIntyre 2006
30 - 55	N/A	11		191			Early weaned male lambs	Orskov *et al.* (1971)
35 - 50	13.5	15.4		190		PD x Mo lambs	Sorghum based diets, ME estimated ?, wheaten hay ad lib @ 6 ME & 7.44% CP	Bowen et al. 2006
35 - 50	13.5	17.4		190		PD x Mo lambs	Sorghum based diets, ME estimated ?, wheaten hay ad lib @ 6 ME & 7.44% CP	Bowen et al. 2006
	11.3	16.3		189		10 mo PD x Mo	virginiamycin	Ryan & McIntyre 2006
35 - 50	13.5	18		187		PD x Mo lambs	Sorghum based diets, ME estimated ?, wheaten hay ad lib @ 6 ME & 7.44% CP	Bowen et al. 2006
	10.1	18.5	10.6	186			Pellets; High degradability	Francis 2002 PhD thesis
			8.6 : 1	185			Range:2.8 – 73.8	Linden 2006 Rutherglen trial
	11.3	16.3		182		10 mo PD x Mo	Grain / hay	Ryan & McIntyre 2006
	10.5	14.4	11.8	180			Feedlot, pellets	Wiese *et al.* 2003
30 - 55	N/A	11		177			Early weaned female lambs	Orskov *et al.* (1971)
	11.3	16.3		175		10 mo PD x Mo	Finisher pellet	Ryan & McIntyre 2006
30	10.87	20	7.48	172	57	3rd cross Texel Corriedale		Zundt *et al.* 2002
35 - 50	13.5	17.1		172		PD x Mo lambs	Sorghum based diets, ME estimated ?, wheaten hay ad lib @ 6 ME & 7.44% CP	Bowen et al. 2006

LW (Kgs)	ME[1]	Protein (%)	FCR	Growth rate[2]	Period (days)	Breed	Comment	Author
20-35	11.4	16.9	6.2	171		Merino lambs	oats, pasture hay, lupins	Roberts *et al.* 1984 cited in Kirby and Beretta 2004 p. 59
35 - 50	13.5	16.6		170		PD x Mo lambs	Sorghum based diets, ME estimated ?, wheaten hay ad lib @ 6 ME & 7.44% CP	Bowen et al. 2006
	11.3	16.3		170		10 mo PD x Mo	TMR	Ryan & McIntyre 2006
	11.3	16.3		170		10 mo PD x Mo	Grain / hay	Ryan & McIntyre 2006
25 +	11.29	15		169	100	Kordish		Moghadam *et al.* 2000
26	11.6	18.5	5.85	168	Day 35-160	Mo wether lambs - 26 kg @ 7mths	Outdoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
30	10.87	24	7.55	168	57	3rd cross Texel Corriedale		Zundt *et al.* 2002
25 +	10.46	12.5		166	100	Kordish		Moghadam *et al.* 2000
20-35	11.2	18.5	4.2	162		Merino lambs	oats, oaten chaff, lupins	McDonald and Suiter 1982 cited in Kirby and Beretta 2004 p. 59
34.5 - 41.4	10.46	14.7	8.3	162		Naeini		Foroozandeh *et al.* 2001
	11.3	16.3		162		10 mo PD x Mo	Grain / hay	Ryan & McIntyre 2006
			5	140-160		Crossbred lambs	Average prodn targets for feedlot finishing of lambs	Suiter 1990 cited in Kirby and Beretta 2004 p. 57
	10.8	17.4%	8.7	160		Merino		Gardner *et al.* 1999
				159		Merinos & XB's	Pellet	McIntyre & Ryan 2005
24	N/A	13 (urea)	6.69	157		BL x Mo	Preconditioned to ration	Tomes & Dymond (1976)
	10.7	19		156		10 mo PD x Mo	Grain / hay	Ryan & McIntyre 2006
30	10.87	16	8.13	154	57	3rd cross Texel Corriedale		Zundt *et al.* 2002
30	10.87	12	8.18	154	57	3rd cross Texel Corriedale		Zundt *et al.* 2002
24	N/A	16 (urea)	6.26	153		BL x Mo	Preconditioned to ration	Tomes & Dymond (1976)
35	7.5	18.93	7.8	151		BLxMo		Ahmad & Davies 1986
35 - 50	13.5	12.2		149		PD x Mo lambs	Sorghum based diets, ME estimated ?, wheaten hay ad lib @ 6 ME & 7.44% CP	Bowen et al. 2006
23 - 40	10.7	10	5.6	148		Awassi	Graph data	Haddad *et al.* 2001

LW (Kgs)	ME[1]	Protein (%)	FCR	Growth rate[2]	Period (days)	Breed	Comment	Author
	10.3	15.7		146		10 mo PD x Mo	Grain / hay	Ryan & McIntyre 2006
	10.1	18.3		145		2nd cross	Lucerne silage	Kaiser *et al.* 2000
				144		Merinos & XB's	Loose mix (TMR)	McIntyre & Ryan 2005
26	11.6	18.5	6.64	143	Day 35-160	Mo wether lambs - 26 kg @ 7mths	Indoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
20-35	12.2	15.1		143		Crossbred lambs	wheat, pelleted lucerne	Cotterill and Roberts 1979 cited in Kirby and Beretta 2004 p. 59
				142		Merinos & XB's	Ad lib hay / grain	McIntyre & Ryan 2005
			6	130-140		Merino lambs	Average prodn targets for feedlot finishing of lambs	Suiter 1990 cited in Kirby and Beretta 2004 p. 57
25 +	9.62	10		137	100	Kordish		Moghadam *et al.* 2000
	10.3	13.7		135		10 mo PD x Mo	TMR	Ryan & McIntyre 2006
26	10.41	11.7	6.59	130	Day 35-160	Mo wether lambs - 26 kg @ 7mths	Indoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
			7	130		Merino lambs	After 2-3 weeks adaptation to feedlot conditions; Average prodn targets for feedlot finishing of lambs	Hack *et al.* 1997 cited in Kirby and Beretta 2004 p. 57
				130		2nd cross	Oaten silage + 74% barley, 26% lupins	Kaiser *et al.* 2000
26	10.41	11.7	6.88	128	Day 35-160	Mo wether lambs - 26 kg @ 7mths	Outdoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
26	11.6	18.5	4.44	127	Day 0-34	Mo wether lambs - 26 kg @ 7mths	Indoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
26	11.43	9.7	5.6	125	Day 35-160	Mo wether lambs - 26 kg @ 7mths	Outdoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
34.5 - 41.4	9.41	13.2	10.4	124		Naeini		Foroozandeh *et al.* 2001
26	11.43	9.7	7.27	113	Day 35-160	Mo wether lambs - 26 kg @ 7mths	Indoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
	10.3	15.4		108		Fine wool Merinos UNE	UNE imprinting study; Pellets ground	Savage *et al.* no date as yet
	10.3	15.4		107		Fine wool weaner Merino lambs	UNE imprinting study; not imprinted at all	Savage *et al.* no date as yet

LW (Kgs)	ME[1]	Protein (%)	FCR	Growth rate[2]	Period (days)	Breed	Comment	Author
	10.3	15.4		105		Fine wool Merinos UNE	UNE imprinting study; Pellets trough	Savage *et al.* no date as yet
15 - 40		'Low' CP	10 - 12	100		BL x Mo	Preconditioned to ration	Tomes & Dymond (1976)
20-35	11.8	16		100		Crossbred lambs	barley, fishmeal, straw; average growth rate during 6 week period from 23-27 kg	Ikin and pearce 1978 cited in Kirby and Beretta 2004 p. 59
24	N/A	9.12	7.43	99		BL x Mo	Preconditioned to ration	Tomes & Dymond (1976)
34.5 - 41.4	8.37	11.7	14.3	74		Naeini		Foroozandeh *et al.* 2001
26	11.6	18.5	11.3	47	Day 0-34	Mo wether lambs - 26 kg @ 7mths	Outdoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
26	10.41	11.7	15.5	35	Day 0-34	Mo wether lambs - 26 kg @ 7mths	Outdoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
	9.5	14.8		3		2nd cross	Oaten silage	Kaiser *et al.* 2000
35	8.62	14.2	↑	↑		Awassi		Gorgulu Ozturkcan 1992
35	9.41	18.4	↑	↑		Awassi		Gorgulu Ozturkcan 1992
35	10.37	18.4?	↑	↑		Awassi		Gorgulu Ozturkcan 1992
26	10.41	11.7	31.8	-16	Day 0-34	Mo wether lambs - 26 kg @ 7mths	Indoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
26	11.43	9.7	12	-39	Day 0-34	Mo wether lambs - 26 kg @ 7mths	Indoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
26	11.43	9.7	9.74	-51	Day 0-34	Mo wether lambs - 26 kg @ 7mths	Outdoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
	N/A	N/A	10.58			Crossbred lambs	Ad lib hay / grain; FCR incl wastage	McIntyre & Ryan 2005
	11	15	10.82			Crossbred lambs	Loose mix (TMR); FCR incl wastage	McIntyre & Ryan 2005
	11	15	11.7			Crossbred lambs	Pellet; FCR incl wastage	McIntyre & Ryan 2005
	N/A	N/A	13.34			Mo lambs	Ad lib hay / grain; FCR incl wastage	McIntyre & Ryan 2005
	11	15	13.88			Mo lambs	Pellet; FCR incl wastage	McIntyre & Ryan 2005
	11	15	13.95			Mo lambs	Loose mix (TMR); FCR incl wastage	McIntyre & Ryan 2005

[1] ME (MJ / kg DM); [2] Growth rate (grams / head / day)

Appendix 2 Summary of feeding trials reviewed, listed by author

LW (Kgs)	ME[1]	Protein (%)	FCR	Growth rate[2]	Period (days)	Breed	Comment	Author
35	11.3	19.31	5.3	200		BLxMo		Ahmad & Davies 1986
35	7.5	18.93	7.8	151		BLxMo		Ahmad & Davies 1986
23	10.58		4.4	278		Konya Merino		Aktas *et al.* 2001
23	11.5		4.33	296		Konya Merino		Aktas *et al.* 2001
23	12.42		4.58	299		Konya Merino		Aktas *et al.* 2001
		14.6		368		95% conc Romanov's		Beauchemin *et al.* 1995
			8-5	150-300			Average prodn targets for feedlot finishing of lambs	Bell *et al.* 1998 cited in Kirby and Beretta 2004 p. 57
40			6.5	250			Average prodn targets for feedlot finishing of lambs	Bell *et al.* 2003 cited in Kirby and Beretta 2004 p. 57
30-50			10-5	200-320			Average prodn targets for feedlot finishing of lambs	Bell *et al.* 2003 cited in Kirby and Beretta 2004 p. 57
35 - 50	13.5	12.2		149		PD x Mo lambs	Sorghum based diets, ME estimated ?, wheaten hay ad lib @ 6 ME & 7.44% CP	Bowen et al. 2006
35 - 50	13.5	16.6		170		PD x Mo lambs	Sorghum based diets, ME estimated ?, wheaten hay ad lib @ 6 ME & 7.44% CP	Bowen et al. 2006
35 - 50	13.5	18		187		PD x Mo lambs	Sorghum based diets, ME estimated ?, wheaten hay ad lib @ 6 ME & 7.44% CP	Bowen et al. 2006
35 - 50	13.5	15.4		190		PD x Mo lambs	Sorghum based diets, ME estimated ?, wheaten hay ad lib @ 6 ME & 7.44% CP	Bowen et al. 2006
35 - 50	13.5	17.4		190		PD x Mo lambs	Sorghum based diets, ME estimated ?, wheaten hay ad lib @ 6 ME & 7.44% CP	Bowen et al. 2006
35 - 50	13.5	17.1		172		PD x Mo lambs	Sorghum based diets, ME estimated ?, wheaten hay ad lib @ 6 ME & 7.44% CP	Bowen et al. 2006

LW (Kgs)	ME[1]	Protein (%)	FCR	Growth rate[2]	Period (days)	Breed	Comment	Author
20-35	12.2	15.1		143		Crossbred lambs	wheat, pelleted lucerne	Cotterill and Roberts 1979 cited in Kirby and Beretta 2004 p. 59
38.9-45.2	10.8	16%	6.1	286	22	Merino	Pellets (pen trial)	Davidson *et al.* 2000
40.5-47.9	10.8	16%	6	336	22	BL x Mo	Pellets (pen trial)	Davidson *et al.* 2000
41.9-48.4	10.8	16%	6.4	295	22	EF x Mo	Pellets (pen trial)	Davidson *et al.* 2000
40.5-48.4	10.8	16%	5.4	359	22	SAMM x Mo	Pellets (pen trial)	Davidson *et al.* 2000
42.4-48.4	10.8	16%	6.1	318	22	PD x Mo	Pellets (pen trial)	Davidson *et al.* 2000
20-35	12.3	17.2	4.5	240		Crossbred lambs	wheat, lucerne hay, meat meal	Davis *et al.* 1976 cited in Kirby and Beretta 2004 p. 59
to 45		16%	3.1	335			Pelleted diet; Early weaned to 45kg LW	Flanagan 1999
to 45		16%	3.2	332			Loose mix; Early weaned to 45kg LW	Flanagan 1999
to 45		16%	3.7	325			Pelleted diet; Early weaned to 45kg LW	Flanagan 1999
to 45		16%	3.3	291			Loose mix; Early weaned to 45kg LW	Flanagan 1999
34.5 - 41.4	8.37	11.7	14.3	74		Naeini		Foroozandeh *et al.* 2001
34.5 - 41.4	9.41	13.2	10.4	124		Naeini		Foroozandeh *et al.* 2001
34.5 - 41.4	10.46	14.7	8.3	162		Naeini		Foroozandeh *et al.* 2001
			6.69	368			Pellets; Choice: H/L	Francis 2002 PhD thesis
	10.1	18.5	10.6	186			Pellets; High degradability	Francis 2002 PhD thesis
	9.8	19	6.17	232			Pellets; Med degradability	Francis 2002 PhD thesis
	9.4	18.5	7.09	352			Pellets; Low degradability	Francis 2002 PhD thesis
			6.19	348			Pellets; Choice: H/M	Francis 2002 PhD thesis
			6.4	395			Pellets; Choice: M/L	Francis 2002 PhD thesis
	13.3	N/A	2.84	409			Early weaned male lambs; whole barley	Fraser & Orskov 1974
	12.7	N/A	3.1	360			Early weaned male lambs; rolled barley pellets	Fraser & Orskov 1974
	13.4	N/A	3.55	260			Early weaned female lambs; rolled barley pellets	Fraser & Orskov 1974
	13.09	N/A	3.55	270			Early weaned female lambs; whole barley pellets	Fraser & Orskov 1974

LW (Kgs)	ME[1]	Protein (%)	FCR	Growth rate[2]	Period (days)	Breed	Comment	Author
	13.44	N/A	3.33	264			Early weaned female lambs; unprocessed barley	Fraser & Orskov 1974
	10.8	17.4%	8.7	160		Merino		Gardner *et al.* 1999
		9		266	84	Suffolk wether lambs		Gentry *et al.* 1999
		12.1		257	84	Suffolk wether lambs		Gentry *et al.* 1999
		12.8		276	84	Suffolk wether lambs	Added Cr	Gentry *et al.* 1999
		14.4		250	84	Suffolk wether lambs	Added Cr	Gentry *et al.* 1999
35	8.62	14.2	↑	↑		Awassi		Gorgulu Ozturkcan 1992
35	9.41	18.4	↑	↑		Awassi		Gorgulu Ozturkcan 1992
35	10.37	18.4?	↑	↑		Awassi		Gorgulu Ozturkcan 1992
			7	130		Merino lambs	After 2-3 weeks adaptation to feedlot conditions; Average prodn targets for feedlot finishing of lambs	Hack *et al.* 1997 cited in Kirby and Beretta 2004 p. 57
			6	200		Crossbred lambs	After 2-3 weeks adaptation to feedlot conditions; Average prodn targets for feedlot finishing of lambs	Hack *et al.* 1997 cited in Kirby and Beretta 2004 p. 57
23 - 40	10.7	10	5.6	148		Awassi	Graph data	Haddad *et al.* 2001
23 - 40	10.7	12	4.5	227		Awassi	Graph data	Haddad *et al.* 2001
23 - 40	10.7	14	4.6	223		Awassi	Graph data	Haddad *et al.* 2001
23 - 40	**10.7**	**16**	**4.4**	**287**		Awassi	Graph data	Haddad *et al.* 2001
23 - 40	10.7	18	4.6	259		Awassi	Graph data	Haddad *et al.* 2001
	11.8	15		349	43	PDBM, 6 months	Lot fed	Hopkins *et al.* 1996
	11.8	15		301	43	TBM, 6 months	Lot fed	Hopkins *et al.* 1996
	11.8	15		278	43	PDM, cryptorchids	Lot fed	Hopkins *et al.* 1996
	11.8	15		256	43	TM	Lot fed	Hopkins *et al.* 1996
20-35	11.8	16		100		Crossbred lambs	barley, fishmeal, straw; average growth rate during 6 week period from 23-27 kg	Ikin and Pearce 1978 cited in Kirby and Beretta 2004 p. 59

LW (Kgs)	ME[1]	Protein (%)	FCR	Growth rate[2]	Period (days)	Breed	Comment	Author
	10.1	18.3		145		2nd cross	Lucerne silage	Kaiser *et al.* 2000
	9.5	14.8		3		2nd cross	Oaten silage	Kaiser *et al.* 2000
				204		2nd cross	Lucerne silage + 74% barley, 26% lupins	Kaiser *et al.* 2000
				130		2nd cross	Oaten silage + 74% barley, 26% lupins	Kaiser *et al.* 2000
26.7	13	13.9	4.56	281		Targhee	1983	McClure *et al.* 1994
23	13	13.9	4.22	237		Suffolk composite	1984	McClure *et al.* 1994
22.7	13	13.9	4.85	253		Targhee	1985	McClure *et al.* 1994
20-35	11.2	18.5	4.2	162		Merino lambs	oats, oaten chaff, lupins	McDonald and Suiter 1982 cited in Kirby and Beretta 2004 p. 59
	N/A	N/A	10.58			Crossbred lambs	Ad lib hay / grain; FCR incl wastage	McIntyre & Ryan 2005
	11	15	10.82			Crossbred lambs	Loose mix (TMR); FCR incl wastage	McIntyre & Ryan 2005
	11	15	11.7			Crossbred lambs	Pellet; FCR incl wastage	McIntyre & Ryan 2005
	N/A	N/A	13.34			Mo lambs	Ad lib hay / grain; FCR incl wastage	McIntyre & Ryan 2005
	11	15	13.88			Mo lambs	Pellet; FCR incl wastage	McIntyre & Ryan 2005
	11	15	13.95			Mo lambs	Loose mix (TMR); FCR incl wastage	McIntyre & Ryan 2005
				159		Merinos & XB's	Pellet	McIntyre & Ryan 2005
				144		Merinos & XB's	Loose mix (TMR)	McIntyre & Ryan 2005
				142		Merinos & XB's	Ad lib hay / grain	McIntyre & Ryan 2005
			7-5.5	250-350		Crossbred lambs	Average prodn targets for feedlot finishing of lambs	Milton 2001 cited in Kirby and Beretta 2004 p. 57
			7.5-6	220-320		Merino lambs	Average prodn targets for feedlot finishing of lambs	Milton 2001 cited in Kirby and Beretta 2004 p. 57
25 +	9.62	10		137	100	Kordish		Moghadam *et al.* 2000
25 +	10.46	12.5		166	100	Kordish		Moghadam *et al.* 2000
25 +	11.29	15		169	100	Kordish		Moghadam *et al.* 2000
		14.4		275		100% conc Awassi		Mulwala *et al.* 1994
			8.6 : 1	185			Range:2.8 – 73.8	Linden 2006 Rutherglen trial
Fed to 50 kg	13.5	15.1	4.06	381		¼ Finn		Notter *et al.* 1991
Fed to 50 kg	13.5	15.1	4.82	351		Rambouillet Suffolk		Notter *et al.* 1991

LW (Kgs)	ME[1]	Protein (%)	FCR	Growth rate[2]	Period (days)	Breed	Comment	Author
30 - 55	N/A	11		191			Early weaned male lambs	Orskov *et al.* (1971)
30 - 55	N/A	15.7		270			Early weaned male lambs	Orskov *et al.* (1971)
30 - 55	N/A	19.4	highest	330			Early weaned male lambs	Orskov *et al.* (1971)
30 - 55	N/A	11		177			Early weaned female lambs	Orskov *et al.* (1971)
30 - 55	N/A	15.7		225			Early weaned female lambs	Orskov *et al.* (1971)
30 - 55	N/A	19.4	highest	301			Early weaned female lambs	Orskov *et al.* (1971)
	n/a		3.13 - 3.9	277 - 326	25, 33 or 41		Early weaned	Orskov, Fraser & Gill (1973)
20-35	12.6	19.5	5.4	205		Merino lambs	triticale, pasture hay, lupins	Roberts *et al.* 1984 cited in Kirby and Beretta 2004 p. 59
20-35	11.4	16.9	6.2	171		Merino lambs	oats, pasture hay, lupins	Roberts *et al.* 1984 cited in Kirby and Beretta 2004 p. 59
18 - 31	10.99	16	4.75	220		Santa Ines ram lambs (haired)	80% barley; 20% sugarcane bagasse	Rocha *et al.* 2004
18 - 31	10.99	14	4.65	228		Santa Ines ram lambs (haired)	80% barley; 20% sugarcane bagasse	Rocha *et al.* 2004
18 - 31	10.99	18	4.83	230		Santa Ines ram lambs (haired)	80% barley; 20% sugarcane bagasse	Rocha *et al.* 2004
18 - 31	10.99	20	4.93	231		Santa Ines ram lambs (haired)	80% barley; 20% sugarcane bagasse	Rocha *et al.* 2004
	10.3	13.7		135		10 mo PD x Mo	TMR	Ryan & McIntyre 2006
	11.3	16.3		197		10 mo PD x Mo	virginiamycin	Ryan & McIntyre 2006
	10.6	18.9		235		10 mo PD x Mo	Grain / hay	Ryan & McIntyre 2006
	10.7	19		156		10 mo PD x Mo	Grain / hay	Ryan & McIntyre 2006
	10.3	15.7		146		10 mo PD x Mo	Grain / hay	Ryan & McIntyre 2006
	11.3	16.3		175		10 mo PD x Mo	Finisher pellet	Ryan & McIntyre 2006
	11.3	16.3		170		10 mo PD x Mo	TMR	Ryan & McIntyre 2006
	11.3	16.3		189		10 mo PD x Mo	virginiamycin	Ryan & McIntyre 2006
	11.3	16.3		182		10 mo PD x Mo	Grain / hay	Ryan & McIntyre 2006
	11.3	16.3		170		10 mo PD x Mo	Grain / hay	Ryan & McIntyre 2006
	11.3	16.3		162		10 mo PD x Mo	Grain / hay	Ryan & McIntyre 2006
	10.2	11.5		286		10 mo PD x Mo	**Intro** pellet	Ryan & McIntyre 2006 CRC

LW (Kgs)	ME[1]	Protein (%)	FCR	Growth rate[2]	Period (days)	Breed	Comment	Author
	10.3	15.4		107		Fine wool weaner Merino lambs	UNE imprinting study; not imprinted at all	Savage *et al.* no date as yet
	10.3	15.4		108		Fine wool Merinos UNE	UNE imprinting study; Pellets ground	Savage *et al.* no date as yet
	10.3	15.4		105		Fine wool Merinos UNE	UNE imprinting study; Pellets trough	Savage *et al.* no date as yet
			7-5	250-300		Crossbred lambs	Average prodn targets for feedlot finishing of lambs	Seymour 2000 cited in Kirby and Beretta 2004 p. 57
			8-6	150-250		Merino lambs	Average prodn targets for feedlot finishing of lambs	Seymour 2000 cited in Kirby and Beretta 2004 p. 57
26	11.6	18.5	11.3	47	Day 0-34	Mo wether lambs - 26 kg @ 7mths	Outdoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
26	11.6	18.5	5.85	168	Day 35-160	Mo wether lambs - 26 kg @ 7mths	Outdoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
26	10.41	11.7	15.5	35	Day 0-34	Mo wether lambs - 26 kg @ 7mths	Outdoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
26	10.41	11.7	6.88	128	Day 35-160	Mo wether lambs - 26 kg @ 7mths	Outdoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
26	11.43	9.7	9.74	-51	Day 0-34	Mo wether lambs - 26 kg @ 7mths	Outdoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
26	11.43	9.7	5.6	125	Day 35-160	Mo wether lambs - 26 kg @ 7mths	Outdoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
26	11.6	18.5	4.44	127	Day 0-34	Mo wether lmb-26kg @ 7mths	Indoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
26	11.6	18.5	6.64	143	Day 35-160	Mo wether lambs - 26 kg @ 7mths	Indoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
26	10.41	11.7	31.8	-16	Day 0-34	Mo wether lambs - 26 kg @ 7mths	Indoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
26	10.41	11.7	6.59	130	Day 35-160	Mo wether lambs - 26 kg @ 7mths	Indoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
26	11.43	9.7	12	-39	Day 0-34	Mo wether lambs - 26 kg @ 7mths	Indoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987

LW (Kgs)	ME[1]	Protein (%)	FCR	Growth rate[2]	Period (days)	Breed	Comment	Author
26	11.43	9.7	7.27	113	Day 35-160	Mo wether lambs - 26 kg @ 7mths	Indoor feedlot; oats, lupins & roughage	Suiter & McDonald 1987
			5	140-160		Crossbred lambs	Average prodn targets for feedlot finishing of lambs	Suiter 1990 cited in Kirby and Beretta 2004 p. 57
			6	130-140		Merino lambs	Average prodn targets for feedlot finishing of lambs	Suiter 1990 cited in Kirby and Beretta 2004 p. 57
15 - 40		'Low' CP	10 - 12	100		BL x Mo	Preconditioned to ration	Tomes & Dymond (1976)
24	N/A	9.12	7.43	99		BL x Mo	Preconditioned to ration	Tomes & Dymond (1976)
24	N/A	13 (urea)	6.69	157		BL x Mo	Preconditioned to ration	Tomes & Dymond (1976)
24	N/A	16 (urea)	6.26	153		BL x Mo	Preconditioned to ration	Tomes & Dymond (1976)
24	N/A	16 (lup)	4.05	242		BL x Mo	Preconditioned to ration	Tomes & Dymond (1976)
24	N/A	13 (lup)	3.54	243		BL x Mo	Preconditioned to ration	Tomes & Dymond (1976)
20-35	11.4	14.7	3.5	243		Crossbred lambs	barley, oaten straw, lupins	Tomes & Dymond 1976 cited in Kirby and Beretta 2004 p. 59
20-35	11.9	18.9	4	242		Crossbred lambs	barley, oaten straw, lupins	Tomes & Dymond 1976 cited in Kirby and Beretta 2004 p. 59
	10.5	14.4	6.2	272			Feedlot, pellets	Wiese *et al.* 2000
	10.5	14.4	7	220			Feedlot, pellets	Wiese *et al.* 2000
	10.5	14.4	6.8	242			Feedlot, pellets	Wiese *et al.* 2000
	10.5	14.4	11.8	180			Feedlot, pellets	Wiese *et al.* 2003
	10.6	14.3	7.1	233			Feedlot, pellets	Wiese *et al.* 2003
	10.5	14.4	6.2	272			Feedlot, pellets	Wiese *et al.* 2003
	11	15	5.1	296			Feedlot, pellets	Wiese *et al.* 2003
	11	15%	6.1	243		Merino		Wiese *et al.* 2003
30	10.87	20	7.48	172	57	3rd cross Texel Corriedale		Zundt *et al.* 2002
30	10.87	16	8.13	154	57	3rd cross Texel Corriedale		Zundt *et al.* 2002
30	10.87	12	8.18	154	57	3rd cross Texel Corriedale		Zundt *et al.* 2002
30	10.87	24	7.55	168	57	3rd cross Texel Corriedale		Zundt *et al.* 2002

[1] ME (MJ / kg DM); [2] Growth rate (grams / head / day)

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