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Chapter 1. The sheep meat industry - B.L. McIntyre, P.J. Holst and R.M. Kirby

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Chapter 7. Adaptation to grain feeding - R.M. Kirby, F.M. Jones, D.M. Ferguson and A.O. Fisher

Appendix - Feeding sheep for finishing questionnaire - R.J. Bryant and R.M. Kirby

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AUSTRALIAN SHEEP INDUSTRY
COOPERATIVE RESEARCH CENTRE

FEEDING GRAIN FOR SHEEP MEAT PRODUCTION

2004

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Feeding grain for sheep meat production

Chapter 1. The sheep meat industry

B.L. McIntyre, P.J. Holst and R.M. Kirby

CHAPTER 1. THE SHEEP MEAT INDUSTRY

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Introduction

Grain is used in a variety of lamb finishing systems ranging from intensive indoor feedlots, where it is the main source of nutrition, to supplementation in paddocks where it may be targeting specific deficiencies in the lamb's diet, for example lambs on cereal stubbles may be supplemented with lupin grain to provide protein. The level of inputs and outputs vary depending on the intensity of the enterprise. The existence of a wide range of systems throughout the sheep meat industry demonstrates that many different finishing systems are perceived to be profitable. Profitability is dependent on the costs and efficiencies associated with production. Costs change depending on the economic environment but if the biological parameters have been established, an economic environment can be overlaid to predict the profitability. This review discusses the current specifications and requirements of the sheep meat industry and assesses the biological performance of lambs and sheep that are grown for slaughter using grain feeding systems.

Development of the sheep meat industry

Australia is one of the world's major producers of sheep meat contributing around 10 per cent of the world's total lamb and mutton production. In 2000, over 16.3 million sheep (mutton) and 18.4 million lambs (lamb) were slaughtered for a total sheep meat production of 710,000 tonnes carcase weight (ABARE 2001a). The production of 365,000 tonnes of lamb was slightly higher than the 345,000 tonnes of mutton. The major market for lamb is the domestic market which in the year 2000 consumed about 65 per cent of all production. In comparison with this, almost 70 per cent of mutton produced was exported (MLA 2003). Meat and Livestock Australia (MLA) reported that lamb consumption in Australia in 2001 was 11.7 kg/head and mutton 5.3 kg/head (MLA 2003).

Lamb production has increased markedly since 1980 to current levels (Figure 1.1). This additional product has been mainly destined for export, domestic consumption of lamb having remained relatively constant over the period. The proportion of lamb exported has risen from around 15 per cent in 1980 to over 30 per cent in 2000 (ABARE 2001a).

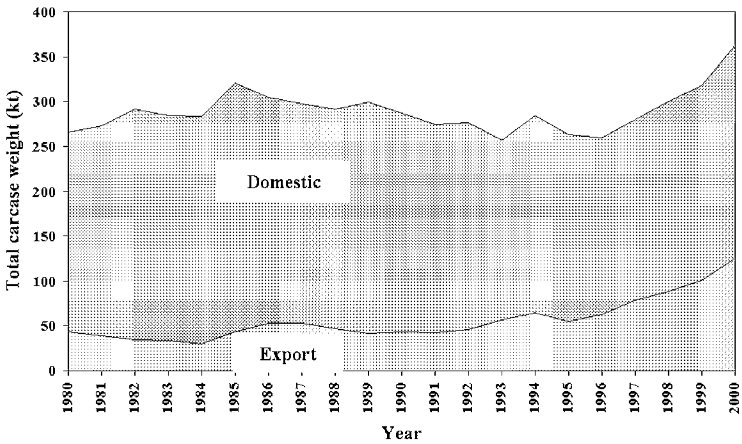

Figure 1.1. Domestic and export consumption of Australian lamb from 1980 to 2000 (ABARE 2001a).

The Australian lamb industry has undergone major changes particularly in the last 10 years. During this time the profitability of wool declined and as a result, more emphasis was placed on meat production. Changes in the lamb industry have been largely driven by consumers, particularly in the market for lambs. Consumers have become more demanding in terms of their requirements for a more consistent high quality product, especially one that is lower in fat content. This demand was recognised in the early 1990s when a coordinated national program was devised in response to the decline in domestic consumption of sheep meat and to stimulate exports (Thatcher 1992). This was known as the 'Elite Lamb Program' and was based on the production of heavier, leaner lambs. The Elite Lamb Program initially set specifications of 18-26 kg carcase weight and fat score 2-3 but with development, efforts concentrated on weights above 22 kg and GR fat measurement[1] 6-15 mm (McLaughlin 1992).

Current specifications and requirements

The Elite Lamb specifications for larger, leaner lambs represented a major advance in directing production requirements that better matched consumer expectation. Today's markets also demand the continuous availability of a product that is of consistently high eating quality.

Large, lean lambs

Specifications for carcase weight and fatness may differ from place to place and from time to time within the domestic market and also between different export markets. Davis (2003) has categorised the market specifications for lamb in Victoria and these are summarised in Figure 1.2.

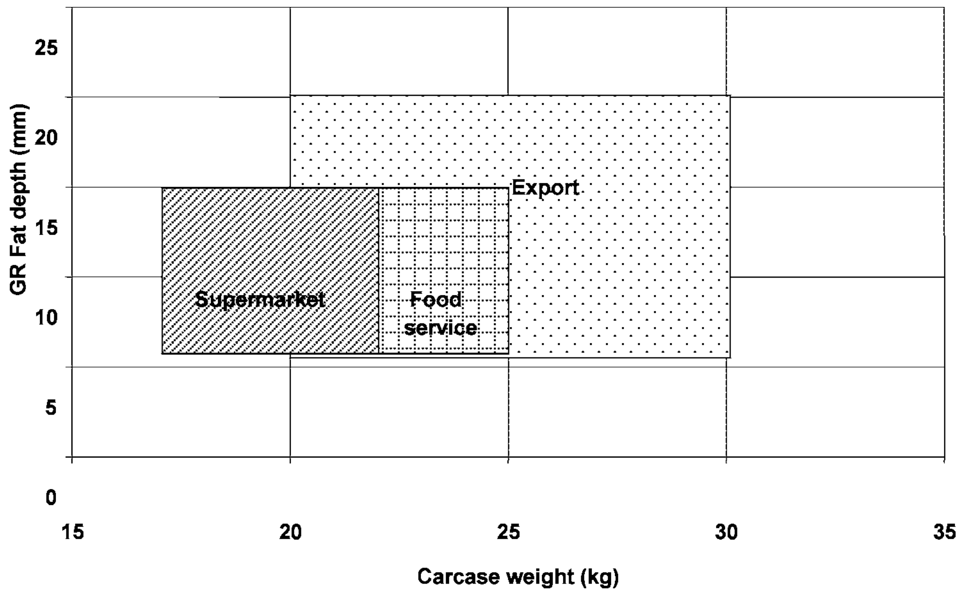

Figure 1.2. Typical market specifications for lamb.

[1] Fat scores refer to the soft tissue depth at the GR site which is at the 12th rib and 110 mm laterally from the spinous processes of the vertebral column over the epaxial musculature [Nugent, T. (2002). 'Practice makes perfect in fat scoring lambs'. *Farming Ahead*, No. 100, pp. 50-51.].

Carcase weight

Hall *et al.* (2000) noted an increase in the average carcase weight of Australian lamb from 17.5 to 19.5 kg between 1990 and 1999, while Shands *et al.* (2002) reported that the average weight of lamb carcases increased by 3 kg between 1990 and 2002. Australian Bureau of Agricultural and Resource Economics (ABARE) statistics indicate that while the average weight of lamb carcases has increased from 16.6 kg in 1980 to 19.9 kg in 2000, the rate of increase has accelerated with over half the increase taking place since 1995 when the average was 17.9 kg (ABARE 2001a). It appears that the trend towards increasing carcase weight is gathering pace.

Fatness

As well as a demand for heavier carcases there has also been a demand for leaner carcases. Price grids used as the basis for trading generally reflect the demand for leaner carcases with highest prices being paid for carcases in the fat score 2-3 range or 6-15 mm GR tissue depth measurement. Hall *et al.* (2000) observed that despite an increase in carcase weight there had been a simultaneous reduction in fat levels in the order of 10-20 per cent. This has created a need to change production systems as the easy solution to provide heavier carcases is to feed animals for longer periods to achieve extra weight targets. However this would result in increasing fatness which is contrary to market demands. White *et al.* (2002) studied relationships between carcase weight and fat depth (GR) measurement in a domestic abattoir in alliance and industry lambs. They found that there was an increase in fat depth of 1 mm for every kilogram increase in carcase weight. At any given carcase weight the alliance lambs were about 2 mm fatter than the industry lambs, which they attributed to differences in genotype and production system. These workers also noted some variation in the fatness at different times of the year after adjusting to equal weight. These variations were attributed to factors such as time of lambing and seasonal pasture growth patterns.

Other carcase specifications

While carcase weight and fatness are the main criteria for determining suitability of lamb for different markets there are others that may be more or less important. Hopkins (1995) attempted to determine the impact of carcase characteristics on retail value by studying assessments made by wholesalers and retailers of carcases with a range in carcase weight, fatness, conformation and fat distribution. There were clear indications that characteristics other than weight and fatness influenced the assessment of value. Meat colour was used although its relative importance varied between assessors. Conformation was a consistent factor considered and when carcases were subjectively valued there was a clear preference for carcases with hind legs that had a muscular 'U' shape rather than an angular 'V' shape. This accords with some industry practices that carcases are graded or visually assessed for quality even if they do meet specifications for weight and fatness.

Meeting weight and fatness specifications

Pirlot *et al.* (1992) did a study in Tasmania in the early stages of the Elite Lamb Program (November 1989-October 1990) of the number of carcases that would meet specifications of 22-26 kg and fat score 2-3. Of the 108,028 lamb carcases that were included in the survey, only 626 met the Elite Lamb specifications (< 0.5%) and only 5095 (4.7%) were within the weight range. Pirlot *et al.* (1992) noted a tendency for heavier carcases to be over-fat and suggested strategies such as producing induced cryptorchids at lamb marking (short scrotum ram lambs). They also suggested a move toward direct sales, because the saleyard system appeared to favour fatter lambs.

In order to comply with the requirement for heavier carcase weight and lower fatness, industry has made use of the LAMBPLAN breeding system to identify genetic material that can more closely match the specifications of the market (Banks 2000). LAMBPLAN allows selection of animals with more desirable traits for growth rate, fat depth and eye muscle depth. This enables shifting of weights to higher levels while restricting and even reducing fatness levels. Another way of achieving this shift is by using crossbreeds with later maturing characteristics (sheep which fatten at heavier weights).

Hall and Holst (1992) suggested the use of breeds differing in their fattening characteristics, variation in type within breed as well as manipulation of sex differences to increase the proportion of lambs that met specifications. They reported the results of an experiment in southern New South Wales which showed that the proportion of lambs meeting Elite Lamb specifications varied according to sire and sex. They found that while only 6 per cent of lambs from ewes sired by rams with a relatively poor lean growth LAMBPLAN index met specifications, 64 per cent of cryptorchids from ewes sired by rams with a relatively high index for lean growth met specifications.

Because factors such as variation in birth date and growth rate increase the difficulty of producing even lines of lambs that meet specifications, Ferrier *et al.* (1995) recognised the desirability of an ability to manipulate composition by nutritional means and studied the effects of a variety of growth paths. These authors, along with Hall *et al.* (2001) found that carcase fatness could be reduced by restricting the rate of growth.

Producers wishing to change from their traditional pasture-based system and target heavyweight lambs may need to adopt grain supplementation systems or finishing strategies. In this situation, the pasture may not sustain adequate growth for the time required to achieve heavier target weights. For example, Moore *et al.* (1993) modelled the forage required for producing large, lean lambs at several different sites in New South Wales and Victoria over a period of years. At all sites, grain supplementation was needed in most years. In New South Wales at Cowra, there was a 50 per cent probability of a suitable season for producing heavy lambs, and supplementation would be necessary in other years; whilst Glen Innes was more reliable at 75 per cent probability, but grain supplementation at lambing would always be needed.

Grain finishing has emerged as one tool that can be used to meet the nutritional needs of growing lambs when pasture declines in quality and quantity at the end of the growing season. The most extreme shortfall of pasture occurs in poor seasons or drought and in these situations there is a rise in the prevalence of opportunistic feedlotting. Opportunistic feedlotting also occurs when terms of trade are favourable.

Meat quality

Tenderness and flavour

Consumers now expect lamb-eating qualities such as tenderness and flavour to be of a high standard and that these standards will be consistent throughout the year. A survey conducted in Victoria and reported by Hall *et al.* (2000), highlighted the variability in tenderness as measured by shear force, an objective measure of the energy required to shear a standard-sized sample of meat. In response to the demands for greater eating quality, a major program has been developed along similar lines to the Meat Standards Australia program for beef, to investigate factors affecting eating quality and to implement a system that will guarantee eating characteristics. Good eating quality has been related to plane of nutrition in finishing lambs (Pethick *et al.* 2000).

Meat colour

Another aspect of quality relates to the visual appeal of the meat and in particular, meat colour. Unappealing meat colour or dark, firm and dry (DFD) meat has been shown to be a significant problem in lamb. The condition is closely linked to muscle glycogen levels at the time of slaughter. Low glycogen levels in meat result in meat with high pH (above 5.7) and a dark, firm and dry (DFD) appearance that is rejected by consumers. DFD also presents problems in cooking and shelf life. The incidence of DFD in lambs processed by a leading Western Australian processor was estimated at around 30 per cent (D.W. Pethick 2003, pers. comm.). Pethick also carried out two studies in which pH was measured in the semimembranosus and semitendinosus muscle of lambs. He reported that 29 per cent of carcases had pH levels above 5.7 in the semimembranosus muscle and 87 per cent in the semitendinosus muscle in one study and 45 per cent and 82 per cent respectively in a second study (D.W. Pethick 2003, pers. comm.). In a retail audit of lamb sold in Sydney, Canberra, Melbourne and Perth, Safari *et al*. (2002) found that 10.3 per cent had a pH above 5.8.

The effects of nutrition were studied by Pethick and Rowe (1996) who fed sheep on 4 levels of intake of a pelleted ration estimated to result in growth rates of 0, 50, 100 and 200 g/day. Muscle glycogen levels measured in the semimembranosus and the semitendinosus muscles by biopsy and following slaughter showed that a significant and linear increase in glycogen levels occurred with increased feed intake. This study highlighted the importance of good nutrition prior to slaughter as a strategy to minimise the occurrence of DFD meat. Short-term grain finishing is one method that producers have adopted to ensure forward growth rate is maintained to maximise glycogen levels in muscle prior to slaughter. While this management strategy has become popular, recent work has shown that eating quality of pasture-finished lambs is equivalent to grain-finished lambs when an adequate growth rate can be maintained (Pethick *et al.* 2002). Grain finishing aimed at optimising meat quality is therefore most relevant at times of the year when pasture or alternative feed sources are not adequate to maintain lamb growth.

Consistent supply

The lamb meat industry requires a consistent, year-round supply of lambs for high value domestic and export markets and to make efficient use of processing facilities. Traditional lamb production systems rely on turnoff of suckers at the end of the growing season so that there is a short period of abundant supply followed by long periods without a supply. This is particularly the case in areas like Western Australia where there is a very seasonal pasture production pattern. The extension of the supply of lambs has been made possible through the use of a greater spread of lambing times and the use of an increasing variety of production systems. While most lambs are finished on pasture, a range of other systems have been developed based on fodder crops, use of feed budgeting and supplementary feeding. Lot feeding has been a further development that enables the supply of lambs to be maintained independently of pasture availability. It is an important management strategy for finishing lambs during the annual autumn feed gap through to early winter in Mediterranean environments such as Western Australia.

Marketing systems

A number of selling systems are available for sheep meat ranging from 'over-the-hooks' sales where price is based on carcase weight and fat specifications, to paddock sales based on price per head. It is generally accepted that over-the-hooks sales are favoured where it is important that carcases meet relatively tight specifications as is increasingly the case with today's lamb markets. Premium prices are paid when the carcase meets specifications and discounts applied to carcases that do not meet specifications. This system has the advantage of providing a guarantee of price where a producer is confident of meeting the specifications and removing the risk to the processor of paying too much for carcases that are of low value. Over-the-hooks or direct sales also provide a mechanism for feedback of carcase and price data that can be used by producers to indicate where improvements can be made in production systems. Despite the advantages of over-the-hooks marketing, a survey reported by ABARE (2001b) showed that auction sales were the dominant sale method for lambs in 1999-2000, accounting for 45 per cent of sales while over-the-hooks and paddock sales were the only other significant methods accounting for 33 per cent and 22 per cent respectively. In New South Wales, over-the-hooks marketing had increased to 40 per cent of sales but recent droughts have affected marketing decisions, reduced carcase weight specifications and tested the loyalty of alliance members to their processor.

The last 10 years have seen the emergence of a number of partnerships or alliances that have been developed in response to the need for a product that meets tight specifications, is consistently in supply and provides guaranteed returns. These alliances generally involve producers, processors and sometimes retailers and can be formal or informal. Formal alliances may have membership fees, a code of practice, well defined target carcase specifications and may brand their product to promote consumer recognition. There are now more than 20 branded lamb alliances throughout Australia and in 2001, more than 10 per cent of all lambs slaughtered were sold through an alliance (Hancock and Stephens 2002). An example is the 'Q Lamb' alliance in Western Australia, which started as a combination of producers and a lamb processor. In the initial stages only about 70 per cent of lambs were hitting weight and fat targets and other qualities were variable (Trefort 2002). However with use of feedback information and close consultation on development of production systems, the success rate has improved dramatically. The introduction of a retail partner and development of the Q Lamb brand appears to have guaranteed continued success of the venture. Similarly the 'Tender Plus' brand, located in northern New South Wales has benefited from the formation of an alliance. Tender Plus is a manufacturer of lamb, beef and smallgoods providing customised portions for the hotel and restaurant trade in Australia and Asia. Tender Plus needed to ensure continuous supply of suitable lamb to meet increased demand and began working with a New South Wales Agriculture Product Development Officer in 2000. An alliance was formed between producers and processor. From an initial kill of < 600 lambs weekly they are now forecasting a demand of 3000 weekly (P.J. Holst 2003, pers. comm.).

Role of grain feeding in sheep meat production

Grain finishing systems in the Australian prime lamb industry

In the 2002 ABARE survey of prime lamb producers, the majority identified pasture as their management strategy for finishing prime lambs for slaughter (Connell *et al.* 2002). The survey showed that 59 per cent of producers used pasture as their main method of finishing lambs, with a further 24 per cent indicating pasture with the use of supplements (Table 1.1). Only 3 per cent of producers nominated feedlotting as their main method of production.

Table 1.1. Main method of finishing lambs for slaughter, by State. Adapted from Connell *et al.* (2002).

State	Grain finishing			Non-grain finishing	
	Feedlotting	Pasture plus supplement	Fodder crops plus supplement	Pasture	Fodder crop
Western Australia	19%	29%	3%	49%	
New South Wales	2%	27%	15%	50%	7%
Victoria	1%	20%	5%	64%	9%
South Australia	1%	22%	4%	72%	1%
Queensland		9%		75%	16%
Tasmania		14%	14%	56%	16%
All States	**3%**	**24%**	**8%**	**59%**	**6%**

Feedlotting was most common in Western Australia, where 19 per cent of prime lamb producers identified it as their main finishing method (Table 1.1). One per cent of prime lamb producers in South Australia and Victoria and 2 per cent in New South Wales used feedlotting. There was no specialist feedlotting of lambs in Queensland or Tasmania.

Supplementation was identified as a key strategy for finishing prime lambs in both pasture and fodder-based systems (Table 1.1). The use of grain in paddock-based feeding systems is common in most States with a national average of approximately one third of producers using grain and pasture as their predominant method of finishing lambs.

Sheep meat enterprises

Sheep meat enterprises can be classified as:

1. a specialist crossbred prime lamb production system;
2. prime Merino lamb production that exists in conjunction with a wool enterprise; and
3. mature cull animals, predominantly Merino, that are slaughtered for mutton (Dowling and Wiese 2001).

In specialist prime lamb production systems, terminal sires are mated to Merino or Merino-cross ewes with the intention that all progeny will be sold as prime lambs. The focus of these enterprises is the production of meat. In contrast, there are many competing markets for sheep produced in a traditional Merino wool-based system. Sheep can be sold for slaughter as prime lambs, sold for live export as lambs or adult wethers, or retained for breeding and wool production and eventually sold into the mutton market when culled for age or other reasons. Clearly, the focus of Merino-based production systems is not always meat production therefore grain is more likely to be used in lower amounts for strategic supplementation and maintenance feeding.

In a specialist prime lamb production enterprise, the use of grain will depend on the availability of alternative feed resources and specific target market specifications of the enterprise. When cheaper feeds are available, grain is less likely to be used.

Finishing prime lambs

The majority of prime lambs in Australia are finished on pasture or fodder crops (Table 1.1). In areas with a suitably long growing season or in favourable seasons, good management of paddock feed will ensure a high quality, inexpensive source of feed. Grain is a more expensive feed source and while grain-based diets can promote higher growth rates and a better feed conversion ratio than pasture, the economics of various feed sources have to be considered (McClure *et al.* 1994; Notter *et al.* 1991; Pethick *et al.* 2002).

The comparative advantages of different finishing systems change with the economic and climatic environments. During the late 1970s and early 1980s, there was increased interest in intensive feedlots in Australia (Hall and Mulholland 1982). The interest diminished when producers and researchers concluded that there was no benefit from using intensive feeding systems due to problems with adaptation of sheep to the diet and confinement (Hall and Mulholland 1982; Mulholland 1986; Suiter and McDonald 1987). In addition, the profitability was often marginal. However, the consumer pressure placed on the industry for more consistent supply and quality has led to renewed interest in intensive grain feeding. The definition of 'feedlotting' has expanded to include not only intensive indoor or outdoor feedlots, but also finishing systems for animals confined to small paddocks with self-feeders. However, the continued operation of feedlots and other semi-intensive systems is only possible because of the price differentials generated by the demand for high quality consistent product in the marketplace.

Supplementing prime lambs with grain

The role of grain feeding in backgrounding[2] or growing strategies for prime lambs varies in different regions of Australia. In most cases only a portion of the lamb crop will need supplementation because the early-born, single lambs usually attain marketable weights within the forage growth season. Key influences determining the extent of supplementary grain use are the local climate and associated growing season, the availability of alternative feed resources and the availability of irrigation. Grain is used as a supplement in a wide variety of paddock-based feeding systems including stubbles, dry pastures and fodder crops. Grain is more expensive than the basal feed source in these feeding systems so strategic supplementation is used to achieve the growth rate required to reach the target market.

When supplements are offered to grazing animals, in principle the intake of basal feed can either stay the same (supplementation), increase (complementation) or decrease (substitution). Ideally, the intake of basal feed will remain the same so the full benefit of additional protein and energy supplied by the supplement can be realised, but in practice this rarely occurs. When feeding for production as opposed to maintenance, using increased quality and quantity of supplements, the substitution rate is likely to be greater (Dove 2002). The challenge in simple paddock-based grain feeding systems is to maximise the use of all feed resources by achieving complementation and/or minimising substitution.

Finishing older sheep

Mutton is a significant industry, representing around 50 per cent of the annual sheep meat production in Australia (Meat and Livestock Australia 2002). Sheep slaughtered for mutton are predominantly culled Merino animals sold either through saleyards, direct paddock sales or consignment to an abattoir (Dowling and Wiese 2001). The carcase requirements of the mutton industry can generally be met by extensive grazing systems but grain supplementation may be required to finish animals during seasonal feed gaps. Although intensive feeding does not result in economic feed conversion ratios, producers who have established a feedlot for finishing lambs may also use this area to finish older sheep for sale or slaughter (Bryant and Kirby, refer appendix). Despite the apparent inefficiencies of using grain for finishing cull animals, this strategy creates a wide range of benefits and options for producers (Gulbransen 1990). Strategic finishing of cull animals can be a profitable enterprise due to benefits such as the increased price per kilogram for a better finish, reduced grazing pressure, accelerated disposal of cull animals, earlier cash-flow and out-of-season production.

The relative price commanded by lamb and mutton reflect the fact that eating quality of meat declines as sheep age (Pethick *et al.* 2003). Recent research by Wiese *et al.* (2000) and Pethick *et al.* (2003) has demonstrated that criteria for the current AUS-MEAT Ltd. dentition categories for sheep meat (lamb - 0 permanent incisors, hogget or yearling mutton - 1 to 2 permanent incisors, mutton - 1 to 8 permanent incisors) do not necessarily correlate with meat eating quality. Therefore it may be advantageous for the Australian sheep meat industry to consider alternative classifications. An increased role for grain feeding of older sheep could arise if a niche market for larger, older carcases developed and price premiums were offered for high quality sheep in this age category.

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[2] Backgrounding is the system of preparing weaners on a property for entry into a feedlot at the correct body weight and already adapted to a grain diet. Sheep are grown at a slower rate in comparison to finishing growth rates for a reduced cost. Animals are normally introduced to trough feeding (e.g. containing grain and hay) and become used to confinement in small paddocks/yards and human handlers.

References

ABARE (2001a). *Australian Commodity Statistics.* Australian Bureau of Agricultural and Resource Economics, Canberra.

ABARE (2001b). *Australian Prime Lamb Industry 2001.* Australian Bureau of Agricultural and Resource Economics, Canberra.

Banks, R. (2000). 'LAMBPLAN: A sheep breeding strategy'. *ICAR Technical Series No. 3*, Galal, S., Boyazoglu, J. and Hammond, K. (eds). ICAR, Rome, pp. 521-539.

Connell, P., Hooper, S. and Helali, S. (2002). 'Australian Prime Lamb Industry 2002', *Report of the Australian Agricultural and Grazing Industries Survey of Prime Lamb Producers.* ABARE Research Report 02.3, Canberra.

Davis, J. (2003). *Guidelines to feedlotting lambs.* Department of Primary Industries, Victoria.

Dove, H. (2002). 'Principles of supplementary feeding in sheep-grazing systems'. In: *Sheep Nutrition.* Freer, M. and Dove, H. (eds). CSIRO Publishing, Collingwood, pp. 119-142.

Dowling, E. and Wiese, S.C. (2001). 'Sheep meat enterprises in Western Australia'. In: *The Good Food Guide for Sheep.* Croker, K. and Watt, P. (eds). Government of Western Australia, Department of Agriculture, Perth, Bulletin 4473, pp. 7-12.

Ferrier, G.R., Thatcher, L.P. and Cooper, K.L. (1995). 'The effects of lamb growth manipulation on carcass composition'. In: *Meat '95; Proceedings Meat Industry Research Conference, Gold Coast, September 1995*, Session 8A, pp. 17-19.

Gulbransen, B. (1990). 'Using supplementary grain to increase the marketability of culled cows'. *Animal Production in Australia,* vol. 18, pp. 228-231.

Hall, D.G. and Holst, P.J. (1992). 'Production systems for Elite lamb'. *Animal Production in Australia,* vol. 19, p. 176.

Hall, D.G., Kelf, T., Fogarty, N.M. and Murray, P.J. (2000). 'Opportunities for meat from lambs and goats in Australia'. *Animal Production in Australia,* vol. 23, pp. 330-340.

Hall, D.G. and Mulholland, J.G. (1982). 'Some problems of introducing feedlot rations to lambs'. *Animal Production in Australia,* vol. 14, p. 650.

Hall, D.G., Gilmour, A.R., Fogarty, N.M., Holst, P.J. and Hopkins, D.L. (2001). 'Growth and carcass composition of second-cross lambs. 1. Effect of sex and growth path on pre- and post-slaughter estimates of carcass composition'. *Australian Journal of Agricultural Research,* vol. 52, pp. 859-867.

Hancock, B. and Stephens, E. (2002). *The Australian Prime Lamb Group Compendium.* Prepared by the Australian Lamb Product Development Officers, Publishing Services Branch, PIRSA.

Hopkins, D.L. (1995). 'Understanding the factors wholesalers and retailers use to value lamb carcasses'. In: *Meat '95; Proceedings Meat Industry Research Conference, Gold Coast, September 1995,* Session 8A, pp. 1-5.

McClure, K.E., Van Keuren, R.W. and Althouse, P.G. (1994). 'Performance and carcass characteristics of weaned lambs either grazed on orchard grass, ryegrass or alfalfa or fed all-concentrate diets in drylot'. *Journal of Animal Science,* vol. 72, pp. 3230-3237.

McLaughlin, J.W. (1992). 'The prime lamb program'. *Animal Production in Australia*, vol. 19, p. 173.

Meat and Livestock Australia (2002). *Market Information Services Statistical Review July 2001-June 2002.* Meat and Livestock Australia, North Sydney.

MLA (2003). Meat and Livestock Australia [WWW document]. URL http://www.mla.com.au (accessed 15/3/04).

Moore, A.D., Donnelly, F.B., Freer, M. and Langford, C.M. (1993). 'Production system studies', *Report to the Meat Research Committee, Sydney*, Project CS 149.

Mulholland, J.G. (1986). 'Introducing supplements to newly weaned lambs'. *Animal Production in Australia,* vol. 16, pp. 287-290.

Notter, D.R., Kelly, R.F. and McClaugherty, F.S. (1991). 'Effects of ewe breed and management system on efficiency of lamb production: II. Lamb growth, survival and carcass characteristics'. *Journal of Animal Science,* vol. 69, pp. 22-33.

Pethick, D.W., Baud, S., Walker, P., Thompson, J., Hopkins, D.L. and Skerritt, J. (2002). 'Defining and quantifying some on-farm factors influencing sheep meat eating quality'. CD-ROM, *Proceedings Wool Industry Science and Technology Conference*, *Hamilton, Australia.*

Pethick, D.W., Cummins, L., Gardner, G.E., Jacobs, R.H., Knee, B.W., McDowell, M., McIntyre, B.L., Tudor, G., Walker, P.J. and Warner, R.D. (2000). 'The regulation of glycogen level in the muscle of ruminants by nutrition'. *Proceedings of the New Zealand Society of Animal Production,* vol. 60, pp. 94-98.

Pethick, D.W., Hopkins, D.L., D'Souza, D.N., Thompson, J.T. and Walker, P. (2003). 'The impact of animal age on the eating quality of sheepmeat derived from Merino ewes'. *Final report to Meat and Livestock Australia*, Project SMEQ.016.

Pethick, D.W. and Rowe, J.B. (1996). 'The effect of nutrition and exercise on carcass parameters and the level of glycogen in skeletal muscle of Merino sheep'. *Australian Journal of Agricultural Research,* vol. 47, pp. 525-537.

Pirlot, K.L., Hopkins, D.L. and Roberts, A.H.K. (1992). 'Distribution of lamb carcasses according to weight and fatness'. *Animal Production in Australia,* vol. 19, p. 172.

Safari, E., Channon, H.A., Hopkins, D.L., Hall, D.G. and van de Ven, R. (2002). 'A national audit of retail lamb loin quality in Australia'. *Meat Science,* vol. 61, pp. 267-273.

Shands, C.G., Farrell, T.C., Fogarty, N. and Hegarty, R.S. (2002). 'Growth and carcass specifications of heavyweight first- and second-cross feedlot-finished lambs'. *Animal Production in Australia,* vol. 24, p. 352.

Suiter, R.J. and McDonald, C.L. (1987). 'Growth of Merino weaners fed grain-based diets while grazing dry pasture or housed in feedlots'. *Australian Journal of Experimental Agriculture,* vol. 27, pp. 629-632.

Thatcher, L.P. (1992). 'Development program for the prime lamb industry - the Elite lamb program'. *Animal Production in Australia,* vol. 19, p. 173.

Trefort, P. (2002). 'Science and the Q-Lamb dream'. In: *Proceedings Lamb for Dollars Symposium*, *Perth Zoo*, *Perth, 21 August 2002.*

White, A.K., Salmon, G.J. and Salmon, G.M. (2002). 'Production and financial comparison of prime lamb finishing and breeding systems in high rainfall regions of NSW'. *Animal Production in Australia,* vol. 24, pp. 261-264.

Wiese, S.C., Milton, J.T.B., Davidson, R.H. and Pethick, D.W. (2000). 'Teeth eruption and eating quality in young sheep'. Meat and Livestock Australia, Project SMEQ.002.

Feeding grain for sheep meat production

Chapter 2. Nutritional requirements of growing lambs: Protein and energy requirements

F.M. Jones, R.S. Hegarty and J.J. Davis

CHAPTER 2. NUTRITIONAL REQUIREMENTS OF GROWING LAMBS: PROTEIN AND ENERGY REQUIREMENTS

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Introduction

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. How animals metabolise absorbed nutrients will be modified by the supply of these and other nutrients in relation to tissue requirements at that time. The greatest demand by the tissues of the growing animal is for energy, specifically metabolisable energy (ME), to fuel protein synthesis from amino acids. Measurements of animal growth have provided the basis for defining the energy and protein requirements of animals used in global feeding standards. This review of the principles underlying the protein and energy requirements of lambs, explains how and why these requirements change through the life of a lamb and how genotype and growth path can modify tissue deposition. The protein and energy content of cereal grains is considered relative to the nutrient requirements of the microorganisms in the rumen and of the metabolic requirements of a finishing lamb.

The physiological basis for energy and protein requirements

Energy

The synthetic processes in lambs, as in all mammals, require adenosine triphosphate (ATP) to fuel the reaction and this ATP results from oxidation of high-energy substrates. In ruminants the principal energy substrates for ATP synthesis are the volatile fatty acids (VFA) arising from microbial fermentation of dietary carbohydrates in the rumen (Ørskov and Ryle 1990). Acetate is quantitatively the most important substrate, but propionate also plays an essential role as a glycogenic precursor to ensure the energy requirements of the neural system are met (Blaxter 1962). Feeding of grains such as sorghum and maize, which resist rumen fermentation, may also provide glucose for direct absorption from the small intestine. While extremely high levels of grain have been associated with soft fats (Duncan *et al.* 1972), feeding of less degradable cereal grains is now being considered as a way of stimulating the ATP citrate lyase pathway by providing glucose to the intestine, increasing the synthesis of intracellular lipid associated with marbling in meat (Pethick *et al.* 1995; Rowe and Pethick 1994).

Protein

There is no single figure that can adequately describe the percentage of crude protein that finishing lambs require in their diet. When considering the protein requirements of lambs, it is critical to partition the requirement for amino acids and other nitrogenous compounds into that required by the rumen microorganisms (in order to grow and so ferment feedstuffs) and that required by the host animal (the lamb) for deposition and endogenous losses.
Figure 2.1 illustrates this division between the true amino acid requirement of the ruminant which is met through the combination of undegraded dietary protein (UDP) and microbial protein. In contrast, the rumen microbial requirement for protein precursors is met through rumen degradable protein (RDP).

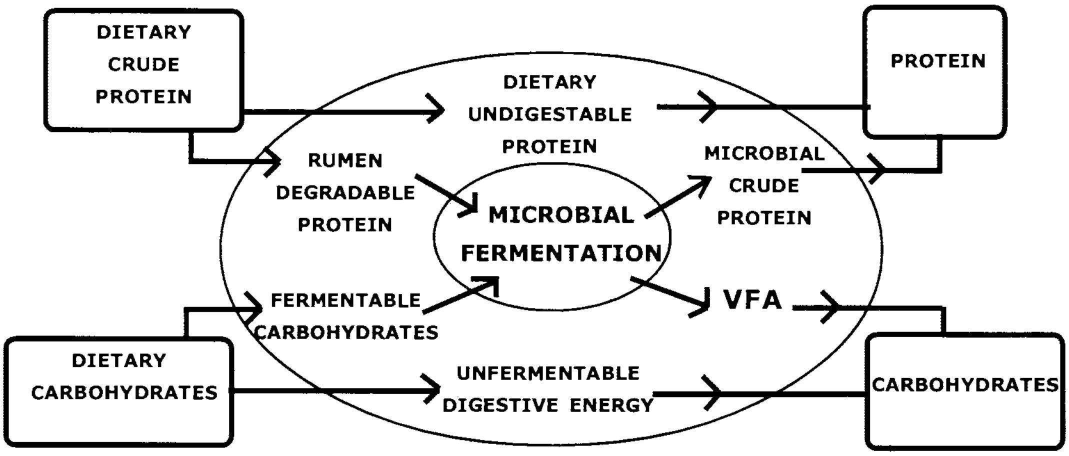

Figure 2.1. **Process and products of rumen fermentation of feed. Microbial fermentation of energy sources releases VFA as end-products while liberating energy to allow rumen degradable nitrogen to be synthesised into microbial protein. Some dietary protein flows past the rumen undegraded (Rumen Undegradable Dietary Protein) as do unfermented sugars. Both the microbial protein and the undegradable dietary protein comprise the protein pool available for digestion and absorption at the small intestine.**

Rumen degradable protein (RDP) requirements

Due to the differing yield of energy that rumen microbes obtain from production of the individual VFAs, the quantity of microbial growth and so protein produced varies with the VFA pattern, which is in turn determined by the nature of the carbohydrates being fermented. The type of diet determines the microbial cell yield and so the quantity of RDP required per MJ of ME. For high quality diets, this is typically 11 g RDP per MJ of ME available, decreasing to 8.4 and 6.1 for less digestible forages and silages respectively (SCA 1990). This yield will also vary with the time of year and level of intake but for high-grain diets, the RDP requirement is assumed to be approximately 10 g RDP per MJ of ME in practical formulations. Considering protein in cereal grains is typically 80 per cent rumen degradable (Neutze 1991), a crude protein content of 12.5 g/MJ of ME may be required to meet the ruminal requirement for unrestricted microbial growth. If the RDP:ME ratio is less than this, voluntary feed intake will be below the potential intake of the lamb.

Amino acid requirements

Amino acids reaching the intestine of growing lambs are inevitably partitioned into wool, organ accretion and endogenous urinary and faecal losses. The balance of these is dependent upon the genotype of the animal as well as stage of maturity, energy intake, the intake and characteristics of the protein itself (e.g. intestinal degradability, amino acid profile). Protein deposition in muscle, which is the desired outcome of feeding prime lambs, is intimately reliant upon the supply of energy (ATP) to support anabolism. Unlike RDP requirements however, there is no near-constant relationship by which the balance of energy and amino acids required by the lamb can be simply calculated. A description of the development pattern of lambs is provided below for the purpose of demonstrating why and how the amino acid requirement of lambs changes during growth. On the basis of these principles, it should be apparent when and why, a response to extra amino acids should be expected for a given lamb on a given diet.

Stage of growth effects on energy and protein requirements

The general allometric pattern of maturation of tissues in sheep was well defined by Brody (1945) and more thoroughly by Butterfield (1988). Associated with this pattern of development is an average pattern of accretion of fat, muscle and ash (or minerals) in the body, with bone maturing first, then muscle and finally fat (Figure 2.2).

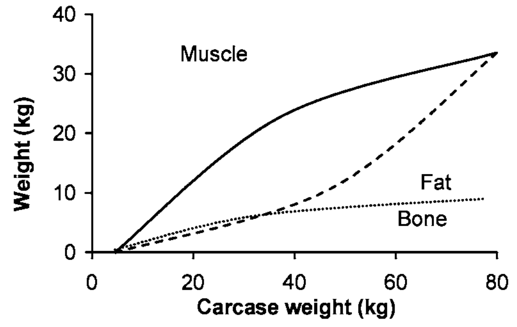

Figure 2.2. **Pattern of allometric growth of bone muscle and fat (after Sainz and Cubbage 1997).**

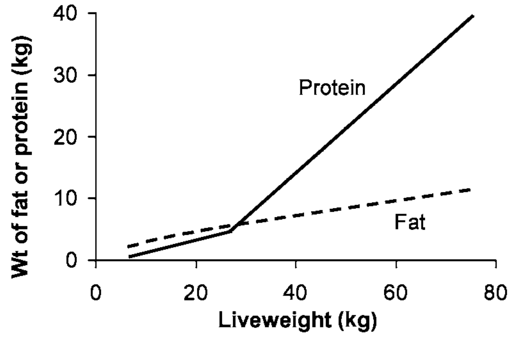

Figure 2.3. **Accretion of total body fat and protein in lambs (after Searle and Graham 1970).**

In sheep the rapid development of fat is initiated between 35 and 40 kg liveweight, immediately prior to the time when lambs typically commence on grain-based finishing rations (Figure 2.3). Implicit in this developmental pattern is the fact that as lambs mature postnatally, the quantity of protein (23.6 MJ/kg) in every kilogram of body gain decreases while the proportion of fat (39.3 MJ/kg) increases, meaning every successive kilogram of liveweight contains more energy than the one before (Figure 2.4). This pattern of increasing energy content in gain as lambs mature was confirmed by Searle and Graham (1970) with crossbred lambs from 5 kg (6.3 MJ/kg) to 50 kg (27.6 MJ/kg).

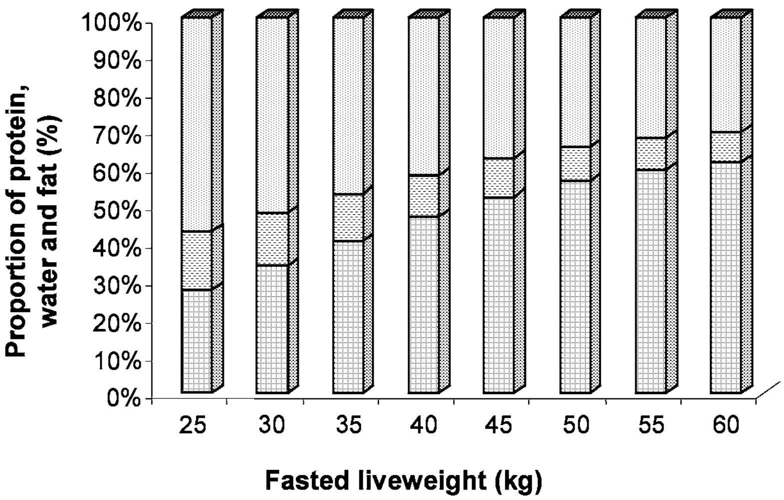

Figure 2.4. **Proportion of protein (spots), water (lines) and fat (grid) in each additional kilogram of fasted liveweight for lambs (Standard reference weight = 60 kg) indicating that composition of gain changes as lambs approach maturity. Calculations based on equations 1.32 and 1.34, SCA (1990).**

Associated with a change in the protein and energy content of deposited tissues with maturity is a change in the balance of energy and amino acids required for growth. Simulations in GrazFeed™ (ver. 4.1.5) were run to estimate the daily feed intake of crossbred lambs consuming a grain:lucerne pellet (80:20; M/D [Megajoules of ME/kg DM] = 12.8) sufficient to sustain approximately 240 g/day liveweight gain as they matured from 20 to 60 kg liveweight (Figure 2.5). The lamb requirements for protein (UDP and RDP) and energy (ME for maintenance and for growth) were obtained either directly from the GrazFeed™ results or from equations in SCA. GrazFeed™ assessed a RDP requirement of 8.9 g RDP/MJ MEI [Maintenance energy intake].

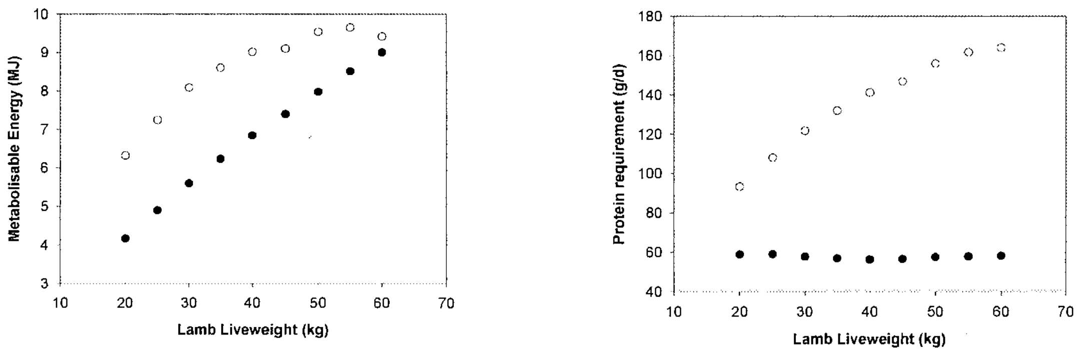

Figure 2.5a. **Increase in energy requirements for maintenance (•) and gain (○) of crossbred lambs sustaining a growth rate of 240 g/day as they mature.**

Figure 2.5b. **Change in requirements for rumen degradable protein (○) and protein to the intestine (•) by crossbred lambs sustaining a growth rate of 240 g/day as they mature.**

Figure 2.5a demonstrates that while maintenance energy requirements rise with liveweight, energy available for gain does not correspondingly increase as voluntary feed intake approaches the biological limit. Considering the energy content of liveweight gain is also increasing (Figure 2.3), it is not surprising that growth rates of 400 g/day, which are readily seen in unweaned lambs, are uncommon for lambs in feedlots, even when grain-based energy dense diets are fed.

Figure 2.5b demonstrates that while the daily requirement for RDP increases to enable greater microbial activity to ferment the increasing intake of energy, the protein requirement to the intestine (for tissue synthesis and endogenous losses) hardly changes. The implications of this are that efficient feedlot finishing of lambs to heavy weights will need to focus primarily on ensuring the RDP supply is sufficient to match the ME intake and support uninhibited rumen fermentation. Provision of additional proteins (protected, bypass or undegraded) will be unnecessary in grain finishing diets, since the microbial protein synthesised from supplying adequate RDP will be more than sufficient to meet tissue requirements of the host animal.

Setting the allometric pattern of growth

The general principles of how growth, feed intake and body composition interact to continuously change the nutritional requirement of lambs on a gram/day and gram/kilogram feed basis are consistent across all types of lamb. Between lambs however, the pattern of development (Figure 2.2) will deviate in accordance with the genetic and physiological attributes of the lamb as described below.

Breed and genetics

Genotypes that are heavier at maturity generally grow faster and are leaner when compared at the same weight (Black 1983; Searle and Griffiths 1976b; Tatum *et al.* 1998; Theriez *et al.* 1981). It is generally accepted that recognised meat breeds or crossbreds tend to grow faster than Merinos (Gardner *et al.* 1999; Wiese *et al.* 2003; Wynn and Thwaites 1981) and second-cross lambs have been reported to grow faster than first-cross lambs due to greater hybrid vigour (Atkins and Thompson 1979; Holst *et al.* 1998; Hopkins *et al.* 1996) but these principles are not always supported (Davidson *et al.* 2000; Gardner *et al.* 1999). When comparisons are made at the same liveweight, tissue depth at the GR site is generally lower in Merinos followed by first- then second-cross lambs (Atkins and Thompson 1979; Searle and Griffiths 1976b; Shands *et al.* 2002).

The choice of mating system (e.g. first- vs second-cross), or breed selection, may not be based purely on maximising growth rate and feed conversion efficiency. It can be influenced by many factors including local environmental conditions and the relative importance of the lamb enterprise in the whole farming system. Regardless of the production system, the benefits of selecting sires with high estimated breeding values for growth and leanness have been clearly demonstrated (Fogarty *et al.* 1997; Hall *et al.* 2002; Hegarty 2002; Wiese 2000).

Age, body weight and sex

Body composition is linked closely with body weight but there is no inherent relationship between age and body composition (Black 1983). As animals reach physiological maturity there is a transition from lean growth toward an increasing rate of fat deposition. This transition occurs earlier in ewes than rams (Searle and Griffiths 1976a). When animals are slaughtered prior to the transition to increased fat deposition, there may not be a difference in tissue depth at the GR site, but when slaughtered at heavy weights there tends to be an increase in GR depth or fatness according to sex; rams < cryptorchids < wethers < ewes (Andrews and Ørskov 1970b; Atkins and Thompson 1979; Lee 1986a).

Growth rate tends to be influenced by sex, being faster in rams than cryptorchids, followed by wethers, then ewes. The difference in growth rate between sexes can be of the order of that created by different nutritional treatments (Andrews and Ørskov 1970a; Arnold and Meyer 1988; Atkins and Thompson 1979; Holst *et al.* 1997; Jackson *et al.* 1990; Lee 1986a; Van Vleck *et al.* 2000; Wynn and Thwaites 1981). Interestingly, the difference in growth rate between sexes is primarily related to differences in feed intake so may not be expressed when nutrition is limiting (Lee 1986a, 1986b).

Breaking the allometric pattern of growth (more muscle and less fat)

Once lambs are of an appropriate weight to be grain finished (> 30 kg liveweight), there appears to be little scope to modify body composition simply by providing amino acids in excess of those required for allometric growth (Hegarty *et al.* 1999). A low rumen degradable nitrogen (RDN) intake simply limits voluntary food intake (Hegarty *et al.* 2001). Any scope to modify the composition of gain for an individual lamb to achieve greater muscle and reduced fat deposition through finishing is dependent upon conditioning the lamb through its prior nutritional history, be it prenatal, preweaning or postweaning.

Prenatal

Foetal undernutrition can reduce mature size of sheep (Bell 1992; Schinckel and Short 1961) although post-natal growth rate at least to 20 kg liveweight is not compromised by foetal undernutrition (Greenwood *et al.* 1998). The composition of postnatal growth however is modified by foetal undernutrition, with less bone, less muscle and more fat making up the gain (Greenwood *et al.* 1998, 2000; Greenwood and Bell 2003). There does not appear to be any mechanism for manipulation of foetal nutrition to stimulate the more desirable aberration of enhancing muscle growth while suppressing fat accretion once lambs are born.

Postnatal

The priority for energy utilisation in growth is to fuel protein deposition, which is typically limited by amino acid availability, with residual energy deposited as fat (Oltjen *et al.* 1986). Nutritional restriction of young ruminants (< 40% maturity) can have long-term suppressive effects on muscle and bone growth capacities, so subsequent refeeding will cause them to deposit additional fat (Oddy and Sainz 2002). When growth is nutritionally restricted in more mature lambs, it is likely to lead to a more marked reduction in fat accretion than muscle accretion, leading to lambs being typically leaner after a period of slow continuous growth (Ball and Thompson 1997; Thatcher and Gaunt 1992). Lambs that have been grown slowly due to inadequate nutrition will therefore be leaner at commencement of grain feeding and be likely to exhibit compensatory growth, which will further accelerate growth rate and the lean content of that growth (Table 2.1). It is likely that this will increase the tissue amino acid requirement (UDP) as the rate of protein synthesis increases during realimentation (Kreienbring *et al.* 1994).

Table 2.1. Effect of nutritionally induced slow growth (LOW) or unimpeded rapid growth (HIGH) prior to finishing on the rates of fat and protein gain in the carcase of crossbred lambs during finishing. Lambs were provided with 0 (P_o) or 90 (P_{90}) g of cottonseed meal supplement daily during finishing on a diet providing 10 MJ of ME/kg (after Hegarty *et al.* 1999).

	LOW		HIGH	
	P_0	P_{90}	P_0	P_{90}
Starting liveweight	36.55	36.55	51.66	51.66
Starting fat mass (kg)	4.35	4.35	8.02	8.02
LWG during finishing (g/day)	188.00	200.00	133.00	131.00
Carcase protein gain (g/day)	14.10	13.70	6.60	7.10
Carcase fat gain (g/day)	19.20	30.60	39.10	40.00

Grain as a protein and energy source

Cereal grains are one of the most energy dense feedstuffs available for ruminants and so there is a high requirement for RDN to ensure maximum fermentation of grain carbohydrates. While protein requirement of the lamb changes with maturity, the RDN:ME requirements of the rumen microbes do not change as the lamb grows and a ratio of approximately 10 g RDP per MJ of ME consumed is required to optimise rumen fermentation and feed intake. In the Metabolisable Protein Feeding Standards developed in the United Kingdom (AFRC 1993), a comparable ratio of approximately 10 g of effectively degradable rumen protein (ERDP) to fermentable metabolisable energy (FME) ratio is sought. Protein in cereal grains is readily degraded in the rumen and approximately 80 per cent of the crude protein in grain can be considered rumen degradable. A brief overview of the energy to protein ratio in feed grains indicates most cereal grains have a slight deficiency in RDN relative to the energy they contain (Table 2.2).

Table 2.2. Concentrations of rumen degradable protein (RDP) and metabolisable energy (ME) in feed grains and lupins. Energy and crude protein (CP) concentrations obtained from NSW Agriculture Feeds evaluation service. Protein degradability estimates from Neutze (1991).

Grain	ME (MJ/kg)	CP (%)	Degradability (%)	RDP (g/kg)	RDP:ME (g/MJ)
Sorghum	12.4	10	45	45	3.3
Maize	13.5	10	45	45	3.6
Oats	10.5	11	70	77	7.4
Barley	11.6	12	75	92	7.9
Lupin	11.3	31	72	221	19.6

Conclusions

The ruminant lamb has two distinct spheres of nutritional requirement, being the requirements of the rumen microbes and the requirements of the animal tissues themselves. A tendency to describe these requirements using a single term such as crude protein is naive and restricts practical nutritional management. First in digestive/fermentation sequence and in importance are the requirements of the rumen microbial population. Rumen fermentation requires a synchronised supply of fermentable energy and rumen degradable nitrogen, either in a protein or non-protein form. RDP should be provided in a ratio of approximately 10 g RDP/MJ of ME intake. While the protein in cereal grains is highly degradable in the rumen, most grains have less than this optimal RDP relative to energy, and inclusion of a secondary source of RDN in the ration is required to maximise voluntary feed intake. While the RDN requirements of the rumen can be considered fixed in relation to energy intake, the amino acid and energy requirements of the lamb itself change dramatically over time.

The standard pattern of sequential growth (bone, muscle, fat) occurs in lambs but the level and timing of growth and its components are influenced by mature size, other aspects of genotype and growth history. During early life, lambs have a high daily requirement for amino acids but are constrained by a low potential feed intake. Maximum liveweight gain by small lambs is reliant upon optimising RDN intake, to ensure feed intake and microbial protein production is maximised, but additional UDP will be required to ensure the tissue requirements for amino acids are met. As lambs mature, their voluntary intake increases while the daily requirement for amino acids is little changed. Consequently, microbial protein synthesised from RDN can meet the amino acid requirement for tissue and for obligatory losses in finishing lambs, so no growth benefit is likely to result from providing UDP in grain-based finishing systems.

Importantly, animals require certain quantities of nutrients per day (g, mole, MJ); they do not require an absolute percentage of nutrients in the diet. It is the voluntary intake of the animal and the level of other diluents in the diet that are important in translating a daily requirement for a quantity of nutrient into an estimated concentration of nutrient that must be present in the feedstuff.

Efforts to use high levels of amino acid supply to enhance muscle growth in finishing lambs have proved unsuccessful and nutritional modification of body composition is best effected by management of growth rate and comparative growth in preparation for finishing.

References

AFRC (1993). *Energy and Protein Requirements of Ruminants.* An Advisory Manual Prepared by the AFRC Technical Committee on Responses to Nutrients. CAB International, Wallingford, UK.

Andrews, R.P. and Ørskov, E.R. (1970a). 'The nutrition of the early weaned lamb. 1. The influence of protein concentration and feeding level on rate of gain in body weight'. *Journal of Agricultural Science, Cambridge,* vol. 75, pp. 11-18.

Andrews, R.P. and Ørskov, E.R. (1970b). 'The nutrition of the early weaned lamb 2. The effect of dietary protein concentration, feeding level and sex on body composition at two liveweights'. *Journal of Agricultural Science, Cambridge,* vol. 75, pp. 19-26.

Arnold, A.M. and Meyer, H.H. (1988). 'Effects of gender, time of castration, genotype and feeding regimen on lamb growth and carcass fatness'. *Journal of Animal Science,* vol. 66, pp. 2468-2475.

Atkins, K.D. and Thompson, J.M. (1979). 'Carcass characteristics of heavyweight crossbred lambs. I. *Growth and carcass measurements*'. *Australian Journal of Agricultural Research,* vol. 30, pp. 1197-1205.

Ball, A.J. and Thompson, J.M. (1997). 'Changes in body composition during compensatory growth of sheep and cattle'. In: *Growth and Development of Cattle: Proceedings of the growth and development workshop.* Hennessy, D.W., Mclennan, S.R. and Oddy, V.H. (eds). Meat Quality CRC, Armidale, Australia, pp. 19-27.

Bell, A.W. (1992). 'Foetal growth and its influence on postnatal growth and development'. In: *The Control of Fat and Lean Deposition.* Buttery, P.J., Boorman, K.N. and Lindsay, D.B. (eds). Butterworth-Heinemann, Oxford, UK, pp. 111-127.

Black, J.L. (1983). 'Growth and development of lambs'. In: *Sheep Production.* Haresign, W. (ed.). Butterworths, London, pp. 21-58.

Blaxter, K.L. (1962). *The energy metabolism of ruminants.* Hutchinson Scientific and Technical, London.

Brody, S. (1945). *Bioenergetics and Growth.* Rheinhold, New York.

Butterfield, R.M. (1988). *New concepts in sheep growth.* Department of Veterinary Anatomy, University of Sydney, Sydney.

Davidson, R.H., Milton, J.T.B., Vercoe, P.E., Sewell, J.W. and Sewell, B. (2000). 'Feed intake, growth rate and feed efficiency of Merino and first cross prime lambs fed a grain-based pelleted diet'. *Animal Production in Australia,* vol. 23, p. 173.

Duncan, W.R.H., Ørskov, E.R. and Garton, G.A. (1972). 'Fatty acid composition of triglycerides of lambs fed on barley-based diets'. *Proceedings of the Nutrition Society,* vol. 31, pp. 19A-20A.

Fogarty, N.M., Gilmour, A.R. and Hopkins, D.L. (1997). 'The relationship of crossbred lamb growth and carcass traits with LAMBPLAN EBVs of sires'. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics,* vol. 12, pp. 304-307.

Gardner, G.E., Kennedy, L., Milton, J.T.B. and Pethick, D.W. (1999). 'Glycogen metabolism and ultimate pH of muscle in Merino, first-cross, and second-cross wether lambs as affected by stress before slaughter'. *Australian Journal of Agricultural Research,* vol. 50, pp. 175-182.

Greenwood, P.L., Hunt, A.S., Hermanson, J. and Bell, A.W. (1998). 'Effects of birth weight and postnatal nutrition on neonatal sheep. I. Body growth and composition, and some aspects of energetic efficiency'. *Journal of Animal Science,* vol. 76, pp. 2354-2367.

Greenwood, P.L., Hunt, A.S., Hermanson, J. and Bell, A.W. (2000). 'Effects of birth weight and postnatal nutrition on neonatal sheep. II. Skeletal muscle growth and development'. *Journal of Animal Science,* vol. 78, pp. 50-61.

Greenwood, P.L. and Bell, A.W. (2003). 'Prenatal nutritional influences on growth and development of ruminants'. *Recent Advances in Animal Nutrition in Australia,* vol. 14, pp. 57-74.

Hall, D.G., Gilmour, A.R., Fogarty, N.M. and Holst, P.J. (2002). 'Growth and carcass composition of second-cross lambs. 2. Relationship between estimated breeding values of sires and their progeny performance under fast and slow growth regimes'. *Australian Journal of Agricultural Research,* vol. 53, pp. 1341-1348.

Hegarty, R.S., Neutze, S.A. and Oddy, V.H. (1999). 'Effects of protein and energy supply on the growth and carcass composition of lambs from differing nutritional histories'. *Journal of Agricultural Science, Cambridge,* vol. 132, pp. 361-375.

Hegarty, R.S., Neutze, S.A. and Nicholls, P.J. (2001). 'Effects of liveweight and dietary rumen degradable nitrogen on the growth and feed intake responses of concentrate-fed lambs to escape protein supplements'. *Recent Advances in Animal Nutrition in Australia,* vol. 13, pp. 97-108.

Hegarty, R.S. (2002). 'Optimising the nutritional and genetic management of lambs to meet market specification'. MLA funded Management Solutions project reported at 1.3.1. workshop, 2 November.

Holst, P.J., Hall, D.G., Stanley, D.F. and Nolan, J.V. (1997). 'Effects of sex and liveweight on feeding behaviour of crossbred weaner lambs receiving oaten grain supplement on lucerne pasture'. *Australian Journal of Experimental Agriculture,* vol. 37, pp. 611-615.

Holst, P.J., Kilgour, R.J., Nolan, J.V. and Stanley, D.F. (1998). 'Feeding behaviour and growth response of lambs at a stationary self-feeder'. *Animal Production in Australia,* vol. 22, p. 283.

Hopkins, D.L., Holst, P.J., Fogarty, N.M. and Stanley, D.F. (1996). 'Growth and carcass characteristics of first and second cross lambs lot-fed to heavy weights'. *Animal Production in Australia,* vol. 21, pp. 181-184.

Jackson, W.J., Hopkins, D.L. and Fumo, T. (1990). 'The commercial feasibility of running winter-born cryptorchid lambs'. *Animal Production in Australia,* vol. 18, p. 497.

Kreienbring, F., Krawielitzki, K., Klien, M. and Schaderiet, R. (1994). 'Influence of food restriction and compensatory growth on protein synthesis and breakdown in growing rats'. *Isotopenpraxis Environmental Health Studies,* vol. 30, pp. 89-97.

Lee, G.J. (1986a). 'Growth and carcass characteristics of ram, cryptorchid and wether Border Leicester × Merino lambs: Effects of increasing carcass weight'. *Australian Journal of Experimental Agriculture,* vol. 26, pp. 153-157.

Lee, G.J. (1986b). 'Growth and carcass composition of ram and wether lambs fed at two levels of nutrition'. *Australian Journal of Experimental Agriculture,* vol. 26, pp. 275-278.

Neutze, S. (1991). 'Degradation of feed protein in the rumen: Degradability of common feeds and factors affecting degradation'. *NSW Agriculture Advisory Bulletin,* Agdex 400/54.

Oltjen, J.W., Bywater, A.C., Baldwin, R.L. and Garrett, W.N. (1986). 'Development of a dynamic model of beef cattle growth and composition'. *Journal of Animal Science,* vol. 62, pp. 86-97.

Oddy, V.H. and Sainz, R.D. (2002). 'Nutrition for sheep-meat production'. In: *Sheep Nutrition.* Freer, M. and Dove, H. (eds). CSIRO Publishing, Collingwood, pp. 237-262.

Ørskov, E.R. and Ryle, M. (1990). *Energy nutrition in ruminants.* Elsevier Applied Science Publishers, London.

Pethick, D.W., Phillips, N., Rowe, J.B. and McIntyre, B.L. (1995). 'The effect of different dietary grains on the expression of ATP citrate lyase in the adipose tissue of sheep'. *Proceedings of the Nutrition Society of Australia,* vol. 19, p. 132.

Rowe, J.B. and Pethick, D.W. (1994). 'Starch digestion in ruminants-problems, solutions and opportunities'. *Proceedings of the Nutrition Society of Australia,* vol. 18, pp. 40-52.

SCA (1990). *Feeding standards for Australian livestock: Ruminants.* Standing Committee on Agriculture and Resource Management. CSIRO, Melbourne.

Sainz, R.D. and Cubbage, J.S. (1997). 'Growth production and meat'. *Proceedings, 43rd International Congress on Meat Science and Technology*, *Auckland*, pp. 144-155.

Schinckel, P.G. and Short, B.F. (1961). 'The influence of nutritional level during pre-natal and early post-natal life on adult fleece and body characteristics'. *Australian Journal of Agricultural Research,* vol. 12, pp. 176-202.

Searle, T.W. and Griffiths, D.A. (1976a). 'The body composition of growing sheep during milk feeding, and the effect on composition of weaning at various body weights'. *Journal of Agricultural Science, Cambridge,* vol. 86, pp. 483-493.

Searle, T.W. and Griffiths, D.A. (1976b). 'Differences in body composition between three breeds of sheep'. *Animal Production in Australia,* vol. 11, pp. 57-60.

Searle, T.W. and Graham, N. McC. (1970). 'Body composition of growing sheep and its relevance to pasture evaluation'. *Animal Production in Australia,* vol. 8, pp. 472-475.

Shands, C.G., Farrell, T.C., Fogarty, N. and Hegarty, R.S. (2002). 'Growth and carcass specifications of heavyweight first- and second-cross feedlot-finished lambs'. *Animal Production in Australia,* vol. 24, p. 352.

Thatcher, L.P. and Gaunt, G.M. (1992). 'Effects of growth path and post-slaughter chilling regime on carcass composition and meat quality of ewe lambs'. *Australian Journal of Agricultural Research,* vol. 43, pp. 819-830.

Tatum, J.D., DeWalt, M.S., LeValley, S.B., Savell, J.W. and Williams, F.L. (1998). 'Relationship of feeder lamb frame size to feedlot gain and carcass yield and quality grades'. *Journal of Animal Science,* vol. 76, pp. 435-440.

Theriez, M., Tissier, M. and Robelin, J. (1981). 'The chemical composition of the intensively fed lamb'. *Animal Production,* vol. 32, pp. 29-37.

Van Vleck, L.D., Leymaster, K.A. and Jenkins, T.G. (2000). 'Genetic correlations for daily gain between ram and ewe lambs fed in feedlot conditions and ram lambs fed in pinpointer units'. *Journal of Animal Science,* vol. 78, pp. 1155-1158.

Wiese, S.C. (2000). *High/low LAMBPLAN comparison - technical report.* Meat and Livestock Australia, PIRD Report, 98/W07.

Wiese, S.C., White, C.L., Masters, D.G., Milton, J.T.B. and Davidson, R.H. (2003). 'The growth performance and carcass attributes of Merino and Poll Dorset × Merino lambs fed rumen-protected methionine (Smartamine™-M)'. *Australian Journal of Agricultural Research,* vol. 54, pp. 507-513.

Wynn, P.C. and Thwaites, C.J. (1981). 'The relative growth and development of the carcass tissues of Merino and crossbred rams and wethers'. *Australian Journal of Agricultural Research,* vol. 32, pp. 947-956.

Feeding grain for sheep meat production

Chapter 3. Nutritional requirements of growing lambs: Mineral supplementation of sheep in feedlots

R.J. Suter and N.D. Costa

CHAPTER 3. NUTRITIONAL REQUIREMENTS OF GROWING LAMBS: MINERAL SUPPLEMENTATION OF SHEEP IN FEEDLOTS

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Introduction

Minerals added to sheep feedlot rations can be divided into two groups based upon the reason for their use. One group contains the protective minerals and the other group the possible carcase-composition-modifying minerals. The protective minerals include calcium, phosphorus, sodium, selenium, copper and cobalt; and the possible carcase-composition-modifying group include magnesium and chromium. In general the protective minerals do not improve performance of sheep in feedlots, but do prevent production losses and deaths. Often in commercial lot feeding situations the difference between profit and loss can be as little as the cost of a few sheep deaths. It is prudent and simple to minimise these losses by adding some minerals to rations.

The traditional way of classifying minerals is based upon the order of magnitude of their requirements for maintenance of the animal, thus there are macro-minerals (required in the order of grams per kilogram of dry matter intake), trace minerals (milligrams per kilogram of dry matter intake) and ultra-trace minerals (micrograms or less per kilogram) (Underwood and Suttle 1999).

The theory and practice of mineral supplementation can be at odds with each other. Mineral supplements should be used only when requirements cannot be met from the appropriate combination of available feedstuffs. This approach depends on knowing the mineral composition of the feedstuff or having access to a comprehensive database to gain this information. However, it is not sufficient to know the mineral composition of a feedstuff because this does not translate into complete availability of the mineral. The actual intake, the chemical form, the presence of interacting factors and the physiological state of the animal all influence availability to varying degrees that are not always predictable. For instance, inorganic forms of chromium are very poorly absorbed by sheep whereas organic forms have some proven efficacy (Underwood and Suttle 1999). In addition, the animal may have sufficient reserves in tissue storage to sustain the needs for a particular mineral over periods varying from days to over a month. Providing minerals beyond the animal's requirements can be an economic waste because this practice does not lead to any additional benefit and may in fact be harmful in some cases. Nevertheless responsible manufacturers legitimately sell to farmers ready-mixed mineral supplements that are of considerable value to sheep. Notwithstanding this, farmers should be on the alert for exaggerated claims and should seek independent substantiation of these claims in relation to particular benefits to the class of stock under local conditions.

Current usage of minerals

Two major feedlot diet manufacturers in Western Australia were contacted in June 2003 to ascertain what minerals were currently being used in sheep feedlot rations.

For short-term lamb finishing (less than 30-40 days) one manufacturer rarely added limestone, but rather used dicalcium phosphate (DCP) to achieve a pellet with 1.0 per cent calcium and 0.2-0.3 per cent phosphorus (or a Ca:P ratio of 3:1-5:1). Bicarbonate of soda was rarely used by this manufacturer, and salt was not added either, so the pellet had a final sodium content of 0.04-0.05 per cent. A mineral premix was used for two reasons;

commercial expectations that manganese, zinc, iron, iodine, selenium and cobalt would be included in the ration, and historical evidence of deficiencies of selenium and cobalt in Western Australia. For live export pellets (also relatively short-term feeding), no premix or DCP was used by customer request, but lime was added at 1 or 2 per cent to act primarily as a binder to reduce dust rather than as a source of calcium. Other electrolytes (such as potassium) were occasionally included in the feed by this manufacturer (information provided commercial in-confidence).

A second manufacturer also indicated that bicarbonate of soda was not included as a routine, but this depended upon the fibre length of straw in the pellet and the fineness of the milling of the cereal grains. This manufacturer's pellets were made for short-term finishing, often in less than 3 weeks. Magnesium oxide (causmag) and potassium chloride were often included at 0.3-0.5 per cent DM because straw was relatively deficient in magnesium and potassium when compared to hays. DCP was included at the same rate where particular feedstuffs in the pellet were recognised as being low in phosphorus (unlike cereal grains). Depending upon client requirements, gypsum (calcium sulphate) and limestone were added. In addition, sodium chloride was provided proportional to the content already present (i.e. the water salinity) on the feedlot property. The vitamin-mineral premix used by this manufacturer included vitamins A, D, E, and B_1 (with more vitamin E used nowadays compared to a decade ago), and the trace minerals copper (to a final level of 5 mg/kg DM), iron, manganese, zinc, iodine, cobalt, and selenium. Chromium has also been a recent inclusion into the mineral premix (information provided commercial in-confidence).

Protective minerals

Calcium

The main role of calcium (and phosphorus) in the sheep's body is building bone density and strength, and skeletal bone can act as a reservoir during short-term deficiencies of calcium intake. Calcium also has a role in muscle activation. Calcium requirements for growing lambs have been factorially estimated in the range of 2.4-7.0 g/kg DM depending upon body weight, rate of gain, and feed quality (Underwood and Suttle 1999). However, there is no clear definition of calcium requirements for adult sheep mainly because of the lack of agreement over a realistic absorption coefficient for calcium. AFRC (1991) recommend an average absorbability of 68 per cent for all feeds.

Most feedlot rations are based upon cereal grains that are low in calcium. For instance, whole grain barley contains a mean calcium concentration of 0.7 g/kg DM with a range of 0.22-1.46 g/kg DM (AFIC-CSIRO 1987). Whole grain oats contain a mean calcium concentration of 1.17 g/kg DM with a range of 0.44-2.0 g/kg DM (AFIC-CSIRO 1987). Wheat straw contains 1.7 g/kg DM and lupins 2.2 g/kg DM. A typical feedlot ration formulated to 14 per cent crude protein and comprising the following ingredients: 50 per cent straw, 18 per cent barley and 32 per cent lupins would contain approximately 1.68 g Ca/kg DM. As a rule of thumb, Underwood and Suttle (1999) suggest that performance of sheep should not be affected on any diet providing an average of 3 g Ca/kg DM throughout the year. This ration would have a Ca:P ratio of 0.55:1.0 mainly because cereal grains have a poor Ca:P ratio, often of the order of 1:4. Ruminants do not tolerate Ca:P ratios below 1.0:1.0 even though they can tolerate relatively high ratios of 3.0:1.0 even to 7.0:1.0. Therefore calcium is incorporated into feedlot rations in the form of limestone, lime or dicalcium phosphate to produce a Ca:P ratio in the ration in the range 1:1-2:1 (Underwood and Suttle 1999). For short-term feeding, as in finishing lambs, the addition of calcium salts may not be necessary (notwithstanding the risk of urolithiasis), as the homeostatic mechanisms within the body can adjust to a wide range in the Ca:P ratio (see section on phosphorus), and mobilise the large reserves present in bone. Sheep on a cereal grain-based diet for any length of time (for instance, drought feeding) should have a balanced Ca:P ratio to prevent loss of calcium from bone which leads to anorexia, pathologic fractures and predisposes to outbreaks of hypocalcaemia. An inclusion rate of 1.5 per cent limestone (i.e. 0.5% Ca) is commonly recommended in cereal-based diets (Ashby and Morbey 1997).

A poor Ca:P ratio in the diet can also predispose to struvite urinary calculi (magnesium ammonium phosphate) resulting in the condition recognised as 'Water belly' and death of the affected sheep, usually rams or wethers. Urinary calculi have been reported after periods of as little as 3 weeks on a cereal-based diet, although the deaths did not occur until 3 weeks after returning to normal paddock feed (E.G. Taylor 2003, pers. comm.).

Phosphorus

Phosphorus has a role, along with calcium, to maintain bone density and strength, and the bones act as a reservoir during short periods of reduced phosphorus intake. Cereal-based diets usually have an excess of phosphorus, as phosphorus (in the form of superphosphate) is added to soils when growing cereals, thus phosphorus deficiency should never arise when significant amounts of cereal concentrates are fed to sheep (Underwood and Suttle 1999). Dietary requirements for phosphorus are estimated factorially to be in the range of 2.0-2.8 g/kg DM.

Sheep can perform optimally when the Ca:P ratio is within the range of 1:1 to 7:1, due the bone reserves and homeostatic mechanisms. A Ca:P ratio less than this range (< 1:1) results in a severe reduction in performance, as does a ratio greater than this range (> 7:1) but not as severely. These wide ratios are best tolerated when the diet contains at least 2.6 g P/kg DM such as in the ration described above in the calcium section. Severe bone disorders develop when the ration contains only 0.8 g P/kg DM. Excess dietary phosphorus (> 4.6 g/kg DM) can predispose to struvite urinary calculi, but adjustment of the Ca:P ratio can ameliorate this risk (Rogers 2001). Phosphorus present as phytic acid or phytates does not influence the availability of P or other minerals such as calcium or zinc in ruminants because the phytates are degraded in the rumen.

Sodium

Sodium has a major role in maintaining the water balance of the body, in particular in homeostasis of intra- and extra-cellular osmolarity. Regulation of sodium and water homeostasis in the body is performed in the kidneys by altering the concentration of sodium within urine. Cereal grains are low in sodium, and feedlot rations often have salt (sodium chloride) added at the rate of 1.0 per cent. The ARC (1980) estimates that the sodium requirement for growing lambs is 0.6-0.7 g/kg DM, with the lower level applicable to higher growth rates.

The palatability of cereal grain rations can be improved by the addition of salt (Grovum and Chapman 1988). After several weeks on a low salt diet, rapidly growing lambs will develop inappetence and growth retardation (Underwood and Suttle 1999). The addition of salt may not be necessary in short-term finishing systems.

Sodium can also be added to rations in the form of buffers such as sodium bicarbonate (initially 1%, then reducing to 0.5%) or sodium bentonite (initially 2% reducing to 1%). The mechanism of action of these mineral buffers is the subject of much debate, as on a quantitative basis they are included in rations at a rate that would be insufficient to neutralise the lactic acid produced by fermentation of grain (Rowe 2003). It has been proposed that the buffering effect of these sodium salts is by their osmotic action, drawing water into the rumen and increasing rumen outflow rate. This results in an increase in rumen pH (Hutjens 1991). Sodium chloride could work in a similar manner.

Prevention of lactic acidosis due to the rapid fermentation of starch in cereal grains is a major aim of dietary management in feedlots, as this is the most common cause of reduced performance or death in sheep feedlots.

Use of salt will also aid in the prevention of urinary calculi of all compositions by promoting the excretion of dilute urine. In addition to struvite calculi, the other common calculi seen in sheep in feedlots are composed of silicates, a component of the husk of grains (especially oats) and the stems of rangeland grasses (including cereal hays).

When determining the inclusion rate of sodium (and calcium) in rations it is important to consider the content of these minerals in the water supply used within the feedlot, because saline or hard water contains these minerals.

Potassium

Generally diets for sheep are not potassium deficient, although cereal grains are in the range of 3-5 g/kg DM, and alkali-treated straws will have potassium levels lowered by 25 per cent. If non-protein nitrogen sources and leached straws are used in a cereal-based diet, a potential exists for potassium deficiency. Deficiency results in reduced appetite leading to reduced performance.

Dietary requirement for potassium for growing lambs have been estimated at 3-5 g/kg DM, although some reports suggest peak growth occurs at higher levels (up to 7 g/kg DM) (Underwood and Suttle 1999).

Major trace minerals - selenium, copper and cobalt

A deficiency of any of the trace minerals Se, Cu and Co may produce an illthrift syndrome in growing sheep, with a poor growth rate recognised as one sign of deficiency. Deficiencies of each of these minerals have been recognised in lambs and sheep grazing on pastures growing on leached, acidic soils such as in the south-west of Western Australia, Kangaroo Island, and Strathbogie Ranges (Victoria) and are frequently associated with lush springs (i.e. warm and wet with rapid pasture growth). Cereal grains, particularly oats and barley, and lupins can be extremely low in selenium (< 0.02 mg Se/kg DM) (Moir and Masters 1979). Selenium concentrations of pastures and hays are reduced by regular applications of superphosphate and inclusion of a significant proportion of legumes into the sward. A minimum selenium requirement of 0.05 mg/kg DM has been estimated factorially for lambs fed on a highly digestible diet (Grace 1994).

Most farmers now prophylactically treat sheep in selenium-deficient areas either in the short-term by inclusion of selenium in a drench or vaccination at marking, or the long-term by the use of intraruminal pellets or selenium fertilisers. Therefore, unless the sheep entering the feedlot are already suffering depletion of selenium reserves, a short period of feeding is unlikely to result in illthrift. Thus one potential deficiency scenario could be when lambs enter a feedlot after an excellent spring having only received a short-term selenium treatment or no treatment at all. Long-term feeding of deficient rations can deplete body reserves of selenium, so mineral supplementation of sheep in long-term feedlots would be necessary.

Diets based on dry feeds should not be supplemented with copper (Underwood and Suttle 1999). Dry feeds have more available copper than green pastures, so long-term supplementation could result in liver stores of copper approaching critical toxic levels. The estimated dietary requirement for copper is 4-6 mg Cu/kg DM, but this requirement is influenced by available sulphur, molybdenum and iron. Thiomolybdates (reduced complexes of sulphur and molybdenum) and high iron concentrations dramatically decrease the absorption of copper in functional ruminants. Nevertheless care should be taken to sustain the copper level at around 5 mg/kg DM to maintain crimp in wool. Complete diets containing over 15 mg Cu/kg DM can cause toxicity in sheep particularly in breeds such as the Texel and their crosses which are particularly susceptible to copper toxicity. Consumption of plants such as *Heliotropium europaeum* containing hepatotoxic alkaloids predisposes sheep to copper poisoning.

Cereal grains are poor sources of cobalt (Kennedy *et al.* 1992) with levels of 0.01-0.06 mg/kg DM that at best only approach the marginal requirements for growth defined at 0.05-0.08 mg/kg DM (Underwood and Suttle 1999). A single injection of 1 mg of hydroxycobalamin protected lambs for 14 weeks (Hannan *et al.* 1980) and therefore a treatment like this given to lambs prior to feedlot entry for short-term finishing may be all that is required. Diets should not contain greater than 30 mg Co/kg DM in order to avoid cobalt toxicity (ARC 1980).

Care should be taken when supplementing Se, Cu and Co into the diets of sheep. Over-supplementation with parenterally administered treatments would be especially dangerous since selenium toxicity can occur acutely in over-supplemented animals, and copper can also cause an acute toxicity syndrome resulting from an underlying chronic accumulation of copper in the liver (Radostits *et al.* 1994).

Minor trace minerals - manganese, zinc, iron and iodine

Manganese, zinc, iron and iodine may be included in mineral premixes used in Western Australian sheep feedlots. The reason for this is often based upon historical precedent. Both iron and zinc have biological half-lives of about 120 days in sheep, so should not become deficient in short-term finishing systems.

Dietary iodine should be within the range of 0.1-0.3 mg/kg DM for sheep. The main signs of a marginal deficiency are reduced growth rate and with a more severe deficiency, goitre (enlarged thyroid glands). Dietary goitrogens (such as those found in *Brassica* species of plants) and the minerals selenium and iron can increase requirements for iodine (Underwood and Suttle 1999).

Dietary requirements for iron in growing lambs are in the range of 25-40 mg/kg DM. Iron is abundantly available in most forages and grains. Cereal grains typically contain 30-60 mg/kg DM and oilseeds more, and although some grasses on sandy soils contain 'low' iron levels (30 mg/kg DM), southern Australian pastures are reported to have from 70-2300 mg/kg DM (Underwood and Suttle 1999). Iron deficiency results in anaemia, however it is extremely unlikely that deficiency of iron would occur in sheep in an outdoor feedlot.

Manganese requirements have been well defined for growing sheep and 13 mg Mn/kg DM is adequate for growth and wool production and 16 mg/kg DM for testicular growth (Masters *et al.* 1988). Deficiency results in skeletal abnormalities. Cereal grains contain from 8-43 mg/kg DM depending upon grain, but bran and pollard contain higher levels. Diets with manganese in the range of 8-20 mg/kg DM may show a response to supplementation.

Western Australian soils are recognised as zinc deficient, and crop growth rates can be improved with zinc fertilisers. Zinc requirements have been estimated at 8.8-27.0 mg/kg DM depending upon liveweight and growth rate. Autumn and winter pastures in Western Australia typically can contain less than 20 mg Zn/kg DM, and zinc supplementation can have a positive effect on lamb birth rates and weaning weights if administered to ewes in early pregnancy (Masters and Fels 1980). However, this effect is not universal. Masters and Fels (1980) reported that they were unable to repeat the result in the year following the original experiments. Cereal grains typically contain around 40 mg/kg DM depending upon soil zinc status. Cereal straws typically contain around one third of this, often less than 12 mg/kg DM. Zinc deficiency causes a severe and characteristic depression of appetite, which leads to reduced performance.

Possible carcase composition modifiers

Magnesium

The magnesium requirement of sheep varies from 0.7-1.8 g/kg DM (Underwood and Suttle 1999) depending on factors such as the amount of potassium in the diet, the ruminal pH and the presence of ammonium chloride. Magnesium is unusual amongst the minerals in that it is absorbed predominantly across the rumen wall against an electrochemical gradient. Potassium can increase the potential difference and consequently decrease the absorption of magnesium. Increases in ruminal ammonia also decrease magnesium absorption. Acid conditions in the rumen (such as pH 5.5) increase the absorption of magnesium. The extreme variability of magnesium absorption makes it difficult to define magnesium requirements for sheep. Moreover, magnesium is passively mobilised from bone under the influence of calcitrophic hormones such as parathyroid hormone and 1,25 dihydroxycholecalciferol (the active form of vitamin D) during periods of low blood calcium. Excess magnesium will be filtered and excreted from the kidney possibly predisposing to struvite urinary calculi. It is recommended to keep dietary magnesium below 0.23 per cent to prevent this (Rogers 2001).

Magnesium fed at 1.0 per cent DM as the oxide causmag (MgO which is 60% Mg) for 4 days prior to slaughter reduced the loss of muscle glycogen during lairage, and consequently reduced the incidence of dark, firm, dry meat (Gardner *et al.* 2001). This amount of magnesium is more than 3 times the highest requirement specification for magnesium and near the NRC (1985) tolerable limit for magnesium (5 g Mg/kg DM). Mild toxicity was observed at 14 g Mg/kg DM in sheep (Chester-Jones *et al.* 1989). However, the inclusion of 6 g/kg DM was for 4 days in the study by Gardner *et al.* (2001). Moreover, the degree of protection against incidence of dark cutting afforded by supplementing with magnesium was far less than the degree of protection afforded by the provision of a high carbohydrate diet prior to slaughter. Thus the use of magnesium to improve meat-eating quality will be one small part of a suite of management strategies to optimise carcase quality. Further study needs to be done to determine more precisely the optimum timing and rate of supplementation of magnesium to utilise this effect. Nevertheless care should be taken when supplementing with these pharmacological rates of magnesium especially since the feedlot rations are certainly likely to decrease ruminal pH and possibly increase ruminal ammonia.

Chromium

The dietary requirements of sheep for chromium have not been defined but appear to be increased by stress. Transportation, infection and strenuous exercise all increase urinary losses of chromium and can therefore increase requirements (Anderson 1987). Organic sources of chromium in the diet are absorbed 20 to 30 times more efficiently than inorganic sources (Starich and Blincoe 1983). Organic chromium in brewer's yeast has been termed 'glucose tolerance factor' because it can enhance the sensitivity of cells to insulin and similar forms have been reported in wheat. Gardner *et al.* (1998) fed two-year old Merino wethers rations based on barley and lupins at 2.2 times maintenance. The ration was supplemented with 1 mg/kg DM of chromium given as the organic form, chromium chelavite (an amino acid chelate). The sheep were also exercised regularly for 2 hours, 3 times per week to 60 per cent of VO_2 max. Chromium increased the sensitivity of cells to insulin through increases in activity of the enzyme, ATP citrate lyase, a key enzyme in fat synthesis from glucose. Instead of increasing fat synthesis as a result of stimulating this enzyme, the chromium led to a 20 per cent decrease in fat depth over the 12th rib (Gardner *et al.* 1998). The chromium treatment did not affect growth rate, carcase weight or muscle glycogen concentration (Gardner *et al.* 1998). If the sheep meat industry deems the issue to be important, it would be necessary to carry out further experiments to determine the optimum use of chromium to reduce fat deposition over the ribs of sheep.

Conclusions

In relation to mineral supplementation, there appears to be a divergence between what the scientific literature recommends and what is practiced in sheep feedlots. Commercial use of minerals is based upon 'what the customer wants' or commercial expectation, historical precedent, and as yet unproven scientific work. These variations may not have a significant effect on sheep performance in short-term finishing systems, but could prove significant if sheep are left on grain for periods beyond 3 to 4 weeks.

References

Anderson, R.A. (1987). 'Chromium'. In: *Trace Elements in Human and Animal Nutrition.* Mertz, W. (ed.). Academic Press, New York, pp. 225-244.

AFIC-CSIRO (1987). *Australian feed composition tables: National collection (1970-1987.* Ostrowski-Meissner, H.T. (ed.). Australian Feeds Information Centre, Sydney.

AFRC (1991). 'A reappraisal of the calcium and phosphorus requirements of sheep and cattle'. Technical Committee on Responses to Nutrients, Report Number 6. *Nutrition Abstracts and Reviews (Series B),* vol. 61, pp. 573-612.

ARC (1980). *Nutrient Requirements of Ruminants.* CAB, Farnham Royal.

Ashby, B. and Morbey, T. (eds) (1997) *Feeding Sheep.* Primary Industries and Resources SA., Adelaide.

Chester-Jones, H., Fontenot, J.P., Veit, H.P. and Webb, K.E. (1989). 'Physiological effects of feeding high levels of magnesium to sheep'. *Journal of Animal Science,* vol. 67, pp. 1070-1081.

Gardner, G.E., Pethick, D.W. and Smith, G. (1998). 'Effect of chromium chelavite supplementation on the metabolism of glycogen and lipid in adult Merino sheep'. *Australian Journal of Agricultural Research,* vol. 49, pp. 137-145.

Gardner, G.E., Jacob, R.H. and Pethick, D.W. (2001). 'The effect of magnesium oxide supplementation on muscle glycogen metabolism before and after exercise and at slaughter in sheep'. *Australian Journal of Agricultural Research,* vol. 52, pp. 723-729.

Grace, N.D. (1994). *Managing Trace Element Deficiencies.* New Zealand Pastoral Agricultural Research Institute, Palmerston North.

Grovum, W.L. and Chapman, H.W. (1988). 'Factors affecting the voluntary intake of food by sheep. 4. The effect of additives representing the primary tastes on sham intakes by oesophageally fistulated sheep'. *British Journal of Nutrition,* vol. 59, pp. 63-72.

Hannan, R.J., Judson, J.G., Reuter, D.J., McLaren, L.D. and McFarlane, J.D. (1980). 'Effects of vitamin B_{12} injections on the growth of young Merino sheep'. *Australian Journal of Agricultural Research,* vol. 31, pp. 347-355.

Hutjens, M.F. (1991). 'Feed Additives'. *Veterinary Clinics of North America: Food Animal Practice,* vol. 7, pp. 525-540.

Kennedy, D.G., Young, P.B, McCaughey, W.J., Kennedy, S. and Blanchflower, W.J. (1992). 'Cobalt-vitamin B_{12} deficiency decreases methionine synthase activity and phospholipid methylation in sheep'. *Journal of Nutrition,* vol. 12, pp. 1384-1390.

Masters, D.G., Paynter, D.I., Briegel, J., Baker, S.K. and Purser, D.B. (1988). 'Influence of manganese intake on body, wool and testicular growth of young rams and on the concentration of manganese and the activity of manganese enzymes in the tissues'. *Australian Journal of Agricultural Research,* vol. 39, pp. 517-524.

Masters, D.G. and Fels, H.E. (1980). 'Effect of zinc supplementation on the reproductive performance of grazing Merino ewes'. *Biological Trace Element Research,* vol. 2, pp. 281-290.

Moir, D.C. and Masters, H.G. (1979). 'Hepatosis dietetica, nutritional myopathy, mulberry heart disease and associated hepatic selenium levels in pigs'. *Australian Veterinary Journal,* vol. 55, pp. 360-364.

NRC (1985). *Nutrient requirements of sheep.* Subcommittee on Sheep Nutrition, Committee on Animal Nutrition, Board on Agriculture, National Research Council, 6th rev. edn, National Academy Press, Washington, DC.

Radostits, O.M., Blood, D.C. and Gay, C.C. (1994). *Veterinary Medicine.* Bailliere Tindall, London.

Rogers, P. (2001). 'Urinary calculi in lambs and calves' [WWW document]. URL http://homepage.tinet.ie/~progers/calculi.htm (accessed 31/3/04).

Rowe, J. (2003). 'Fermentative acidosis and gut function in sheep'. In: *Proceedings of the Australian Sheep Veterinary Society 2003 - Cairns Conference.* Australian Sheep Veterinary Society, Indooroopilly, vol. 13, pp. 8-14.

Starich, G.H. and Blincoe, C. (1983). 'Dietary chromium - forms and availabilities'. *The Science of the Total Environment,* vol. 28, pp. 443-454.

Underwood, E.J. and Suttle, N.F. (1999). *The Mineral Nutrition of Livestock.* 3rd edn, CABI Publishing, Oxon.

Feeding grain for sheep meat production

Chapter 4. Nutritional characteristics of cereal grains

V. Beretta and R.M. Kirby

CHAPTER 4. NUTRITIONAL CHARACTERISTICS OF CEREAL GRAINS

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Characteristics of cereal grains

Feed grains are a major source of nutrients for sheep meat production. Winter cereal grains, barley, wheat and oats comprised 54, 16 and 8 per cent, of the total amount of grain consumed by ruminants in Australia during 1990-1991 (Schaefer and Kreitals 1991). Summer cereal grains, sorghum and maize are used extensively for animal feeding in other countries of the world but little used for feeding sheep in Australia (QDPI 2004). The choice of grain used for livestock production is determined mainly by agro-ecological and market differences between regions and the volume of research on each grain reflects the level of use by industry.

Feeding grain to growing and finishing lambs to achieve potential liveweight gains and carcase targets has increased the demand for information about the benefit of including different types of grain in rations. Cereal grains vary in their nutritive value. Part of this variation is associated with differences in chemical and physical properties but some variation will also depend on the interaction between grains and animal characteristics. For example, the level of intake, feeding management, grain to forage ratio, feed processing and adaptation period can all influence the level of nutrients that the animal obtains from grain. Quantitative data of the expected liveweight gain, feed conversion ratio and carcase characteristics associated with various grains under different feeding systems are necessary to evaluate the potential economic benefit of their utilisation.

Table 4.1. Nutrient content and structure of different cereal grains.

Chemical composition[1]	Units	Wheat	Barley	Oats	Maize	Sorghum
Metabolisable energy	MJ/kg DM	13.0	11.6	10.5	13.5	12.4
Crude protein	% DM	13.0	12.0	11.0	10.0	10.0
Rumen undegradable protein[2]	% CP	18	25	30	55	55
Acid detergent fibre	% DM	2.6	5.3	14.0	2.4	2.8
Starch[3]	% DM	70.3	64.3	58.1	75.7	71.3
Ca	% DM	0.04	0.08	0.07	0.02	0.02
P	% DM	0.36	0.37	0.39	0.35	0.30
Grain Structure[4]						
Hulls	% DM		13.0	25.0		
Testa+ pericarp+ aleurone	% DM	15.0	7.7	9.0	6.0	7.9
Starchy endosperm	% DM	82.4	76.2	63.0	82.0	82.3
Embryo	% DM	2.6	3.0	3.0	12.0	9.8

[1] Cottle (1991), Agriculture NSW (2004); [2] Neutze (1991); [3] Herrera-Saldana *et al.* (1990); [4] Evers *et al.* (1999).

The nutritional value of grain can vary widely due to environmental influences such as location and season. For comparative purposes, average chemical composition for winter and summer cereal grains is presented (Table 4.1). Cereal grains consist of the embryo, endosperm, testa or seedcoat and pericarp. The dominant tissue of the grain is the endosperm. The endosperm represents approximately 82 per cent of the mass of wheat, maize and sorghum grain and less in barley and oats due to the presence of hulls (Table 4.1). The endosperm predominantly contains cells filled with starch but has an increasing concentration of protein toward the periphery. Wheat has a relatively high proportion of protein in the endosperm (8-16%, Evers *et al.* 1999) compared to other cereals and the endosperm cells of oats have a relatively high lipid content. The structure of starch granules characteristically differs between cereal grains and this contributes to variation in starch degradation rates between grains.

In general, the metabolisable energy of wheat and maize are higher than sorghum and barley, while oat grain has the lowest metabolisable energy of all cereal grains. Protein content of the winter cereals is generally higher than for maize and sorghum.

Starch concentration per unit of dry matter is higher for wheat, maize and sorghum than for barley or oats (Table 4.1). This is a consequence of the greater relative importance of the starchy endosperm in the whole grain and to the absence of hulls (Table 4.1, Evers *et al.* 1999). Variation in total starch content may be observed between hybrids and varieties and also associated with changes in agronomic practices, such as plant density or to varying environmental conditions during growth (Defoor *et al.* 2000, 2001). O'Brien (1999) reported important year and location effects, and genotype × environment interactions on the nutritive value of grains. Maize and sorghum registered the lowest coefficients of variation in terms of starch content (2.4 and 3.7% respectively) when compared to wheat, barley and oats (4.1%, 5.2%, 7.1%) as reported by Herrera-Saldana *et al.* (1990). Higher variability for oats compared to other grains has also been reported by Moran (1986).

Winter and summer cereals differ in the rate of fermentation of dry matter, protein and starch, and also the site and extent of digestion. Only 17-27 per cent of protein from winter cereal grains bypasses the rumen. In comparison, more than half of maize and sorghum protein is not degraded in the rumen and passes intact to the small intestine (Table 4.1). Because of this, some authors have suggested that adjustments in terms of rumen degradable protein might be necessary when feeding whole grain diets based on maize or sorghum (Loe *et al.* 2000, 2001).

The rate and extent of rumen fermentation of starch from maize and sorghum are lower than those observed for wheat, barley or oats (Bird *et al.* 1999). The digestibility of starch is influenced by the structure and composition of the granules and the nature of the protein matrix that surrounds the starch granules (Rooney and Pflugfelder 1986). Several reviews have focused on this aspect describing starch differences between cereal grains and the effect on digestion (Huntington 1997; Rooney and Pflugfelder 1986).

The rate of production of fermentation products of different species of grain have been characterised using an *in vitro* gas production technique (Opatpatanakit *et al.* 1994). Gas production was highest in wheat > triticale > oats > barley > maize > rice and sorghum, indicating that rate of fermentation is lower for sorghum and maize than for winter cereals. Variations due to varietal differences (mostly related to horny/floury endosperm ratio or to tannin content) and region of production of the grains were observed. *In situ* trials show that the soluble fraction and rate of fermentation of starch in the rumen is significantly lower for maize and sorghum than for wheat and barley (Herrera-Saldana *et al.* 1990). Although oat grain has a low rate of fermentation, the starch is almost completely degraded (96.6%) (Herrera-Saldana *et al.* 1990). *In vitro* trials by the same authors confirm that after oats, wheat and barley, sorghum and maize rank as the cereal grains with the lowest starch ruminal availability. This lower rate of rumen degradation reduces the risk of acidosis and related metabolic disorders in sheep. Hence maize and sorghum are comparatively safer than barley (Keating *et al.* 1965) or wheat (Kreikemeier *et al.* 1987) when fed in high concentrate rations to sheep.

Processing grains for sheep

The primary purpose of processing grain is to improve the utilisation of cereal starch by gelatinising the starch to allow more effective microbial digestion or to reduce particle size to increase surface area for amylolytic attack. However, the whole-tract digestibility of cereal starch by sheep approaches 100 per cent for common feed grains so there is limited potential for increasing the efficiency of digestion of grains (Table 4.2). This has been noted in many comprehensive reviews (e.g. Hale 1973; Ørskov 1976, 1986; Rowe *et al.* 1999; Rowe and Pethick 1994; Theurer 1986).

Table 4.2. Starch digestion by sheep of whole or minimally processed cereal grain.

	Treatment	Whole tract digestibility (% of starch intake)	Fermented in rumen (% of starch intake)	Reference
Barley	Whole		95	(MacRae and Armstrong 1969)
	Rolled		97	(MacRae and Armstrong 1969)
	Rolled	100	93	(Ørskov *et al.* 1969)
Maize	Whole	97		(Hejazi *et al.* 1999)
	Flaked	100	96	(Beever *et al.* 1970)
Sorghum	Rolled	97	89	(Holmes *et al.* 1970)
	Coarse ground	93		(Buchanan-Smith *et al.* 1968)
		97	85	(Rowe *et al.* 1999)

The increase in digestion by cattle of processed grain over whole grain is well documented (e.g. Huntington 1997 for review). In comparison, whole grain is utilised effectively by sheep due to efficient mastication. Ørskov *et al.* (1974a) evaluated the chewing behaviour of lambs given whole loose or pelleted barley and observed that for the same grain intake, those lambs fed with whole loose barley, spent significantly more time ruminating and regurgitated more boluses of rumen digesta. This effect has been reported not only for lambs but also for ewes (Vipond *et al.* 1985).

There is little response in either starch digestibility (Table 4.2) or dry matter digestibility (Table 4.3) when cereal grains are processed prior to feeding to sheep. Vipond *et al.* (1985) reported an increase in digestibility of rolled barley but not rolled oats compared to the same grain fed whole. In contrast, other authors report no increase, and sometimes even a decrease in digestibility of starch, digestibility of dry matter or animal performance with increasing level of grain processing (Beever *et al.* 1970; Fluharty *et al.* 1999; Hart and Glimp 1991; Hejazi *et al.* 1999; MacRae and Armstrong 1969; Ørskov *et al.* 1969, 1974b).

Table 4.3. Dry matter digestion by sheep of whole or processed cereal grain.

	Digestion of dry matter (%)[1]		Reference
	Whole	Processed	
Wheat	84	88	(Ørskov *et al.* 1974b)
Barley	83	79	(Ørskov *et al.* 1974b)
	68	83	(Vipond *et al.* 1980)
Oats	71	69	(Ørskov *et al.* 1974b)
	72	76	(Vipond *et al.* 1980)
Maize	81		(Vipond *et al.* 1980)
	86	84	(Ørskov *et al.* 1974b)
	86	81	(Hart and Glimp 1991)

[1] Adapted from organic matter digestibility where necessary, by assuming all grains contain 98% organic matter on a dry matter basis.

The extent of starch digestion is not affected by processing, but the rate of starch fermentation is increased when cereal grains are processed, thus increasing the risk of acidosis. Feeding whole grain is beneficial for rumen health compared to feeding processed grain (Ørskov 1976, 1979, 1986). Compared to processed grain, whole grain is fermented more slowly, animals spend more time eating and ruminating and there is higher saliva production and consequently higher rumen pH (Weston 1979). Additional stimulation of rumination through the addition of supplementary fibre to whole grain diets has been shown to further improve the performance of lambs fed whole grain. Hejazi *et al.* (1999) reported that adding soybean hulls or peanut hulls to a whole maize diet increased intake and daily gain, compared to high concentrate diets lacking supplemental fibre. Similarly, Weston (1974) showed an increase in feed intake when straw content of whole wheat diets was increased from 2 per cent to 14 per cent.

Processing does not increase the efficiency of grain utilisation by sheep but it may be desirable to develop processing methods that alter the site of digestion of starch. Starch that bypasses the rumen is available for digestion in the small intestine. The two main objectives for shifting the site of digestion of starch to the small intestine of sheep have been discussed by Rowe *et al.* (1999). It is more energetically efficient for starch to be digested and absorbed as glucose rather than fermented in the rumen with subsequent loss of energy as heat, methane or hydrogen (Black 1971) and the absorbed glucose may promote intra-muscular fat deposition (Pethick *et al.* 1997).

Sorghum shows the most potential for strategic processing to manipulate the site of digestion due to the resistant nature of starch in this grain. The deposition of fat indicated by activity of ATP citrate lyase is higher when sheep are fed steam-flaked sorghum compared to whole sorghum (Pethick *et al.* 1995). Starch from processed sorghum is available for absorption in the small intestine, which increases the amount of absorbed glucose and stimulates fat deposition. The processing method can affect the extent of starch digestion in the small intestine. For example, Mendoza *et al.* (1999) reported that the amount of starch escaping rumen fermentation was 47.1 per cent for dry rolled sorghum compared to only 11 per cent bypass starch reported for steam-rolled sorghum (Holmes *et al.* 1970). Carcase fat characteristics may also be manipulated by exploiting the natural variation in starch characteristics between cereal grains. Stimulation of ATP citrate lyase was greater for maize-based diets than for diets of whole barley, sorghum or wheat (Pethick *et al.* 1995).

References

Agriculture NSW (2004). 'Nutritive value of feeds, database' [WWW document]. URL http://www.agric.nsw.gov.au/feedbase (accessed 31/3/04).

Beever, D.E., Coehlo da Silva, J.F. and Armstrong, D.G. (1970). 'The effect of processing maize on its digestion in sheep'. *Proceedings of the Nutrition Society,* vol. 29, pp. 43A-44A.

Bird, S.H., Rowe, J.B., Choct, M., Stachiw, S., Tyler, P. and Thompson, R.D. (1999). '*In vitro* fermentation of grain and enzymatic digestion of cereal starch'. *Recent Advances in Animal Nutrition in Australia,* vol. 12, pp. 53-61.

Black, J.L. (1971). 'A theoretical consideration of the effect of preventing rumen fermentation on the efficiency of utilisation of dietary energy and protein in lambs'. *British Journal of Nutrition,* vol. 25, pp. 31-55.

Buchanan-Smith, J.G., Totusek, R. and Tillman, A.D. (1968). 'Effect of methods of processing on digestibility and utilisation of grain sorghum by cattle and sheep'. *Journal of Animal Science,* vol. 27, pp. 525-530.

Cottle, D.J. (1991). *Australian Sheep and Wool Handbook.* Inkata Press, Melbourne.

Defoor, P.J., Cole, N.A., Galyean, M.L. and Jones, P.J. (2001). 'Effects of grain sorghum planting density and processing method on nutrient digestibility and retention by ruminants'. *Journal of Animal Science,* vol. 79, pp. 19-25.

Defoor, P.J., Galyean, M.L., Cole, N.A. and Jones, P.J. (2000). 'Effects of planting density and processing method on laboratory characteristics of grain sorghum for ruminants'. *Journal of Animal Science,* vol. 78, pp. 2032-2038.

Evers, A.D., Blakeney, A.B. and O'Brien, L. (1999). 'Cereal structure and composition'. *Australian Journal of Agricultural Research,* vol. 50, pp. 629-650.

Fluharty, F.L., Lowe, G.D. and Clevenger, D.D. (1999). 'Effects of feed-delivery system and corn processing on lamb growth and carcass characteristics'. In: *Research and Reviews: Beef and Sheep, Special Circular*, Ohio State University, pp. 170-199. [WWW document]. URL http://ohioline.osu.edu/sc170/sc170_16.html (accessed 15/3/04).

Hale, W.H. (1973). 'Influence of processing on the utilisation of grains (starch) by ruminants'. *Journal of Animal Science,* vol. 37, pp. 1075-1080.

Hart, S.P. and Glimp, H.A. (1991). 'Effect of diet composition and feed intake level on diet digestibility and ruminal metabolism in growing lambs'. *Journal of Animal Science,* vol. 69, pp. 1636-1644.

Hejazi, S., Fluharty, F.L., Perley, J.E., Loerch, S.C. and Lowe, G.D. (1999). 'Effects of corn processing and dietary fibre source on feedlot performance, visceral organ weight, diet digestibility, and nitrogen metabolism in lambs'. *Journal of Animal Science,* vol. 77, pp. 507-515.

Herrera-Saldana, R.E., Huber, J.T. and Poore, M.H. (1990). 'Dry matter, crude protein and starch degradability of five cereal grains'. *Journal of Dairy Science,* vol. 73, pp. 2386-2393.

Holmes, J.H.G., Drennan, M.J. and Garrett, W.N. (1970). 'Digestion of steam-processed milo by ruminants'. *Journal of Animal Science,* vol. 31, pp. 409-413.

Huntington, G.B. (1997). 'Starch utilisation by ruminants: From basics to the bunk'. *Journal of Animal Science,* vol. 75, pp. 852-867.

Keating, E.K., Saba, W.J., Hale, W.H. and Taylor, B. (1965). 'Further observation on the digestion of milo and barley by steers and lambs'. *Journal of Animal Science,* vol. 24, pp. 1080-1085.

Kreikemeier, K.K., Stock, R.A., Brink, D.R. and Britton, R.A. (1987). 'Feeding combinations of dry corn and wheat to finishing lambs and cattle'. *Journal of Animal Science,* vol. 65, pp. 1647-1654.

Loe, E.R., Bauer, M.L., Lardy, G.P., Berg, G.T. and Moore, B.L. (2000). 'Addition of rumen degradable and undegradable protein to corn-based lamb finishing diets' [WWW document]. URL http://www.ag.ndsu.nodak.edu/hettinge/livestock/2000sheepday/9905Bsheepday.htm (accessed 15/3/04).

Loe, E.R., Encinias, A.M., Bauer, M.L., Lardy, G.P. and Caton, J.S. (2001). 'Level of rumen degradable intake protein (DIP) in high-grain diets fed to feedlot lambs' [WWW document]. URL http://www.ag.ndsu.nodak.edu/hettinge/livestock/2001sheepday/loe.htm (accessed 15/3/04).

MacRae, J.C. and Armstrong, D.G. (1969). 'Studies on intestinal digestion in the sheep 2. Digestion of some carbohydrate constituents in hay, cereal and hay-cereal rations'. *British Journal of Nutrition,* vol. 23, pp. 377-387.

Mendoza, G.D., Britton, R.A. and Stock, R.A. (1999). 'Effect of feeding mixtures of high moisture corn and dry-rolled grain sorghum on ruminal fermentation and starch digestion'. *Small Ruminant Research,* vol. 32, pp. 113-118.

Moran, J.B. (1986). 'Cereal grains in complete diets for dairy cows: A comparison of rolled barley, wheat and oats and of three methods of processing oats'. *Animal Production,* vol. 43, pp. 27-36.

Neutze, S.A. (1991). 'Degradation of feed protein in the rumen: Degradability of common feeds and factors affecting degradation'. *NSW Agriculture, Advisory Bulletin*, Agdex 400/54.

O'Brien, L. (1999). 'Genotype and environment effects on feed grain quality'. *Australian Journal of Agricultural Research,* vol. 50, pp. 703-719.

Opatpatanakit, Y., Kellaway, R.C., Lean, I.J., Annnison, G. and Kirby, A. (1994). 'Microbial fermentation of cereal grain *in vitro'. Australian Journal of Agricultural Research,* vol. 45, pp. 1247-1263.

Ørskov, E.R. (1976). 'The effect of processing on digestion and utilisation of cereals by ruminants'. *Proceedings of the Nutrition Society,* vol. 35, pp. 245-252.

Ørskov, E.R. (1979). 'Recent information on processing of grain for ruminants'. *Livestock Production Science,* vol. 6, pp. 335-347.

Ørskov, E.R. (1986). 'Starch digestion and utilisation in ruminants'. *Journal of Animal Science,* vol. 63, pp. 1624-1633.

Ørskov, E.R., Fraser, C. and Gordon, J.G. (1974a). 'Effect of processing of cereals on rumen fermentation, digestibility, rumination time, and firmness of subcutaneous fat in lambs'. *British Journal of Nutrition,* vol. 32, pp. 59-69.

Ørskov, E.R., Fraser, C. and Kay, R.N.B. (1969). 'Dietary factors influencing the digestion of starch in the rumen and small and large intestine of early weaned lambs'. *British Journal of Nutrition,* vol. 23, pp. 217-226.

Ørskov, E.R., Fraser, C. and McHattie, I. (1974b). 'Cereal processing and food utilisation by sheep 2. A note on the effect of feeding unprocessed barley, maize, oats and wheat on food utilisation by early-weaned lambs'. *Animal Production,* vol. 18, pp. 85-88.

Pethick, D.W., McIntyre, B.L., Tudor, G. and Rowe, J.B. (1997). 'The partitioning of fat in ruminants - can nutrition be used as a tool to regulate marbling'. *Recent Advances in Animal Nutrition in Australia,* vol. 11, pp. 151-158.

Pethick, D.W., Rowe, J.B. and McIntyre, B.L. (1995). *Feeding systems for increasing marbling in cattle.* Meat Research Corporation, Final Report DAW.053, Murdoch University, Perth.

QDPI (2004). 'A guide to sorghum production in Queensland' [WWW document]. URL http://www.dpi.qld.gov.au/fieldcrops/8729.html (accessed 31/3/04).

Rooney, L.W. and Pflugfelder, R.L. (1986). 'Factors affecting starch digestibility with special emphasis on sorghum and corn'. *Journal of Animal Science,* vol. 63, pp. 1607-1623.

Rowe, J.B., Choct, M. and Pethick, D.W. (1999). 'Processing cereal grains for animal feeding'. *Australian Journal of Agricultural Research,* vol. 50, pp. 721-736.

Rowe, J.B. and Pethick, D.W. (1994). 'Starch digestion in ruminants - problems, solutions and opportunities'. *Proceedings of the Nutrition Society of Australia,* vol. 18, pp. 40-52.

Schaefer, K. and Kreitals, J. (1991). 'Feed grains: The challenge and the opportunity'. In: *Grains 2000 Conference.* Grains Council of Australia, Canberra, pp. 1-9.

Theurer, C.B. (1986). 'Grain processing effects on starch utilisation by ruminants'. *Journal of Animal Science,* vol. 63, pp. 1649-1662.

Vipond, J.E., Abdulla, S.A. and King, M.E. (1980). 'The value of processing cereal grains for sheep'. *Animal Production,* vol. 30, pp. 487-488.

Vipond, J.E., Hunter, E.A. and King, M.E. (1985). 'The utilisation of whole and rolled cereals by ewes'. *Animal Production,* vol. 40, pp. 297-301.

Weston, R.H. (1974). 'Factors limiting the intake of feed by sheep VIII. The roughage requirement of the ruminant lamb fed on concentrate diets based on wheat'. *Australian Journal of Agricultural Research,* vol. 30, pp. 553-541.

Weston, R.H. (1979). 'Factors limiting the intake of feed by sheep IX. Further studies of the roughage requirement of the ruminant lamb fed on concentrate diets based on wheat'. *Australian Journal of Agricultural Research,* vol. 30, pp. 553-541.

Feeding grain for sheep meat production

Chapter 5. Feeding grain to grazing sheep

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CHAPTER 5. FEEDING GRAIN TO GRAZING SHEEP

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Introduction

Sheep grazing paddock feed can be fed grain for backgrounding prior to entry into feedlots for finishing, or for the purpose of finishing prior to slaughter. Paddock feed may consist of crop stubbles, senesced annual pastures or perennial pastures. Characteristically the nutrients most limiting in dry paddock feed are the macronutrients energy and protein, although mineral and vitamin limitations may exist as well (Purser 1983). Grain is an appropriate feed supplement for finishing or backgrounding lambs on paddock feed because it contains both energy and protein. This facilitates the utilisation of feed that would otherwise be of variable or low nutritive value to sheep (Purser and Southey 1984). Sheep grazing paddock feed generally have no requirement for fibre from other sources such as hay or silage because their fibre intake is already high.

This chapter provides a brief account of the current state of knowledge of the nutritive value of paddock feed, the liveweight patterns of sheep grazing paddock feed and the response of sheep fed grain whilst grazing paddock feed.

Nutritive value of dry paddock feed

Stubbles

In Australia the area sown to crops is in the order of 11.5 million ha for wheat, 3.7 million ha for barley 784,000 ha for oats, 1.1 million ha for lupins, 823,000 ha for grain sorghum and 1.3 million ha for canola (Anonymous 2001). There are regional differences for crop plantings; in particular grain sorghum is produced mainly in Queensland and New South Wales and lupins are produced mainly in Western Australia. Potentially all of these areas are available for grazing with sheep although farmers may elect not to graze stubbles under certain farming systems. A major benefit of grazing stubbles is utilisation of residual grain that otherwise would be left in the paddock. Upon germination, residual grain may become a weed problem or act as a disease bridge to subsequent crops in some farming systems. Another benefit of utilising grain from stubbles is to introduce sheep to starch diets with a relatively low risk of acidosis, before exposing them to finishing diets containing high levels of starch. This applies particularly to wheat, barley and pea stubbles because the grains of these crop varieties contain high levels of starch.

Stubbles are characteristically heterogeneous in composition because they consist of some components that are high in nutritive value and other components that are low in nutritive value for grazing sheep. Residual grain has the highest nutritive value followed by leaf, cocky chaff (seed husks) and stem material. Sheep tend to consume the high value components preferentially to the low value components such that the nutritive value of stubble paddocks reduces progressively with grazing time. This effect is evident when sheep graze both cereal and lupin stubbles (Table 5.1 and 5.2).

Table 5.1. The consumption and quality of the various components of wheat stubble grazed by sheep (Rowe *et al.* 1989).

Stubble component	Initial quantity (kg/ha)	Final quantity (kg/ha)	Utilisation (%)	Initial digestibility (%)	Final digestibility (%)	Initial protein content (%)	Final protein content (%)
Grain	34	0.2	99.4	80.9	64.6	14.3	11.4
Weeds	220	54	75.4	39.3	47.6	7.3	9.1
Leaf and chaff	550	440	20.0	58.2	49.3	6.2	5.7
Stem	1380	910	34.1	45.3	42.1	3.0	3.2

In the studies of Rowe *et al.* (1989) and Dunlop (1984) the preferential selection of the various components of the stubble was shown to relate to their nutritive values. The grain component which had the highest protein content and digestibility also had the highest utilisation percentage (Table 5.1 and 5.2).

Table 5.2. The dietary selection of the various components of lupin stubble grazed by sheep (Dunlop 1984).

Stubble component	Digestibility (%)	Protein content (%)	Initial quantity (kg/ha)	Final quantity (kg/ha)	Utilisation
Grain	85	30.2	250	7	93.2
Pod	55	2.6	545	260	52.3
Leaf	52	10.4	660	109	83.4
Stem	44	6.4	1054	903	14.3

Of the different stubble components, stem material has the lowest nutritive value and is present in the largest quantities (Table 5.1). For cereal stubbles the nutritive value of stem material depends on a number of factors including species, variety, soil type, and rainfall zone. Stem material from oats and barley is generally more digestible than that of wheat; stubbles grown on heavy soils are more digestible than stubbles grown on light soils and stubbles from low rainfall regions are more digestible than stubbles from high rainfall regions (Aitchison *et al.* 1986). Techniques to improve utilisation of stem material by harvesting it and treating it with sodium hydroxide (alkalage) or urea have been studied in the past. Sodium hydroxide improves the digestibility of straw by hydrolysing ester bonds between lignin and hemicellulose. Urea acts principally by supplying non-protein nitrogen although it has some alkaline activity as well (Morrison 1974; Southey 1981). Techniques to improve straw are difficult and expensive to implement and results have been more variable for sheep than for cattle. Grazing is still the most cost effective way for sheep to use stubbles.

Liveweight responses of sheep grazing stubble

The pattern of liveweight change characteristically consists of an initial period during which liveweight may increase, followed by a period during which liveweight decreases (Figure 5.1). This pattern of liveweight change has been attributed to the heterogeneous nature of stubbles and the selective grazing pattern of sheep (Jacob 1984). When sheep commence grazing a stubble paddock they select a diet that is relatively high in grain and leaf material (Table 5.1 and 5.2). Selective depletion of leaf material and grain results in a decline in the value of the material left for grazing to below the maintenance requirements of the sheep for energy and protein. The sheep will lose liveweight if they are not fed grain after this initial period.

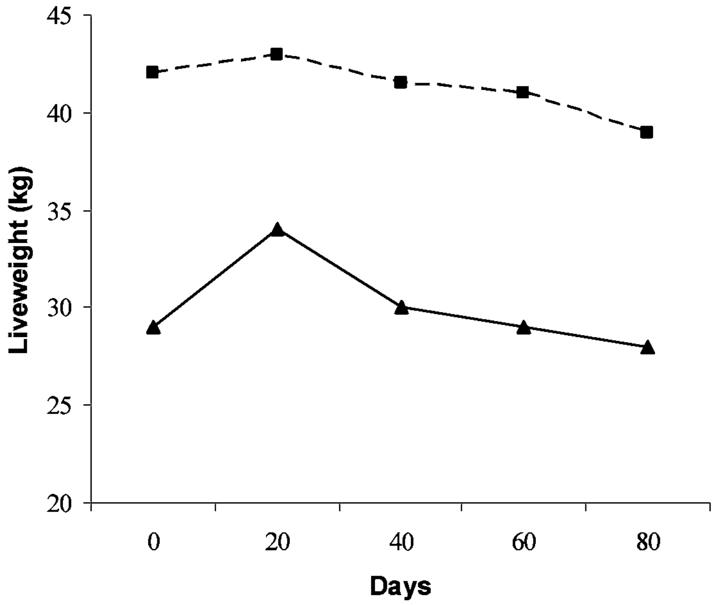

Figure 5.1. **The liveweight change of sheep grazing wheat stubble (▲) at 10 head/ha and barley stubble (■) at 18 head/ha (Coombe *et al.* 1987).**

The length of time for liveweight gain at the beginning of grazing varies. Croker (K.P. Croker 2003, pers. comm.) measured the residual grain in stubbles in 2002 across the agricultural region of Western Australia and found that the average quantity of wheat grain in these stubbles was 94 kg/ha. It can be hypothesised that if the average grain intake of sheep was 1 kg/head/day then a 94 kg/ha grain reserve would last for 9.4 days when the paddock was stocked at the rate of 10 head/ha. This agrees with anecdotal evidence that the period of weight gain for sheep grazing stubbles often lasts for about 2 weeks. The initial period of liveweight gain can be used as a strategy for backgrounding lambs, provided they are moved to fresh ungrazed stubbles before liveweight loss occurs.

When the grazing period extends beyond the time required for sheep to consume the residual grain, the mean liveweight change for sheep grazing stubbles is often negative because the remaining stubble components are low in protein and energy. Liveweight changes reported for sheep grazing wheat stubbles have ranged from a loss of 176 g/day for animals grazing stubble at 10 head/ha (Rowe and Ferguson 1986) to a gain of 65 g/day for animals grazing stubble at 15 head/ha (Mulholland *et al.* 1976). However, the wheat stubble used by Rowe and Ferguson (1986) had been grazed by ewes at the stocking rate of 8 head/ha for 3 weeks before the trial started. Thus much of the residual grain would have been consumed reducing the total nutritional value of the stubble available before the trial commenced. In the trial of Mulholland *et al.* (1976), significant summer rainfall maintained the growth of green material in the stubble throughout the trial, above 1000 kg/ha at one point, and this green feed was heavily selected for.

Chaff heaps

A practice used to manage herbicide resistance is to dump the chaff effluent from harvesting machines into discrete 'chaff heaps'. This limits the distribution of herbicide resistant weed seeds and the heaps can be burnt, moved or grazed in the paddock. The nutritive value of chaff heaps varies from 7-10 MJ/kg of metabolisable energy and 4-10 per cent crude protein on a dry matter basis depending on the stubble. Therefore chaff heaps may be able to maintain the liveweight of adult dry sheep for short periods of time. Studies have shown that chaff heaps improve the utilisation of stubbles by grazing sheep, particularly if the heaps are placed away from water points (Roberts and Devenish 2001).

Rainfall

Rainfall is usually detrimental to the nutritive value of paddock feed. Rain causes leaching of water soluble nutrients from feed material (Purser 1983) whilst microbial action and oxidation may further degrade it (Brown 1977). Grain may be buried by rain and become less accessible to grazing sheep although the nutritive value of this grain may be unaffected by the rain. However if the rainfall has been sufficient to cause germination of weeds then the liveweight of sheep grazing the stubble may subsequently increase. Mulholland *et al.* (1976) found that if the weight of the green feed was above 40 kg of DM/ha it made up 80 per cent of the diet selected by the sheep. The liveweight change of sheep grazing wheat stubbles at two stocking rates where the weeds had been killed by an application of herbicide were -19 g/day for 15 head/ha and -75 g/day for 30 head/ha. In contrast, liveweight changes for sheep grazing wheat stubbles at the same two stocking rates where the weeds had not been killed, were 13 g/day and -32 g/day. Small amounts of green material may have a complementary effect on forage intake.

Stocking rate

Stocking rate will affect the liveweight response of sheep grazing stubbles. This was demonstrated by Mulholland *et al.* (1976) who showed that when lambs grazing oat stubble were stocked at 15 head/ha they grew at the rate of 71 g/day, whereas lambs that lost weight at the rate of 71 g/day were stocked at twice the stocking rate (30 head/ha) and were grazing oat stubble that had been sprayed to kill the green weeds (Table 5.3).

Table 5.3. The performance of first-cross Border Leicester x Merino lambs grazing oat stubble at different stocking rates and for different grazing periods (Mulholland *et al.* 1976).

Age (months)	Weight change (g/day)	Stocking rate (head/ha)	Grazing days	Initial weight (kg)	Final weight (kg)
17	50	13	110	30.8	36.3
17	-5	26	110	30.8	30.3
10	49	15	92	30.7	35.2
10	-43	30	92	30.7	26.7
16	6	15	77	36.0	36.5
16	-71	30	77	36.0	30.5
16	71	15	77	36.0	41.5
16	-13	30	77	36.0	35.0

Cereal stubbles

Although stem material from barley and oat stubbles may have a higher digestibility than that from wheat stubbles (Aitchison *et al.* 1986), its nutritive value is generally below the maintenance requirements of lambs. Similar liveweight responses have been observed for lambs grazing barley, oat and wheat stubbles. For example, Coombe *et al.* (1987) reported liveweight changes of -62 g/head/day and -115 g/head/day in 17-month old Merino wethers grazing barley stubbles for 84 days.

The risk of acidosis is generally low for cereal stubbles despite the high starch content of wheat and barley grain. 'Water belly' (Urolithiasis), a condition which causes sporadic deaths in male sheep has been associated with grazing cereal stubbles, particularly oat stubbles (Crosbie *et al.* 1985; Nottle and Armstrong 1966). High intakes of soluble plant silicates may be the predisposing cause of the disease in sheep grazing oat stubble (Nottle and Armstrong 1966).

Lupin stubbles

Lupin stubbles differ from cereal stubbles in a number of ways. Lupin grain is higher in energy and rumen degradable protein and contains a lower level of starch compared to cereal grains (Corbett 1990). The amount of residual grain in lupin stubbles tends to be higher than for cereal stubbles. Residual grain in lupin stubbles was calculated to be 3 times that of the greatest amount measured in cereal stubbles (lupins 327 kg/ha versus wheat 94 kg/ha) (K.P. Croker 2003, pers. comm.). Similar levels of residual lupin grain have been seen in other studies; 343 kg/ha, 316 kg/ha and 250 kg/ha respectively (Croker *et al.* 1979, 1994; Dunlop 1984).

Lupin stubbles can be toxic to sheep when the fungus *Diaporthe toxica* (formerly *Phomopsis leptostromiformis*) colonises lupin stems and produces the hepatotoxin phomopsin. When sheep ingest phomopsin they may develop the disease 'Lupinosis' and this can be a problem particularly for lupin varieties that are not resistant to *Diaporthe toxica* (Allen and Chapman 1988). Lupins are generally grown on soil types that are prone to erosion due to the effects of overgrazing.

Sheep grazing legume stubble generally achieve better growth rates for similar yields of dry matter when compared to cereal stubble (Table 5.4). This has been attributed to the higher protein in legume stubbles compared to cereal stubbles. However, there may be other factors contributing to these higher growth rates. If sheep actively select the grain component of legume stubble, rumen function will not be upset due to acidosis and feed intake not reduced, compared to the same scenario in sheep on cereal stubble.

Table 5.4. Studies on the performance of Merino wether lambs grazing lupin stubble.

Age (months)	Weight change (g/day)	Stocking rate (head/ha)	Residual grain (kg/ha)	Grazing days	Initial weight (kg)	Final weight (kg)	Reference
5	56	25.0	343	79	22.6	27.0	(Croker *et al.* 1979)
	11	50.0	386	79	22.5	23.4	
	35	9.1	197	91	26.5	29.7	
	58	8.3	316	83	30.2	35.0	
	80	9.4	183	87	31.5	38.5	
7	21			94	25.0	27.0	(Arnold *et al.* 1976)

Estimates of seed density have been used to make decisions about the length of time sheep should graze lupin stubbles because seed density is relatively easier to measure in lupin stubbles, than cereal stubbles. This technique has been used for preventing Lupinosis, monitoring sheep productivity and prevention of soil erosion. The predictive value of seed density can be inconsistent and sheep monitoring should always be done in conjunction with any paddock seed assessments (A.R. Butler 2004, pers. comm.).

Sheep drink more water when grazing lupin stubbles than when grazing cereal stubbles (Jacob 1989). The reason for this difference is unclear but may be due to increased intake of rumen degradable protein causing an increase in urea excretion when sheep eat lupin grain. The need for water may limit the distance sheep graze from water points in large paddocks (Croker *et al.* 1994). Croker *et al.* (1994) found that moving water points around the paddock in lupin stubbles increased the number of grazing days obtained from these stubbles. Moving the water point on several occasions also reduced the likelihood of wind erosion of the ground close to the water point.

Annual pastures

Annual pastures are a feature of low and medium rainfall cropping-based farming systems. Annual pastures usually consist of mixed swards of annual grasses; ryegrass (*Lolium rigidum),* barley grass *(Hordeum leporinum),* legume species; subterranean clover (*Trifolium subterreanean),* medics (*Medicago* spp.) and a range of broadleaf species.

Sheep graze senesced annual pastures selectively and weathering is more relevant to these pastures because residual grain is not such a large part of the feed reserve as it is in stubbles. Brown (1977) found that the rate of disappearance of pasture plants due to weathering was associated with the fibre, nitrogen, sulphur, calcium and sodium concentrations of the plant. Clover and capeweed (*Arctotheca calendula*) disappeared at 2 to 3 times the rate of perennial species over a 139 day period at Kybybolite, South Australia. Pastures consisting of a mixed sward will probably become more grass dominant through the summer even without livestock selectively grazing certain species. Metabolisable energy and rumen degradable protein decrease as pasture matures and decays. Freer *et al*. (1985) showed that the crude protein of annual pasture fell from 9.4 per cent to 6.5 per cent in senesced pasture. For this reason, dry annual pasture should be grazed early in the season and prior to stubbles, if possible. The liveweight response of sheep grazing dry pasture cannot be predicted by measuring pasture quantity as is the case with green pasture (Thompson 1989).

Perennial pastures

Perennial pastures provide much of the feed for livestock in the medium to high rainfall temperate areas of the Eastern States of Australia. These perennial pastures consist of species such as kangaroo grass (*Themeda australis*), wallaby grass (*Danthonia* spp.) and weeping grass (*Microlaena stipoides*) mixed with the less desirable annual grass species of barley grass (*Hordeum leporinum*), brome grasses (*Bromus* spp.) and squirrel and rat's tail fescues (*Vulpia* spp.). The addition of subterranean clover (*Trifolium subterranean*) and phosphate fertiliser around the 1950s dramatically improved the productivity of perennial grass pastures. Despite this, livestock production has been limited by the low production of perennial pastures early in the growing season (late autumn and early winter) and by their low nutritive value over the summer months.

Improved technologies and pasture seed availability enable exotic perennial grasses such as cocksfoot (*Dactylis* spp.), phalaris (*Phalaris* spp.) and tall fescue (*Festuca arundinacea)* to be widely sown along with companion legumes (Dear *et al.* 1996). However these pastures also have limitations such as low feed quantity in winter and poor quality over the summer and autumn months.

In the past, lucerne (*Medicago sativa*) has been used to fill the feed gap that occurs in the summer months (Donnelly *et al.* 1985; Reeve and Sharkey 1980). Unfortunately with increasing soil acidification, establishing lucerne is becoming more difficult and costly for producers and more recently chicory (*Cichorium intybus*) has been identified as a useful alternative species because it tolerates more acidic soils than lucerne (Upjohn *et al.* 2002).

Conclusions

Paddock feeds are heterogeneous feed sources that change in nutritive value with grazing and weathering. Rainfall has negative impacts on the grazing of dry paddock feeds unless substantial germination occurs subsequent to the rainfall event. Sheep will tend to lose weight when grazing dry annual pasture except in the early part of the season. Although some basic principles exist, it is difficult to predict the grazing value of stubbles in large paddocks. For the purpose of backgrounding or finishing lambs, some level of grain feeding will normally be required if the grazing period extends beyond the initial period of liveweight gain attributed to residual grain. Monitoring of sheep liveweight and paddock observations are required to facilitate decisions about grain feeding strategies for sheep grazing dry paddock feed.

Feeding grain to sheep grazing paddock feed

Feed intake of sheep fed grain

Grazing sheep have the opportunity to select their own diet, and the feeding of grain can have an influence on their forage intake. Generally three outcomes are recognised in relation to the effect of grain intake on feed intake. These outcomes are: complementation, supplementation, and substitution (Dove 2002). When the dry matter intake of forage is increased by the feeding of grain, the grain is complementary to grazing. When the dry matter intake of forage is unchanged by the feeding of grain, the grain is supplementary to grazing. When the dry matter intake of forage is reduced by the feeding of grain, the sheep are substituting forage for grain. The rate of substitution is the reduction in pasture intake per unit increase in the intake of the grain (Dove 2002). This aspect of feeding grain to grazing sheep is complex and still being researched. Dove (2002) cites a number of general factors that determine the rate of substitution including factors relating to the forage available, the grain fed and the physiological status of the sheep. Although it is not possible to use these factors to predict the response to a supplement, they are important considerations when grain is being fed to sheep grazing paddock feed.

Substitution is likely to be greater when either the quantity or the quality of standing paddock feed is low (Dixon and Stockdale 1999; Langlands 1969). Sheep show a preference for a readily accessible supplement compared to expending energy to procure feed through grazing (Dove 2002). The rate of substitution is generally increased by increasing the quantity of the grain fed, although this has not been consistently found in all experiments. For example, Freer *et al.* (1985) found that giving a supplement of 400 g/head/day of oats and sunflower meal to lambs increased their pasture intake from 710 g/head/day to 820 g/head/day but when the supplement was increased to more than 400 g/head/day, the intake of pasture decreased. When supplement levels reached 800 g/head/day, the pasture intake was reduced to only 350 g/head/day. However in Langlands' (1969) work, increases in the quantity of a wheat supplement fed to grazing sheep did not lead to greater levels of substitution.

The type of grain can affect the degree of substitution. Starch fermentation causes a reduction in the pH of the rumen and a reduction in the fermentation of cellulose and hemicellulose (Rowe 1983). Grains high in starch may therefore depress fermentation of fibre by rumen microbes and reduce the intake of forage (Dixon and Stockdale 1999). On the other hand, a protein supplement may overcome a deficiency of rumen degradable protein and increase microbial fermentation of fibre (Dove *et al.* 2000).

Sheep that have high nutritional requirements (Dixon and Stockdale 1999) tend to have a low rate of substitution. Dove *et al.* (2000) found that lactating ewes grazing on pasture had a lower rate of substitution when supplemented with pellets compared to pregnant ewes fed the same supplement.

The frequency and method of feeding may also influence the rate of substitution but the evidence in the literature is equivocal and difficult to interpret in a practical sense (reviewed by Dove 2002).

The value of complementary and supplementary grain feeding systems is that paddock feed has some nutritional and financial value. This represents an advantage for feeding grain in the paddock compared to feeding a complete mixed ration in a feedlot, because the cost of the roughage component of the diet can be lower in real and relative terms. However the nutritive value of the paddock feed diminishes as the level of substitution increases. Furthermore if the additional energy supplied by supplementary grain is being used to fuel movement for sheep to graze paddock material, then there is no net benefit of feeding the grain in terms of animal production.

Liveweight responses to grain feeding

As might be expected from the variation in the nutritive values of paddock feed components and the liveweight response of lambs grazing paddock feeds, the liveweight response to grain feeding is variable and difficult to predict. Butler and McDonald (1986) achieved 155 g/day increase in the growth rate of nine-month old Merino weaners grazing wheat stubble by offering 686 g/head/day of an oat/lupin mix containing 15.2 per cent crude protein. In comparison, Morcombe and Ferguson (1990) reported an increase in growth rate of only 40 g/day and 81 g/day when they supplemented Merino weaners with 500 g/head/day of wheat or lupin grain. Several aspects of this variation have been investigated including type of stubble, type of grain fed, amount of grain fed, and stocking rate. Other factors might also be important, such as lamb genotype and age, but definitive data on these factors is difficult to find in relation to finishing or backgrounding lambs grazing paddock feed. GrazFeed™ is a simulation model that can be used to predict liveweight responses of sheep fed grain when grazing pasture (Freer *et al.* 1997).

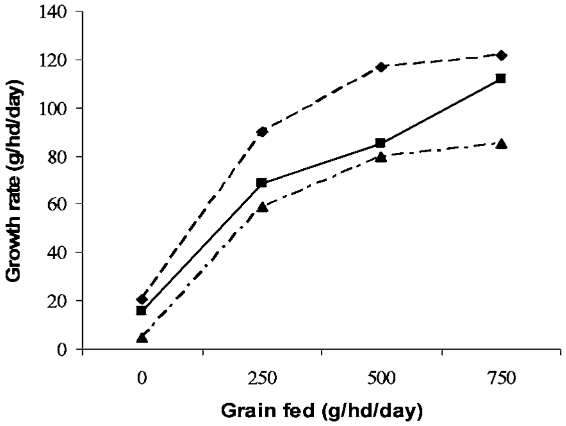

Figure 5.2. Growth rate of lambs grazing lupin (◆), pea (■) or vetch (▲) stubble and supplemented with grain (Arnold *et al.* 1976).

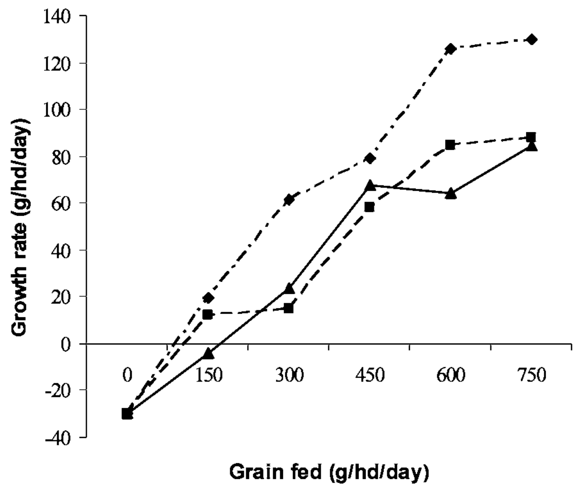

Figure 5.3. Growth rate of Merino wether lambs fed lupins (◆), oats (■) or barley (▲) when grazing wheat stubble (Rowe *et al.* 1989).

Type of paddock feed

Comparison of paddock feeds is inherently difficult because of the variation within a large paddock. Arnold *et al.* (1976) found that the response to grain supplement was greater on lupin and pea stubbles than vetch stubbles. In their experiment, seven-month old Merino wethers weighing 25 kg were grazed stubbles for 90 days at a stocking rate of 50 head/ha. Lambs on lupin stubble were fed lupin grain, those on pea stubbles were fed pea grain and those on vetch stubble were fed vetch grain (Figure 5.2).

Type of grain fed

Several studies have shown the value of high protein supplements to lambs grazing cereal stubbles (Suiter 1990). In the trial of Butler and McDonald (1986) oats and urea supplemented at 477 g/head/day resulted in a growth rate 35 g/day higher than the same sheep supplemented only with 496 g/head/day oats. At all the different levels of supplementation in the trial of Rowe *et al.* (1989) sheep supplemented with lupins had higher growth rates than those supplemented with either oats or barley (Figure 5.3).

Morcombe and Ferguson (1990) reported that sheep grazing wheat stubble supplemented with peas and lupins had higher growth rates than sheep supplemented with the same level of wheat (Figure 5.4). They speculated that the lower liveweight change found with wheat compared to lupins was due to a greater rate of substitution effect for wheat, due to low rumen pH induced by the higher starch content of the wheat. However they did not measure feed intake or rumen conditions to be able to confirm this. Pereira and Bonino (1998) increased liveweight gain by 6 per cent compared to non-supplemented lambs, by supplementing 10-month old Corriedale lambs with sorghum grain from June to September, on a grass-legume pasture (950 kg DM/ha, 10 head/ha). Grain conversion rate was 28.7:1.

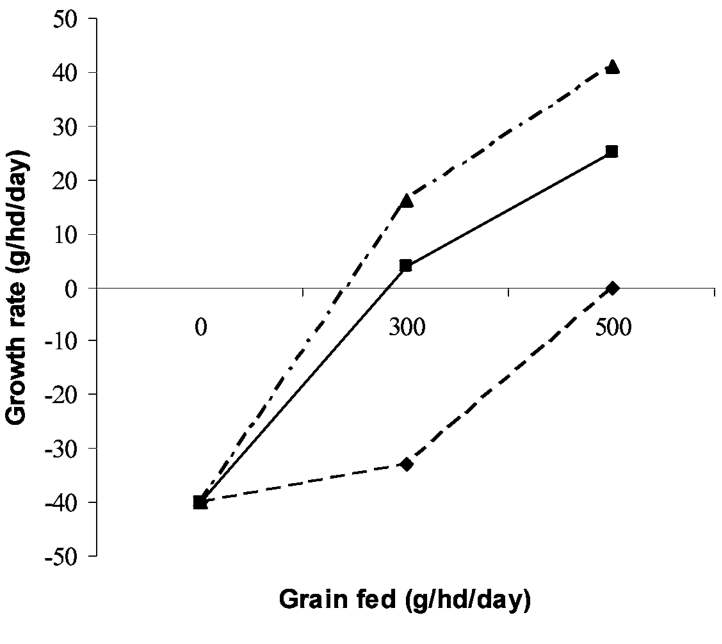

Figure 5.4. **Growth rate for sheep fed lupins (▲), peas (■) or wheat (◆) when grazing wheat stubble (Morcombe and Ferguson 1990).**

Gardner *et al.* (1993) proposed that poor utilisation of the pasture caused by insufficient protein accounted for the performance of sheep fed barley being poor compared to those fed lupin grain (Figure 5.5).

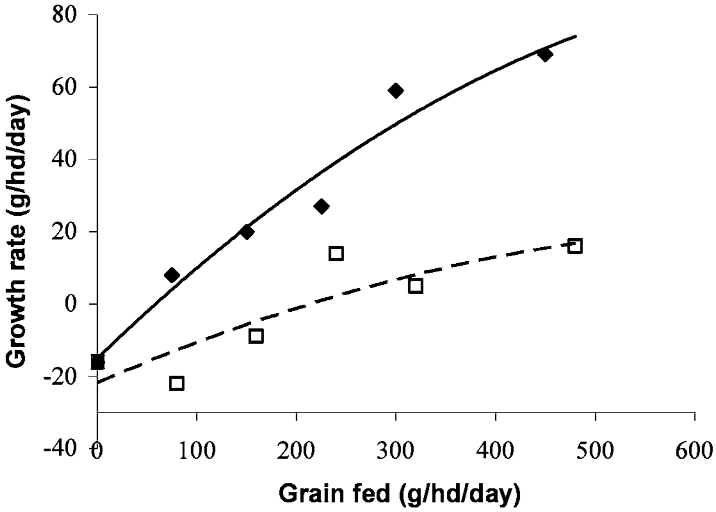

Figure 5.5. **Growth rate for sheep fed lupins (◆) or barley (□) when grazing annual pasture (adapted from Gardner *et al.* 1993).**

Amount of grain fed

Rowe *et al.* (1989) assessed the response of Merino wethers grazing wheat stubble to incremental increases in lupin, oat and barley grain feeding and found that the relationship between the amount of grain fed and growth rate was curvilinear (Table 5.5). At the higher end of feeding, the growth responses diminished indicating a decrease in feed efficiency with each 150 g increase in the amount of grain fed. This trend is consistent with the concept proposed by Freer *et al.* (1985) that as more grain is made available to grazing sheep, the rate of substitution of forage for grain increases. Some studies have shown negative responses to very high levels of grain feeding (Rowe and Ferguson 1986).

Table 5.5. **The incremental increase in growth rate for sheep grazing wheat stubble with each 150 g increase in supplementation of lupins oats and barley (Rowe *et al.* 1989).**

Feeding rate (g/head/day)	Incremental increase in growth rate (g/head/day)		
	Lupin grain	Oat grain	Barley grain
150	50	42	26
300	42	3	28
450	18	44	44
600	47	26	-3
750	4	4	20

The reduced efficiency at higher levels of supplementation can be seen again from the growth rates obtained by Arnold *et al.* (1976) (Table 5.6). The reduction in efficiency in the response to increases in supplements for both lupins and vetch was reduced to an increase of 5 g/day when the supplement was increased from 500 to 750 g/head/day.

Table 5.6. The increase in growth rate for sheep grazing stubble with each 250 g increase in supplementation of lupin grain, pea grain or vetch grain (Arnold *et al.* 1976).

Feeding rate (g/head/day)	Growth rate increase (g/head/day)		
	Lupin grain	Pea grain	Vetch grain
0	0	0	0
250	69	53	54
500	27	16	21
750	5	27	5

Stocking rate

Stocking rate can have a significant effect on the response to grain feeding when paddock feed is an important contribution to the sheep's diet. This was demonstrated by the experiment of Mulholland *et al.* (1976) (Figure 5.6). The lambs in this study were 16-month old Border Leicester x Merino cross wethers. When fed 132 g/head/day of a wheat mixture on wheat stubbles for 77 days, the higher stocking rate had a negative effect on their growth rate. This effect was greater when the stubble had been sprayed to remove green weeds. This is consistent with paddock feed making a significant contribution to the dietary intake of sheep fed grain at supplementary levels.

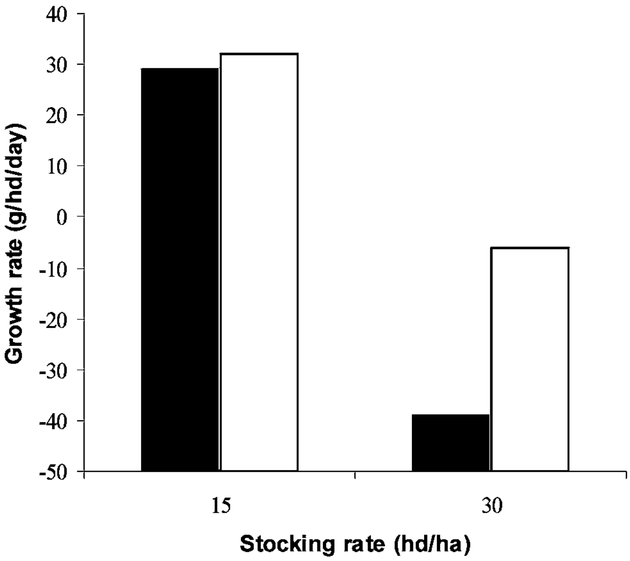

Figure 5.6. The effect of stocking rate (head/hectare) on the growth rate of lambs fed grain on weedy (■) or weed free (□) wheat stubbles (Mulholland *et al.* 1976).

Feeding method

Feeding method and the frequency of feeding are important considerations in terms of the time required to feed the grain, control of grain intake, grain wastage, the rate of forage substitution, the type of grain that can be fed, and the performance of the sheep being fed. Methods include self-feeders, troughs, trail feeding, and spinning out with a fertiliser spreader.

Self-feeders and trough feeding are suitable for high rates of grain feeding when high rates of forage substitution are expected. Rowe and Ferguson (1986) investigated the method of spinning out lupin grain to weaners grazing wheat stubble at intervals of 1, 2 and 4 weeks.

This was found to be a successful technique for the purpose of body weight maintenance when the level of lupin grain fed was equivalent to 150 g/head/day.

Carcase attributes

Although the liveweight responses to grain supplementation of lambs grazing paddock feeds have been investigated, there is little information on the effects of these feeding regimes in relation to body composition or meat eating quality. It is possible that grain feeding might influence body composition as well as growth rate and such an effect might depend on the nature of the stubble and the grain fed (Maloney 1998).

Some processors believe that legume stubbles predispose lamb meat to the condition known as 'dark cutting' and impose restrictions through protocols that discourage the grazing of legume stubbles during the final phase of finishing prime lamb. Gardner (2001) however, found no evidence to suggest that the high intake of rumen degradable protein associated with lupin grain would cause meat to be dark cutting due to low glycogen concentration and high ultimate pH (pHu).

Perennial pastures

Grain supplements have been used to overcome the poor quality and low biomass of perennial pastures in summer and autumn. Supplementation strategies allow producers to maintain high stocking rates, manage the risk of poor seasons and improve profitability through alternative animal production systems. In the eastern states of Australia the most commonly supplemented grain is oats because it is produced on-farm and there is a relatively low risk of acidosis associated with oats compared to other cereal grains. Lupins, oilseed meals or lucerne hay are generally added to the oat supplement when there is a need for protein supplementation. More recently triticale (a hybrid of wheat and rye) has been grown as an alternative to oats.

There have been a limited number of studies conducted on the supplementation of young weaner sheep grazing reasonable quality perennial pasture. Holst *et al.* (1997) reported that the growth rates of five-month old mixed sex Poll Dorset x (Border Leicester x Merino) supplemented with 282 g/head/day oats while grazing lucerne was 153 g/day for induced cryptorchid wethers and 112 g/day for ewes. Holst *et al.* (1998) reported better growth rates in sheep from chicory than lucerne. Further research is required to determine the factors affecting variation in growth rates of lambs supplemented with grain whilst grazing various legume and grass perennial pastures.

Conclusions

Grain feeding improves the growth rate of lambs grazing standing paddock feed. The feed conversion efficiency of the grain fed will be better when grain feeding rates are kept low. Grain feeding rates of less than 300 g/head/day are desirable when backgrounding lambs on paddock feed in order to avoid high rates of substitution. To satisfy the protein requirements of lambs, legume grains, particularly lupins, may achieve better results than cereal grains. Alternatively, cereal grain fortified with non-protein nitrogen in the form of urea may also give better results than cereal grains fed alone.

References

Aitchison, E., Murray, P. and Rowe, J. (1986). 'Improving the nutritive value of round bales of straw by treatment with urea or supplementation with lupins'. *Proceedings of the Australian Society of Animal Production,* vol. 6, pp. 123-126.

Allen, J.G. and Chapman, H.M. (1988). 'Conditions associated with lupins'. In: *Sheep Health and Production.* The University of Sydney Postgraduate Committee in Veterinary Science, Sydney, Proceedings No. 100, pp. 431-456.

Anonymous (2001). 'Agriculture Crops'. In: *Year Book Australia.* Australian Bureau of Statistics, Canberra.

Arnold, G.W., Charlick, A.J. and Wallace, S.R. (1976). 'Comparisons of crops of lupins, peas and vetches for weaner sheep in summer in a Mediterranean environment'. *Animal Production in Australia*, vol. 11, pp. 361-364.

Brown, T. (1977). 'Rate of loss of dry matter and change in chemical composition of nine pasture species over summer'. *Australian Journal of Experimental Agriculture and Animal Husbandry*, vol. 17, pp. 75-79.

Butler, L.G. and McDonald, C.L. (1986). 'Growth responses of young Merino wethers to *ad libitum* feeding of oat grain mixed with either lupin seed or a urea solution'. *Australian Journal of Experimental Agriculture*, vol. 26, pp. 643-646.

Coombe, J.B., Axelsen, A. and Dove, H. (1987). 'Rape and sunflower seed meals as supplements for sheep grazing cereal stubbles'. *Australian Journal of Experimental Agriculture*, vol. 27, pp. 513-523.

Corbett, J. (1990). In: *Feeding Standards for Australian Livestock - Ruminants.* CSIRO Publications, Canberra.

Croker, K.P., Allen, J.G., Masters, H.G. and Petterson, D.S. (1979). 'The effect of residual grain on the utilisation of sweet lupin stubbles and concurrent changes associated with lupinosis, in particular changes in liver copper and zinc in weaner sheep'. *Australian Journal of Agricultural Research*, vol. 30, pp. 929-938.

Croker, K.P., McDonald, C.L., Devenish, K.L. and Rix, G.S. (1994). 'Movement of the water points in phomopsis-resistant lupin stubbles increases the efficiency of the stubble use by weaner sheep'. *Animal Production in Australia*, vol. 20, p. 408.

Crosbie, G., Tarr, A., Portmann, P. and Rowe, J. (1985). 'Variation in hull composition and digestibility among oat genotypes'. *Crop Science*, vol. 25, pp. 678-680.

Dear, B.S., Virgona, J.M. and Sutherland, G. (1996). 'Legumes in low input perennial pastures of southern Australia: Historical role and future development'. *New Zealand Journal of Agricultural Research*, vol. 39, pp. 579-589.

Dixon, R.M. and Stockdale, C.R. (1999). 'Associative effects between forages and grains: Consequences for feed utilisation'. *Australian Journal of Agricultural Research*, vol. 50, pp. 757-773.

Donnelly, J.R., McKinney, G.T. and Morley, F.H.W. (1985). 'The productivity of breeding ewes grazing on lucerne or grass and clover pastures on the tablelands of southern Australia IV. Lamb growth'. *Australian Journal of Agricultural Research*, vol. 36, pp. 469-481.

Dove, H. (2002). 'Principles of supplementary feeding in sheep-grazing systems'. In: *Sheep Nutrition.* Freer, M. and Dove H. (eds). CSIRO Publishing, Collingwood, pp. 119-142.

Dove, H., Freer, M. and Foot, J.Z. (2000). 'The nutrition of grazing ewes during pregnancy and lactation: A comparison of alkane-based and chromium/*in vitro* based estimates of herbage intake'. *Australian Journal of Agricultural Research*, vol. 51, pp. 765-777.

Dunlop, A.C. (1984). 'The nutritive value of stubble and pasture'. In: *How much wheat do sheep grow?* The Western Australian Department of Agriculture and the North Midland branch of the Australian Society of Animal Production, Northam.

Freer, M., Dove, H., Axelsen, A., Donnelly, J.R. and McKinney, G.T. (1985). 'Response to supplements by weaned lambs grazing mature pasture or eating hay in yards'. *Australian Journal of Experimental Agriculture*, vol. 25, pp. 289-297.

Freer, M., Moore, A.D. and Donnelly, J.R. (1997). 'GRAZPLAN: decision support systems for Australian grazing systems II. The animal biology model for feed intake, production and reproduction and the Grazfeed DSS'. *Agricultural Systems*, vol. 54, pp. 77-126.

Gardner, G. (2001). 'Nutritional regulation of glycogen metabolism in cattle and sheep', PhD thesis, Murdoch University, Perth.

Gardner, J.J., Doyle, P.T., Rowe, J.B., Hetherington, R., Spicer, P., McQuade, N. and Crowhurst, M. (1993). 'Supplementation of young Merino sheep grazing annual pastures with lupin, barley grain, or silage'. *Australian Journal of Experimental Agriculture*, vol. 33, pp. 403-409.

Holst, P.J., Hall, D.G., Stanley, D.F. and Nolan, J.V. (1997). 'Effects of sex and liveweight on feeding behaviour of crossbred weaner lambs receiving oaten grain supplement on lucerne pasture'. *Australian Journal of Experimental Agriculture*, vol. 37, pp. 611-615.

Holst, P.J., Kemp, D.R., Goodacre, M. and Hall, D.G. (1998). 'Summer lamb production from puna chicory (*Cichorium intybus*) and lucerne (*Medicago sativa*)'. *Animal Production in Australia*, vol. 22, pp. 145-148.

Jacob, R.H. (1984). 'Utilisation of cereal stubble for sheep feed'. In: *How much wheat do sheep grow?* The Western Australian Department of Agriculture and the North Midland branch of the Australian Society of Animal Production, Northam.

Jacob, R.H. (1989). 'Moving water points on lupin stubbles'. Government of Western Australia, Department of Agriculture, *Farmnote* No. 106/1989.

Langlands, J.P. (1969). 'The feed intake of sheep supplemented with varying quantities of wheat while grazing pasture differing in herbage availability'. *Australian Journal of Agricultural Research*, vol. 20, pp. 919-924.

Maloney, A. (1998). 'Growth and carcass composition in sheep offered isoenergetic rations which resulted in different concentrations of ruminal metabolites'. *Livestock Production Science*, vol. 56, pp. 157-164.

Morcombe, P.W. and Ferguson, J. (1990). 'Lupin, pea and wheat grain as supplements for young Merino sheep grazing wheat stubble'. *Animal Production in Australia*, vol. 18, pp. 304-307.

Morrison, I.M. (1974). 'Structural investigations on the lignin-carbohydrate complexes of *Lolium perenne*'. *Biochemical Journal*, vol. 139, pp. 197-204.

Mulholland, J.G., Coombe, J.B., Freer, M. and McManus, W.R. (1976). 'An evaluation of cereal stubbles for sheep production'. *Australian Journal of Agricultural Research*, vol. 27, pp. 881-893.

Nottle, M. and Armstrong, J. (1966). 'Urinary excretion of silica by grazing sheep'. *Australian Journal of Agricultural Research*, vol. 17, pp. 165-73.

Pereira, J. and Bonino, J. (1998). 'The effect of supplementary feeding with concentrates on the growth rate and fattening of lambs'. *Produccion Ovina*, vol. 11, pp. 27-39.

Purser, D.B. (1983). 'The nutritive value of stubbles'. In: *Stubble Utilisation.* Rural and Allied Industries Council, Perth, pp. 13-26.

Purser, D.B. and Southey, I.N. (1984). 'Fluctuations in the nutrient supply in the south west of Western Australia'. In: *Wool production in Western Australia.* Australian Society of Animal Production (Western Australian branch), Perth, pp. 99-111.

Reeve, J.L. and Sharkey, M.J. (1980). 'The effect of stocking rate, time of lambing and inclusion of lucerne on prime lamb production in Northeast Victoria'. *Australian Journal of Experimental Agriculture*, vol. 20, pp. 637-653.

Roberts, D. and Devenish, K. (2001). 'Chaff heaps - A useful feed source for sheep and cattle'. Government of Western Australia, Department of Agriculture, *Farmnote* No. 55/2001.

Rowe, J.B. (1983). 'The nutritive value of stubbles'. In: *Stubble Utilisation.* Rural and Allied Industries Council, Perth, pp. 27-33.

Rowe, J.B., Brown, G., Ralph, I.G., Ferguson, J. and Wallace, J.F. (1989). 'Supplementary feeding of young Merino sheep, grazing wheat stubble, with different amounts of lupin, oat or barley grain'. *Australian Journal of Experimental Agriculture*, vol. 29, pp. 29-35.

Rowe, J.B. and Ferguson, J. (1986). 'Lupin grain as a supplement to sheep grazing cereal stubble'. *Animal Production in Australia*, vol. 16, pp. 343-346.

Southey, I.N. (1981). In: *Chemical treatment of stubble in Western Australia.* Western Australian Society of Animal Production, Perth.

Suiter, R.J. (1990). *Finishing lambs and shippers in feedlots and paddocks.* Government of Western Australia, Department of Agriculture, Perth, Bulletin No. 4192.

Thompson, K.F. (1989). In: *Feed Budgeting Workshops.* Government of Western Australia, Department of Agriculture, Perth, pp. 10-16.

Upjohn, B., Kemp, D.R. and Parker, M. (2002). 'Chicory'. Agriculture New South Wales, *Agfact* 2nd edn, P2.5.40.

Feeding grain for sheep meat production

Chapter 6. Feeding grain to confined sheep

R.M. Kirby an

CHAPTER 6. FEEDING GRAIN TO CONFINED SHEEP

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Introduction

A feedlot is defined as 'a management system in which naturally grazing animals are confined to a small area which produces no feed and are fed on stored feeds' (Blood and Studdert 1990). In the classic sense of the definition, a feedlot is a specialised facility where the operator has strict control over the diet. In practice, the sheep meat industry currently uses a wide variety of grain feeding systems that fit the definition of feedlotting but due to varying degrees of control over the diet, these may result in different growth rates and performance. The main systems of feeding in feedlots are:

1. *ad libitum* access to loose total mixed rations fed in open troughs;
2. *ad libitum* access to balanced pelleted diets usually fed in self-feeders;
3. *ad libitum* access to loose grain mix (with minerals) fed in open troughs or self-feeders with *ad libitum* access to roughage.

There are several comprehensive guides published by various Australian State Departments of Agriculture that cover the practicalities of setting up and running a feedlot (Bell *et al.* 1998; Milton 2001; Davis 2003; Giumelli 2003).

Growth rates and feed conversion ratios indicated in Departments of Agriculture extension literature have evolved over the past 15 years, presumably on the basis of available scientific literature and anecdotal evidence from industry experience. There are many recommendations but little in the way of comparative trials to demonstrate how the conclusions have been reached. The figures in Table 6.1 are examples of those provided in the literature as a guide to performance of lambs in feedlots and are not related to particular feeding systems or equipment used in feedlots.

Table 6.1. Average production targets for feedlot finishing of lambs taken from Australian State Departments of Agriculture extension publications.

Growth rate (g/day)		Feed conversion ratio		Reference
Crossbred lamb	Merino lamb	Crossbred lamb	Merino lamb	
140-160	130-140	5:1	6:1	1
200	130	6:1	7:1	2#
150-300		8:1 to 5:1		3
250-350	150-250	7:1 to 5:1	8:1 to 6:1	4
250-350	220-320	7:1 to 5.5:1	7.5:1 to 6:1	5
250		6.5:1		6*
200-320		10:1 to 5:1		6**

After 2-3 weeks adaptation to feedlot conditions; * Average 40 kg finishing lamb; ** Finishing lamb from 30 to 50 kg.

[1] Suiter (1990); [2] Hack *et al.* (1997); [3] Bell *et al.* (1998); [4] Seymour (2000); [5] Milton (2001); [6] Bell *et al.* (2003).

Confinement feeding for purposes other than finishing

In response to poor seasons during recent years there has been an interesting evolution of feeding systems. The feeding systems are many and varied. Individual producers have developed systems that make use of resources available on their farm and integrate with their farming system. The common theme between feeding systems is that sheep are confined, usually in a small paddock, and all nutrients are supplied to the animals. Confinement feeding systems differ from production feedlots in that they are used for purposes in addition to finishing, e.g. deferred grazing, feeding pregnant and lactating ewes, maintenance of dry stock and backgrounding lambs (J.T.B. Milton 2003, pers. comm.; Bryant and Kirby, refer appendix).

Confinement feeding systems are generally simple and low-cost. Profitability is hard to determine and is often not a priority because it is difficult to assign a monetary value to many of the benefits such as preserving breeding stock, avoiding agistment and associated problems, preventing erosion, deferring grazing, flexibility and alternative feeding options. Nevertheless, there is an opportunity to draw on the expertise and innovation of industry leaders who are developing simple and profitable feeding systems.

The remainder of this review considers only confinement feeding and feedlotting systems that focus on backgrounding and finishing of prime lambs.

Loose total mixed rations fed in open troughs

Specialised milling and mixing equipment is utilised to process roughage, combine ingredients and feed out into troughs. Feed mixes are prepared immediately prior to feeding and feeding may occur once or twice daily. Feeding frequency is a compromise between available labour and providing an adequate quantity of fresh feed to maximise intake by all animals. The main disadvantages of this feeding system are the high level of up-front capital investment to purchase the necessary feeding equipment and the ongoing labour required. The primary advantage of the system is that the producer has complete control over the nutritional specification of the ration by incorporating specific amounts of roughage, grain and minerals into the mix. This system also offers the flexibility of altering the ingredient composition to prepare introductory and finishing diets, and the flexibility of incorporating low-cost, novel or by-product ingredients, e.g. chaff cart residues, bakery waste, brewer’s grain.

There are very few examples in the scientific literature of the biological performance of sheep fed loose, mixed, rations and even fewer that describe this system in relation to modern genetics and target market specifications. The market specifications for prime lambs and the role of intensive grain feeding have changed significantly since reports of early feedlotting research conducted in the 1970s and 1980s. The common slaughter weight of prime lambs at that time was approximately 35 kg and liveweight at feedlot entry was 20-25 kg. Loose mixed ration feeding systems produced growth rates ranging from 100-240 g/day for crossbred lambs and around 160-205 g/day for Merino lambs with feed conversion ratios of 6.2:1 to 3.5:1 (Table 6.2). The relevance of early data to modern feeding systems is questionable. Comparisons with modern production systems are unlikely to be valid due to improved sheep genetics, production of increasingly heavy carcases and the evolution of intensive grain feeding systems that are often focused primarily on the finishing phase.

Table 6.2. Performance of lambs fed loose mixed rations in feedlots and grown from 20-25 kg to 35 kg liveweight. Feed conversion ratio (FCR), calculated crude protein of diet (CP), calculated metabolisable energy of diet (ME).

Growth rate (g/day)	FCR	Diet composition	CP (%)[1]	ME (MJ/kg DM)[1]	Reference
Crossbred lambs					
243	3.5:1	barley, oaten straw, lupins	14.7	11.4	1
242	4:1	barley, oaten straw, lupins	18.9	11.9	1
240	4.5:1	wheat, lucerne hay, meat meal	17.2	12.3	2
100*		barley, fishmeal, straw	16.0#	11.8	3
143		wheat, pelleted lucerne	15.1	12.2	4
Merino lambs					
162	4.2	oats, oaten chaff, lupins	18.5#	11.2	5
205	5.4	triticale, pasture hay, lupins	19.5#	12.6	6
171	6.2	oats, pasture hay, lupins	16.9#	11.4	6

Measured crude protein reported in paper; * Average growth rate during 6 week period from 23 to 27 kg.

[1] Tomes and Dymond (1976); [2] Davis *et al.* (1976); [3] Ikin and Pearce (1978); [4] Cotterill and Roberts (1979); [5] McDonald and Suiter (1982); [6] Roberts *et al.* (1984).

Key issues

Several key issues arise from experimental examination of the loose mixed ration feeding system. Not all of the issues are unique to this feeding system but the complexity of the system creates some challenges that need to be overcome.

Sheep will selectively consume preferred feeds and have a recognised ability to separate components of a mixed ration. For example, White Suffolk x Merino lambs fed a loose mixed diet had lower feed intake and a growth rate of 138 g/day compared to 210 g/day for lambs offered the same diet as a pellet (Jones *et al.* 2000). Examination of feed residues showed that lambs avoided the straw component of the loose diet and therefore altered the intended nutrient specification of the ration. One of the advantages of a loose mixed ration feeding system is the level of control that the producer has over the nutritional specification of the diet. This control is negated if the lambs are able to actively select preferred feed components. The success of a loose mixed feeding system is dependent on optimising the diet to avoid selection either by including palatable roughage, or by processing and mixing the diet in a manner that precludes selection.

The producer has control over the nutritional composition of the loose mixed ration but in order to exercise the control, the nutritional composition of feed ingredients must be measured. Early work investigating feedlot finishing of Merino lambs in Western Australia concentrated on performance of lambs fed oats and lupins, the most commonly feed grains of the time (McDonald and Suiter 1982; Suiter *et al.* 1982). Lambs were fed in either indoor or outdoor feedlots on loose mixed rations consisting of 1.7 per cent minerals, 9.9 per cent oaten chaff and either 88.4 per cent Swan oats, 88.4 per cent West oats or 53.0 per cent West oats plus 35.4 per cent lupins. The nutritional specification of the oat/lupin diet was adequate but the oat-based diets were deficient in protein compared to current recommendations and this was reflected in the poor performance of the lambs. Lambs offered the oat/lupin diet had a modest growth rate of around 140 g/day from the starting

[1] Values calculated for crude protein and metabolisable energy using average book values reported in : Croker, K. and Watt, P. (eds) (2001). *The Good Food Guide for Sheep*. Government of Western Australia, Department of Agriculture, Perth, Bulletin 4473.

liveweight of ~27 kg to 45 kg and feed conversion ratio of 6.4:1 and 6.2:1 for outdoor and indoor feedlots[2]. In contrast, the growth of lambs fed the oat-based diets was around 90-110 g/day indicating that these animals were restricted by the poor nutritional specification of the diets. It is important to have feed analysed and use this information to formulate a ration that will match nutritional requirements to maximise growth rate.

Adaptation of the rumen to high grain diets is the biggest hurdle to success of intensive grain feeding systems. It is evident from some of the early reports, that despite an introductory period, lambs took some time to reach an acceptable growth rate. Ikin and Pearce (1978) investigated the possibility of strategically feedlotting lambs at different stages of growth and found that in each instance, lambs lost liveweight at the beginning of the feedlot period. Similarly, lambs in indoor and outdoor feedlots performed poorly over the first 34 days of the experiment, despite a 12-day introductory program at the commencement of feedlotting (Suiter and McDonald 1987). Subclinical acidosis was considered to be a primary reason for poor performance during feedlot introduction in both of these experiments. Introduction to intensive grain feeding becomes even more critical when the feeding system is targeted at finishing rather than growing lambs, because the time frame for growth is restricted.

Potential to use novel feed ingredients

Feed mixing equipment can be used to incorporate a wide range of ingredients into a loose total mixed ration. This provides the opportunity to reduce the cost of a feedlot diet by utilising by-products from cropping enterprises such as chaff cart residues and grain screenings or novel by-product ingredients from human food industries such as bakery waste and brewer's grain. The main constraints to inclusion of by-product feed sources are the variable nutritional composition and the presence of anti-nutritive compounds, chemical or physical contaminants.

Chaff residues and grain dust arise as by-products of the grain industry. Chaff cart collection systems were developed to remove herbicide resistant ryegrass seeds from affected paddocks at harvest and grain dust is produced and collected during bulk handling of grain. Chaff and weed seeds collected at harvest have a higher nutritional specification than the remaining stubble and could be incorporated into feedlot diets as a source of roughage (Roberts and Devenish 2001). The nutritive value of chaff residues is variable and is influenced by the type of crop from which it was collected and the equipment used for collection (Roberts and Devenish 2001). The nutritional specification of grain dust is similar to that of cereal grain (Knott and Hyde 2001). Chaff residues are readily accepted by sheep, although they tend to select the more digestible components when grazing chaff heaps (Roberts and Devenish 2001). Inclusion in feedlot diets is restricted by the relatively low nutritional value and the potential presence of toxins, e.g. toxins produced by *Rathayibacter toxicus* [Annual ryegrass toxicity] and *Diaporthe toxica* [Lupinosis]. The level of inclusion of grain dust is restricted by the potential risks of acidosis, the presence of chemical residues, and mycotoxins (Knott and Hyde 2001).

Canola screenings and lentil screenings are suitable for inclusion in lamb feedlot diets at low to moderate inclusion levels (Stanford *et al.* 1999, 2000). Grain screenings produced during seed cleaning consist of small, immature and cracked grains of the parent crop, grains from volunteer crop species, weed seeds, chaff and dust (Beames *et al.* 1986). Although Stanford *et al.* (1999, 2000) reported proximate analyses, screenings were incorporated into diets as a replacement for barley and/or canola meal at fixed percentages rather than formulated on the basis of their nutritive value. Growth rate of lambs decreased linearly with increasing inclusion of grain screenings but due to the relative cost difference between traditional

[2] Calculations based on data presented in: Suiter, R.J. and McDonald, C.L. (1987). 'Growth of Merino weaners fed grain-based diets while grazing dry pasture or housed in feedlots'. *Australian Journal of Experimental Agriculture,* vol. 27, pp. 629-632. Intake and growth data for oat-based diets extrapolated beyond measured period to calculate averages to 45 kg liveweight.

ingredients and grain screenings, cost of gain in these examples was maximised at inclusion rates of approximately 33 per cent canola screenings and 25 per cent lentil screenings (Stanford *et al.* 1999, 2000).

Frost damaged grain that does not meet delivery standards is generally sold as feed grain at heavy discounts. Assessment of the nutritive value of frosted wheat from the 1998/99 harvest in New South Wales showed that although severe frosting reduced the estimated ruminant metabolisable energy by 0.8 MJ, the metabolisable energy still fell well within the expected range for wheat (Richardson *et al.* 2001). The price discount reflects the perceived reduction in nutritional value but there are indications that the feeding value for ruminants may not be affected to the same degree as that for monogastrics so frosted grain may be a relatively good, low cost feed source for inclusion in lamb feedlot diets (Richardson *et al.* 2001).

By-products of human food industries are accepted as alternative feed sources in the beef feedlot industry (Blackwood *et al.* 2000; Kubik and Stock 1990) but there has been relatively little evaluation of by-product feeds for lambs in feedlots. Hetherington and Krebs (2002) demonstrated that bakery waste can be incorporated into lamb feedlot diets. Merino lambs fed bakery waste at up to 50 per cent of the diet grew at the same rate (around 190 g/day) as those fed a grain-based diet of similar nutrient specification. Citrus peel, potatoes and grape marc have been recommended as alternative feed sources during drought (Hack and Moreby 1997). Other human food industry by-products have varying nutritional value for ruminants, e.g. citrus pulp, grape marc, brewer's grain, distiller's grain, molasses, malt combings, mill run, bran, pollard (Cottle 1991; Hack and Moreby 1997). Waste by-product ingredients are often available for the cost of transport or low-cost relative to their nutritive value so incorporation of by-product ingredients represents a good opportunity to reduce the overall cost of a lamb feedlot diet.

Despite the variable nature of by-product ingredients, careful sampling and analysis would enable these useful feed sources to be incorporated into feedlot rations. Recommendations for inclusion levels of by-products must be modified according to the nutritional analysis of the sample that will be used. In addition, consideration must be given to the presence of anti-nutritional factors, mycotoxins, chemical residues from crop treatment, and other chemical or physical contaminants when deciding appropriate inclusion levels for these feed sources.

Conclusions

Anecdotal evidence suggests that the use of loose total mixed rations is increasing in popularity, but there has been very little experimental verification of sheep performance in these systems. The lack of literature indicates a basic need to assess finishing performance and economic viability of this system compared to other intensive grain finishing systems. The suitability of loose diets for sheep should be assessed at a commercial level to determine whether performance is affected by the ability of sheep to selectively consume diet components. Finally, there may be some benefit in evaluating alternative feed sources for inclusion in feedlot diets, especially those that could be available as part of the farming system, e.g. chaff residues and grain screenings.

Balanced pelleted diet in self-feeders

Commercial pelleted diets generally provide a complete balanced diet, consisting of roughage, grain and minerals. Pelleted diets are commonly used in conjunction with self-feeders but may be fed in troughs or trailed on the ground. The main disadvantages of pelleted feed are the cost of processing and potentially, an increased risk of acidosis. During the pellet manufacturing process, the grain is hammer-milled and then steam treated prior to pelleting. This procedure does not improve the digestibility of the ration for sheep and can increase the risk of acidosis by presenting the rumen with a highly digestible starch substrate.

Self-feeder systems in combination with formulated pellets offer the advantage of convenience due to the reduced frequency of feeding and the ability to supply a complete balanced diet. Pelleted feed can be stored and handled using basic equipment and the physical presentation of the feed prevents selection.

Early research

There is a long history of the use of pelleted diets in intensive sheep feeding. Early work by researchers in the United Kingdom investigating the nutrition of early weaned lambs was based on pelleted cereal-based diets primarily because these diets had been used successfully for cattle (Andrews and Orskov 1970a, 1970b). Ørskov (1976) provides an interesting commentary of the discovery that highly processed diets were adversely affecting fat metabolism and in fact, diets based on whole grains gave equal performance in young lambs without the negative metabolic implications.

Despite the potential metabolic implications, pelleted diets have been widely used in the sheep industry at various times. In the early 1980s, researchers in Western Australia commented that 'feeding pelletised rations to sheep has become a popular practice' and 'commercially prepared sheep pellets are now being widely used both by the stud industry and occasionally in finishing sheep' (Kessell 1982; McDonald and Suiter 1982). Although there was a perception of widespread use of pellets, evaluations of oat-based pellets fortified with urea demonstrated poor growth and feed conversion performance on these diets compared to oat/lupin loose mixed diets (Kessell 1982; McDonald and Suiter 1982). Kessell (1982) reported a weight loss due to poor voluntary feed intake for 31.3 kg sheep fed *ad libitum* pellets and McDonald and Suiter (1982) reported average growth rates of < 100 g/day for Merino weaners grown from 26.6 kg to 45 kg liveweight. In contrast, wheat-based pellets were used successfully to finish Border Leicester x Merino store lambs from liveweights of approximately 30 kg to ~37 kg during the 1982/83 drought in New South Wales. Growth rates of 230 g/day and 180 g/day with feed conversions of 5.0:1 and 5.8:1 were reported for two drafts of lambs finished on a diet of 32 per cent wheat-based pellets, 53 per cent wheat, 4 per cent hay, 9 per cent minerals and 2 per cent monensin (Donnelly and Morrison 1984). All authors commented that there were advantages related to handling and presentation of pelleted diets despite the mixed production performance.

More recently, pelleted diets have been used to examine a variety of principles related to sheep meat production. The biological performance of different genotypes and sexes fed pellets has been recorded in these situations but was not always the primary focus of the experiment. The literature reporting biological performance of lambs has been segregated on the basis of mating system so there is some repetition where experiments involved lambs from different mating systems.

First-cross

The growth rates reported for pellet-based finishing systems using first-cross lambs range from 184-359 g/day and feed conversion ratios range from 8.2:1 to 5.1:1 (Table 6.3). Although there is a two-fold variation in the range of reported growth rates, data from scientific literature generally supports the expected performance recommendations given in extension material (Table 6.1).

Table 6.3. Breed and performance of first-cross lambs fed on pelleted diets with metabolisable energy (ME) and crude protein specifications of diet indicated. Feed conversion ratio (FCR), liveweight (LW).

Breed (sire x dam)	Growth rate (g/day)	FCR	Initial LW (kg)	Final LW (kg)	Carcase weight (kg)	Diet specification		Reference
						Crude protein (%)	ME (MJ/kg DM)	
BL x M	336^{a}	6.0	40.5	47.9	21.0	16.0	10.8	1
EF x M	295^{a}	6.4	41.9	48.4	21.2			
PD x M	318^{a}	6.1	42.4	49.4	22.3			
SAMM x M	359^{a}	5.4	40.5	48.4	21.2			
WS x M	210	5.9	36.4	41.3		18.0	10.6	2
(T x PD) x M	220^{x}	7.0	32.0	42.9	19.9	14.4	10.5	3
	242^{x}	6.8	32.0	43.7	20.3	14.4	10.5	
	272^{y}	6.2	32.0	45.2	20.5	14.4	10.5	
T x M	256^{m}					15.0	11.8	4,5
PD x M	278^{m}							
PD x M	296	5.1	35.2	43.5	19.4	15.0	11.0	6
S x M	197^{x}	7.7	33.0	44.6	20.7	15.9	10.8	7
	184^{x}	8.2	33.0	44.1	20.4	16.2	10.1	
PD x M	190*	7.0	31.6	42.9	20.1	17.4	10.8	8

BL: Border Leicester; EF: East Friesian; M: Merino; PD: Poll Dorset; S: Suffolk; SAMM: South African Meat Merino; T: Texel; WS: White Suffolk; * Feed was restricted to 1.3 kg/day in this experiment. Within each experiment, growth rates with the same superscript are not significantly different.

[1] Davidson *et al.* (2000); [2] Jones *et al.* (2000); [3] Wiese *et al.* (2000); [4] Hopkins *et al.* (1996); [5] Holst *et al.* (1998); [6] Wiese *et al.* (2003); [7] Pethick *et al.* (2003b); [8] Gardner *et al.* (1999).

The experiments reporting better performance tended to be those where there was more control over individual feed intake. Sex of lambs used in different experiments may also have contributed to the variation in reported growth rates. First-cross wethers gained an average of 327 g/day when fed for 22 days housed in individual indoor pens with *ad libitum* access to a pelleted diet of barley, lupins, canola meal, cereal hay, minerals and vitamins (Davidson *et al.* 2000). Although there was a large numerical range of growth rates reported for different terminal sires, this investigation involved only a small number of animals per treatment and there were no significant differences between sires for growth rate or feed conversion ratio (Table 6.3). Jones *et al.* (2000) reported a growth rate of only 210 g/day over 23 days in a similar experiment where first-cross lambs were housed indoors in individual pens with *ad libitum* access to a pelleted diet containing barley straw, barley, lupins, canola meal, minerals and vitamins. There were some differences in the diet composition compared to that used by Davidson *et al.* (2000) and the animals were ewe lambs rather than wether lambs but it is unlikely that these two variables would entirely account for the large difference in growth rates.

The feed conversion ratios recorded in these two experiments were similar (average 6.0:1 vs 5.9:1) so the main factor contributing to differences in growth rate was feed intake. In a commercial feeding situation, the lower growth rate may have less significance because the cost of feed to produce liveweight gain is the same, however, slow growing animals would take longer to reach their target liveweight so the cost of labour and other overheads would be higher.

Intermediate growth rates of 220-272 g/day were reported for wether lambs housed indoors in individual pens, fed isonitrogenous and isocaloric pelleted diets with three different protein sources (Wiese *et al.* 2000). Lambs fed a canola meal-based diet grew faster than those fed either a lupin or a urea-based diet. Feed conversion of lambs fed the canola meal diet was 6.2:1 and this tended to be more efficient than those fed other diets. Feed conversion of lambs fed lupin or urea-based diets was numerically less efficient in this experiment compared to other animals housed in similar conditions (Davidson *et al.* 2000; Jones *et al.* 2000).

Some feeding systems that emulated commercial scenarios reported good growth rates in the 250-300 g/day range (Hopkins *et al.* 1996; Wiese *et al.* 2003). Small groups of first-cross induced cryptorchid lambs were confined in paddocks and offered a pelleted diet of lupins, wheat, oats and minerals through a self-feeder plus 200 g/head/day of lucerne chaff in a replicated experiment (Hopkins *et al.* 1996). The use of cryptorchids may have contributed to high growth rates in this experiment, although higher growth rates were reported by Wiese *et al.* (2003) for a large scale experiment using wether lambs housed indoors in group pens of 6 animals. The average growth rate of 120 lambs fed a pelleted diet containing straw, lupins, oats, barley and minerals over a 28-day feeding period was 296 g/day with a feed conversion ratio of 5.1:1. In contrast, lambs housed indoors in small group pens and fed either a 'high' energy pelleted diet of hay, lupins, barley, wheat, minerals and vitamins or a 'moderate' energy pellet of hay, lupins, wheat, minerals and vitamins achieved only moderate growth rates of around 190 g/day (Pethick *et al.* 2003b). A similar growth rate of 190 g/day was reported for first-cross wether lambs housed indoors in small group pens and offered a pelleted diet of straw, lupins, barley, canola meal, minerals, vitamins and monensin (Gardner *et al.* 1999). These two experiments also had similar feed conversion ratios of around 7:1 to 8:1. However, feed offered in the latter experiment was restricted to 1.3 kg/head/day and the authors observed that feed was consumed in less than one hour so these lambs had the potential to consume more feed which may have improved growth rate and feed efficiency.

Most current research has concentrated on finishing systems that produce 18-22 kg carcases, e.g. Table 6.3. More recently some focus has moved to evaluating finishing systems for lean, heavyweight lambs (24+ kg) in response to the continual market demand for heavier carcases. Feedlot finishing is suitable for producing heavyweight lambs and good growth rates have been demonstrated in a group pen scenario (Shands *et al.* 2002). Performance of progeny from high estimated breeding value (EBV) sires was monitored in a feedlot finishing system as part of the Central Progeny Test program. Mixed ewes and cryptorchids from first- and second-cross matings were housed in group pens and offered a diet consisting of 60 per cent commercial pellets, lucerne hay, lupins and cottonseed meal (C.G. Shands 2003, pers. comm.). The composite diet contained 11.3 MJ ME/kg DM and 19.0 per cent crude protein. The average growth rate across both sex and mating types was 275 g/day and feed conversion was 4.55:1 with growth rates ranging from 200-360 g/day during the 60-day feeding period. Lambs had an average carcase weight of 27.9 kg and at the end of the 60-day feeding period, 49 per cent of lambs produced carcases in the desired range of 22+ kg and 8-20 mm GR depth.[3]

Second-cross

Growth rates reported for second-cross lambs in pellet-based finishing systems are 300-350 g/day (Table 6.4). There are a limited number of investigations of growth performance of second-cross lambs. The highest growth rate was achieved in a commercial simulation where small groups of second-cross induced cryptorchid lambs were confined in paddocks and offered a pelleted diet (Hopkins *et al.* 1996). This experiment included both first- and second-cross lambs and has been described in the above section. There was no difference between the performances of second-cross lambs of different genotypes but growth of second-cross lambs by Poll Dorset sires had a significantly higher growth rate than

[3] The 12th rib GR site is 110 mm from the backbone (vertebral column).

first-cross lambs (Table 6.3 and Table 6.4). The use of induced-cryptorchid lambs may have contributed to high growth rates in this experiment. These growth rates are in agreement with expected growth rates promoted in State Agriculture Department extension material (Table 6.1).

Table 6.4. Breed and performance of second-cross lambs fed on pelleted diets with metabolisable energy (ME) and crude protein specifications of diet indicated. Feed conversion ratio (FCR), liveweight (LW).

Breed (sire x dam)	Growth rate (g/day)	FCR	Initial LW (kg)	Final LW (kg)	Carcase weight (kg)	Diet specification		Reference
						Crude protein (%)	ME (MJ/kg DM)	
T x (BL x M)	301[a]					15.0	11.8	1, 2
PD x (BL x M)	349[a]							
PD x (BL x M)	180*	7.5	32.1	42.4	20.2	17.4	10.8	3
PD x (BL x M)	206		28.2	54.0	25.3	11.4	10.7	4

BL: Border Leicester; M: Merino; PD: Poll Dorset; T: Texel; * Feed was restricted to 1.3 kg/day in this experiment; Within each experiment, growth rates with the same superscript are not significantly different.

[1] Hopkins *et al.* (1996); [2] Holst *et al.* (1998); [3] Gardner *et al.* (1999); [4] Hegarty *et al.* (1999).

Other authors have reported lower growth rates for second-cross lambs but evaluation of growth performance was not the primary aim of these experiments so growth rate may have been compromised by other factors (Gardner *et al.* 1999; Hegarty *et al.* 1999). Second-cross lambs fed a pelleted diet of lucerne and triticale for an extended period of time maintained an average growth rate of 206 g/day when grown from 28 kg initial liveweight to 54 kg final liveweight (Hegarty *et al.* 1999). These animals were housed indoors in individual pens and the lengthy feeding period (128 days) was used to create a contrast for further investigations rather than evaluate finishing performance. Nevertheless, it is interesting to note that moderate average growth rates can be maintained over an extended intensive feeding period.

The potentially superior growth rate of second-cross lambs is related to their higher and faster feed intake compared with first-cross lambs (Holst *et al.* 1998). Feed intake was restricted to 1.3 kg/head/day in the experiment reported by Gardner *et al.* (1999) so the potential growth rate was not realised. The authors observed that the daily feed ration was consumed in less than one hour, indicating that lambs would have consumed more feed if it was available and this would probably have improved growth rate.

Merino

The scientific literature contains a few reports on the performance of prime Merino lambs that are relevant to modern sheep meat production systems and each report has unique aspects that make it difficult to draw general conclusions. Growth rates range from 143-286 g/day and feed conversions from 8.7:1 to 6.1:1 (Table 6.5). Recent extension publications suggest expected growth rates of 150-320 g/day for Merino lambs in commercial feedlot finishing systems (Milton 2001; Seymour 2000). The small volume of literature does not support the higher end of this range.

Higher growth rates were reported in controlled feeding situations that were further removed from commercial pellet feeding. Merino wethers gained 286 g/day when fed for 22 days housed individually in indoor pens with *ad libitum* access to a pelleted diet of barley, lupins, canola meal, cereal hay, minerals and vitamins (Davidson *et al.* 2000). In comparison, when animals were housed in small groups in indoor pens the reported growth rates were 243 g/day and 160 g/day on pelleted diets containing straw, lupins, oats, barley and minerals or straw, lupins, barley, canola meal, minerals, vitamins and monensin (Gardner *et al.* 1999;

Wiese *et al.* 2003). The feeding system that most closely correlated with a commercial situation produced growth rates of 148 g/day (Pethick *et al.* 2003a). In this experiment, 150 Merino ewes were confined in a small paddock and offered a pelleted diet of hay, lupins and barley from a self-feeder.

Table 6.5. Performance of Merino lambs with metabolisable energy (ME) and crude protein specifications of diet indicated. Feed conversion ratio (FCR), liveweight (LW).

Growth rate (g/day)	FCR	Initial LW (kg)	Final LW (kg)	Carcase weight (kg)	Diet specification		Reference
					Crude protein (%)	ME (MJ/kg DM)	
286	6.1	38.9	45.2	19.4	16.0	10.8	1
243	6.1	37.0	47.2	19.9	15.0	11.0	2
160	8.7	30.3	39.2	17.9	17.4	10.8	3
148			40.9	18.2	17.9	10.5	4
176	6.3	38.0	~50.3	23.6	15.0	11.9	5

[1] Davidson *et al.* (2000); [2] Wiese *et al.* (2003); [3] Gardner *et al.* (1999); [4] Pethick *et al.* (2003a); [5] Pethick and Rowe (1996).

This approach oversimplifies the variables present between different experiments. The work reported by Pethick *et al.* (2003a) was undertaken using ewes while the remaining three experiments involved wether lambs. Social interactions in addition to those created by the large group may also have occurred because 25 ewe lambs were confined with 125 mixed age Merino ewes. In the experiment reported by Gardner *et al.* (1999) intake and growth rate were potentially restricted through the feeding of a fixed amount of 1.3 kg pellets/head/day. There were also small differences in the nutritional specification of the diets and liveweight ranges between experiments that may have affected growth rate (Table 6.5).

During a longer feeding period of 10 weeks, individually penned Merino wethers fed a pelleted diet of straw, lupins, barley, minerals, vitamins and virginiamycin maintained an average growth rate of 176 g/day (Pethick and Rowe 1996).

Conclusions

Generally, pelleted diets are more expensive to purchase than unprocessed grain. However, pellets have the advantages over unprocessed grain of convenience, ease of handling and purchasing a formulated ration. In order to assess the cost-benefit of feeding a pelleted diet, it is necessary to establish the expected growth rate and feed conversion rate of lambs in this feeding system. A considerable amount of the recent scientific literature describes pellet-based feedlot finishing systems and these systems have become popular due to their use by producer/processor alliances (e.g. Q Lamb and Prime Merino Lamb Alliance). Although more data are available for these feeding systems than other feeding systems, the growth performance reported in the literature is quite variable and may not reflect what would occur in a commercial situation. Further experimental verification of biological performance in pellet-based feeding systems at a commercial scale would be beneficial.

Loose grain mix fed in open troughs or self-feeder and separate roughage

A whole grain mix is prepared using existing on-farm grain handling equipment and delivered to a self-feeder or troughs. Minerals and other additives may be incorporated with the grain or offered free choice. Hay, silage or other roughage is offered separately, either on the ground or fed in hay racks. There are many variations to this simple feeding system but the common principles are the adaptation of existing basic equipment to facilitate mixing and delivery of feed and *ad libitum* access to grain and roughage, which allows animals to select their own diet. The disadvantage of this system is that allowing sheep to select their own diet can compromise growth rate and feed conversion. Intake of grain and roughage components will vary and individual animals may consume excess grain, increasing the risk of acidosis or excess roughage thus reducing their growth rate. Low capital investment and reduced labour requirements are the key advantages of this feeding system. This system is the predominant feeding method adopted in opportunistic feedlots where costs are kept to a minimum by utilising existing infrastructure and equipment.

Animal performance

In current industry feeding systems, roughage is commonly provided *ad libitum* and placed on the ground in the feedlot with grain mix supplied *ad libitum* via a self-feeder, or less often in troughs (Bryant and Kirby, refer appendix). When grain and roughage are fed separately, growth rate of lambs is generally higher if the roughage component is restricted or when more grain is available. Brook *et al.* (1996) reported that when roughage was available *ad libitum*, lambs selected up to 38 per cent of their diet as roughage and consequently had growth rates of around 150 g/day. Similarly, lambs with *ad libitum* access to wheat from a self-feeder and offered either lucerne hay or oaten hay selected 42 per cent and 29 per cent of their diet as roughage and grew at 167 g/day or 132 g/day (File 1976). In contrast, Brand and van der Merwe (1994) reported average growth rates of 190 g/day for South African Mutton Merino lambs fed triticale or maize-based diets with access to lucerne hay at 10 per cent of *ad libitum* intake. Similarly, Kenney (1986) reported growth rates of around 200 g/day for second-cross lambs fed cereal-based diets with lupin supplementation and access to 10 per cent hay. Most recently, Davis and Quilford (2001) reported growth rates of around 260 g/day for second-cross lambs fed cereal-based diets with hay at 12 per cent of the diet. Limiting the proportion of roughage invariably increases the digestibility and energy density of the diet leading to higher growth rates.

The presentation of roughage affects the level of wastage and therefore affects feed conversion ratio. Presentation of hay in racks or restriction of access so that lambs cannot spoil the feed can reduce wastage of hay. Milton *et al.* (2002) reported that 77 per cent more hay was required to achieve the same growth rate when prime lambs were fed hay on the ground compared to a covered hay rack. The cost of feed to achieve the same liveweight gain was around 35 per cent higher for the lambs fed on the ground due to the amount of hay that was wasted. Fibre length also affects wastage. Milling hay into smaller lengths has been shown to reduce wastage. File (1976) estimated that 32 per cent of lucerne hay and 43 per cent of oaten hay was wasted when presented in a long form in hay racks. The author commented that poorly designed hay racks and damp conditions accentuated the wastage. Feed conversion ratio of lambs tended to be improved when hay was presented milled or milled and mixed compared with long in hay racks (File 1976). While it is clear that wastage of roughage can be reduced by improved feeding equipment, the impact on profitability depends on the number of lambs that will be fed using the equipment.

In a commercial scenario, when grain and roughage are fed separately, there will be more variation in intake of feed components between individuals compared to a pellet-based feeding system. In a pellet feeding system, total intake may vary between individuals, but the balance of diet that each animal is receiving is controlled. Animal performance could therefore be compromised when diet components are fed separately. It is difficult to draw conclusions as to whether this concept is supported by the literature because there has been limited evaluation of loose grain mix feeding for finishing lambs to current market specifications. Davis and Quilford (2001) investigated performance of second-cross lambs grown from an average of 35 to 46 kg over 42 days in a commercial scale feedlot. Growth rates of 241-271 g/day and feed conversion from 6.7:1 to 8:1 were achieved on a range of diets with similar energy and protein but different protein sources. The range of growth rates achieved in this simple feedlot system are lower than those reported by Hopkins *et al.* (1996) for second-cross lambs fed pellets but within the wide range reported for various feeding systems (Table 6.2 to Table 6.5).

In some cases, growth rate can be closely related to the total intake of metabolisable energy. The grain component of the diet generally has a higher concentration of metabolisable energy than the roughage component so growth rate increases linearly with intake of grain or energy (Figure 6.1, Brook *et al.* 1996; Holst *et al.* 1999).

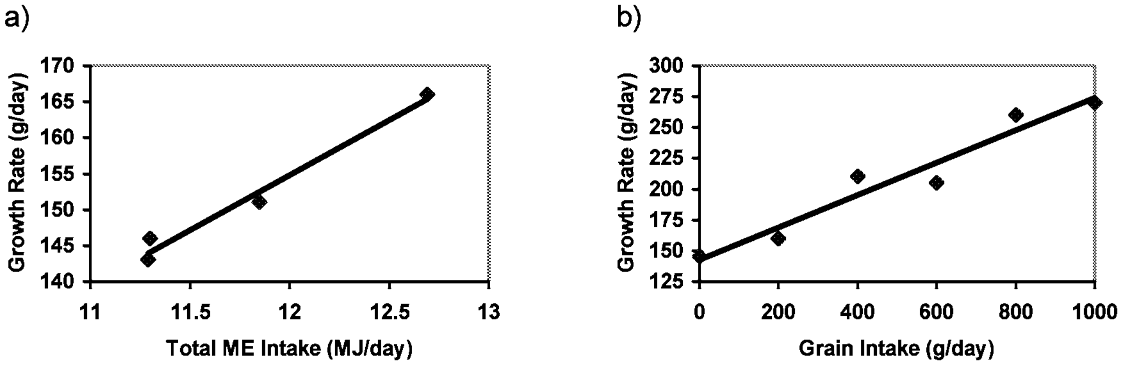

Figure 6.1. **Relationship between energy intake and growth rate in mixed grain and roughage diets; a) calculated from Brook *et al.* (1996) and b) adapted from Holst *et al.* (1999).**

Interactions between grain and forage

Interactions between grain and forage can affect both digestibility and intake of the dietary components (Dixon and Stockdale 1999). Fermentation of the fibrous components of forage and starch from grains are facilitated by different species of rumen microflora. The microbial population in the rumen adapts to maximise the rate of fermentation of dietary components for example when sheep are fed a grain-based diet, there is a proliferation of amylolytic bacteria and a decrease in the number of fibrolytic bacteria leading to a decrease in the rate of digestion of forage (El-Shazly *et al.* 1961). In addition to a depression of digestibility, intake of forage is reduced due to substitution for grain and this results in inefficiencies in the utilisation of grain (Dixon *et al.* 1993; Dixon and Stockdale 1999).

The degree of interaction between grain and forage is variable, depending on the quality and availability of the different feed components. The type of grain supplement can influence the extent of the effect on roughage intake and digestibility, even when the different supplements provide similar amounts of metabolisable energy (Dixon *et al.* 1993). Dixon *et al.* (1993) reported a decrease in roughage intake but overall increase in metabolisable energy intake when roughage was supplemented with barley or lupins but when it was supplemented with cottonseed meal, there was little effect on roughage intake and a small increase in digestibility. The interaction between grain and forage may also depend on the presentation of the two components. When lambs on a silage-based diet were supplemented with grain, growth rate was generally increased more when grain and silage were offered separately than when the two dietary components were mixed (Holst *et al.* 1999). There are clearly significant digestive and metabolic interactions when grain and forage diets are fed and an improved understanding of interactions between dietary components is particularly important in a feedlot system where grain mix and separate roughage are offered *ad libitum*.

Conclusions

It has been noted, particularly in the cattle industry, that even when grain is offered *ad libitum*, animal performance in conserved fodder feeding systems is not as good as feedlot systems (Dixon and Stockdale 1999). It could be expected that this would also be true for lamb finishing systems where the animals have some choice between diet components; however, conclusive data is lacking to support this concept. Further investigation is warranted of simple feedlotting systems with either *ad libitum* or limited access to forage.

Anecdotal reports of growth rate

There is little information available in the scientific literature on commercial scale monitoring of biological performance in modern finishing systems and available data are quite variable. Anecdotal reports of animal performance and expected growth rates and feed conversion reported in extension material are consequently a valuable source of performance information. For example, of the commercial producers who responded to a recent survey, 19 per cent measured growth rate; 71 per cent of this group indicated growth rates of 200-300 g/day, 21 per cent indicated growth rates of 100-200 g/day and 7 per cent indicated growth rates of 300-400 g/day (Bryant and Kirby, refer appendix). This suggests that growth rates commonly achieved by industry are at the lower end of expected performance indicated in extension material. In response to a similar survey from the early 1970s, producers indicated growth rates of around 100 g/day, so it would appear that there has been some improvement in the growth rates reported by producers for feedlot finishing systems over the last 30 years (Tomes and Dymond 1976).

Biological performance of older sheep in intensive feeding systems

Adult sheep that are slaughtered for mutton have a low potential growth rate compared to lambs because they have already reached mature size. McDonald (1982) reported growth rates of 143 g/day for store wethers on dry pasture supplemented with oat/lupin diets from self-feeders. A range of lupin inclusion rates was evaluated and no difference found between the growth rates of animals offered 50 per cent, 75 per cent or 100 per cent lupins (McDonald 1982). When lupin content of the diet was reduced to 25 per cent, the growth rate was reduced to 119 g/day but all animals still met market specifications. Thus the most cost effective feeding strategy may be to meet market targets rather than maximise growth rate.

Higher growth rates have been reported when greater control was exercised over individual intake. Individually penned two-year old Merino wethers were offered 200 g/day of chaff plus 1 kg/day of barley, maize, sorghum, wheat or flaked sorghum for an 8 week period (Pethick *et al.* 1995). The resulting growth rates were around 145-180 g/day. It is likely that the young wethers in this experiment were still not expressing their maximum potential growth rate because the amount of feed offered was limited.

From an industry perspective it may be more meaningful to consider the performance of older sheep in a group feeding situation. Pethick *et al.* (2003b) reported growth rates ranging from 105-173 g/day for adult ewes aged from 20 months to 68.5 months offered a pelleted diet from a self-feeder. Interestingly, ewes in the 44.5 and 56.5 month categories had a significantly higher growth rate than either younger or older animals (173 g/day vs. 125 g/day). The animals with the highest liveweight gain had lower carcase weights than animals in other groups suggesting that they may have been in poorer condition at the commencement of the feeding period. Liveweight change in response to feeding is mainly due to fat deposition so potential growth rate will depend on initial body condition.

Use of maize and sorghum in growing and finishing diets for lambs

Grain finishing systems in Australia are commonly based on winter cereal grains; however, there is widespread use of summer cereal grains such as maize and sorghum in lamb grain finishing systems in other countries. Because of limited data on the use of summer cereal grains in Australia, research from other parts of the world has been included in this review.

Table 6.6. Growth rate and feed conversion ratio (FCR) of lambs fed grain diets. Summary of trials.

Animals				Grain			Response				Ref.
Breed	LW (kg)	Age (days)	No.	Source	Processing	(%)	Growth rate (g/day)	FCR (kg/kg)	DMI (kg/day)	Days on feed	
(S x FL x DH)	15	35-49	64	Maize Barley Wheat Oats	Whole	90 *ad lib.*	345 340 303 241	2.52 2.75 2.97 3.07	0.87 0.94 0.90 0.74		1
----	----	----		Maize Barley			227 217	6.80 6.34	1.54 1.37		2
SAMM	19	56	60	Maize Triticale		90 *ad lib.*	202 192	4.97 5.71	0.99 1.04		3
R x S	29	----	80	100 Maize 75 Maize:25 Wheat 50 Maize:50 Wheat 25 Maize:75 Wheat 100 Wheat	Whole:Ground	70 *ad lib.*	340 330 320 290 250	4.13 4.16 4.25 4.46 4.80	1.40 1.37 1.36 1.29 1.20	70	4
----	----	36	143	Maize Wheat		100	195 172			166	5
HX	38		80	Maize Maize + Soybean Meal Maize + Feather Meal Maize + Feather Meal + Soybean Meal	Dry Rolled	75 Adj.	346 346 405 378	4.48 4.42 4.07 3.95	1.55 1.53 1.65 1.49	63	6
HX	38		80	Maize Maize + 0.3% Urea Maize + 0.6% Urea Maize + 1% Urea	Dry Rolled	74 Adj.	477 485 485 477	3.51 3.54 3.54 3.44	1.67 1.72 1.72 1.64	98	7
X	38		74	Maize + 6% rup Maize + 7% rup Maize + 8% rup Maize + 9% rup	Dry Rolled	75 *ad lib.*	279 302 306 302	4.85 4.60 4.85 4.76	1.35 1.39 1.46 1.44	74	8
MX	20	60		Maize 80 Maize:20 Sorghum 60 Maize:40 Sorghum		85	375 326 315	3.24 3.61 3.78	1.22 1.18 1.19	63	6
----	----	----	454	Sorghum 40 Sorghum:60 Wheat		100	223 204				9
X	----	----		Sorghum Barley			300 247	6.48 6.47			2

Grain (%): Percentage of grain in the diet, offered *ad libitum* (*ad lib.*) or daily adjusted (adj.); FCR: Feed conversion ratio, kg feed/kg gain; DMI: Dry matter intake; H: Hampshire; LW: Liveweight; M: Merino; No.: number of animals used; rup: rumen undegradable protein; R: Rambouillet; SAMM: South African Meat Merino; S: Suffolk; X: Crossbred.

[1] Ørskov *et al.* (1974); [2] Lardy (1999), average of various trials from North Dakota Sate University reported by this author; [3] Brand and van der Merwe (1994); [4] Kreikemeier *et al.* (1987); [5] Phillips (1993); [6] Loe *et al.* (2000); [7] Loe *et al.* (2001); [8] Reed *et al.* (2002); [9] Krajinovic *et al.* (1992).

The response to the inclusion of grain in diets for growing and finishing lambs depends on the ratio of grain to forage. More variation in animal response is expected in supplementary systems due to the lower relative importance of the grain in the diet and the strong interactions between grain and forage. Different feeding systems may be described by the varying proportion of grain in the diet, including 100 per cent whole-grain diets (Umberger 1997) to 30:70 ratio (Dulce *et al.* n.d.). As the proportion of forage in the diet increases, forage quality and interaction between forage intake and grain digestion becomes more important. Associative effects between the two components may affect the efficiency of nutrient utilisation.

Lamb performance on whole-grain diets

Umberger (1997) describes whole grain diets as those consisting of whole, unprocessed grains mixed with a pelleted protein, vitamin and mineral supplement. Roughage is not incorporated into whole-grain diet or supplemented on the side. Table 6.6 summarises results of lamb performance when fed maize or sorghum in grain feeding trials, where grain constituted more than 70 per cent of the diet.

There are few studies comparing performance of lambs offered different types of grain in the same trial. Data reported in Table 6.6 mostly correspond to performance of lambs fed maize grain. Less information is available on the use of sorghum in finishing systems and none of the research is specific for conditions in Australia. Mitchell and Roberts' study (1976) comparing different grains in whole-grain diets versus a pelleted stock feed as control using 26 kg Dorset x Merino lambs, is the only Australian study that reports performance data for lambs fed sorghum or maize compared to other grains. These authors reported lower liveweight gain for oats. Liveweight gain did not differ between sorghum, maize, barley and wheat-diets, but barley and sorghum-based diets produced similar liveweight gain to the control group.

All data in Table 6.6 are for crossbred lambs from different genotypes. Expected liveweight gains will vary depending on genotype, however data for performance in grain-feeding systems based on maize or sorghum generally falls within the expected range (Latif and Owen 1980; Seymour 2000). Feed conversion ratios are reported to vary between 7:1 to 5:1 (Seymour 2000). Reported values for maize and sorghum are closer to or even lower than 5:1. Age, sex and genotype would affect these variables, but a higher efficiency associated with all concentrate diets may also explain these values. Latif and Owen (1980) report that feed conversion ratios of about 3:1 should be expected for early-weaned lambs raised on all-concentrate diets to slaughter. Additional variation could be associated with *ad libitum* versus adjusted grain feeding. Feed delivery systems have been reported to affect animal performance. Fluharty *et al.* (1999) evaluated feedlot performance of lambs fed whole or ground maize *ad libitum*, or adjusted daily or weekly. In this study, lambs with weekly adjusted feeding had lower liveweight gains (288 g/day) when compared to lambs with daily adjusted feeding (378 g/day) or *ad libitum* access to feed (387 g/day). The difference in liveweight gain was mainly due to variation in intake of whole grain maize, with no differences in feed conversion ratio between the groups (3.5-3.8:1).

Lambs fed maize as the only grain source gained on average 363 g/day and registered a feed conversion ratio of 4:1 (Table 6.6). Partially or totally substituting maize with another grain or by-product reduced daily gain and increased feed conversion ratio (304 g/day and 4.4:1).

Early weaned lambs fed a 90 per cent concentrate diet until slaughter at around 35 kg liveweight performed better when fed maize in comparison to barley, wheat or oats. This suggests that the source of grain affects liveweight gain (Ørskov *et al.* 1974). Umberger (1997) reported that in whole grain feeding systems, lamb performance was reduced by approximately 10 per cent when barley was fed rather than maize. He suggested that lambs preferred maize to barley and because of this, these grains should not be fed together

(Umberger 1997). This tendency was confirmed by Lardy (1999) from an analysis of data from several trials on the performance of lambs fed different grains at the North Dakota State University (Table 6.6). On average, liveweight gains for lambs fed maize or sorghum were 4 per cent and 5 per cent higher than with barley. However, feed conversion ratio was increased when lambs were fed maize, but no difference was observed for sorghum. Lardy (1999) also reported that carcase weight, dressing percentage and back fat were higher in lambs fed sorghum compared to barley and that no benefit was noted from the inclusion of barley in sorghum diets.

Brand and van der Merwe (1994) comparing different triticale cultivars to maize concentrate in lamb feedlot diets reported no differences in liveweight gain, grain or forage intake between treatments, but lambs receiving maize tended to have a better feed conversion ratio (13%) than those consuming triticale. Feeding value of triticale based on these parameters ranged from 65 per cent to 94 per cent of that of maize diets, depending on the triticale cultivar.

In Australia, there is limited availability of maize and the price is much higher than for other grains or by-products, however due to the high nutritive value of maize, some research is required to quantify the effect of partially substituting it into rations. Dhakad *et al.* (2002) concluded from their study that half of the maize grain can be safely and economically replaced with wheat bran in the concentrate mixture of growing lambs without any adverse effect on their performance.

Phillips (1993) evaluated the effect of substituting maize with wheat grain in the diet offered to feeder lambs for a 166-day period. He observed that as the proportion of wheat in the lambs' diet increased, feed conversion ratio was not affected but liveweight gain decreased. When sorghum was substituted with wheat, as the amount of wheat in the diet increased from 0 to 60 per cent, average daily weight gain decreased from 223 to 204 g/day. Dry matter intake was similar across all treatments but feed conversion ratio was poorer for diets containing more than 20 per cent wheat.

Some authors have hypothesised that feeding maize or sorghum in whole grain diets, may limit available rumen degradable protein, microbial protein synthesis and total metabolisable protein for lamb production (Loe *et al.* 2000, 2001; Reed *et al.* 2002). Loe *et al.* (2001) evaluated different levels of rumen degradable protein in maize whole-grain diets, finding that for lambs with the ability to gain at least 470 g/day, the optimal level of rumen degradable protein does not appear to be greater than 6.1 per cent of the diet dry matter; however feeding levels between 6.1 and 11.0 per cent does not affect gain or feed efficiency. Increasing rumen undegradable protein in this feeding system did not affect lamb performance, except that rib-eye area tended to increase linearly with increasing level of rumen undegradable protein (Reed *et al.* 2002).

Performance of lambs fed maize or sorghum on high roughage ration

Table 6.7 reports lamb performance data when sorghum or maize were fed as part of a feedlot diet where forage represented more than 50 per cent of the diet. The inclusion of a forage source affects feed conversion ratio. Reducing whole maize grain while increasing the alfalfa proportion from 0 to 100 per cent in the diet of lambs and maintaining an isoenergetic diet adjusted to animal requirements, did not affect liveweight gain but it increased feed conversion ratio from 4.5:1 when 100 per cent grain was fed, to 7.8:1 when only alfalfa was fed (Fluharty 1999).

Table 6.7. Liveweight gain (LWG) and feed conversion ratio (FCR) of lambs fed whole grain diets. Summary of trials.

Animals			Grain		Forage		Response			Ref
Breed	LW (kg)	Number	Source	g/day	Source	g/day	Growth rate (g/day)	FCR (kg/kg)	FI (g/day)	
	9.8	12	60 Maize:40 Wheat Bran 30 Maize:70 Wheat Bran 100 Wheat Bran	115 112 106	Wheat Straw	*ad lib.*	79 [ab] 88 [b] 68 [a]	6.0 5.7 6.5	174 194 128	1
M x BL	19.3		Control Maize Sorghum Oats Meat meal	0 79[1] 87 92 100	Oaten Chaff	*ad lib.*	75 81 88 112 148		639 418 497 560 661	2
T	25		Control Sorghum Wheat	0 250[2] 250[2]	Lucerne Hay	*ad lib.*	168 208 256	6.7 5.9 5.2		3
T	25		Control Sorghum Wheat	0 250[2] 250[2]	Pasture Silage	*ad lib.*	-28 130 52	7.8 20		3
SX	47	230	Maize (whole grain)	100[3] 80 60 40 20 0	Alfalfa Pellets	0[3] 20 40 60 80 100	347 365 351 351 364 342	4.5 4.6 5.5 6.2 6.9 7.8		4

[1] Grams/animal isoenergetic quantities (estimated based on NRC, 1996); [2] Grain adjusted to 1.0 per cent BW during the experimental period; [3] Proportion of the diet.
ad lib.: *ad libitum*; BL: Border Leicester; FI: Forage intake; FCR: Feed conversion ratio; LW: Liveweight; M: Merino; No.: Number of animal used; S: Suffolk; SX: Suffolk Crossbred; T: Texel.

[1] Dhakad *et al.* (2002); [2] Kempton (1982); [3] Dulce (n.d.); [4] Fluharty (1999).

BACK | FORWARD

The role of maize and sorghum in simple feeding systems

Simple systems of grain feeding have been proposed for cattle supplementation in Australia, to meet the need for alternative systems that reduce labour and costs, while maintaining liveweight gain and feed conversion rates (Rowe and Zorrilla-Rios 1993). The introductory period has been identified as one of the constraints to be overcome from conventional lot feeding.

Acidosis or sub-acute acidosis can occur when cattle and sheep over-consume readily fermentable carbohydrates (Al-Jassim and Rowe 1999; Kaiser 1999). The highest risk of acidosis is during the introductory period to high grain diets and it results in variable intake patterns that may cause reduced weight gains. Low weight gains during the adaptation period may compromise the whole efficiency of the grain-feeding program, depending on the duration of this period. Maize and sorghum, given their lower rumen degradability, appear to be safer grains compared to wheat or barley. Kreikemeier *et al.* (1987) suggest that when diets are based on grains which have rapid fermentation, a mixture with slow degradable grains may be a method for overcoming acidosis. They fed lambs on a 70 per cent grain diet, and observed that increasing the proportion of whole dry maize with respect to wheat from 25 per cent to 100 per cent increased the lambs' intake during the 21-day adaptation period. Liveweight gain and feed conversion ratio showed a significant quadratic effect.

Mendoza *et al.* (1999) feeding different combinations of high moisture maize and dry rolled sorghum grain in a 75 per cent grain diet found that even when there was no evidence of subacute acidosis the highest starch intake was registered for the mixture containing 33 per cent high moisture maize and 67 per cent dry rolled sorghum.

Conclusions

Limited data exist describing the performance of lambs fed maize or sorghum grain under Australian conditions. Research from other countries shows that lambs fed high concentrate diets of summer cereal grains perform as well or better than when fed winter cereals in terms of liveweight gains and feed conversion ratios.

Processing maize does not appear to improve total tract digestibility. Lambs fed whole maize in high concentrate diets have higher liveweight gains and lower feed conversion ratios than when offered ground maize. The effect of processing on sorghum fed to lambs is not as clear as for maize. Some evidence indicates processing may be used to manipulate carcase fat characteristics.

Higher variability in terms of liveweight gain and conversion rates may be expected when feeding maize or sorghum in diets with high levels of forage compared with high concentrate diets. Increasing forage in the diet increases feed conversion ratios and even reduces liveweight gains depending on forage quality.

Because of their low rate of fermentation, maize and sorghum appear to be safer grains than wheat and barley and could play an important role in simple grain feeding systems where there is less control of grain intake.

References

Al-Jassim, R.A.M. and Rowe, J.B. (1999). 'Supplementary grain feeding of pregnant and lactating Merino ewes'. *Recent Advances in Animal Nutrition in Australia,* vol. 12, p. 16A.

Andrews, R.P. and Orskov, E.R. (1970a). 'The nutrition of the early weaned lamb 1. The influence of protein concentration and feeding level on rate of gain in body weight'. *Journal of Agricultural Science, Cambridge,* vol. 75, pp. 11-18.

Andrews, R.P. and Orskov, E.R. (1970b). 'The nutrition of the early weaned lamb. 2. The effect of dietary protein concentration, feeding level and sex on body composition at two liveweights'. *Journal of Agricultural Science, Cambridge,* vol. 75, pp. 19-26.

Beames, R.M., Tait, R.M. and Litsky, J. (1986). 'Grain screenings as a dietary component for pigs and sheep. I. Botanical and chemical composition'. *Canadian Journal of Animal Science,* vol. 66, pp. 473-481.

Bell, A.K., Shands, C.G. and Hegarty, R.S. (1998). 'Feedlotting lambs'. NSW Agriculture, *Agnote* DAI/42, pp. 1-11.

Bell, A.K., Shands, C.G., Hegarty, R.S. and Duddy, G. (2003). 'Feedlotting lambs'. NSW Agriculture, *Agnote* DAI/42, pp. 1-11.

Blackwood, I., Graham, J., House, J., McKiernan, B. and Walker, B. (2000). *Opportunity lotfeeding of beef cattle.* NSW Agriculture.

Blood, D.C. and Studdert, V.P. (1990). *Balliere's Comprehensive Veterinary Dictionary.* Balliere Tindall, London.

Brand, T.S. and van der Merwe, G.D. (1994). 'Comparison of triticale cultivars with maize grain for finishing lambs'. *South African Journal of Animal Science,* vol. 24, pp. 143-146.

Brook, D.S., Hosking, B.J. and Holmes, J.H.G. (1996). 'Barley and field peas for lot-fed lambs'. *Animal Production in Australia,* vol. 21, pp. 258-261.

Cotterill, P.P. and Roberts, E.M. (1979). 'Crossbred lamb growth and carcase characteristics of some Australian sheep breeds'. *Australian Journal of Experimental Agriculture and Animal Husbandry,* vol. 19, pp. 407-413.

Cottle, D.J. (1991). *Australian Sheep and Wool Handbook.* Inkata Press, Melbourne.

Croker, K. and Watt, P. (eds) (2001). *The Good Food Guide for Sheep.* Government of Western Australia, Department of Agriculture, Perth, Bulletin 4473.

Davidson, R.H., Milton, J.T.B., Vercoe, P.E., Sewell, J.W. and Sewell, B. (2000). 'Feed intake, growth rate and feed efficiency of Merino and first cross prime lambs fed a grain-based pelleted diet'. *Animal Production in Australia,* vol. 23, p. 173.

Davis, C.H., Saville, D.G. and McInnes, P.M. (1976). 'Production feeding of weaner lambs with diets based on wheat - effect of diets and management'. *Animal Production in Australia,* vol. 11, pp. 433-436.

Davis, J. (2003). *Feedlotting lambs.* Landlinks Press, Collingwood.

Davis, J.J. and Quilford, M. (2001). 'A simple lot feeding system for lambs'. *Recent Advances in Animal Nutrition in Australia,* vol. 13, p. 5A.

Dhakad, A., Garg, A.K., Singh, P. and Agrawal, D.K. (2002). 'Effect of replacement of maize grain with wheat bran on the performance of growing lambs'. *Small Ruminant Research,* vol. 43, pp. 227-234.

Dixon, R.M. and Stockdale, C.R. (1999). 'Associative effects between forages and grains: Consequences for feed utilisation'. *Australian Journal of Agricultural Research,* vol. 50, pp. 757-773.

Dixon, R.M., Thomas, R., Thalen, A. and Egan, A.R. (1993). 'Responses of young sheep to supplements'. *Recent Advances in Animal Nutrition in Australia*, vol. 9, pp. 1-12.

Donnelly, F.B. and Morrison, K.J. (1984). 'Fattening lambs on predominantly wheat diets'. *Animal Production in Australia,* vol. 15, p. 671.

Dulce, E., Jaurena, G., Wawrzkliewikz, M. and Vitezica, Z. (n.d.). 'Effect of supplementary energy source on productive traits and carcass quality in Texel lambs' [WWW document].
URL http://www.agro.uba.ar/catedras/ovinos/alpa_vange.pdf (accessed 15/3/04).

El-Shazly, K., Dehority, B.A. and Johnson, R.R. (1961). 'Effects of starch on the digestion of cellulose *in vitro* and *in vivo* by rumen micro-organisms'. *Journal of Animal Science,* vol. 20, pp. 268-273.

File, G.C. (1976). 'The effects of roughage quality, physical form and mode of presentation with a wheat based diet on the performance of lot fed lambs'. *Animal Production in Australia,* vol. 11, pp. 437-440.

Fluharty, F.L. (1999). 'Effects of pelleted alfalfa and whole-shelled corn combination on lamb growth and carcass characteristics'. In: *Research and Reviews: Beef and Sheep, Special Circular*, Ohio State University, pp. 170-199, [WWW document]. URL http://ohioline.osu.edu/sc170/sc170_13.html. (accessed 15/3/04).

Fluharty, F.L., Lowe, G.D. and Clevenger, D.D. (1999). 'Effects of feed-delivery system and corn processing on lamb growth and carcass characteristics'. In: *Research and Reviews: Beef and Sheep, Special Circular*, Ohio State University, pp. 170-199, [WWW document].
URL http://ohioline.osu.edu/sc170/sc170_16.html. (accessed 15/3/04).

Gardner, G.E., Kennedy, L., Milton, J.T.B. and Pethick, D.W. (1999). 'Glycogen metabolism and ultimate pH of muscle in Merino, first-cross, and second-cross wether lambs as affected by stress before slaughter'. *Australian Journal of Agricultural Research,* vol. 50, pp. 175-182.

Giumelli, E. (2003). 'Establishing feedlots for sheep'. Government of Western Australia, Department of Agriculture, *Farmnote* No. 53/2003.

Hack, W., Ashton, B. and Giles, B. (1997). 'Rations when production feeding'. In: *Feeding sheep.* Ashton, B. and Morbey, T. (eds). Primary Industries and Resources, South Australia, pp. 44-46.

Hack, W. and Moreby, T. (1997). 'Citrus peel and other material for drought feeding'. In: *Feeding sheep.* Ashton, B. and Morbey, T. (eds). Primary Industries and Resources, South Australia, pp. 35-36.

Hegarty, R.S., Neutze, S.A. and Oddy, V.H. (1999). 'Effects of protein and energy supply on the growth and carcass composition of lambs from differing nutritional histories'. *Journal of Agricultural Science, Cambridge,* vol. 132, pp. 361-375.

Hetherington, R.F. and Krebs, G.L. (2002). 'The use of bakery wastes in feedlot rations for sheep'. *Animal Production in Australia,* vol. 24, pp. 89-92.

Holst, P.J., Kaiser, A.G. and White, A. (1999). 'Increasing usage of silage by the development of efficient silage production and feeding systems for lamb'. Meat and Livestock Australia, LAMB.373, Sydney.

Holst, P.J., Kilgour, R.J., Nolan, J.V. and Stanley, D.F. (1998). 'Feeding behaviour and growth response of lambs at a stationary self-feeder'. *Animal Production in Australia,* vol. 22, p. 283.

Hopkins, D.L., Holst, P.J., Fogarty, N.M. and Stanley, D.F. (1996). 'Growth and carcass characteristics of first and second cross lambs lot-fed to heavy weights'. *Animal Production in Australia,* vol. 21, pp. 181-184.

Ikin, T.L. and Pearce, G.R. (1978). 'Feedlotting of slow-growing lambs at different stages of growth'. *Australian Journal of Experimental Agriculture,* vol. 18, pp. 355-360.

Jones, F.M., Davidson, R.H., Vercoe, P.E. and Milton, J.T.B. (2000). 'Finishing prime lambs on either a pelleted or loose diet'. *Animal Production in Australia,* vol. 23, p. 172.

Kaiser, A.G. (1999). 'Increasing the utilisation of grain when fed whole to ruminants'. *Australian Journal of Agricultural Research,* vol. 50, pp. 737-756.

Kempton, T.J. (1982). 'Growth of lambs given a roughage diet and isocaloric amounts of various supplements'. *Animal Production in Australia,* vol. 14, p. 649.

Kenney, P.A. (1986). 'Productivity of early weaned lambs fed high-grain diets of wheat, oats or barley with or without lupin grain'. *Australian Journal of Experimental Agriculture,* vol. 26, pp. 279-284.

Kessell, D.M. (1982). 'Wagin pellets'. In: *Discussion paper - Nutrition of grazing sheep.* Department of Agriculture, Western Australia, Perth.

Knott, S.A. and Hyde, M. (2001). 'An evaluation of the novel feedstuff, grain dust, as a feed for sheep'. *Recent Advances in Animal Nutrition in Australia,* vol. 13, p. 6A.

Krajinovic, M., Kunc, V. and Cinkulov, M. (1992). 'Testing the possibility of using sorghum as a maize substitute in diets for fattening lambs'. *Savremena Poljoprivreda,* vol. 40, pp. 9-13.

Kreikemeier, K.K., Stock, R.A., Brink, D.R. and Britton, R.A. (1987). 'Feeding combinations of dry corn and wheat to finishing lambs and cattle'. *Journal of Animal Science,* vol. 65, pp. 1647-1654.

Kubik, D. and Stock, R. (1990). 'By-product feedstuffs for beef and dairy cattle'. NebGuide, University of Nebraska, Lincoln.

Lardy, G. (1999). 'Feeding barley to sheep' [WWW document]. URL http://www.ext.nodak.edu/extpubs/ansci/sheep/eb71w.htm (accessed 15/3/04).

Latif, M.G.A. and Owen, E. (1980). 'A note on the growth performance and carcass composition of Texel- and Suffolk- sired lambs in an intensive feeding system'. *Animal Production,* vol. 30, pp. 311-314.

Loe, E.R., Bauer, M.L., Lardy, G.P., Berg, G.T. and Moore, B.L. (2000). 'Addition of rumen degradable and undegradable protein to corn-based lamb finishing diets' [WWW document]. URL http://www.ag.ndsu.nodak.edu/hettinge/livestock/2000sheepday/9905Bsheepday.htm (accessed 31/3/04).

Loe, E.R., Encinias, A.M., Bauer, M.L., Lardy, G.P. and Caton, J.S. (2001). 'Level of rumen degradable intake protein (DIP) in high-grain diets fed to feedlot lambs' [WWW document]. URL http://www.ag.ndsu.nodak.edu/hettinge/livestock/2001sheepday/loe.htm (accessed 15/3/04).

McDonald, C.L. (1982). 'Producing shippers out-of-season'. In: *Feeding Sheep to Produce Meat.* Suiter, R.J. (ed.). Government of Western Australia, Department of Agriculture, Perth, Bulletin No. 4071, pp. 23-27.

McDonald, C.L. and Suiter, R.J. (1982). 'A comparison of oat based rations either fed as whole grain or processed commercially into pellets for finishing sheep'. In: *Feeding Sheep to Produce Meat.* Suiter, R.J. (ed.). Government of Western Australia, Department of Agriculture, Perth, Bulletin No. 4071, pp. 19-22.

Mendoza, G.D., Britton, R.A. and Stock, R.A. (1999). 'Effect of feeding mixtures of high moisture corn and dry-rolled grain sorghum on ruminal fermentation and starch digestion'. *Small Ruminant Research,* vol. 32, pp. 113-118.

Milton, J.T.B. (2001). 'Lot-feeding prime lambs'. In: *The Good Food Guide for Sheep.* Croker, K. and Watt, P. (eds). Government of Western Australia, Department of Agriculture, Perth, Bulletin 4473, pp. 79-84.

Milton, J.T.B., Davidson, R.H. and Gray, S.J. (2002). 'Less hay is wasted when fed in covered racks to prime lambs in wet weather'. *Animal Production in Australia,* vol. 24, p. 332.

Mitchell, B. and Roberts, E.M. (1976). 'A comparison of the growth and meat characteristics of crossbred lambs fed several complete whole grain diets'. *Animal Production in Australia,* vol. 11, p. 15P.

Ørskov, E.R. (1976). 'The effect of processing on digestion and utilisation of cereals by ruminants'. *Proceedings of the Nutrition Society,* vol. 35, pp. 245-252.

Ørskov, E.R., Fraser, C. and McHattie, I. (1974). 'Cereal processing and food utilisation by sheep 2. A note on the effect of feeding unprocessed barley, maize, oats and wheat on food utilisation by early-weaned lambs'. *Animal Production,* vol. 18, pp. 85-88.

Pethick, D.W., Hopkins, D.L., D'Souza, D.N., Thompson, J.T. and Walker, P. (2003a). 'The impact of animal age on the eating quality of sheepmeat derived from Merino ewes'. Final report to Meat and Livestock Australia, Project SMEQ.016.

Pethick, D.W., Jacob, R.H., Skerritt, J., Thompson, J.M., Hopkins, D.L., Walker, P. and Baud, S. (2003b). 'Impact of feeding/finishing systems on lamb growth rates and product quality'. Final report to Meat and Livestock Australia, Project SMEQ.016.

Pethick, D.W. and Rowe, J.B. (1996). 'The effect of nutrition and exercise on carcass parameters and the level of glycogen in skeletal muscle of Merino sheep'. *Australian Journal of Agricultural Research,* vol. 47, pp. 525-537.

Pethick, D.W., Rowe, J.B. and McIntyre B.L. (1995). 'Feeding systems for increasing marbling in cattle'. *Meat Research Corporation, Final Report,* DAW.053, Murdoch University, Perth.

Phillips, W.A. (1993). 'Feedlot performance of feeder lambs fed diets containing different proportions of wheat, corn and sorghum'. *Sheep Research Journal,* vol. 9, pp. 71-75.

Reed, J.J., Bauer, M.L., Lardy, G.P. and Berg, P.T. (2002). 'Level of rumen undegradable protein (RUP) in high-grain diets fed to feedlot lambs' [WWW document]. URL http://www.ag.ndsu.nodak.edu/hettinge/livestock/2002sheepday/jakereed.htm (accessed 31/3/04).

Richardson, E.C., Kaiser, A.G. and Piltz, J.W. (2001). 'The nutritive value of frosted wheat for sheep'. *Australian Journal of Experimental Agriculture,* vol. 41, pp. 205-210.

Roberts, D. and Devenish, K. (2001). 'Chaff heaps - a useful source of feed for sheep and cattle'. Government of Western Australia, Department of Agriculture, *Farmnote* No. 55/2001.

Roberts, G.B., Kenney, P.A. and Smith, G.H. (1984). 'Use of lupin hay and triticale grain for fattening sheep'. *Animal Production in Australia,* vol. 15, pp. 557-560.

Rowe, J.B. and Zorrilla-Rios, J. (1993). 'Simplified systems of feeding grain to cattle in feedlots and under grazing conditions'. *Recent Advances in Animal Nutrition in Australia,* vol. 9, pp. 89-96.

Seymour, M. (2000). 'Lotfeeding prime lambs'. Government of Western Australia, Department of Agriculture. *Farmnote* No. 72/2000.

Shands, C.G., Farrell, T.C., Fogarty, N. and Hegarty, R.S. (2002). 'Growth and carcass specifications of heavyweight first- and second-cross feedlot-finished lambs'. *Animal Production in Australia,* vol. 24, p. 352.

Stanford, K., Wallins, G.L., Lees, B.M. and Mundel, H.H. (1999). 'Use of lentil screenings in the diets of early weaned lambs and ewes in the second trimester of pregnancy'. *Animal Feed Science and Technology,* vol. 81, pp. 249-264.

Stanford, K., Wallins, G.L., Smart, W.G. and McAllister, T.A. (2000). 'Effects of feeding canola screenings on apparent digestibility, growth performance and carcass characteristics of feedlot lambs'. *Canadian Journal of Animal Science,* vol. 80, pp. 355-362.

Suiter, R.J. (1990). *Finishing lambs and shippers in feedlots and paddocks.* Government of Western Australia, Department of Agriculture, Perth, Bulletin No. 4192.

Suiter, R.J. and McDonald, C.L. (1987). 'Growth of Merino weaners fed grain-based diets while grazing dry pasture or housed in feedlots'. *Australian Journal of Experimental Agriculture,* vol. 27, pp. 629-632.

Suiter, R.J., McDonald, C.L. and King, W.R. (1982). 'Results of feedlotting work conducted at Wongan Hills Research Station during 1980'. In: *Feeding Sheep to Produce M*eat. Suiter, R.J. (ed.). Government of Western Australia, Department of Agriculture, Perth, Bulletin No. 4071, pp. 30-32.

Tomes, G.J. and Dymond, J.E. (1976). 'Lamb performance in feedlots'. *Animal Production in Australia,* vol. 11, pp. 429-432.

Umberger, S.H. (1997). 'Whole-grain diets for finishing lambs' [WWW document]. URL http://www.ext.vt.edu/pubs/sheep/410-024/410-024.pdf (accessed 15/3/04).

Wiese, S.C., White, C.L., Masters, D.G., Davidson, R.H. and Milton, J.T.B. (2000). 'The performance of prime lambs fed diets with urea, lupins or canola meal as a source of protein'. *Animal Production in Australia,* vol. 23, p. 152.

Wiese, S.C., White, C.L., Masters, D.G., Milton, J.T.B. and Davidson, R.H. (2003). 'The growth performance and carcass attributes of Merino and Poll Dorset X Merino lambs fed rumen-protected methionine (Smartamine™-M)'. *Australian Journal of Agricultural Research,* vol. 54, pp. 507-513.

Feeding grain for sheep meat production

Chapter 7. Adaptation to grain feeding

R.M. Kirby, F.M. Jones, D.M. Ferguson and A.D. Fisher

CHAPTER 7. ADAPTATION TO GRAIN FEEDING

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Introduction

The efficiency of grain feeding is limited by the rate of adaptation to both the feed and feeding system. The speed of introduction to grain in supplementary feeding situations and intensive feedlots is influenced by several factors. The animal must adjust physiologically to the new diet and depending on the grain used there may be a high risk of acidosis during the adjustment phase. Sheep have to adapt to the novel aspects of the feeding situation such as feeding equipment, diet format and possibly the type of grain. Finally, there will be altered patterns of social interaction, especially in a confined feeding system.

Acidosis can occur when sheep are introduced to a high starch diet without an adequate introductory period. The risk of acidosis is high during confinement feeding due to the level of feeding and availability of grain, but it can also occur during introduction to grain in supplementary feeding situations. Acidosis has long been recognised as a significant impediment to successful grain feeding (Bigham and McManus 1975; Ikin and Pearce 1978) and continues to be identified as the primary health problem in feedlots despite the management and intervention strategies that have been developed (Langman and Ashton 2000; Seymour 2000). Advisers from Primary Industries and Resources South Australia carried out a survey of farmers who were lot feeding sheep in drought conditions and reported that 19 per cent of the farmers identified acidosis as the main cause of deaths in their feedlot (Langman and Ashton 2000).

Social or behavioural adaptation to grain feeding is equal in importance to physiological adaptation. Social interaction and animal dominance can cause variation in intake between animals, contributing to variation in growth rate. At the extreme, there will be a proportion of animals that do not adapt at all to supplementary feeding and these animals are referred to as 'shy-feeders'. The incidence of shy-feeders is increased by the intensity of the feeding system and it is usual to budget for at least 5 per cent shy-feeders in a feedlot operation (Bell *et al.* 2003). However, the amount eaten of a new food can vary by as much as four- to five-fold between sheep within a similar age group (Juwarini *et al.* 1981). Clearly, the rate of adaptation to diets continues to impact on grain finishing systems and this is an area that requires further investigation.

Physiological adaptation to grain feeding

Acidosis (lactic acidosis)

By definition, acidosis is 'a pathological condition resulting from accumulation of acid or depletion of the alkaline reserve (bicarbonate content) in the blood and body tissues and characterised by increase in hydrogen ion concentration (decrease in pH)' (Blood and Studdert 1990). When applied to ruminants, the term acidosis more specifically encompasses a range of metabolic disturbances that arise from the excess production of lactate and other acids by bacteria in the rumen or hindgut. Acidosis can be separated into two main categories, acute or subclinical (chronic). Acute acidosis presents as an overt illness following excessive consumption of highly fermentable carbohydrates and may lead to death. In contrast, chronic acidosis may not be associated with obvious clinical signs but commonly causes a reduction in feed intake and an accompanying decrease in performance.

Subclinical acidosis is perhaps more economically important for large feedlot operations, but acute acidosis can be a significant problem during introduction to high-grain diets.

The common cause of acidosis in ruminants is the production and absorption of large quantities of fixed acid such as lactic acid and the excess loss of the bicarbonate ion during acute carbohydrate engorgement (Blood *et al*. 1983). The introduction of highly fermentable carbohydrates to the rumen leads to rapid production of volatile fatty acids, including lactate. Lactate removal from the rumen is slow and when the rate of production exceeds the rate of removal, the pH may fall below 6.0. This favours the rapid growth of lactic acid-producing bacteria including *Streptococcus bovis* and *Lactobacillus* spp. The pH continues to fall, exacerbating the imbalance between lactate-producing and lactate-using bacteria by allowing *Lactobacillus* spp. to proliferate (Al-Jassim and Rowe 1999). Ruminal pH of 5.2 and 5.6 have been suggested as benchmarks for clinical diagnosis of acute and subclinical acidosis (Owens *et al*. 1998).

Acidosis can also occur in the hindgut (caecum and colon) as a result of starch passing through to the small intestine without complete digestion. During a grain engorgement challenge, the pH of digesta in the caecum and colon decreases to levels similar to or lower than those seen in the rumen (Godfrey *et al*. 1993a; Lee 1977). Godfrey *et al*. (1993a) suggested that post-ruminal changes in pH and digesta dry matter are important in the development of clinical signs of acidosis, especially diarrhoea (scouring).

Strategies to control acidosis predominantly rely on management practices or feed additives (Figure 7.1). Management strategies such as choice of grain and method of feeding reduce the level of fermentation substrates entering the rumen and thereby decrease the risk of acidosis. Intervention strategies within the rumen aim to control lactate accumulation either by decreasing production or increasing utilisation. Acidosis is initiated by the proliferation of lactate-producing bacteria; therefore a logical strategy for controlling acidosis is to prevent lactate production through use of selective antibiotics or vaccines. Other investigations have focussed on methods of promoting lactate utilisation by inoculation with rumen fluid or bacterial cultures, dosing with probiotics and dicarboxylic acids. The addition of buffering salts is aimed at maintaining a more favourable pH in the rumen to control the clinical signs of acidosis.

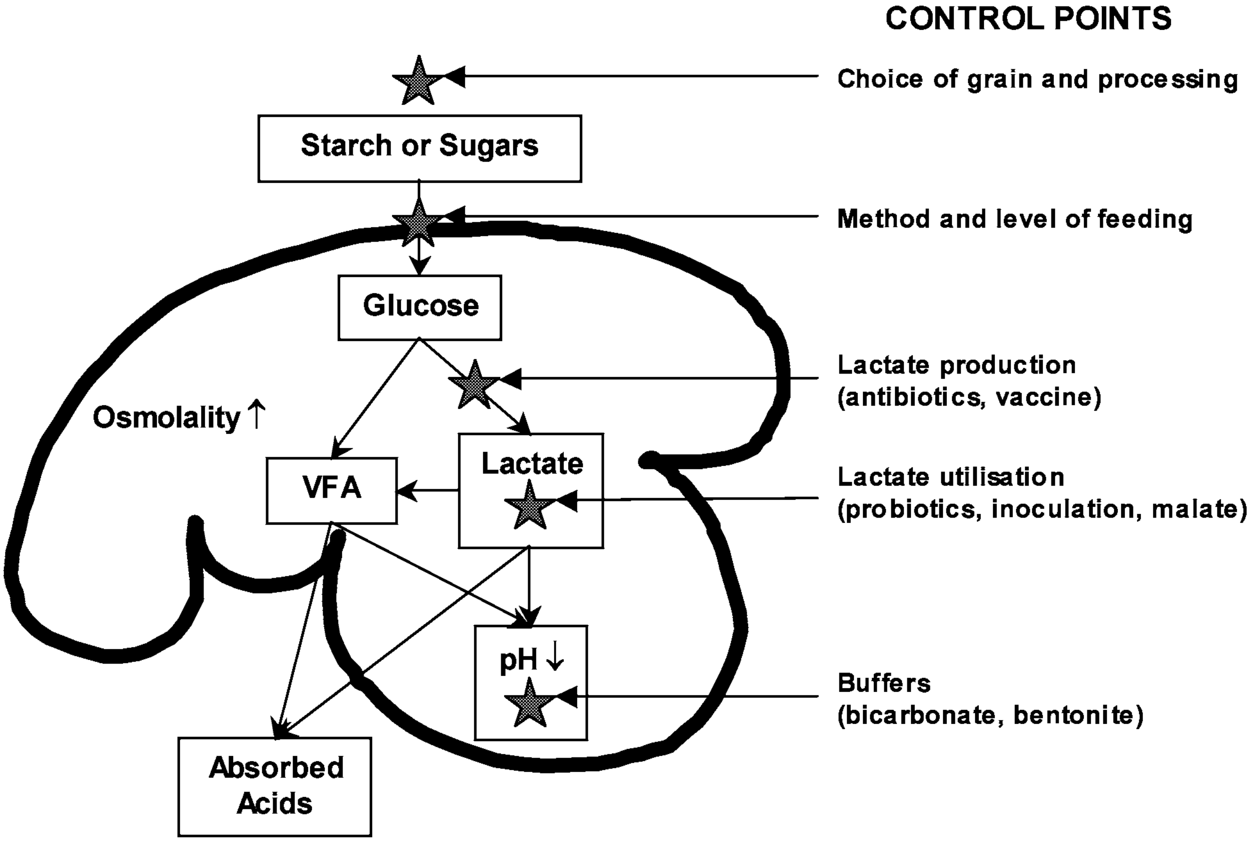

Figure 7.1. **Principal reactions and control points for managing acidosis (Owens *et al.* 1998; Rowe *et al.* 2002).**

Rumen modifying antibiotics

Antibiotic compounds that have selected activity against gram-positive bacteria are useful for controlling the accumulation of lactic acid, because many lactate-producing bacteria are gram-positive, while lactate users are gram-negative. Several antibiotic compounds have been investigated for their efficacy in preventing acidosis in ruminants. The compound that has been most thoroughly investigated under Australian conditions is virginiamycin.

There has been limited registration of antibiotics for use as feed additives for sheep in Australia. Sheep production systems are predominantly extensive so there has been relatively little demand or funding for development of feed additives for sheep compared to other livestock (e.g. pigs, poultry and cattle). The ionophore lasalocid is registered for use as a feed additive in sheep (and cattle) rations for reduction of gram-positive bacteria in the rumen and faecal shedding of coccidia and virginiamycin[1] is registered for use in ruminant rations to reduce the risk of acidosis when feeding grains.

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[1] As of 1 January 2004 all veterinary chemicals containing virginiamycin became Schedule 4 Poisons (Prescription Animal Remedies) and must be supplied or prescribed by a Veterinarian. The change in scheduling relates to the view that the continued unrestricted use of this product poses an unacceptable risk to humans from the development and transfer of resistance to this class of antibiotics. Draft review report available at [WWW document]. URL http://www.apvma.gov.au/chemrev/virginiamycin.pdf (accessed 31/3/04).

Non-ionophore antibiotics

Over the last four decades a number of antibiotics have undergone *in vitro* or *in vivo* evaluation for potential to prevent lactate accumulation and the development of acidosis in ruminants. Early evaluations of antibiotics including tetracycline, penicillin, capreomycin disulfate, oxamycin and thiopeptin were reviewed by Nagaraja *et al.* (1981). These authors concluded that tetracycline and penicillin had limited usefulness due to existing resistance to these antibiotics and their negative effects on production of volatile fatty acids. In addition, penicillin has been shown to suppress lactate fermentation for less than 16 h, so has limited effectiveness at preventing acidosis (Muir *et al.* 1980b).

During the late 1970s and early 1980s, there was some interest in thiopeptin, a sulfur-containing peptide antibiotic with high specificity for *S. bovis*. It was shown to be highly active against *S. bovis* in an *in vitro* system and effective at preventing acidosis during an acute challenge (Kezar and Church 1979; Muir and Barreto 1979; Muir *et al.* 1980b). Inclusion of 11 ppm or more of thiopeptin in the ration improved feed intake and growth rate of lambs during an 8-week finishing period where a high starch diet was abruptly introduced (Muir *et al.* 1980a). Muir *et al.* (1980a) also demonstrated that lower doses of thiopeptin were able to prevent death although there was no improvement in performance compared to controls, suggesting that at least 11 ppm of thiopeptin was required to prevent subclinical acidosis. Other thiopeptin-like antibiotics were similarly successful at preventing acidosis without inhibiting normal volatile fatty acid production (Muir *et al.* 1980b). The available literature suggests that thiopeptin and related compounds are suitable for prevention of acidosis but there has been no commercial development of these products for use in sheep.

The gram-positive spectrum glycopeptide antibiotics, avoparcin and flavomycin (bambermycin; flavophospholipol) have been examined for their potential to prevent acidosis. Preliminary *in vivo* investigation showed that flavomycin did not prevent lactate accumulation during an acute grain challenge (Aitchison *et al.* 1987; McDonald *et al.* 1987). McDonald *et al.* (1987) and Aitchison *et al.* (1987) reported that lactate concentration was reduced by dosing with avoparcin prior to, or during an acute grain challenge. However, avoparcin was less effective for controlling lactate production *in vitro* than other antimicrobial compounds (Nagaraja *et al.* 1987). Subsequently, Butler *et al.* (1992) reported that avoparcin depressed feed intake and liveweight change rather than provided a beneficial effect on ruminal fermentation. Avoparcin and flavomycin do not appear to be effective for use in alleviating acidosis. In addition, avoparcin is no longer considered suitable for use as an animal feed additive as it is closely related to antibiotics used in human medicine (APVMA 2001; JETACAR 1999).

The antibiotic that has been most thoroughly investigated in Australia for the mitigation of acidosis in ruminants is the streptogramin antibiotic, virginiamycin. Virginiamycin is highly effective at reducing lactate concentration and acidity during *in vitro* fermentation of rumen fluid and during an acute grain challenge *in vivo* (Godfrey *et al.* 1995; Nagaraja *et al.* 1987). Godfrey *et al.* (1995) simulated abrupt introduction to grain supplementation by offering 2.1 kg wheat either with or without virginiamycin to sheep maintained on 300 g/day chaff for the previous 9 days. In support of *in vitro* results, rumen L-lactate concentration and hydrogen ion concentrations were lower in sheep offered wheat with virginiamycin compared to sheep fed wheat only. During simulation of long-term grain supplementation under grazing conditions, Godfrey *et al.* (1993b) demonstrated that inclusion of virginiamycin with barley resulted in higher liveweight gains, higher chaff intake and a reduction in the incidence of diarrhoea compared to a diet of barley alone. These results suggest that inclusion of virginiamycin controls acute acidosis during grain introduction and subclinical acidosis during intermittent grain supplementation.

In grazing situations where animals are harvesting residual grain from stubbles or failed crops it is not possible to include antibiotics with the grain. Preliminary investigations have been conducted to examine the feasibility of treating the animal directly with virginiamycin for the prevention of acidosis during grain feeding. Pre-dosing sheep with virginiamycin prior to a single acute grain challenge was successful in maintaining a higher pH in the rumen (Thorniley *et al.* 1996) and preventing lactate accumulation in the caecum and colon (Godfrey *et al.* 1993a). To be successful under commercial feeding conditions, treatment with virginiamycin must give protection against the accumulation of lactic acid while the rumen population adapts to a high-grain diet. Thorniley *et al.* (1998) demonstrated that a single drench treatment with at least 80 mg virginiamycin reduced rumen acidity and consequently increased rumen pH of sheep with no prior introduction to grain when they were offered wheat for 14 days. The sheep treated with virginiamycin resumed eating more rapidly than untreated animals following inappetence caused by overeating when grain was first offered. Interestingly, animals drenched with virginiamycin did not overeat to the same degree as untreated animals, so the severity of acidosis may have been reduced simply because intake of starch was lower. Thorniley *et al.* (1998) suggest that this may be an important mechanism of action of virginiamycin that complements the direct antibiotic activity. It would be valuable to isolate the magnitude of effects of restricted intake and direct antibiotic activity in preventing acidosis during abrupt introduction to grain.

The development of virginiamycin for use in sheep has focussed mainly on extensive grazing situations where grain supplements are used. There are fewer studies investigating inclusion of virginiamycin in complete grain-based rations. McDonald *et al.* (1994) showed that inclusion of virginiamycin in a barley-based shipping pellet increased the number of sheep that began feeding during a simulated export assembly period. In contrast, Murray *et al.* (1992) reported decreased feed intake by sheep when virginiamycin was included in grain-based pelleted diets. Unpublished studies summarised in the APVMA review of virginiamycin failed to show any production benefits when virginiamycin was included in pelleted diets (APVMA 2003). However the production situations and experimental detail were not clear from the summaries so it is not possible to determine whether this conclusion is relevant to intensive feeding for meat production. Other evidence suggests that virginiamycin may have a role in preventing subclinical acidosis in production feeding situations. Where grain has been introduced gradually to prevent acute acidosis, inclusion of virginiamycin in beef feedlot diets has been shown to improve weight gain and feed conversion efficiency and reduce the development of liver abscesses (unpublished data APVMA 2003). There may be some scope to clarify the efficacy of virginiamycin for the prevention of subclinical acidosis during confined production feeding; however alternative ionophore antibiotics may be more suitable for this purpose.

In the future, the use of antibiotics may be restricted or potential applications altered and therefore avenues for strategic use or alternative acidosis controlling strategies should be investigated. The report produced by the Joint Expert Technical Advisory Committee on Antibiotic Resistance (JETACAR 1999) recommended a review of the use of virginiamycin for animal treatment due to concerns that its use may impair the efficacy of related therapeutic antibiotics for humans through the development of resistant strains of organisms. The resulting draft review of the Australian Pesticides and Veterinary Medicines Authority recommended the following changes to the registration of virginiamycin for use in sheep production (Table 7.1, APVMA 2003).

The recommended label changes indicate that the long-term use of virginiamycin within feeding regimes will be restricted. Presently there is no recommendation for period of in-feed inclusion of virginiamycin placed on labels but some producers rely on use for the duration of the grain feeding program. The proposed label amendments mean that virginiamycin will no longer be approved for prophylactic use in feedlot diets; however, it will still be available as a management strategy for extensive grain feeding.

Table 7.1. An extract of the draft recommendations for the use of virginiamycin when grain feeding sheep (APVMA 2003) [For current schedule refer footnote 1].

Product	49111 Eskalin wettable powder spray-on feed premix.
Active ingredient	virginiamycin 400 g/kg (individual sachets of 20 g).
Poison schedule classification	Schedule 5.
Registrant	Phibro Animal Health.
Claims on APVMA approved label	For use in cattle and sheep rations to reduce the risk of acidosis when feeding grain.
Recommendations	Label changes required. Schedule currently under consideration by NDPSC.
Proposed label amendments	Drought fed sheep and cattle: For use to reduce the risk of acidosis in sheep and cattle fed grain on a weekly or twice weekly basis.
Regulatory decision	Vary conditions of label approval. Affirm registrations.

Virginiamycin has never been approved for prophylactic or therapeutic use for sheep in the European Union, New Zealand or the United States (APVMA 2003). In 1998, the authorisation for use of virginiamycin as a growth promotant for pigs and poultry was withdrawn by the European Union, bringing this antibiotic and the issue of antibiotic resistance to the attention of consumers. Consumer pressure from both domestic and international markets is likely to have as much influence on use of virginiamycin within the sheep industry as any regulatory controls. Identification of alternatives for adaptation of livestock to grain-based diets will be an important priority for the sheep industry.

Ionophores

Ionophores are a class of antibiotics named for their ability to form complexes with particular cations and facilitate their transport across biological membranes (Nagaraja 1995). Carboxylic polyether ionophores have the ability to beneficially modify rumen fermentation through selective activity against gram-positive bacteria and those with a gram-positive cell wall structure (Bergen and Bates 1984; Nagaraja 1995). Following the discovery of the efficacy of monensin in 1976, a range of ionophores were developed or are under investigation for use as growth promotants for ruminants (Nagaraja 1995; Raun *et al.* 1976). In general, ionophores improve feed efficiency, but can have a variable influence on feed intake and weight gain (Table 7.2). Ionophores fed with diets that are high in readily fermentable carbohydrates (grain-based diets) generally lead to a reduction in feed intake with improvements in feed conversion ratio (Schelling 1984). On the other hand, when used in roughage diets that contain β-linked carbohydrates ionophores may not depress feed intake, but the weight gain of the animal is generally improved (Bergen and Bates 1984). The chemical and physical properties of different fibre sources can also influence the digestibility and intake response when fed with ionophores.

Table 7.2. The general response of beef cattle to ionophore antibiotics (↑ increase; ↓ decrease; 0 no change) (Nagaraja *et al.* 1997).

Ionophore	Grain fed			Pasture fed
	Intake	Gain	Efficiency	Gain
Monensin	↓	0	↑	↑
Lasalocid	0.↑	↑	↑	↑
Laidlomycin	0.↑	↑	↑	N/A
Lysocellin	↓	0.↑	↑	↑
Narasin	↓	0	↑	N/A
Salinomycin	0.↓	0.↑	↑	↑
Tetronasin	↓	0.↑	↑	↑

Bergen and Bates (1984) identified three main areas of metabolism that are affected by ionophores that may account for the improvement in feed efficiency in ruminants:

1. Improved efficiency of energy metabolism.
2. Improved nitrogen metabolism.
3. Shift in rumen fermentation away from lactate production and reduction in froth formation, resulting in a reduction in lactic acidosis and bloat.

It is outside the scope of this review to consider the effect of ionophores on energy and nitrogen metabolism. These effects have been well characterised by others, especially in cattle (reviews Bergen and Bates 1984; Nagaraja 1995). It is generally agreed that ionophores produce a consistent improvement in feed efficiency in cattle, but results are more variable for sheep (Daugherty *et al.* 1986; Horton and Stockdale 1981; Muwalla *et al.* 1998; Nagaraja 1995; Spears 1990). Spears (1990) summarised a number of studies and concluded that on average, there was no increase in energy digestibility for sheep fed either lasalocid or monensin.

The potential of ionophores to reduce the prevalence of feedlot disorders such as acidosis has been demonstrated in specific investigations. In contrast to narrow-spectrum antibiotics that are primarily active against gram-positive bacteria, e.g. *S. bovis*, lasalocid and monensin were shown to inhibit a wide range of lactate-producing bacteria *in vitro,* e.g. *Lactobacillus*, *Butyrivibrio*, *Ruminococcus*, *Eubacterium* and *Lachnospira* (Dennis *et al.* 1981b). Studies have also shown that ionophore antibiotics are effective in preventing the accumulation of lactate in rumen fluid *in vitro* (Dennis *et al.* 1981a; Newbold and Wallace 1988). Ionophores have been examined for their efficacy *in vivo* by simulating acute (grain or glucose challenge) and subclinical acidosis in cattle (Burrin and Britton 1986; Nagaraja *et al.* 1981, 1982). Nagaraja *et al.* (1981) reported that acute acidosis was prevented by treating cattle with lasalocid or monensin for 7 days prior to a grain challenge. Monensin alleviated the rumen pH decline during subclinical acidosis induced by an abrupt change from forage to a concentrate ration in steers (Burrin and Britton 1986) but was not effective when administered with the diet or as a controlled release capsule to dairy cows with experimentally induced subclinical acidosis (Mutsvangwa *et al.* 2002).

The ionophores lasalocid and monensin were more effective in the prevention of rumen pH decline in cattle challenged with glucose than the sulfur-containing peptide antibiotic, thiopeptin (Nagaraja *et al.* 1982). This is not surprising considering that the ionophores have a broader spectrum than thiopeptin. Lasalocid and tetronasin were shown to be more effective than monensin at inhibiting lactate production during *in vitro* incubation with rumen fluid from cattle (Dennis *et al.* 1981a; Newbold and Wallace 1988). Nagaraja *et al.* (1987) screened a range of antimicrobial feed additives and found that incubation of rumen fluid from cattle with narasin or salinomycin resulted in higher final pH than incubation with other ionophores.

Improvements in feed efficiency are reported more consistently in cattle than sheep indicating that the inhibitory effects of ionophores exert subtly different pressure on the rumen bacteria populations of each of the two species (Spears 1990). This suggests that it is not appropriate to assume that the mitigation of acidosis by ionophores observed in cattle will be apparent in sheep. There is only one study on the efficacy of ionophores for preventing acidosis in sheep. Rowe (1988) hypothesised that the improved performance of sheep receiving lasalocid during a simulated shipping assembly period was due to alleviation of acidosis. Further investigation is required to determine whether ionophores influence rumen fermentation sufficiently for sheep to avoid acidosis when challenged with high grain diets during production feeding.

Inoculants and probiotics

There is potential to reduce the susceptibility of sheep to acidosis through the introduction of naturally occurring organisms (probiotics) to the rumen (Mackie and McSweeney 2002). The two main approaches to probiotic prevention of acidosis in ruminants have been inoculation with lactate utilising bacteria and inclusion of yeasts in the diet.

Amylolytic, lactate-producing bacteria proliferate when sheep are introduced to grain. If the introduction occurs gradually, lactate-utilising bacteria such as *Megasphaera elsdenii* respond to the increase in their primary substrate and multiply concurrently to prevent lactate accumulation. Several authors have demonstrated that this process can be accelerated by inoculating unadapted animals with crude rumen fluid from animals that are already adapted to grain (Allison *et al.* 1964; Godfrey *et al.* 1993a; Huber 1974). This approach has been refined by targeting the predominant lactate-utilising bacteria in the rumen of animals adapted to a high grain diet. Kung and Hession (1995) reported that *in vitro* inoculation with *M. elsdenii* prevented accumulation of lactate when rumen fluid from cattle was incubated with rapidly fermentable carbohydrates. This finding is supported by *in vivo* investigations in sheep. Wiryawan and Brooker (1995) demonstrated that inoculation of the rumen with *Sel. ruminantium* in combination with *M. elsdenii* prior to acute grain feeding of animals prevented the accumulation of lactate and stabilised ruminal pH for 4 days. Although *Anaerovibrio* spp. have been identified as one of the primary lactate utilising bacteria in the rumen of grain-adapted sheep (Mackie *et al.* 1978), there has been no investigation of their efficacy as an inoculant for the prevention of acidosis. Determining the right combination of probiotics to be included in a feeding regime may help during the initial period of adaptation to grain.

There is interest in microbial feed additives, most commonly based on *Saccharomyces cervisiae* and *Aspergillus oryzae,* as an alternative to hormonal and antibiotic growth promotants. The production responses to these products reported for ruminants are variable, but generally positive (Newbold 1995). Although the mode of action of fungi and yeasts is unclear, the most common effect is an increase in bacterial numbers, including lactate utilising bacteria (Wallace 1996). *S. cervisiae* was shown to prevent the accumulation of lactate in the rumen during fermentation of starch (Williams and Newbold 1990), possibly through a stimulatory effect on *M. elsdenii* and *Sel. ruminantium* (Chaucheyras *et al.* 1996; Nisbet and Martin 1991). These findings suggest that microbial feed additives may be suitable for the prevention of acidosis in sheep; however *in vivo* investigations have not supported this hypothesis. Chademana and Offer (1990) reported no effect on rumen pH when *S. cerevisiae* was included in the diet and pre-dosing sheep with *S. cerevisiae* prior to a grain challenge did not appear to cause any changes in the pattern of rumen fermentation and digestion compared to untreated animals (Godfrey *et al.* 1993a).

It has been proposed that the stimulatory effect of *S. cerevisiae* on lactate utilisation by rumen bacteria is mediated through its high dicarboxylic acid content (Nisbet and Martin 1991, 1994). In support of this hypothesis, Martin (1998) demonstrated that the addition of malate increased final pH during *in vitro* fermentation of starch in rumen fluid. Martin (1998) concluded that there is potential for dicarboxylic acids to be utilised *in vivo* to alleviate acidosis. Further work is required to investigate this hypothesis.

Vaccines

The use of vaccinations to reduce the incidence of lactic acidosis in ruminants may be a long-term option to facilitate rapid adaptation to high grain diets. Brown *et al.* (2002) demonstrated an antibody response in sheep immunised with bacterial isolates of *S. bovis, Sel. ruminantium, S. equis* and *L. vitulinus* suggesting that it may be possible for protective immunity to be conferred via vaccination against a range of lactate-producing bacteria. In support of this hypothesis, immunisation against *S. bovis* was shown to attenuate clinical signs of acidosis when sheep were challenged by an abrupt change to a high grain diet (Gill *et al.* 2000). While Gill *et al.* (2000) were able to demonstrate the effectiveness of the vaccine, the regime used involved three booster immunisations over a period of 56 days. The authors acknowledged that this may not be a practical solution to prevention of acidosis during grain finishing and further investigation of this management strategy is required before it can be applied commercially.

Sodium bicarbonate and bentonite

It is common to include sodium bicarbonate or bentonite in high grain diets to alleviate acidosis. During introduction to grain, the addition of sodium bicarbonate has been shown to result in higher rumen pH (Ha *et al.* 1983; Kezar and Church 1979); however, following the initial adaptation period, the benefits are less apparent (Ha *et al.* 1983; Huntington *et al.* 1977). Interestingly, Phy and Provenza (1998a, 1998b) demonstrated that sheep show a preference for feeds that contain sodium bicarbonate when they are consuming feeds that are likely to promote acidosis.

High concentrate diets are associated with decreased salivary output due to reduced mastication and rumination of feed. This results in a reduction in the amount of bicarbonate entering the rumen in saliva and lowers the buffering capacity of the rumen. Attempts to alleviate this problem have focussed on the addition of exogenous bicarbonate, however Hibberd *et al.* (1995) took a novel approach and investigated the feasibility of increasing saliva flow. They demonstrated that the administration of slaframine, a parasympathomimetic compound, increased salivary output and ruminal pH in steers during a subacute acidosis challenge.

It is generally assumed that the effectiveness of sodium bicarbonate is due to increased buffering in the rumen (Matrone *et al.* 1959), but an alternative hypothesis has been proposed (Russell and Chow 1993). Russell and Chow (1993) suggest that dietary addition of carbonate is unlikely to provide buffering capacity because rumen fluid is already saturated with CO_2 so there is limited opportunity for the equilibrium to shift in favour of decreased hydrogen ions. They postulate that the actions of buffering salts are more likely due to a cascade of events initiated by increased water intake which leads to increased rumen dilution rate causing more rapid passage of starch from the rumen and decreased production of propionate (Russell and Chow 1993). This hypothesis is supported by the observation that pH change in the rumen in response to buffering salts is often negligible and a positive production effect may be apparent without a pH change (Clayton *et al.* 1999).

It may be appropriate to extrapolate the hypothesis proposed by Russell and Chow (1993) to other buffering compounds such as bentonite and limestone that have been observed to have a small effect on rumen pH, but that tend to alleviate acidosis during introduction to high concentrate diets (Ha *et al.* 1983).

Conclusions

Many intervention strategies have been assessed for their potential to reduce the impact of acute and subclinical acidosis. Appropriate introductory feeding to allow microbial populations to adapt to diet change remains one of the most effective tools for limiting the risk of acidosis. Antibiotic feed additives that selectively control gram-positive bacteria efficaciously control acidosis and there is scope for further work to investigate the targeted use of antibiotics during introduction to grain feeding in confined feeding systems. In light of consumer concerns about antibiotic growth promotants, it may be more appropriate to focus research efforts on ionophore compounds rather than non-ionophore antibiotics. The effectiveness of ionophores against subclinical acidosis in sheep has not been thoroughly investigated.

There has been limited investigation into the commercial feasibility of specific vaccination against lactic acid-producing bacteria or inoculation strategies to increase the prevalence of lactic acid using bacteria. Further investigation to develop these strategies is warranted.

Social and behavioural adaptation to grain feeding

The profitability of supplementary or lot feeding is linked to the speed at which animals adapt to the feeding system and reach maximum intake. Livestock quite often display neophobia (i.e. fear of the new) when first exposed to a novel feed (Juwarini *et al.* 1981; Lynch *et al.* 1983), feed delivery device (Chapple *et al.* 1987a; Holst *et al.* 1994) or indeed feeding environment (Burritt and Provenza 1997). Typically when exposed to a new feed, animals sample the feed cautiously before accepting it and it can take a number of days to reach a stable intake pattern. Consequently, within contemporary groups there can be considerable variation in the rate of acceptance of a novel feed (Bowman and Sowell 1997; Juwarini *et al.* 1981). Furthermore, a three- to five-fold variation in feed intake between animals may still prevail even after the initial feed acceptance period (Lynch *et al.* 1992). Several environmental and animal factors underpin this observed variation and these have been reviewed by Bowman and Sowell (1997).

Environmental factors such as the feed delivery method, trough space, and feed formulation and allowance have all been shown to influence feed intake variability (Bowman and Sowell 1997). Often the first hurdle in becoming accustomed to a novel feed such as grain, is overcoming the fear of the feed delivery method (Chapple *et al.* 1987a). For example, Holst *et al.* (1994) reported much higher variation in supplement intake between individuals when the supplement was offered in a self-feeder rather than being offered in a more familiar context such as being trail fed on the ground. Furthermore, a change to the animals' environment is likely to elicit some latency in food acceptance even when the animals are familiar with the feed (Burritt and Provenza 1997). Clearly, when ruminants are placed in a feedlot it represents a significant change in their feeding environment. At this point, apart from ensuring that trough space and feed allowance are optimised, there is very little that can be done to enhance the rate of acceptance of the feed or indeed minimise the level of variation between animals in feed intake.

The prominent attributes of the animal that can influence the variation in the acceptability and intake of a novel feed include social order and prior experience. Whilst social order or dominance hierarchies are not as obvious in sheep as they are in other genera, they are evident particularly in competitive situations (Lynch *et al.* 1992). However, there is little published data examining the effect of social order on feeding behaviour in sheep (Arnold and Maller 1974; Lobato and Beilharz 1979) which is in stark contrast to the extensive literature in cattle, in particular dairy cattle (e.g. Corkum *et al.* 1994; Hasegawa *et al.* 1997; Leaver and Yarrow 1980; Olofsson 1999; Reynolds and Campling 1981). For cattle under intensive feeding conditions or during the provision of supplements, the results indicate that dominant animals can influence the feeding behaviour of subordinates. This was manifest through increased displacements from the feed/feed station and as a consequence, subordinates fed less frequently, spent more time during a feeding bout but often not at the preferred daily times of the individual (Hasegawa *et al.* 1997; Leaver and Yarrow 1980; Olofsson 1999). These changes in feeding behaviour are likely to be exacerbated during increased competition for the feed (e.g. reduced trough or bunk space) (Arnold and Maller 1974; Hasegawa *et al.* 1997; Olofsson 1999). Whilst there is general agreement that behaviour is affected in group feeding situations, the results are not conclusive as to whether feed intake is adversely affected. Leaver and Yarrow (1980) concluded that dominance value was positively correlated with silage intake under restricted access conditions. In contrast, others have shown either no change (Reynolds and Campling 1981) or indeed an increase in feed intake (Olofsson 1999) when competition for the feed resource was increased through reduction of feed access. In the one ovine study where intake was measured, dominance value was positively correlated with the mean intake of oats and hay supplements when provided at pasture (Lobato and Beilharz 1979). Although no firm conclusions can be drawn here with respect to feed intake, there are sufficient grounds in the context of managing group feeding situations and maximising productivity to minimise the impact of social dominance (Phillips and Rind 2002). To that end, the most practical, but not always effective solution would be to ensure that grouped animals are similar in age and body size. Dominance has been shown to be positively correlated with these two variables (Lobato and Beilharz 1979; Lynch *et al.* 1992).

Prior experience with a novel feed has been shown to expedite the acceptability of that food later in life (Bowman and Sowell 1997). For example, Green *et al.* (1984) demonstrated that lambs exposed to wheat at a young age more readily accepted the grain in later life compared to the control group. However, the decrease in food neophobia was dramatically improved if the initial exposure was undertaken in the presence of experienced social partners (Chapple *et al.* 1987b; Green *et al.* 1984; Lynch *et al.* 1983; Thorhallsdottir *et al.* 1990). The study of Green *et al.* (1984) perhaps highlights this effect best. Merino lambs were given access to wheat for 1 h/day for periods varying from 5 to 20 days in the presence or absence of their mothers. After weaning the lambs were exposed to wheat again at 3, 6, 12, 24 and 34 months of age. The lambs given wheat in the presence of their mothers pre-weaning, consumed significantly more at these time points compared to those exposed to wheat in the absence of their mothers or controls. Another compelling result was the proportion of animals consuming wheat after one day, whereby 92 per cent of the lambs from the group exposed to the grain with their mothers, were eating. This is in stark contrast to the results for the group exposed without their mothers (20%) or control group (5%). Even by day 5, there were still large differences between the groups. In a separate study reported by Lynch and Bell (1987), grain-experienced ewes and their naïve lambs were offered grain on three occasions, one day apart. By the third day, most of the lambs were eating the grain. When tested 2 years later (with no other grain feeding since), all the sheep exposed as lambs readily ate offered grain, whereas almost none of their control cohorts from the same farms ate the grain.

It is important to recognise that whilst the social transmission of feeding behaviour is effective; its efficacy can be influenced by the quality of the relationship between the two animals (Veissier *et al.* 1998). In this instance, the maternal influence is certainly stronger than the effect of a non-maternal social partner. This was particularly evident in the study of Thorhallsdottir *et al.* (1990) where the lambs that consumed a novel food in the presence of their mother (pre-weaning) ate twice as much after weaning compared to the lambs exposed in the presence of a dry ewe.

The above results highlight the strength of social models in the transmission of feeding behaviour and food acceptance and also suggest that socially acquired information was more efficient than trial and error learning in the development of feeding behaviour and food acceptance (Veissier *et al.* 1998). In the context of either supplementary feeding or intensive finishing of sheep, it appears that the introduction of pre-weaning exposure of lambs to a novel feed/supplement, together with their experienced dams, in order to expedite the acceptance of such feeds later in life, has considerable practical and economic merits. However, there are several key issues requiring further research. The most obvious is whether the benefit is maintained when the feed type is varied. For example, if lambs are given wheat pre-weaning, will they still readily consume an alternative grain (e.g. sorghum) or novel feed/supplement? Another issue is the duration of exposure, and although there is some evidence to suggest that this may not be important (J.J. Lynch 2003, pers. comm.), research to identify the minimum necessary duration or number of exposures would be valuable.

Conclusions

Rapid adaptation to grain feeding will maximise intake and reduce the variation in intake between individual animals. In comparison to cattle, the period of time on feed for sheep in intensive finishing systems is very short, so rapid acceptance of grain is especially important. The impact of social interaction on variation in feed intake can be addressed by adopting appropriate management strategies to reduce competition. There are existing recommendations for trough spacing, introduction to novel feeds and managing shy-feeders but there may be an opportunity to further investigate management strategies to enhance behavioural adaptation to intensive grain feeding. To that end, further investigation of the usefulness of social transmission of feeding behaviour early in life would appear to offer most promise.

References

Aitchison, E.M., McDonald, C.L., Casson, P. and Rowe, J.B. (1987). 'Feed antibiotics and buffers to control rumen lactic acid: 2. Pre-dosing'. *Proceedings of the Nutrition Society,* vol. 46, p. 41A.

Al-Jassim, R.A.M. and Rowe, J.B. (1999). 'Better understanding of acidosis and its control'. *Recent Advances in Animal Nutrition in Australia,* vol. 12, pp. 91-97.

Allison, M.J., Bucklin, J.A., Dougherty and R.W. (1964). 'Ruminal changes after overfeeding with wheat and the effect of intraruminal inoculation on adaptation to a ration containing wheat'. *Journal of Animal Science,* vol. 23, pp. 1164-1171.

APVMA (2001). 'Special review of avoparcin.' Australian Pesticide and Veterinary Medicine Authority, *NRA Review Series* 01.1, Canberra.

APVMA, (2003). 'The reconsideration of the registration of products containing virginiamycin and their labels (draft review report)'. Australian Pesticide and Veterinary Medicine Authority, [WWW document]. URL http://www.apvma.gov.au/chemrev/virginiamycin.pdf (accessed 31/3/04).

Arnold, G.W. and Maller, R.A. (1974). 'Some aspects of competition between sheep for supplementary feed'. *Animal Production,* vol. 19, pp. 309-319.

Bell, A.K., Shands, C.G., Hegarty, R.S. and Duddy, G. (2003). 'Feedlotting lambs'. NSW Agriculture, *Agnote* DAI/42.

Bergen, W.G. and Bates, D.B. (1984). 'Ionophores: The effect of production efficiency and mode of action'. *Journal of Animal Science,* vol. 58, pp. 1465-1483.

Bigham, M.L. and McManus, W.R. (1975). 'Whole wheat grain feeding of lambs. IV. Effects of an antibiotic, lactic acid, grain moistening and restricted intake on wheat sickness of young sheep'. *Australian Journal of Agricultural Research,* vol. 26, pp. 729-741.

Blood, D.C., Radostits, O.M. and Henderson, J.A. (1983). *Veterinary Medicine*. Bailliere Tindall, London.

Blood, D.C. and Studdert, V.P (1990). *Balliere's Comprehensive Veterinary Dictionary.* Bailliere Tindall, London.

Bowman, J.G. and Sowell, B.F. (1997). 'Delivery method and supplement consumption by grazing ruminants: A review'. *Journal of Animal Science,* vol. 75, pp. 543-550.

Brown, W.Y., Rowe, J.B. and Watson, D.L. (2002). 'Antibody responses to lactic acid producing bacteria in sheep immunised with experimental acidosis vaccines'. *Animal Production in Australia,* vol. 24, p. 277.

Burrin, D.G. and Britton, R.A. (1986). 'Response to monensin in cattle during subacute acidosis'. *Journal of Animal Science,* vol. 63, pp. 888-893.

Burritt, E.A. and Provenza, F.D. (1997). 'Effect of an unfamiliar location on the consumption of novel and familiar foods by sheep'. *Applied Animal Behaviour Science,* vol. 54, pp. 317-325.

Butler, K.L., Watson, M.J. and Verstegen, H.W.A. (1992). 'The influence of slaked lime and avoparcin in complete grain-based diets for the live sheep trade'. *Animal Production in Australia,* vol. 19, pp. 297-299.

Chademana, I. and Offer, N.W. (1990). 'The effect of dietary inclusion of yeast culture on digestion in the sheep'. *Animal Production,* vol. 50, pp. 483-489.

Chapple, R.S., Wodzicka-Tomaszewska, M. and Lynch, J.J. (1987a). 'The learning behaviour of sheep when introduced to wheat. I. Wheat acceptance by sheep and the effect of trough familiarity'. *Applied Animal Behaviour Science,* vol. 18, pp. 157-162.

Chapple, R.S. and Wodzicka-Tomaszewska, M. (1987b). 'The learning behaviour of sheep when introduced to wheat. II. Social transmission of wheat feeding and the role of the senses'. *Applied Animal Behaviour Science,* vol. 18, pp. 163-172.

Chaucheyras, F., Fonty, G., Bertin, G., Salmon, J.M. and Gouet, P. (1996). 'Effects of a strain of *Saccharomyces cerevisiae* (Levucell® SC), a microbial additive for ruminants, on lactate metabolism *in vitro'*. *Canadian Journal of Microbiology,* vol. 42, pp. 927-933.

Clayton, E.H., Lean, I.J., Rowe, J.B. and Cox, J.W. (1999). 'Effects of feeding virginiamycin and sodium bicarbonate to grazing lactating dairy cows'. *Journal of Dairy Science,* vol. 82, pp. 1545-1554.

Corkum, M.J., Bate, L.A., Tennessen, T. and Lirette, A. (1994). 'Consequences of reduction of number of individual feeders on feeding-behaviour and stress level of feedlot steers'. *Applied Animal Behaviour Science,* vol. 41, pp. 27-35.

Daugherty, M.S., Galyean, M.L., Hallford, D.M. and Hageman, J.H. (1986). 'Vitamin B_{12} and monensin effects on performance, liver and serum vitamin B12 concentrations and activity of propionate metabolising hepatic enzymes in feedlot lambs'. *Journal of Animal Science,* vol. 62, pp. 452-63.

Dennis, S.M., Nagaraja, T.G. and Bartley, E.E. (1981a). 'Effect of lasalocid or monensin on lactate production from *in vitro* rumen fermentation of various carbohydrates'. *Journal of Dairy Science,* vol. 64, pp. 2350-2356.

Dennis, S.M., Nagaraja, T.G. and Bartley, E.E. (1981b). 'Effects of lasalocid or monensin on lactate-producing or -using rumen bacteria'. *Journal of Animal Science,* vol. 52, pp. 418-426.

Gill, H.S., Shu, Q., and Leng, R.A. (2000). 'Immunisation with *Streptococcus bovis* protects against lactic acidosis in sheep'. *Vaccine,* vol. 18, pp. 2541-2548.

Godfrey, S.I., Boyce, M.D., Rowe, J.B. and Speijers, E.J. (1993a). 'Changes within the digestive tract of sheep following engorgement with barley'. *Australian Journal of Agricultural Research,* vol. 44, pp. 1093-1101.

Godfrey, S.I., Rowe, J.B., Speijers, E.J. and Toon, W. (1993b). 'Lupins, barley, or barley plus virginiamycin as supplements for sheep at different feeding intervals'. *Australian Journal of Experimental Agriculture,* vol. 33, pp. 135-140.

Godfrey, S.I., Rowe, J.B., Thorniley, G.R., Boyce, M.D. and Speijers, E.J. (1995). 'Virginiamycin to protect sheep fed wheat, barley or oats from grain poisoning under simulated drought feeding conditions'. *Australian Journal of Agricultural Research,* vol. 46, pp. 393-401.

Green, G.C., Elwin, R.L., Mottershead, B.E., Keogh, R.G. and Lynch, J.J. (1984). 'Long term effects of early experience to supplementary feeding in sheep'. *Animal Production in Australia,* vol. 15, pp. 373-375.

Ha, J.K., Emerick, R.J. and Embry, L.B. (19830. '*In vitro* effect of pH variations on rumen fermentation, and *in vivo* effects of buffers in lambs before and after adaptation to high concentrate diets'. *Journal of Animal Science,* vol. 56, pp. 698-706.

Hasegawa, N., Nishiwaki, A., Sugawara, K. and Ito, I. (1997). 'The effects of social exchange between two groups of lactating primiparous heifers on milk production, dominance order, behaviour and adrenocortical response'. *Applied Animal Behaviour Science,* vol. 51, pp. 15-27.

Hibberd, B., Peters, J.P., Chester, S.T., Robinson, J.A., Kotarski, S.F., Croom, W.J. and Hagler, W.M. (1995). 'The effect of slaframine on salivary output and subacute and acute acidosis in growing beef steers'. *Journal of Animal Science,* vol. 73, pp. 516-525.

Holst, P.J., Curtis, K.M.S. and Hall, D.G. (1994). 'Methods of feeding grain supplements and measuring their intake by adult sheep'. *Australian Journal of Experimental Agriculture,* vol. 34, pp. 345-348.

Horton, G.M. and Stockdale, P.H. (1981). 'Lasalocid and monensin in finishing diets for early weaned lambs with naturally occurring coccidiosis'. *American Journal of Veterinary Research,* vol. 42, pp. 433-436.

Huber, T.L. (1974). 'Effect of intraruminal inoculation on adaptation of lambs and heifers to a high-energy ration'. *American Journal of Veterinary Research,* vol. 35, pp. 639-641.

Huntington, G.B., Emerick, R.J. and Embry, L.B. (1977). 'Sodium bentonite or sodium bicarbonate as aids in feeding high-concentrate diets to lambs'. *Journal of Animal Science,* vol. 45, pp. 804-811.

Ikin, T.L. and Pearce, G.R. (1978). 'Feedlotting of slow-growing lambs at different stages of growth'. *Australian Journal of Experimental Agriculture,* vol. 18, pp. 355-360.

JETACAR, (1999). 'The use of antibiotics in food producing animals: Antibiotic-resistant bacteria in animals and humans'. *Joint Expert Technical Advisory Committee on Antibiotic Resistance.*

Juwarini, E., Howard, B., Siebert, B.D., Lynch, J.J. and Elwin, R.L. (1981). 'Variation in the wheat intake of individual sheep measured by use of labelled grain: Behavioural influences'. *Australian Journal of Experimental Agriculture,* vol. 21, pp. 395-399.

Kezar, W.W. and Church, D.C. (1979). 'Effect of thiopeptin and sodium bicarbonate on the prevention of lactic acidosis induced in sheep'. *Journal of Animal Science,* vol. 49, pp. 1396-1402.

Kung, L., Jr. and Hession, A.O. (1995). 'Preventing *in vitro* lactate accumulation in ruminal fermentations by inoculation with *Megasphaera elsdeni'.* *Journal of Animal Science,* vol. 73, pp. 250-256.

Langman, M. and Ashton, B. (2000). 'Health of lot fed sheep'. Primary Industries and Resources, South Australia, *Fact Sheet.*

Leaver, J.D. and Yarrow, N.H. (1980). 'A note on the effect of social rank on the feeding behaviour of young cattle on self-feed maize silage'. *Animal Production,* vol. 30, pp. 303-306.

Lee, G.J. (1977). 'Changes in composition and pH of digesta along the gastrointestinal tract of sheep in relation to scouring induced by wheat engorgement'. *Australian Journal of Agricultural Research,* vol. 28, pp. 1075-1082.

Lobato, J.F.P. and Beilharz, R.G. (1979). 'Relation of social dominance and body size to intake of supplements in grazing sheep'. *Applied Animal Ethology,* vol. 5, pp. 233-239.

Lynch, J.J., Keogh, R.G., Elwin, R.L., Green, G.C. and Mottershead, B.E. (1983). 'Effects of early experience on the post-weaning acceptance of whole grain wheat by fine-wool Merino lambs'. *Animal Production,* vol. 36, pp. 175-183.

Lynch, J.J. and Bell, A.K. (1987). 'The transmission from generation to generation in sheep of the learned behaviour for eating grain supplements'. *Australian Veterinary Journal,* vol. 64, pp. 291-292.

Lynch, J.J., Hinch, G.N. and Adams, D.B. (1992). *The Behaviour of Sheep - Biological Principles and Implications for Production.* CAB International, Oxon.

Mackie, R.I., Gilchrist, F.M.C., Roberts, A.M., Hannah, P.E. and Schwartz, H.M. (1978). 'Microbiological and chemical changes in the rumen during the stepwise adaptation of sheep to high concentrate diets'. *Journal of Agricultural Science, Cambridge,* vol. 90, pp. 241-254.

Mackie, R.I. and McSweeney, C.S. (2002). 'Microbial ecology of the ovine rumen'. In: *Sheep Nutrition.* Freer, M. and Dove, H. (eds). CSIRO Publishing, Collingwood, pp. 71-94.

Martin, S.A. (1998). 'Manipulation of rumen fermentation with organic acids: A review'. *Journal of Animal Science,* vol. 76, pp. 3123-3132.

Matrone, G., Ramsey, H.A. and Wise, G.H. (1959). 'Effect of volatile fatty acids, sodium and potassium bicarbonate in purified diets for ruminants'. *Proceedings of the Society for Experimental Biology and Medicine,* vol. 100, pp. 8-11.

McDonald, C.L., Aitchison, E.M. and Rowe, J.B. (1987). 'Feed antibiotics and buffers to control rumen lactic acid: 1. Dose rates'. *Proceedings of the Nutrition Society,* vol. 46, p. 40A.

McDonald, C.L., Rowe, J.B. and Gittins, S.P. (1994). 'Feeds and feeding methods for assembly of sheep before export'. *Australian Journal of Experimental Agriculture,* vol. 34, pp. 589-594.

Muir, L.A. and Barreto, A., Jr. (1979). 'Sensitivity of *Streptococcus bovis* to various antibiotics'. *Journal of Animal Science,* vol. 48, pp. 468-473.

Muir, L.A., Duquette, P.F., Rickes, E.L. and Smith, G.E. (1980a). 'Thiopeptin for the prevention of ovine lactic acidosis induced by diet change'. *Journal of Animal Science,* vol. 51, pp. 1182-1188.

Muir, L.A., Rickes, E.L., Duquette, P.F. and Smith, G.E. (1980b). 'Control of wheat-induced lactic acidosis in sheep by thiopeptin and related antibiotics'. *Journal of Animal Science,* vol. 50, pp. 547-553.

Murray, P.J., Rowe, J.B., Aitchison, E.M. and Winslow, S.G. (1992). 'Liveweight gain and wool growth in sheep fed rations containing virginiamycin'. *Australian Journal of Experimental Agriculture,* vol. 32, pp. 1037-1043.

Mutsvangwa, T., Walton, J.P., Plaizier, J.C., Duffield, T.F., Bagg, R., Dick, P., Vessie, G. and McBride, B.W. (2002). 'Effects of a monensin controlled-release capsule or premix on attenuation of subacute ruminal acidosis in dairy cows'. *Journal of Dairy Science,* vol. 85, pp. 3454-3561.

Muwalla, M.M., Harb, M.Y. and Crosby, T.F. (1998). 'Effects of lasalocid and protein levels on the performance of Awassi lambs'. *Small Ruminant Research,* vol. 28, pp. 15-22.

Nagaraja, T.G. (1995). 'Ionophores and antibiotics in ruminants'. In: *Biotechnology in Animal Feeds and Animal Feeding*. Wallace, R.J. and Chesson, A. (eds). VCH Publishers Inc., New York, pp. 173-207.

Nagaraja, T.G., Avery, T.B., Bartley, E.E., Galitzer, S.J. and Dayton, A.D. (1981). 'Prevention of lactic acidosis in cattle by lasalocid or monensin'. *Journal of Animal Science,* vol. 53, pp. 206-215.

Nagaraja, T.G., Avery, T.B., Bartley, E.E., Roof, S.K. and Dayton, A.D. (1982). 'Effect of lasalocid, monensin or thiopeptin on lactic acidosis in cattle'. *Journal of Animal Science,* vol. 54, pp. 649-658.

Nagaraja, T.G., Newbold, C.J. and Nevel, C.J.V. (1997). 'Manipulation of ruminal fermentation'. In: *The rumen microbial ecosystem.* Hobson, P.N. and Stewart, C. S. (eds). Blackie Academic and Professional, pp. 523-600.

Nagaraja, T.G., Taylor, M.B., Harmon, D.L. and Boyer, J.E. (1987). '*In vitro* lactic acid inhibition and alterations in volatile fatty acid production by antimicrobial feed additives'. *Journal of Animal Science,* vol. 65, pp. 1064-1076.

Newbold, C.J. (1995). 'Microbial feed additives for ruminants'. In: *Biotechnology in Animal Feeds and Animal Feeding.* Wallace, R.J. and Chesson, A. (eds). VCH Publishers Inc., New York, pp. 259-278.

Newbold, C.J. and Wallace, R.J. (1988). 'Effects of the ionophores monensin and tetronasin on simulated development of ruminal lactic acidosis *in vitro'. Applied and Environmental Microbiology,* vol. 54, pp. 2981-2985.

Nisbet, D.J. and Martin, S.A. (1991). 'Effect of a *Saccharomyces cerevisiae* culture on lactate utilisation by the ruminal bacterium *Selenomonas ruminantium'. Journal of Animal Science,* vol. 69, pp. 4628-4633.

Nisbet, D.J. and Martin, S.A. (1994). 'Factors affecting L-lactate utilisation by *Selenomonas ruminantium'. Journal of Animal Science,* vol. 72, pp. 1355-1361.

Owens, F.N., Secrist, D.S., Hill, W.J. and Gill, D.R. (1998). 'Acidosis in cattle: A review'. *Journal of Animal Science,* vol. 76, pp. 275-286.

Olofsson, J. (1999). 'Competition for total mixed diets fed for *ad libitum* intake using one or four cows per feeding station'. *Journal of Dairy Science,* vol. 82, pp. 69-79.

Phillips, C.J.C. and Rind, M.I. (2002). 'The effects of social dominance on the production and behaviour of grazing dairy cows offered forage supplements'. *Journal of Dairy Science,* vol. 85, pp. 51-59.

Phy, T.S. and Provenza, F.D. (1998a). 'Eating barley too frequently or in excess decreases lambs' preference for barley but sodium bicarbonate and lasalocid attenuate the response'. *Journal of Animal Science,* vol. 76, pp. 1578-1583.

Phy, T.S. and Provenza, F.D. (1998b). 'Sheep fed grain prefer foods and solutions that attenuate acidosis'. *Journal of Animal Science,* vol. 76, pp. 954-960.

Raun, A.P., Cooley, C.O., Potter, E.L., Rathmacher, R.P. and Richardson, L.F. (1976). 'Effect of monensin on feed efficiency of feedlot cattle'. *Journal of Animal Science,* vol. 43, pp. 670-677.

Reynolds, V.S. and Campling, R.C. (1981). 'Competition for feed between dairy cows'. *Animal Production,* vol. 32**,** pp. 366-370.

Rowe, J.B. (1988). 'Use of lasalocid in diets fed during simulated assembly and export of live sheep'. *Animal Production in Australia,* vol. 17, pp. 318-321.

Rowe, J.B., Bird, S. and Channon, A. (2002). 'New approaches to managing acidosis'. In: *Making profit from feedlot research*, Results from the CRC for cattle and beef quality, held at Toowoomba, 27th June 2002. Dundeon, P. (ed.). CRC Beef Quality, pp. 27-29.

Russell, J.B. and Chow, J.M. (1993). 'Another theory for the action of ruminal buffer salts: decreased starch fermentation and propionate production'. *Journal of Dairy Science,* vol. 76, pp. 826-830.

Schelling, G.T. (1984). 'Monensin: Mode of action in the rumen'. *Journal of Animal Science,* vol. 58, pp. 1518-1527.

Seymour, M. (2000). 'Sheep health in a feedlot'. Government of Western Australia, Department of Agriculture, *Farmnote* No. 72/2000.

Spears, J.W. (1990). 'Ionophores and nutrient digestion and absorption in ruminants'. *Journal of Nutrition,* vol. 120, pp. 632-638.

Thorhallsdottir, A.G., Provenza, F.D. and Balph, D.F. (1990). 'Ability of lambs to learn about novel foods while observing or participating with social models'. *Applied Animal Behaviour Science,* vol. 25, pp. 25-33.

Thorniley, G.R., Boyce, M.D. and Rowe, J.B. (1996). 'Feeding grain to sheep is safer with a drench of virginiamycin'. *Animal Production in Australia,* vol. 21, p. 463.

Thorniley, G.R., Rowe, J.B., Cowcher, P.C. and Boyce, M.D. (1998), 'A single drench of virginiamycin to increase safety of feeding grain to sheep'. *Australian Journal of Agricultural Research,* vol. 45, pp. 899-906.

Veissier, I., Boissy, A., Nowak, R., Orgeur, P. and Poindron, P. (1998). 'Ontogeny of social awareness in domestic herbivores'. *Applied Animal Behaviour Science,* vol. 57, pp. 233-245.

Wallace, R.J. (1996). 'The mode of action of yeast culture in modifying rumen fermentation'. In: *Biotechnology in the Feed Industry.* Lyons, T.P. and Jacques, K.A. (eds). *Proceedings of Alltech's 12th Annual Symposium,* pp. 217-232.

Williams, P.E., and Newbold, C.J. (1990). 'Rumen probiosis: The effects of novel microorganisms on rumen fermentation and ruminant productivity'. In: *Recent Advances in Animal Nutrition 1990.* Haresign, W. and Cole, D.J.A. (eds). Butterworths, pp. 211-229.

Wiryawan, K.G. and Brooker, J.D. (1995). 'Probiotic control of lactate accumulation in acutely grain-fed sheep'. *Australian Journal of Agricultural Research,* vol. 46, pp. 1555-1568.

SHEEPCRC

AUSTRALIAN SHEEP INDUSTRY
COOPERATIVE RESEARCH CENTRE

FEEDING GRAIN FOR SHEEP MEAT PRODUCTION

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Feeding grain for sheep meat production

Appendix - Feeding sheep for finishing questionnaire

R.J. Bryant and R.M. Kirby

APPENDIX. 'FEEDING SHEEP FOR FINISHING' QUESTIONNAIRE - REPORT AND RESPONSE SUMMARY

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Background

To address one of the objectives specified within the project namely to review current on-farm and other industry feeding systems, the project team conducted a survey by questionnaire investigating current on-farm practices for feeding sheep for finishing for slaughter in Western Australia. The purpose of the survey was to:

1. **Determine the current practice for grain finishing systems for sheep meat production in Western Australia.**

   There is considerable documentation and anecdotal evidence regarding the types of systems that are in place in Western Australia. However due to the recent increase in the value of sheep meat, as well as several consecutive poor seasons it was time to review current industry practices to assess any changes.

2. **Identify the key issues for sheep meat production**.

   This was to ensure that any suggested research would be relevant to industry.

3. **Ascertain the level of knowledge within industry.**

   The aim was to provide information to target any potential research focus.

4. **Assist in developing any targeted extension aspects of the project objectives**.

The specific role of the questionnaire in the overall context of the project was to be an *indicator* of the practices and attitudes of sheep meat producers within Western Australia. A function of the questionnaire was to give identify areas for future research and extension.

Questionnaire methodology

The project team discussed and agreed to focus on prime lamb finishing systems. It was considered that the majority of finishing systems involved lambs and sourcing a list of a large number of prime lamb producers was achievable within the available time frame. The team approached local alliances (Q Lamb and Prime Merino Lamb Alliance), WAMMCO (West Australian Meat Marketing Corporation), The Western Australian Department of Agriculture, and private consultants for potential questionnaire candidates. This approach was met with limited success with issues of confidentiality creating some difficulties. The plan followed was:

- the questionnaire draft was produced and distributed for peer review;
- 566 questionnaires were posted out in March 2003;
- 147 questionnaires were returned (27%) - within the accepted response rate range for typical questionnaire response (WA Department of Agriculture Biometrician, 2003, pers. comm.);
- 147 questionnaires were collated and analysed.

It is worth noting that the 27 per cent response was quite good considering the nature of the mail out, which would have included producers who finish lambs as suckers. Other producers were in the middle of a drought, so may not have had a production finishing system in place at the time of receiving the questionnaire.

Questionnaire outline

The questionnaire was divided into several sections addressing:

A. General background.

B. Flock structure and mating program.

C. Marketing.

D. How decisions are made as to when sheep are ready for sale.

E. Monitoring performance of lambs in a feedlot.

F. Setting up feedlot.

G. Feeding of lambs in feedlot.

The first four sections covered both lambs and other sheep, but only producers who finished lambs in feedlots were asked to complete the final three sections.

Summary of results

The response summary detailed below gives an overview of questionnaire responses. In addition a few of the more interesting elements of the questionnaire responses have been highlighted. A copy of the survey questionnaire follows the summary of results.

General questions

- ***Do you use a feedlot system to ensure any of your lambs meet market requirements?***

  A large proportion of respondents (over 50%) use a feedlot system to finish some of their lambs (not surprising considering that the growing season in WA on average spans May to October).

- ***Please choose the best description for your finishing system.***

  Of those who said they finish lambs, 58 per cent use small paddocks with self-feeders (Figure 1).

- ***Is your finishing system permanent or opportunistic?***

  69 per cent of respondents suggested that their finishing system is a permanent part of their farming system.

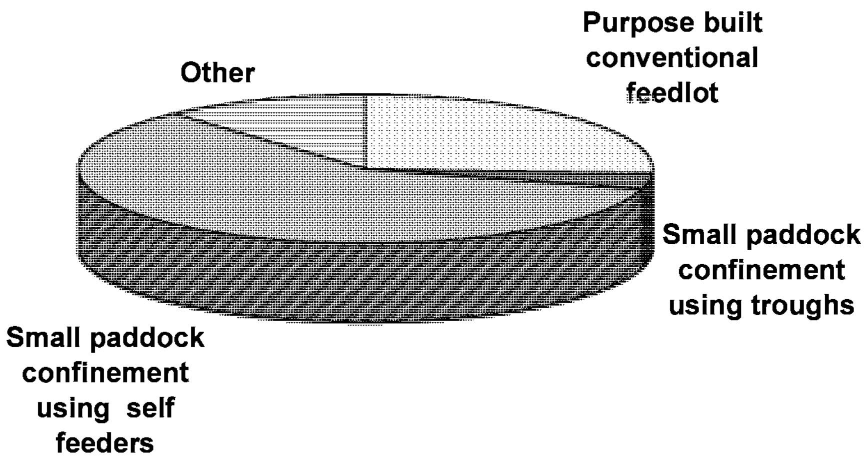


Figure 1. Proportion of feedlot systems used to finish lambs.

Somewhat in contrast, when asked why they considered their feeding system permanent, a significant number of respondents gave justifications that related to an opportunistic system. Interestingly, some comments were based on a farming systems perspective, suggesting feedlots were used to allow paddocks to be locked up to prevent erosion, for feeding/mating ewes in the feedlot, or pasture manipulation for weed control.

Section B - Flock structure and mating program

- ***Please provide more information on mating structure and breeds used in your sheep breeding program for 2002.***

  Over 58 per cent of the respondents mated up to 50 per cent of their ewes to non-Merino rams in 2002. Where respondents had different lambing times for different lambing enterprises, most commented that lambing times were dictated by the amount of green feed available at lambing, as well as some marketing diversification. In some cases the reason was to reduce supplementary feeding costs.

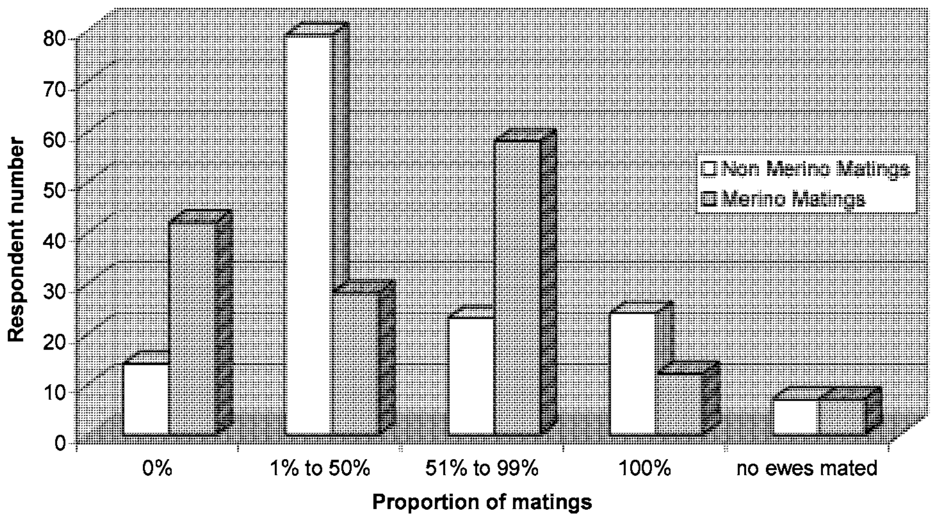


Figure 2. Proportion of ewes mated to either Merino or non-Merino rams, number of respondents in each category.

Section C - Marketing lambs and other sheep

- ***How did you assess whether lambs and other sheep were finished and ready for sale or slaughter?***

  68 per cent of respondents indicated that they condition scored and weighed lambs; targeting an average market specification of 43 kg liveweight and condition score 3. Some respondents indicated that they used both liveweight/condition score and visual assessment as methods for determining that sheep were ready for sale. This suggests quite clearly that animals are visually assessed first, then producers follow up by measuring liveweight and condition score as confirmation. With older sheep, 78 per cent of respondents visually assessed animals for finishing.

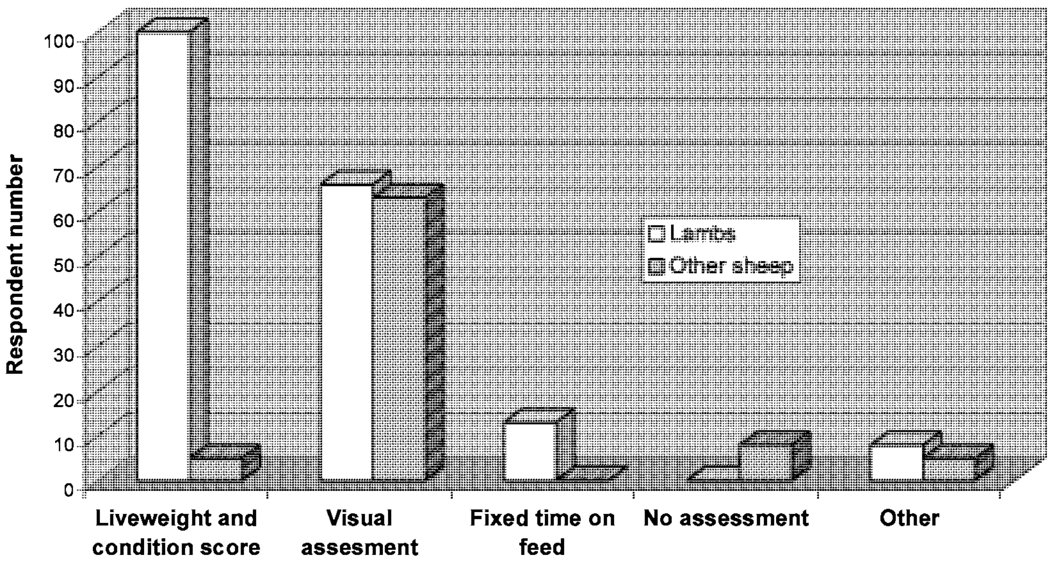
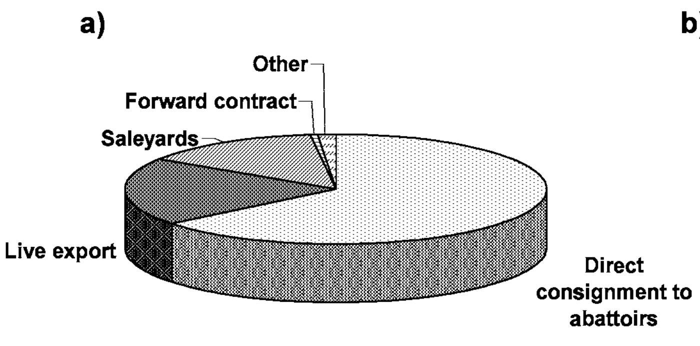


Figure 3. Assessment method used to determine when lambs or other sheep are ready for sale or slaughter.

- ***How did you market your lambs fed for finishing during 2002?***

  Respondents were asked to indicate (via a pick list) how they marketed their lambs during 2002. Choices included a list of local abattoirs (direct consignment), as well as saleyards, live export, forward contracts and CALM (Computer Aided Livestock Marketing). Most producers sold their lambs by direct consignment (65%), although only 24 per cent indicated they were with an alliance. An interesting result was that 14 per cent of respondents indicated they still marketed some of their lambs via the saleyards.



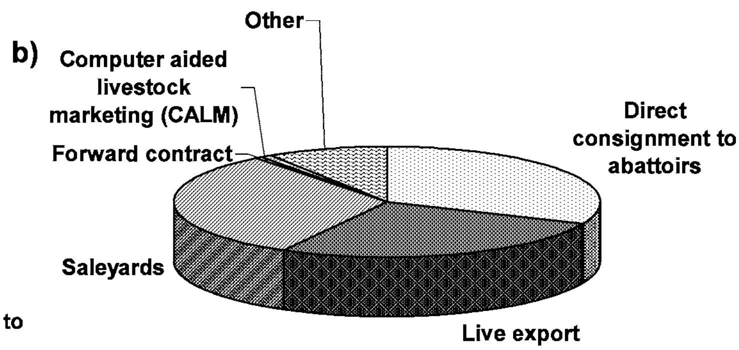


Figure 4. Method of marketing for a) lambs and b) other sheep.

- ***How did you market sheep other than lambs?***

  58 per cent of respondents indicated that animals were marketed primarily through the sale yards or to live export. 31 per cent suggested some of their animals were sold directly to abattoirs.

Section D - Monitoring the performance of lambs to determine market requirements

- ***Do you weigh your lambs?***

  73 per cent of producers indicated that they weigh lambs that are finished in a feedlot. Of the 27 per cent of respondents who don't weigh their lambs, most thought it unnecessary or didn't have scales.

- ***How often do you weigh your lambs?***

  51 per cent of respondents who weigh lambs, do it either fortnightly or on feedlot entry and exit. Of the 25 per cent that said they weighed stock at other times, the majority commented on weighing just prior to, or at sale, or after a visual assessment.

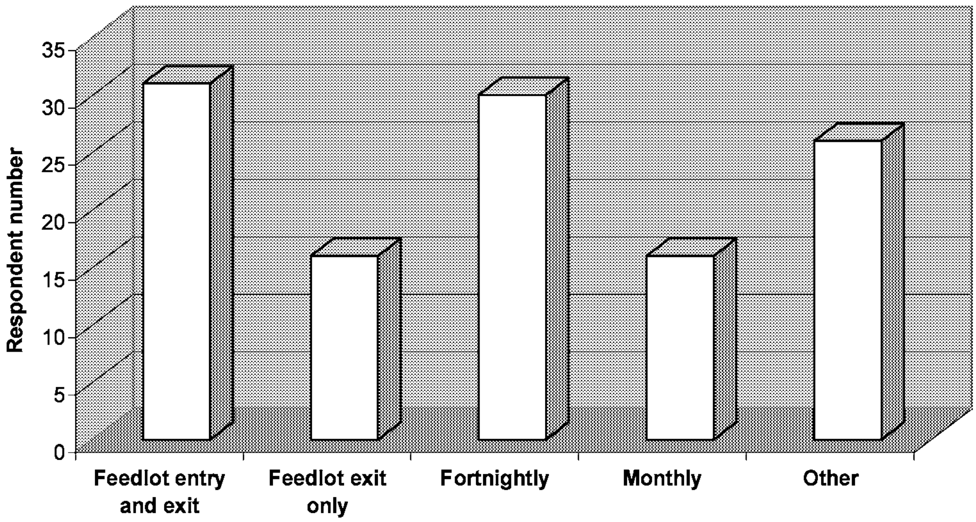


Figure 5. How often lambs finishing in feedlots or confined areas are weighed.

- ***Do you condition score your lambs?***

  56 per cent of respondents said they did condition score their lambs. 44 per cent of respondents said they did not. Of those who don't, most believed it was not necessary. Some of the comments included: 'if weight is ok so is fat'; 'on pellets they don't run to fat'; 'visual good enough'. When producers measured condition score, it was assessed at the same time as weighing.

Section E - Monitoring the performance of lambs in a feedlot

The remaining questions were only to be answered by those who had been feedlotting lambs in 2002. Only 78 respondents contributed to these last sections.

- ***Did you measure the growth rate of your lambs?***

  61 per cent of respondents reported that they did not measure growth rate, yet a considerable number of producers weighed sheep into and out of the feedlot. Of those who responded with a 'no', most believed measuring growth rate was unnecessary or that they didn't have enough time to measure growth rate. Of those who did conduct growth rate measurements, the most common average growth rate selected was 200-300 g/day (68%).

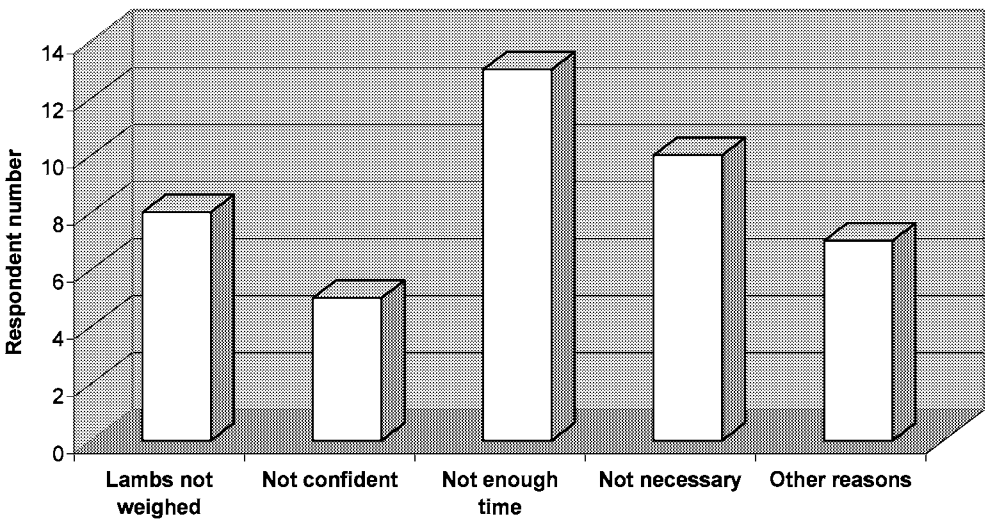


Figure 6. **Main reason identified for why growth rate was not calculated.**

- ***Did you measure the feed conversion ratio (FCR) of your lambs?***

  78 per cent of respondents answered 'no' to this question. The most common responses included, 'feed intake not measured', 'not necessary', or 'not enough time'. Of the 22 per cent of respondents who answered 'yes', the most common FCR range indicated was either 5:1 to 6:1 or 6:1 to 7:1.

- ***Did you monitor how many weeks it took to finish your lambs?***

  79 per cent of respondents answered 'yes' to this question. Of that 79 per cent, 45 per cent took 5-6 weeks to finish and 2 per cent took 7-8 weeks to finish.

When asked what they considered to be the key issues for improving the animal performance monitoring or marketing of their sheep, producers responded with a considerable number of technical questions, on trough size, how to fat score, etc. Some of the more intriguing ones were those on economics of various entry and exit weights, shelter and how it affects growth rate, and feed cost analysis of using on-farm feed versus pellets.

Section F - Setup of your feedlot or confined area

- ***Is the feedlot temporary or permanent?***

  78 per cent of respondents considered their feedlot to be a permanent fixture on their farm.

- ***What type of feeding system do you use within your feedlot, or confined area?***

  93 per cent of respondents use self-feeders. The overriding reasons for self-feeder use are the ease of management and time effectiveness.

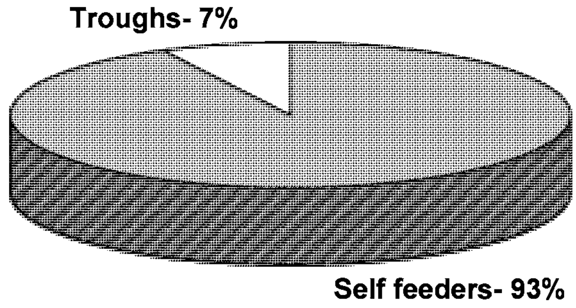


Figure 7. **Type of feeding equipment used in feedlot or confined area.**

There are some concerns about feeding roughage effectively through self-feeders due to concerns with blockages. Some the responses reflected a concern about the inability to be able to control intake when using self-feeders. One respondent asked the question, 'Are we wasting profit'? The feedback to this set of questions suggested that there might be a swing back to troughs, in particular with those using loose mixes.

Section G - Feeding of lambs with in the feedlot/confined area

- ***What type of feed mix rations did you use in your lamb feedlot or confined area in 2002?***

  45 per cent of respondents used commercial pellets and 55 per cent used loose mix rations. As only 24 per cent of respondents were in an alliance where feeding pellets is a mandatory requirement, it appears that pellets are a feed of choice, rather than a requirement. Of those who use loose mix rations, 50 per cent produce their own loose grain mixes (as opposed to a Total Mixed Ration TMR).

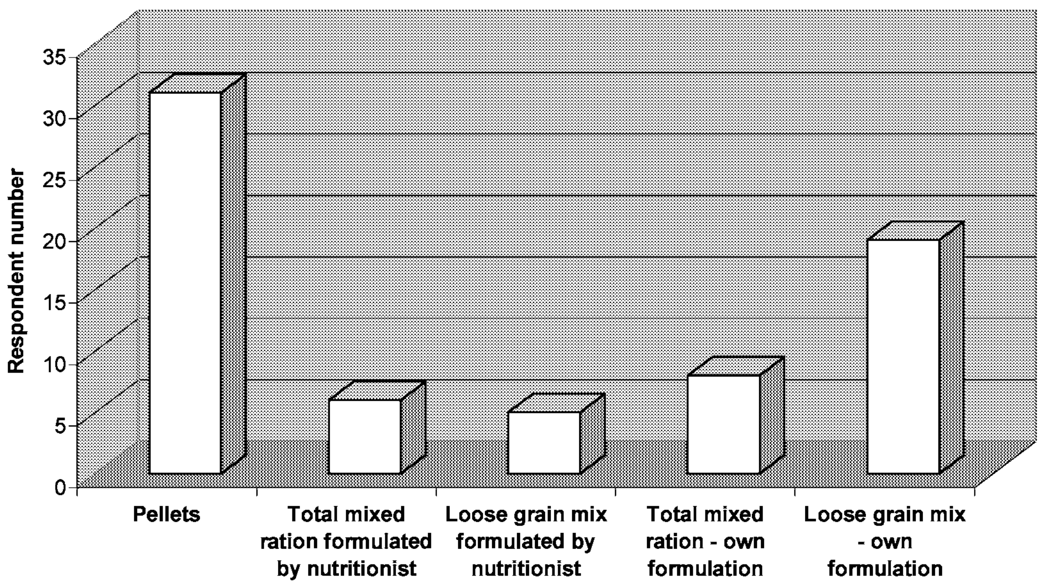


Figure 8. **Type of ration used in the feedlot or confined area.**

When asked why they chose this ration type, the overriding reasons for pellets, were ease of handling, time efficiency, and that pellets were considered a complete ration.

Those who used loose mixes, talked about value adding on-farm produce (straw, screenings included) and the cost-effective nature of using on-farm produce. They also commented on the flexibility of being able to alter the ration.

It appears that home loose mixes are appealing, as they are seen as being a cheaper option when compared to pellets. This was certainly enhanced if using on-farm produce. Pellets on the other hand, are seen as a ready-made vitamin pill, and when coupled with a self-feeder, a fill and forget type mentality appears to be typical. Some of the respondents considered it more cost effective to sell grain and buy back pellets.

- ***Did you use an introductory feed or introduction program in your feedlot during 2002 to reduce the risk of acidosis and allow lambs to adapt to grain feeding?***

  64 per cent of respondents said they did use an introductory program. Of those who did use some form of introductory program there was a wide variety in the type of program being employed. The main conclusion reached from these questions was that the concept of introducing stock gradually to new feeds was poorly understood by a vast majority of respondents. Consequently implementation of introductory programs on-farm appears to be inadequate.

- ***How often do you feed your lambs?***

  90 per cent responded that lambs were given *ad libitum* access to feed, through self-feeders. Convenience, labour minimisation and ease, were all words used to describe the reasons why this method was applied. The small percentage of producers who controlled feed did so to limit intake (only feeding what is required) and to improve acclimatisation to feed.

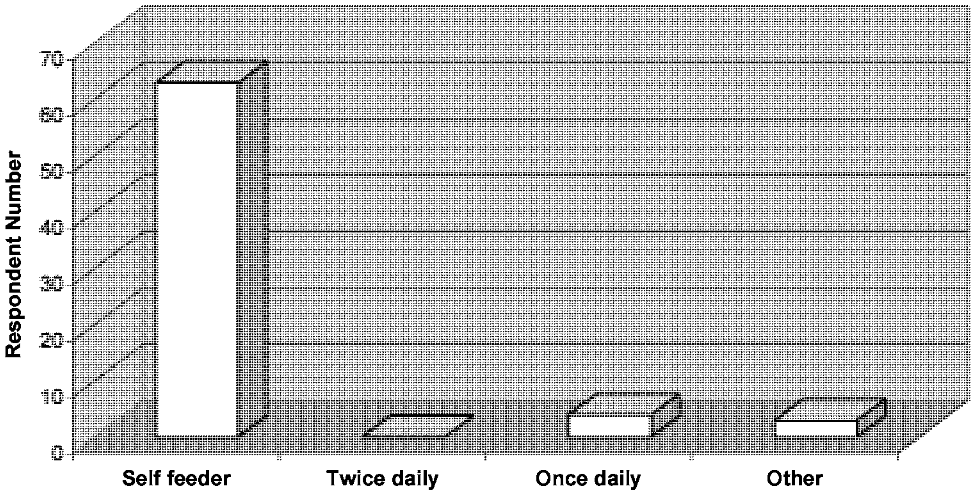


Figure 9. How often lambs in feedlot or confined area were fed.

- ***What additional roughage did you use in your finishing system during 2002?***

  61 per cent of respondents utilised hay as part of the finishing ration. 69 per cent of those who used hay indicated oaten hay as their hay of choice. 23 per cent of responses indicated that they used no form of additional roughage. This 23 per cent were primarily those who were using a pellet, which contained a fibre component. Others were using a loose mix ration with no hay. Other respondents indicated they used straw.

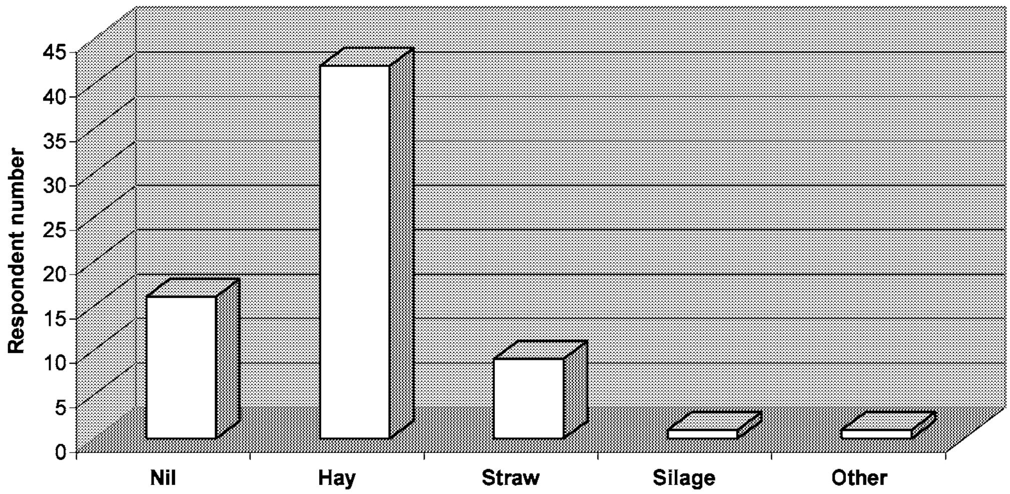


Figure 10. Type of additional roughage used in feedlot or confined area.

- ***How did you feed roughage in your finishing system?***

  62 per cent presented roughage as big hay bales in the pen or paddock. Very few used hay racks or weldmesh rings. 12 per cent incorporated roughage into the feed ration.

- ***Did you use a lab analysis service to measure the quality of feed used in your feedlot?***

  66 per cent of respondents did not have their ration analysed for nutritional composition. The main reason for this was that it was not considered necessary.

- ***Types/quantities of ingredients used in home mix rations and how they are mixed?***

  Wheat, oats and lupins appeared to be the primary sources of grain. Some respondents also used canola meal, hay, minerals and vitamins. There was a considerable variation on the quantities used and how they were formulated. Five-in-one bins and mix-alls appeared to be popular equipment for mixing rations.

- ***Where do you obtain information for your finishing systems?***

  The Department of Agriculture featured as the most popular source of information followed closely by field days and workshops. Other sources of information included system suppliers, experience, stock agents and Independent Lab Services (Dr John Milton).

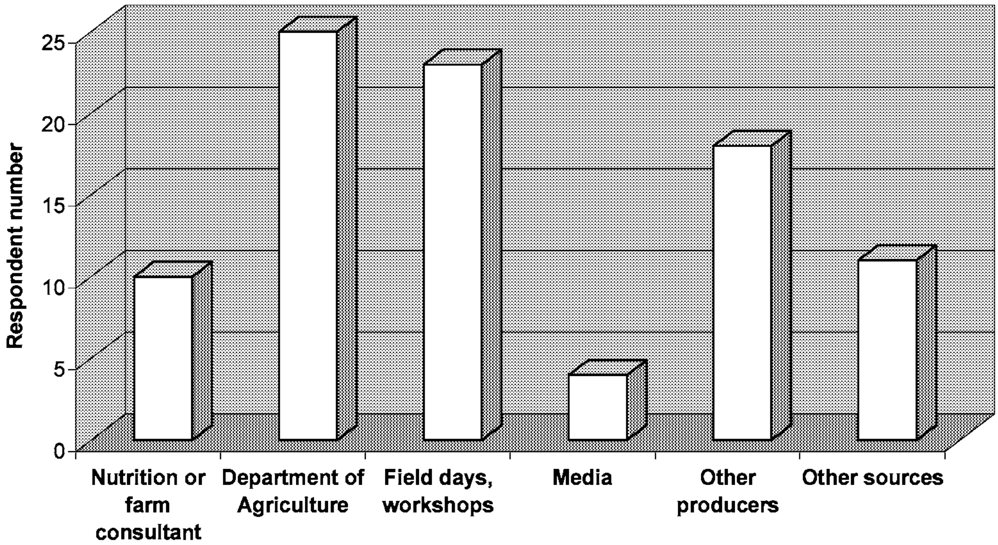


Figure 11. **Main source of information for feedlot and confinement feeding.**

Some of the other issues raised by respondents with respect to their finishing enterprise

- Costs per head - 'Is it worth it when grain prices are high'?
- How to improve growth rates at no extra cost.
- Use of summer crops, mustard seed.
- Best growth rates in relation to protein (value for protein?).
- Self-feeders - 'Are we wasting profit'?
- Getting tail enders/shy-feeders to eat.
- The relevance and requirements for bypass protein in finishing lambs from 35 kg and above.
- Quality testing comparison of feed pellets.

Summary

This questionnaire served as a suitable medium by which to gain a better understanding of the current industry practices with reference to feeding sheep for finishing in Western Australia. Statistical values could not be drawn from the results; however, the results provided a clear indication of the current trends and practices within the industry. Equally important, was the insight it gave as to some of the philosophies and understandings of producers, and the farming systems that they have adopted.

FEEDING SHEEP FOR FINISHING QUESTIONNAIRE

Details

Name: ______________________________

Address: ______________________________

Phone number: ______________________________

Fax number: ______________________________

E-mail address: ______________________________

Average annual rainfall (mm): ______________________________

Annual rainfall received during 2002 (mm): ______________________________

SECTION A. General questions (please tick boxes)

DEFINITION: For the purpose of this questionnaire, a feedlot system is defined as an enclosed area where all feed and water are brought to the animal. This includes any grain finishing system from purpose built facilities through to small paddocks with self-feeders.

1. Based on the above definition, do you use a feedlot system to ensure any of your lambs meet market requirements?

☐ **No**, all lambs are sold as suckers (unweaned) **(*please complete sections A-D*).**

☐ **No**, lambs are finished using an extensive, pasture or fodder-based system **(*please complete sections A-D*).**

☐ **Yes** Please choose the best description for your finishing system.

- ☐ Purpose built, conventional feedlot
- ☐ Small paddock confinement using troughs
- ☐ Small paddock confinement using self-feeders
- ☐ Other (please describe): ______________________________

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2. Based on the above definition, do you use a feedlot system to ensure any of your sheep other than lambs meet market requirements?

☐ **No**, other sheep are finished using an extensive, pasture or fodder-based system **(*please complete sections A-D*).**

☐ **Yes** Please choose the best description for your finishing system.

- ☐ Purpose built, conventional feedlot
- ☐ Small paddock confinement using troughs
- ☐ Small paddock confinement using self-feeders
- ☐ Other (please describe): ______________________________

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3. If you have a feedlot finishing system, do you see your system as: (please tick)

☐ An opportunistic enterprise

☐ A permanent part of your farming system

☐ Other (please describe) ______________________

☐ Why do you consider this the best description for your system? ______________________

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SECTION B. The next 4 questions relate to your flock structure and mating program

4. What was your flock structure as of 31 December 2002?

a. Total number of sheep on property ______________________

b. Number breeding ewes ______________________

c. Number of working rams (Merino) ____________ (non-Merino) ____________

d. Number of weaners (up to 12-months old) ______________________

5. Please provide more information on your breeding program for 2002 drop.

a. Number of Merino ewes mated to Merino rams ______________________

b. Number of Merino ewes mated to non-Merino rams ______________________

c. Number of crossbred ewes mated to non-Merino rams ______________________

d. Number of any other mating structure (please describe) ______________________

6. Did you have the same time of lambing for the different matings outlined in the previous question?

☐ **Yes** Please indicate the approximate time of lambing (month)

Start ____________ End ____________

☐ **No** Please indicate the approximate time of lambing for each enterprise (month)

Mating type	***Start***	***End***
Merino ewe x Merino ram		
Merino ewe x non-Merino ram		
Crossbred ewe x non-Merino ram		
Other		

Why do you have a different time of lambing for different enterprises?

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7. Please indicate what percentage of your breeding ewes fell into each age category in 2002.

White tags (01) ____________ Yellow tags (97) ____________

Black tags (00) ____________ Purple tags (96) ____________

Blue tags (99) ____________ Green tags (95) ____________

Red tags (98) ____________ Orange tags (94) ____________

SECTION C. The next four questions relate to marketing lambs and other sheep that you FINISHED in 2002

8. For each class of sheep that you fed to finish, please indicate the approximate number sold in 2002.

Class of sheep	***Number sold***
Merino lambs	
Crossbred lambs	
Hoggets (two tooth)	
Shippers (sold for live export)	
Adult wethers (sold for slaughter)	
Adult wethers (sale yards/other method of sale)	
Cull ewes	
Other (please specify)	

9. How did you assess whether lambs and other sheep were finished and ready for sale or slaughter?

Lambs	Other Sheep	
☐	☐	Liveweight (target) ____________ and condition score (target) ______
☐	☐	Visual assessment (yourself or stock agent)
☐	☐	Fixed time of feeding (please specify length in weeks) ______________
☐	☐	No assessment
☐	☐	Other (please specify) __________

10. How did you market the lambs and other sheep that you fed to finish during 2002 (please tick the most applicable categories)

Lambs	Other Sheep	
☐	☐	WAMMCO International
☐	☐	Fletcher International Pty Ltd
☐	☐	V and V Walsh Abattoir
☐	☐	Hillside Meats
☐	☐	Goodchild Abattoirs
☐	☐	Direct consignment through another abattoir (please specify) __________ ______________________________
☐	☐	Live export
☐	☐	Sale yards
☐	☐	Forward contract (please specify abattoir) ______________________
☐	☐	CALM (Computer Aided Livestock Marketing)
☐	☐	Other (please specify) ____________________________________

11. Did you market your lambs through an alliance during 2002?

☐ **No**

☐ **Yes** Which alliance?
- ☐ Q Lamb
- ☐ Prime Merino Lamb Alliance
- ☐ Other (please specify) ____________________

SECTION D. The next two questions relate to monitoring the performance of lambs to determine when they would meet market requirements during 2002.

12. Did you weigh your lambs to monitor liveweight?

☐ **No** What was the main reason that sheep were not weighed?
- ☐ Don't have access to scales
- ☐ Don't have enough time
- ☐ Don't have labour available
- ☐ Don't think it is necessary
- ☐ Other (please specify) _______________

☐ **Yes** How often did you weigh?
- ☐ Feedlot entry and exit
- ☐ Feedlot exit only
- ☐ Fortnightly
- ☐ Monthly
- ☐ Other (please specify) _______________

13. Did you condition score your lambs to monitor fatness?

☐ **No** What was the main reason?
- ☐ Not confident in ability to condition score
- ☐ Don't have enough time
- ☐ Don't have labour available
- ☐ Don't think it is necessary
- ☐ Other (please specify) _______________

☐ **Yes** How often did you condition score?
- ☐ Feedlot entry and exit
- ☐ Feedlot exit only
- ☐ Fortnightly
- ☐ Monthly
- ☐ Other (please specify) _______________

The remaining questions are only relevant to producers who are FEEDLOTTING LAMBS. If you did not feedlot lambs during 2002, thankyou for your participation. You have now completed the survey and can return it:

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By Mail: In the enclosed postage paid envelope

SECTION E. The next four questions relate to monitoring the performance of lambs in a feedlot. Please SKIP this section if you do not use a feedlot.

14. Did you measure the growth rate of your lambs?

☐ **No** What was the main reason that growth rate was not measured?

- ☐ Lambs were not weighed
- ☐ Not confident in ability to calculate growth rate
- ☐ Don't have enough time
- ☐ Don't think it is necessary
- ☐ Other (please specify) ____________________

☐ **Yes** What was the flock average growth rate of lambs sold in 2002?

- ☐ Less than 100 g/day
- ☐ 100-200 g/day
- ☐ 200-300 g/day
- ☐ 300-400 g/day
- ☐ More than 400 g/day

15. Did you measure the feed conversion ratio (FCR) of your lambs, i.e. if a lamb eats 6 kilograms of feed for every 1 kilogram of liveweight gain the feed conversion ratio is 6:1?

☐ **No** What was the main reason that feed conversion ratio was not measured

- ☐ Lambs were not weighed
- ☐ Feed intake was not measured
- ☐ Not confident in ability to calculate FCR
- ☐ Don't have enough time
- ☐ Don't think it is necessary
- ☐ Other (please specify) ____________________

☐ **Yes** What was the flock average feed conversion ratio of lambs sold in 2002?

- ☐ More than 8:1
- ☐ 7:1-8:1
- ☐ 6:1-7:1
- ☐ 5:1-6:1
- ☐ Less than 5:1 ____________________________

16. Did you monitor how many weeks it took to finish your lambs?

☐ **No** What was the main reason finishing time was not monitored?

☐ Don't have enough time
☐ Don't think it is necessary
☐ Other (please specify) ____________

☐ **Yes** What was the average time it took for lambs to finish during 2002?

☐ Less than 3 weeks
☐ 3-4 weeks
☐ 5-6 weeks
☐ 7-8 weeks
☐ More than 8 weeks

17. Are there any issues related to animal performance monitoring or marketing for your finishing enterprise where you would like more information? (Please detail)

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SECTION F. The next 4 questions relate to the SETUP of your FEEDLOT or confined area. Please SKIP this section if you do not use a feedlot.

18. Is the feedlot permanent or temporary? ____________________

19. What is the total area of the feedlot in hectares? ________________

20. What is the maximum number of lambs in the feedlot at any one time? ________

21. What type of feeding system do you use in your feedlot or confined area?

☐ Self-feeders (please indicate type or manufacturer) ________________

☐ Troughs Please indicate construction material of troughs?

☐ Commercial troughing
☐ Conveyor belting
☐ Shadecloth
☐ Galvanised iron
☐ Other (please specify) ____________

☐ Other feeding system (please specify) ____________________

SECTION G. The final 14 questions relate to the FEEDLOT and feeding of lambs within the feedlot or confined area. Please SKIP this section if you do not use a feedlot.

22. What type of feed mix rations did you use in your lamb feedlot or confined area in 2002?

☐ Commercial pellets
- O Feed manufacturer ____________________
- O Product types/names ____________________

☐ Commercial loose mix
- O Feed manufacturer ____________________
- O Product types/names ____________________

☐ Formulated by a nutritionist - home mixed total mixed ration (TMR) (a TMR usually includes milled grain, milled roughage, e.g. hay, minerals and other additives mixed in a vertical mixer or feed wagon)

☐ Formulated by a nutritionist - home mixed loose grain mix (a loose grain mix usually includes grain and maybe minerals but does not include milled roughage)

☐ Your own mixture - home mixed total mixed ration (TMR) (see definition above)

☐ Your own mixture - home mixed loose grain mix (see definition above)

23. Why did you choose to use this type of feed ration?

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24. What were the levels of crude protein (CP) and metabolisable energy (ME) in the feed ration?

These nutrients are generally expressed as percentage crude protein on a dry matter basis (DM) and megajoules (MJ) of metabolisable energy (ME) per kilogram dry matter. If you are using a commercial ration or nutritionist, they will be able to provide this information. Please specify for each feed ration used.

☐ Unknown

Ration type ____________ CP (% DM) ____________ ME (MJ/kg DM) ____________

Ration type ____________ CP (% DM) ____________ ME (MJ/kg DM) ____________

25. Did you use an introductory feed or introduction program in your feedlot during 2002 to allow the lambs to adapt to grain feeding?

☐ **No** What was the main reason that an introductory period was not used?

☐ Grain/pellet type used not high risk for grain poisoning

☐ It is inconvenient

☐ Not aware of the need

☐ Other (please specify) ____________________

☐ **Yes** Please describe your introductory feeding program.

____

____

26. How often did you feed the lambs?

☐ Self-feeder system, feed available at all times (*ad libitum)*

☐ Twice daily

☐ Once daily

☐ Other (please specify) ____________________

27. Why did you choose to feed this often?

____

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28. What additional roughage did you use in your finishing system during 2002?

☐ None (please skip the next question)

☐ Hay (please specify type, e.g. oaten hay, pea hay) ____________________

☐ Straw (please specify type, e.g. wheat, barley) ____________________

☐ Silage (please specify type, e.g. oat, pasture) ____________________

☐ Other (please specify) ____________________

29. How did you feed additional roughage in your finishing system?

☐ Bales chopped and incorporated into the feed ration, e.g. total mixed ration

☐ Bales presented in hay racks

☐ Bales surrounded by weldmesh rings or panels

☐ Bales placed in pen or paddock ☐ Big bales ☐ Small bales

☐ Other (please specify) ____________________

30. How many kilograms per day of each feed did you offer each lamb? Please fill in the sections that correspond to the type of feed you used.

Feed type	*Feed offered (kg/head/day)*
Pellets	
Total mixed ration (TMR)	
Grain mix	
Additional roughage	

Please SKIP the following 3 questions if you used COMMERCIAL feed rations.

31. Do you use a laboratory analysis service to measure the quality of feed used in your feedlot?

☐ **No** What is the main reason you don't have feed analysed?

☐ Too expensive

☐ Don't understand the results

☐ Don't think it is necessary

☐ Other (please specify) ______________________________

☐ **Yes**

32. What proportion of each ingredient did you use in your home mixed feed ration during 2002? Please include additives such as molasses, urea, salt, lime, eskalin, etc. in 'other'.

	Ingredient type	*Kilograms per tonne*
Grain 1		
Grain 2		
Grain 3		
Other		
Other		
Hay or other roughage		
Mineral mix		

33. Please describe how you mixed your ration.

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34. Where did you obtain information for your finishing system? (please tick all that apply)

- ☐ Feed/farm consultants
- ☐ Department of Agriculture
- ☐ Papers or magazines (please specify which ones)
  - ☐ Farming Ahead - Kondinin
  - ☐ Australian Farm Journal
  - ☐ Countryman
  - ☐ Farm Weekly
  - ☐ On Farm - Holmes and Sackett
  - ☐ Other ____________________
- ☐ Field days, workshops or meetings
- ☐ Media (radio or television)
- ☐ Other producers with finishing systems
- ☐ Other sources (please specify) ____

35. Are there any issues related to feeding in your finishing enterprise where you would like more information? (Please detail)

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Thank you for your participation. You have now completed the survey and can return it by:

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Mail: In the enclosed postage paid envelope

SHEEPCRC

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The Australian Sheep Industry Cooperative Research Centre is a joint venture established and supported under the Australian Government's Cooperative Research Centres Program

CORE PARTIES

- Australian Meat Processor Corporation
- CSIRO Livestock Industries
- Department of Agriculture, Western Australia
- Department of Primary Industries and Fisheries, Queensland
- NSW Agriculture
- The University of New England

SUPPORTING PARTIES

- Australian Wool Innovation
- AWTA Wool Education Trust
- Bett Trust
- Department of Primary Industries, Victoria
- Department of Primary Industries, Water and Environment, Tasmania
- Elders
- Fletcher International Exports
- Interactive Wool Group
- Meat & Livestock Australia
- Merino Benchmark
- Murdoch University
- Primary Industries and Resource South Australia
- Sheepmeat Council of Australia
- The Mackinnon Project, University of Melbourne
- The University of Sydney
- WoolProducers