SHEEP CRC

Books, Book Reviews, Extracts

Document ID:	SheepCRC_32_23
Title:	Simple & profitable grain finishing systems (Grain feeding review - Pethick et.al.)
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Key words:	sheep; grain feeding; grain finishing;

This publication should be cited as:

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INTRODUCTION

Grain is employed in a variety of lamb finishing systems ranging from intensive indoor feedlots, where grain is the main source of nutrition, to supplementation in paddocks where grain may be targeting specific deficiencies in the diet eg. lupin supplement to provide protein on cereal stubbles. The level of inputs and outputs vary depending on the intensity of the enterprise but the existence of a wide range of systems throughout the industry demonstrates that a broad range of finishing systems are 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 will assess the biological performance of lambs and sheep that are grown for slaughter using grain feeding systems.

DEVELOPMENT OF THE LAMB INDUSTRY

Australia is one of the world's major producers of sheep meat contributing around 10% of the world's total lamb and mutton production. In 2000, over 16.3 million sheep (mutton) and 18.4 million lambs 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 domestic market is the major market for lamb and in the year 2000 consumed about 65% of all production while almost 70% of mutton was exported. MLA (2003) reported lamb consumption in Australia in 2001 was 11.7 kg/head and 5.3 kg/head for mutton.

The current levels of lamb production have increased markedly from 1980 to the present time (Figure 1). This increase has mainly been destined for export as the domestic consumption has remained relatively constant. Over that period the proportion exported has risen from around 15% in 1980 to over 30% in 2000.

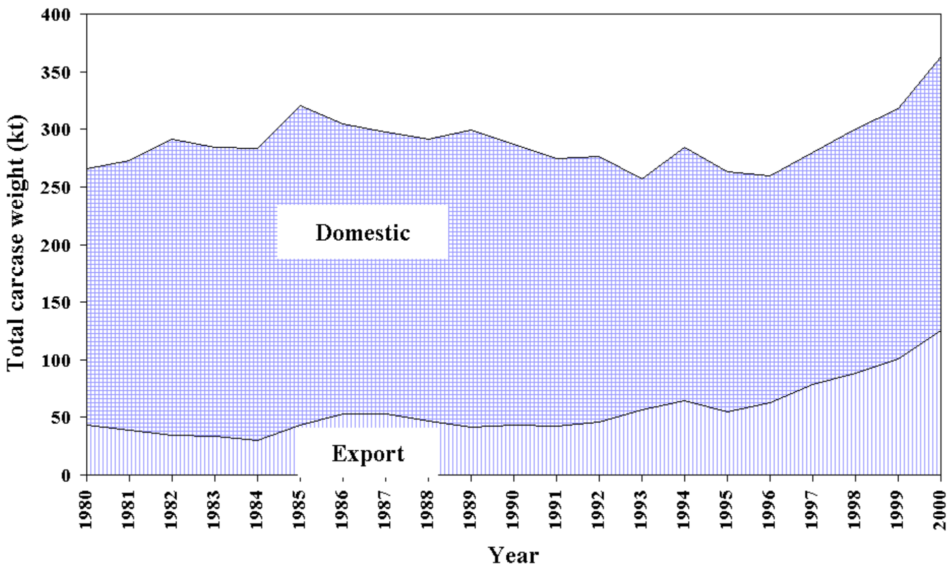

Figure 1. Domestic and export consumption of Australian lamb from 1980 to 2000.

The Australian lamb industry has therefore undergone major changes particularly in the last 10 years. This has coincided with a decline in the profitability of wool and more emphasis being placed on meat production. These changes 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 1990's when a coordinated national program was devised in response to the decline in domestic consumption and to stimulate exports (Thatcher 1992). This was known as the Elite lamb program and was based on the production of heavier, leaner lambs.

What are the specifications?

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 6-15 mm (McLaughlin 1992). While this was the target specification set for the Elite lamb program there are a number of markets both within and outside of this range available for lamb producers. Specifications 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 2.

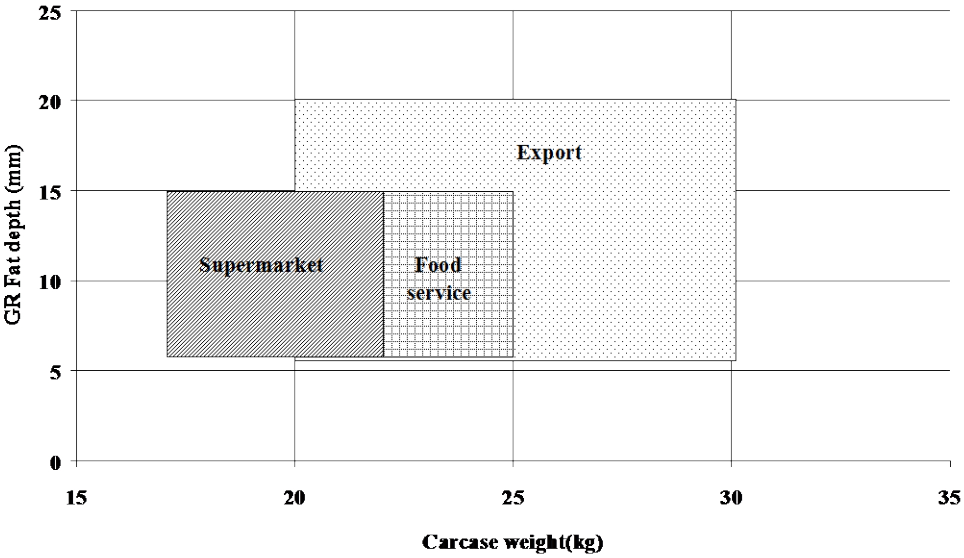

Figure 2. Typical market specifications for lamb.

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. ABARE (2001a) 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. It appears that the trend towards increasing 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 at the 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%. 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 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 there was a clear preference for carcases with a "U" shaped appearance than for a "V" shaped structure. 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.

Marketing systems

A number of selling systems are available 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. It 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% of sales while over-the-hooks and paddock sales were the only other significant methods accounting for 33% and 22% respectively.

How can specifications be met?

Pirlot *et al.* (1992) did a study of the number of carcases that would meet specifications of 22-26 kg and fat score 2-3 in a lamb processor in Tasmania between November 1989 and October 1990. Of the 108,028 lamb carcases that were included in the survey only 626 met the Elite lamb specifications or less than 0.5% while only 5095 (4.7%) were within the weight range. They noted a tendency for heavier carcases to be over fat and suggested strategies such as modifying the sex of castrated males to short scrotum lambs. They also suggested that a move toward direct sales, as the saleyard system appeared to favour fatter lambs.

The demand for heavier carcases has necessitated significant modifications to productions systems. In order to comply with these specifications industry has made use of the LAMBPLAN breeding system to identify genetic material that can more closely match the specifications of the market. The system allows selection of animals with more desirable traits for growth rate, fat depth and eye muscle depth. This enabled shifting of weights to higher levels while restricting and even reducing fatness levels. Other ways of achieving this are by using crossbreeds with later maturing characteristics, ie. fatten at heavier weights.

Hall and Holst (1992) suggested 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 that showed that the proportion of lambs meeting Elite lamb specifications varied according to sire and sex. They found that while only 6% of lambs from ewes sired by rams with a relatively poor lean growth LAMBPLAN index met specifications, 64% 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 increases 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. They found that a period of restricted growth could be used as a means of reducing fatness without compromising meat quality.

Meat quality

Tenderness and flavour

Along with continuity of supply, consumer's expectations for better eating qualities in characteristics such as tenderness and flavour are increasing. A survey reported by Hall *et al.* (2000) conducted in Victoria highlighted the variability in quality as measured by shear force. In response to the demands for greater eating quality, a major programme has been developed along similar line to the Meat Standards Australia program for beef to investigate factors affecting eating quality and to implement a system that will guarantee eating characteristics.

Meat colour

Another aspect of quality relates to the visual appeal of the meat and in particular, meat colour. Meat colour or dark firm and dry (DFD) meat is a particularly important characteristic in relation to lamb as it has been shown to be a significant problem. The condition is closely linked to muscle glycogen levels at the time of slaughter. Low glycogen levels in the meat result in meat with high pH (above 5.7) and a dark firm and dry appearance that is rejected by consumers. DFD also results in problems with cooking characteristics and shelf life. The incidence of DFD in lambs processed by a leading Western Australian processor was estimated at around 30% (Pethick pers. comm.). Pethick (pers. comm.) also carried out two studies in which pH was measured in the semimembranosus and semitendinosus muscle of lambs. He reported that 29% of carcases had pH levels above 5.7 in the semimembranosus and 87% in the semitendinosus in one study and 45% and 82 % respectively in a second. The effects of nutrition were studied by Pethick and Rowe (1996) who fed sheep on four 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 by biopsy and following slaughter showed a significant and linear increase in glycogen levels 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. Some processors now acknowledge that one of the advantages of feedlotting lambs prior to slaughter is ensuring adequate muscle glycogen levels and preventing DFD.

Consistent supply

A further requirement has been the necessity to supply a consistent quality product throughout the year. 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 variety of other systems have been developed based on fodder crops, use of feed budgeting and supplementary feeding. A further development that has been practiced more widely in Western Australia has been the increase in lot feeding.

The last 10 years has seen the emergence of a number of partnerships or alliances that have been developed in response to the need for product that meets tight specifications, is consistently in supply and provides guaranteed returns. These alliances generally involve producers, processors and sometimes retailers. 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 around 70% 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. The Prime Merino Lamb Alliance also operates in Western Australia and involves producers and a processor. The alliance offers premium prices for lamb carcases that meet specifications and they must also be produced according to a code of practice that requires them to be fed on a prescribed feed pellet for at least 14 days prior to delivery (Briscoe 2000).

GRAIN FINISHING SYSTEMS IN 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 indicated that 59% of producers used pasture as their main method of finishing lambs, with a further 24% indicating pasture with the use of supplements (Table 1). Only 3% of producers considered feedlotting as their main method of production.

Table 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 prominent in Western Australia, with 19% of prime lamb producers identifying feedlotting as their main finishing method (Table 1). There was no specialist feedlotting in Queensland or Tasmania, 1% in South Australia and Victoria and 2% in New South Wales.

Supplementation was identified as a key strategy for finishing prime lambs in both pasture and fodder based systems (Table 1). The use of grain in paddock based feeding systems is common in most states with a national average of around one third of producers identifying supplementary systems as their predominant method of finishing.

ROLE OF GRAIN FEEDING IN SHEEP MEAT PRODUCTION

Sheep meat enterprises

Sheep meat enterprises can be classified as;

(i) a specialist crossbred prime lamb production system;
(ii) prime Merino lamb production that exists in conjunction with a wool enterprise; and
(iii) mature cull animals, predominantly Merino, that are slaughtered for mutton (Dowling *et al.* 2001).

In specialist prime lambs 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. The remainder of this section focuses on the key aspects of the role of grain finishing in various meat production systems.

Finishing prime lambs

The majority of prime lambs in Australia are finished on pasture or fodder crops (Table 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 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 can change in different economic environments. During the late 1970's and early 1980's, there was an increase in the prevalence of intensive feedlots in Australia (Hall *et al.* 1982). Researchers at the time generally concluded that there was no benefit using intensive feeding systems due to problems with adaptation to the diet and confinement (Hall *et al.* 1982; Mulholland 1986; Suiter *et al.* 1987). In addition, the economics were 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.

Grain finishing systems have developed in response to three market stimuli;

(i) the demand for consistent supply;
(ii) the demand for large, lean lambs; and
(iii) the expectation of good eating quality.

The key issues faced by producers are influenced by the relative importance placed on each of these three factors within an individual enterprise.

Consistent supply

The lamb industry requires a consistent, year-round supply of lambs to make efficient use of processing facilities and to reliably supply high value export markets. Grain feeding enables lambs to be finished independently of pasture availability. This is particularly important in Mediterranean environments such as Western Australia, where there is a strong seasonal pattern of pasture availability. Grain finishing is an important management strategy for finishing lambs during the annual autumn feed gap through to early winter in these environments.

Larger, leaner lambs

Even when the growing season is longer, systems producing larger carcases may also rely on grain finishing strategies. If an enterprise is targeting heavyweight lambs, the simplest way to produce larger lambs is to grow them for longer. In this situation, the pasture may not sustain adequate growth for the time required to meet target weights. 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.

Good eating quality

Good eating quality has been related to plane of nutrition in finishing lambs (Pethick *et al.* 2000). Dark, firm, dry meat is related to post-mortem metabolism of glycogen and occurs when the level of glycogen is insufficient to result in a meat pH lower than 5.8-6.2. 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.

The length of the feeding period will vary depending on the intended market for the lambs and primary reason for using grain. The grain finishing period is likely to be short eg. 3-4 weeks if the purpose is to optimise meat quality and achieve carcase weight in the 17-22 kg range. A longer grain finishing period may be required if the growing season has ended and the target carcase weight is 24+ kg.

Supplementing prime lambs with grain

The role of grain feeding in backgrounding or growing strategies for prime lambs varies in different regions of Australia. 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 ie. 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% of the annual sheep meat production in Australia (Meat & 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 *et al.* 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, see attached 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.* 2003a). Recent research by Wiese *et al.* (2000a) and Pethick *et al.* (2003a) has demonstrated that criteria for the current category definitions for sheep meat (lamb, hogget, mutton) do not necessarily correlate with meat eating quality and therefore it may be advantageous for the Australian sheep meat industry to consider alternative classifications. There would potentially be an increased role for grain feeding of older sheep if a niche market for larger, older carcases developed and price premiums were offered for high quality sheep in this age category.

FACTORS THAT INFLUENCE BIOLOGICAL PERFORMANCE

The key biological performance parameters linked to profitability of a grain finishing system are rate of growth, composition of growth and feed conversion efficiency. While these parameters can be affected by nutrition, there are strong interactions between nutrition, genetics and environment so it is important to outline other key factors that should be considered when interpreting the literature.

Breed and genetics

Genotypes that are heavier at maturity generally grow faster and are leaner when compared at the same weight (Black 1983; Searle *et al.* 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 *et al.* 1981) and second-cross lambs have been reported to grow faster than first-cross lambs due to greater hybrid vigour (Atkins *et al.* 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 *et al.* 1979; Searle *et al.* 1976b; Shands *et al.* 2002).

The choice of mating system eg. first- vs second-cross, or breed selection eg. Merino vs crossbred, 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 *et al.* 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 *et al.* 1970b; Atkins *et al.* 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 *et al.* 1970a; Arnold *et al.* 1988; Atkins *et al.* 1979; Holst *et al.* 1997; Jackson *et al.* 1990; Lee 1986a; Van Vleck *et al.* 2000; Wynn *et al.* 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; Lee 1986b).

NUTRITION FOR THE PRODUCTION OF LAMB AND SHEEP MEAT PRODUCTS

Sheep meat production has changed direction in the last 10 years in terms of increased carcase weights, lower carcase fat and higher muscling animals and the increased emphasis placed on eating quality and providing consumers with a consistent and pleasant eating experience (Croker *et al.* 2001; Oddy *et al.* 2002). This has impacted on the requirements of livestock and management of their nutrition to address the important commercial attributes of lamb and other sheep meat products.

In addressing the nutritional requirements of livestock there are two main factors that are seen as imperative in feeding of livestock. These are the level and composition of protein, and energy availability. There are several interactions that need to be addressed; these include growth patterns of animals, genetic potential, protein form and energy.

Protein

There are two sources of protein for ruminants, firstly rumen degradable protein, which is incorporated into rumen microflora as they ferment the ingested feed. Also a small proportion is obtained from micro-organisms as they pass from the rumen and are digested along with material that has not been completely broken down in the rumen. The second source of protein is bypass protein that has not been broken down in the rumen either because it is resistant to microbial attack or rumen outflow rate is high so only partially digested.

The composition of amino acids in microbial protein is matched well for the development of muscle protein so growth is usually well supported by microbial protein. In this case, energy is the limiting factor because energy supply drives microbial synthesis. In contrast, in the case of very young animals, or fast growing animals, there is a suggestion that microbial protein may not have an adequate balance of amino acids.

Ruminants depend on the essential amino acids provided indirectly from their feed, particularly animals that are actively growing and increasing in weight (Kung *et al.* 1996; McDonald *et al.* 1988; Wilson 1981). As protein and amino acids are subject to microbial breakdown it is difficult to predict the quantity and quantity of amino acids that are available to the animal (Kung *et al.* 1996). Protein is synthesised in the gut by rumen micro-organisms, with the necessary nitrogen being derived from plant polypeptides in the form of ammonium (Wallace *et al.* 1988). When produced in excess it leads to inefficient usage of the available nitrogen (McDonald *et al.* 1988).

Protein metabolism also depends on the supply of essential amino acids that escape rumen degradation in the form of undegradable dietary protein (McKinnon *et al.* 1995; Wallace *et al.* 1988; Wilson 1981). Improving the quality of absorbable amino acids in the small intestine can be accomplished by feeding proteins, which are resistant to rumen degradation (Kung *et al.* 1996). These proteins are then digested and absorbed directly by the small intestine, thus increasing the amino acids available for meat and wool production.

Animals which have access to adequate energy should respond to increasing levels of dietary protein by growing faster, provided their capacity for protein deposition is not exceeded. Surplus dietary protein is likely to be used as an energy source, converted at a lower efficiency. This can lead to a decrease in growth rates and increase in fat deposition (Purchas 1991).

Sources of bypass protein (protected methionine) fed at varying levels to Merino and crossbred lambs did not appear to influence performance or carcase attributes of the lambs (Wiese *et al.* 2003). The diet was fed at 15% crude protein and 11 MJ ME/kg and synthetic form of protected methionine was fed at 0-5 g/hd/day. In contrast, work done using various forms of protein indicated that feeding urea, lupins and canola meal as different forms of protein did impact on production. The lambs fed canola meal had the highest weight gain while those fed urea had the lowest weight gain, indicating that as the quality of protein increased the weight gain increased. However there was no impact on the carcase quality over the 5 week period (Wiese *et al.* 2000b).

Present recommendations for feeding vary between extension packages (Table 2). The variations in the recommendations within extension material may require an investigation into the correct levels of protein and energy to maximise production levels as well as how this impacts on carcase characteristics.

Table 2. General protein, energy and roughage recommendations in extension material

Energy (MJ ME/kg DM)	Minimum roughage (%)	Crude protein (%)	Reference
11-12	15	14-16	(Seymour 2000a)
10.5-12	N/A	14-16	(Milton 2001b)
>10.5	10-30	15-18	(Davis 2003)

Energy

Feed consumed by ruminants is initially subject to fermentative digestion by the rumen. The products of rumen fermentation are volatile fatty acids (VFA), which are also the principal source of energy for ruminants (Ørskov *et al.* 1990). The main VFA's are acetate, propionate and butyrate (Brockman 1993; McDonald *et al.* 1988; VanSoest 1994). The proportion of VFA's produced is strongly influenced by the diet fed, with roughage diets producing low concentrations of propionate to acetate acids and grain based diets generally produce a higher concentration of propionate to acetate (Czerkawaski 1986). The main aim of manipulating rumen fermentation is to alter the products of fermentation to maximise the efficiency of feed utilisation for meat and wool production (Nagaraja *et al.* 1997).

Energy is essential for the maintenance, growth and production of livestock and is pivotal for the utilisation of available protein. Sheep require energy to maintain body temperature, drive essential metabolic processes and fuel physical activity such as standing and walking to graze. The level of energy that meets these basal requirements with no net gain or loss of energy from tissues is termed 'maintenance'. Energy intake that is above the requirement for maintenance will be used for production, increasing protein retention as muscle, wool and other body tissues (Chowdhury *et al.* 1997; McDonald *et al.* 1988). Estimation of the total energy requirement of growing sheep is arrived at factorially by summing the requirements calculated separately for maintenance and production.

The maintenance requirement represents a significant proportion of the total energy requirement. Even at production levels of feeding, about 40% of the total metabolisable energy (ME) intake is used to maintain basal processes (SCA 1990). The maintenance requirement for energy must be considered separately to the requirement for growth because energy is used with different efficiency for the two processes. The efficiency of use of energy is generally expressed as a function of the metabolisable energy density of the feed (MJ/kg DM = M/D). The efficiency of ME utilisation for maintenance (k_m) ranges from 0.54-0.72 depending on the method of calculation. One method used for calculating k_m suggested by the Standing Committee on Agriculture (SCA 1990) is:

$$k_m = 0.02 \text{ M/D} + 0.5$$

The energy required for growth is equal to the energy retained in body tissues multiplied by the efficiency with which the sheep can convert feed energy to retained energy. The efficiency of ME utilisation for growth (k_g) is lower than the efficiency of use for maintenance. The equation suggested by the by the Standing Committee on Agriculture (SCA 1990) is:

$$k_g = 0.043 \text{ M/D}$$

Incorporating the range of expected energy density of feed, the range calculated for efficiency of use of energy for growth is 0.30-0.57, however, a review of published data suggests that in reality the range is much greater (Oddy *et al.* 2002).

The utilisation of energy for growth is complex so it is not surprising that there is a wide range in the measured values of k_g. The main components of k_g are the efficiency of energy retention for fat (k_f) and protein (k_p). Each component has a different efficiency with k_f being more than 3.7 times higher than k_p (Oddy *et al.* 2002). It is clear that if the composition of gain varies, the overall energy efficiency of growth will also vary due to the relative contribution of k_f and k_p. Current energy systems are based on the ME density of the feed, so have a limited ability to incorporate the complex interactions that occur in the energetics of growing animals.

It is interesting to consider the relative contribution of total energy intake and efficiency of utilisation, to differences observed between high and low growth rate animals. If higher growth rate is simply related to higher feed intake then the same feed inputs are required to produce a finished lamb and the only benefit is a reduction in the finishing time. Animals selected for high weaning weight have a greater rate of feed intake than those selected for low weaning weight but also demonstrate higher feed conversion efficiency at the same body weight (Thompson *et al.* 1985). Furthermore, the efficiency of protein gain is higher in animals selected for high weaning weight compared to those selected for low weaning weight (Oddy *et al.* 1995). There is potential to exploit differences in feed conversion efficiency and especially efficiency of lean growth, to improve the profitability of lamb production (Oddy *et al.* 2002).

Growth patterns of livestock

Growth is an increase in the size of an animal. Growth rate is a function of voluntary feed consumption and the efficiency with which the feed is used to meet requirements for maintenance and growth. The growth potential of an animal is limited by the inherited genes, and how they interact with the environment. Commonly, the environmental effect is expressed through nutrient supply (McDonald *et al.* 1988; Oddy 2002).

Growth of an animal is dependent on the level of feeding, body composition may vary also during times of *ad libitum* feed intake or restricted feed intake. Generally if an animal is restricted during its earlier years the proportion of fat may be higher relative to bone and muscle compared to an unrestricted animal (McDonald *et al.* 1988; Oddy 2002; Oddy *et al.* 2002). This can impact on the target carcase specifications. To optimise carcase composition you not only need the correct genetics but also an animal that has not been restricted during development.

Composition of livestock can also be predicted through an equation that uses the relationship between energy metabolism and the amount of protein and fat deposited in the growing animal (SCA 1990). This is done by expressing liveweight of an animal as the standard reference weight and predicting the fat, protein and hence energy, in gain from all breeds of sheep LWG = ER/(EVGx0.92).

Genetics and feed efficiency

There are heritable differences in growth rate between animals. These differences have been exploited by exerting selection pressure on animals with high growth rates. Selection of livestock using estimated breeding values (EBV) is advantageous particularly when they are in a feedlot environment where nutrition is generally not limiting. Lambs sired by animals with high EBV outperform those sired by animals with low EBV (Fogarty *et al.* 1997; Hall *et al.* 2002; Hegarty 2002; Wiese 2000). The genetic superiority is expressed in a range of nutritional environments, however, the environment can moderate the magnitude of the difference. Hopkins *et al*. (1996) reported that the ranking of growth rates was the same for animals of different breeds fed in feedlot or at pasture. Similarly, Lasslo *et al*. (1985) found that sheep could be successfully selected for weaning weight either in feedlot or extensive feeding systems. Those selected under feedlot conditions performed better than unselected animals in extensive conditions but the difference between growth rates wasn't expressed to the same degree due to the limitation on feed availability. In other situations, researchers have reported that the extra productivity associated with use of high EBV sires is not expressed when there are limitations on nutrition (Hegarty 2002; Wiese 2000).

Work looking at the differences in first and second cross lambs indicated that ingestion rates may have been the reason for a varying growth rate of first and second cross lambs (Holst *et al.* 1998). While work done by Arthur *et al*. (2001) reported that when weaner cattle were chosen on high feed efficiency they required less feed as four year old cows for the same level of performance as low efficiency cows. This indicates that as well as finding options to maximise feed and production issues the selection of livestock to go into feedlots need to be assessed and what sort of an impact this can make on the production costs of an efficient feeding system. There are also other considerations such as work done by Oddy *et al*. (1995) indicating that through selection of the weaning weight traits that they were actually altering the dynamics of protein metabolism in lambs principally through alterations in protein breakdown of muscle. Indicating that associated genetic differences in protein were related to insulin supply. It is important to determine the underlying indicators that we are selecting for when trying to maximise feed efficiency. Therefore determining how selection of particular traits alters the physiological development of particular animals.

NUTRITIONAL CHARACTERISTICS OF GRAIN

Feed grains are a major source of nutrients for sheep meat production. Winter cereal grains, barley, wheat and oats comprised 54, 16 and 8%, of the total amount of grain consumed by ruminants in Australia during 1990-1991 (Schaefer *et al.* 1991). Summer cereal grains, sorghum and maize are extensively used for animal feeding throughout the world but the amount fed to ruminants in Australia is restricted. Schaefer and Kreitals (1991) reported the amount of sorghum and maize represented 17% and 1% of the total fed to ruminants. The choice of grain used for livestock production is mainly determined 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 meet potential liveweight gain and carcase targets has increased the demand for information about the benefit of including different types of grain in the diet. 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.

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 3). In general, the metabolisable energy of wheat and maize are higher than sorghum and barley, while oats has the lowest metabolisable energy of all cereal grains. Protein content of the smaller grain 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 3). This is a consequence of the greater relative importance of the starchy endosperm in the whole grain and to the absence of hulls (Table 3, Evers *et al.* 1999). Variation in total starch content may be observed between hybrids and varieties but also may be associated with changes in agronomic practices, such as plant density or to varying environmental conditions during growth (Defoor *et al.* 2001; Defoor *et al.* 2000). O'Brien (1999) reports important year and location effect, and genotype × environment interaction 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).

Table 3. Nutrient content and structure of different cereal grains

	Units	Wheat	Barley	Oats	Maize	Sorghum
Chemical Composition[1]						
Organic matter	% DM	98.3	97	97.7	98.5	98.3
Metabolisable energy	MJ/kg	13.4	12.6	11.7	13.8	12.6
Crude protein	% DM	16	13.5	13.3	10.1	11.5
Rumen undegradable protein	% CP	23.0	27.0	17.0	55.0	57.0
Neutral detergent fibre	% DM	11.8	18.1	29.3	10.8	16.1
Acid detergent fibre	% DM	4.2	5.8	14.0	3.3	6.4
Lipids	% DM	1.7	2.0	4.7	4.6	3.2
Starch[2]	% DM	70.3	64.3	58.1	75.7	71.3
Ca	% DM	0.14	0.05	0.01	0.07	0.04
P	% DM	1.27	0.35	0.41	0.04	0.34
Grain Structure[3]						
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] (NRC (National Research Council) 1996), [2] (Herrera-Saldana *et al.* 1990), [3] (Evers *et al.* 1999)

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% 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 3). 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; Loe *et al.* 2001).

The rate and extent of rumen fermentation of starch from maize and sorghum are lower than observed for wheat, barley or oats. Structure and composition of starch and their interaction with proteins play a major role in their digestibility and feeding value (Rooney *et al.* 1986). Several reviews have focused on this aspect describing starch differences between cereal grains and its effect on digestion (Huntington 1997; Rooney *et al.* 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 (21.0%; 6.43%/h) and sorghum (3.5%; 5.34%/h) than for wheat (78.2%; 19.3%/h) and barley (36.2%; 14.73 %/h). Oat grain, although it appears to have low fermentation rate (7.05 %/h) presents a high rapidly degraded fraction (96.6%, Herrera-Saldana *et al.* 1990). *In vitro* trials, by the same authors, confirm the lowest rates of degradation between 15 and 60 minutes for sorghum (3.1%/h) and maize (6.4%/h), ranking as the cereals grains with the lowest starch ruminal availability, after oats, wheat and barley. The lower rate of degradation reduces the risk of acidosis and related metabolic disorders in sheep when using maize and sorghum compared to barley (Keating *et al.* 1965) or wheat (Kreikemeier *et al.* 1987) so they may be explored as safer grains when fed in high concentrate rations.

Processing grains for sheep

The primary purpose of grain processing 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% for common feed grains so there is limited potential for increasing the efficiency of digestion of grains (Table

4). This has been noted in many comprehensive reviews (eg. Hale 1973; Ørskov 1976; Ørskov 1986; Rowe *et al.* 1999; Rowe *et al.* 1994; Theurer 1986).

Table 4. Starch digestion by sheep of whole or minimally processed cereal grain.

	Treatment	Whole tract digestibility (% of starch intake)	Fermented in rumen (% of starch intake)	Source
Barley	Whole		95	(MacRae *et al.* 1969)
	Rolled		97	(MacRae *et al.* 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 (eg. 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 fed with whole loose barley spent significantly more time ruminating and regurgitated more rumination boluses. 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) or dry matter digestibility (Table 5) 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 *et al.* 1991; Hejazi *et al.* 1999; MacRae *et al.* 1969; Ørskov *et al.* 1969; Ørskov *et al.* 1974b).

Table 5. 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 *et al.* 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; Ørskov 1979; Ørskov 1986). 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). Further 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% to 14%.

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% for dry rolled sorghum but only 11% bypass starch was 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).

GRAIN FEEDING BIOLOGICAL DATA

Grain is employed in a wide variety of feeding systems ranging in intensity from indoor feedlots to extensive supplementation in paddocks. The biological performance of sheep within these systems is influenced by the ability of the feeding system to provide the appropriate level of nutrition to allow the animals to perform to their genetic potential. The profitability of the feeding system is dependent on the input costs to achieve this, relative to the returns. To facilitate discussion of different grain feeding systems, they have been loosely categorised according to the level of alternative feed source available.

Extensive feeding systems

The use of supplementary feed plays a major role in sheep production in Australia. These supplements can consist of both on farm produce as well as purchased feed. The producer’s decision to either extensively or intensively feed sheep is influenced by a number of factors. The main factors include the available feed resources on farm, the requirement to purchase feed, the cost of infrastructure, including feedlot and feeding machinery and the available time resources. There are also a number of other factors that are individual to each producer that may play a part in the decision to feed intensively or extensively. Supplementing sheep in an extensive system has both positive and negative aspects. One of the negative aspects of an extensive feeding system supplemented with grain is that it does not allow complete control over the diet of the sheep. On the other hand a positive of the system is that it does utilise the on farm feed resources that are available to the producer. These feed resources do not have as high a realised cost as purchased feed, so it is here that some economic gains can be made at the cost of not having complete dietary control.

The need to supplement sheep has arisen through climatic variability and the desire for profitable sheep enterprises that are able to run the minimum stocking rate required to be sustainable where annual pasture can not support year round production (Butler *et al.* 1986; Coombe *et al.* 1987; Dove 2002; Rowe *et al.* 1989). The cost of supplementation is one of the major costs faced by sheep producers and in many situations the cost of supplementary feeding in the bad years is often not compensated for in good years due to sub-optimal stocking rates. The need for supplementation has increased with the market specification for carcase weights changing over the past decade to heavier and leaner carcases. Producers now have to feed their lambs for longer to meet this market and this has meant that they have had to supplement or substitute the diets of their lambs more than in the past. As the traditional annual pasture feed source deteriorates over summer and autumn and the energy and rumen degradable protein in the pasture leaches as it matures, supplements are needed to maintain the high growth rates for production.

Principles of supplementary feeding

A supplement in the simplest definition can be classified as something that is added to remedy a deficiency (Doyle 1987). In many cases in grazing conditions the process is more complicated than simply satisfying a deficiency. Dove (2002) has outlined these complexities and covers the following points in greater detail. To understand the complexity of feeding a supplement and its effect on the grazing sheep, it is first important to understand that there are two systems interacting when sheep are grazing a pasture. The pasture responds to the varying soil and weather conditions as well as the impact of grazing. The sheep then responds to the pasture production through diet selection and intake and these are determined by the nutritional requirements of both the animal and the microbes in the rumen.

When a supplement is introduced into this complex system it may solve the specific deficiency of the forage but it can also have either a positive or a negative effect on the digestibility of the forage and the intake of the forage.

There are two reasons for offering sheep a supplement. The first is to overcome a major deficiency of the forage for example the supply of nitrogen to the rumen. Secondly it can be used to improve the total nutrient supply or the efficiency of how the nutrients are utilised. In this context total nutrient supply can refer to both metabolisable protein and metabolisable energy, with metabolisable protein covering both microbial protein synthesis and undegraded dietary protein. In both these cases the aim is to either maintain or improve the performance of the sheep.

When a supplement is fed it is difficult to known which nutrients are responsible for the production response. The difficulty arises through the fact that supplements are generally fed in extensive system where at best only three facts about the grazing system are known; the first being the production response of the individuals, the second being the quality and quantity of the supplement and thirdly, and only occasionally, the quality and quantity of the forage. From these measurements it is not possible to determine whether the supplement is correcting a deficiency or improving either the total nutrient supply or the efficiency in which the nutrients are being utilised (Dove 2002). The key facts of forage intake and supplement intake by individuals are often the variables that are not measured but are important in determining what method is causing the response.

The interaction between forage and a supplement is very complex and the consumption of a supplement by a sheep grazing forage affects the total amount of digesta in the rumen, the amount of dry matter in the rumen and the rate of digestion of the cell-wall constituents. It also effects the pH and ammonia concentration of the rumen, the rate of microbial protein synthesis, the rate of outflow of liquid and particular material from the rumen and the level of amino acids and energy available at the tissue level (Dove 2002). All of these have the ability to effect the basal intake of the forage and in some cases have can even have pathological consequences (eg. rapid declines in rumen pH causing sub-clinical acidosis).

The rate at which producers feed grain supplements in extensive feeding systems can be adjusted to achieve a desired level of production whether it be to maintain, background or even finish sheep. Three basic situations can occur when grazing sheep are offered a supplement. The first is classified as supplementation and only occurs when the intake of forage is not changed by the inclusion of a supplement into the diet. It is this situation that producers aim for when they offer a supplement. The second situation is classified as substitution whereby most, or the entire supplement is consumed and as a result the intake of the forage is decreased. The rate of substitution is the reduction in pasture intake per unit increase in the intake of the supplement (Dove 2002). For example if the forage intake is reduced by 100 g when the sheep consumes 250 g of a supplement, the substitution rate is 40%. Some level of substitution normal occurs when grazing sheep are given a supplement, and in the worst case of substitution the reduction in pasture intake can be so great that it negates the effect of the supplement. The final classification is complementation and in this situation the consumption of a supplement actual increases forage intake. Generally in this situation the supplement overcomes a deficiency of the forage. An example of this occurs when sheep grazing low quality forage are given a protein supplement, which overcomes the deficiency of rumen degradable protein. Complementation in this situation occurs because the supplement increases the amount of rumen degradable protein, which increases the rate of microbial fermentation of fibre, which in–turn increases the rate of rumen outflow and results in an increased forage intake (Dove 2002).

A wide range of research has been conducted in the area of reduced forage intake when grazing animals consume a high-energy supplement. It is difficult to extrapolate results from penned studies to grazing studies where the ability to quantify the forage and supplement intake is much more difficult. The complexity of this issue is evident from the fact that research is still continuing in this area.

The level of substitution when a supplement is fed to grazing sheep depends on a number of general factors. However it is not possible to use these factors to accurately gain an idea of the response to a supplement. Even so they are important considerations when a supplement is being fed and are as follows:

1) Substitution is likely to be greater with increasing levels of pasture availability (Dixon *et al.* 1999). This has been demonstrated through research by Langlands (1969) in which sheep offered a supplement of wheat, grazing on increasing levels of pasture increased their level of substitution as the level of pasture available to them increased. A possible rational for this given by Dove (Dove 2002) was that when a supplement is freely offered to sheep they showed a preference for the supplement over extensive grazing. A similar rational was suggested by Freer *et al.* (1985) to explain the substitution differences between lambs grazing annual pasture with a supplement and lambs consuming hay in yards with a supplement.

2) The degree of substitution appears to increases as the quality of the forage increases (Dixon *et al.* 1999). However it is important to note that the interaction between the nature of the supplement and the quality of the forage is very complex (Dove 2002). Dixon and Stockdale (1999) report in their recent review that supplements that contain high starch levels can depress the rate of digestion of cell-wall material in the rumen. High levels of starch in the rumen increase amylolytic organism and decrease cellulolytic organisms. If this change is great enough it can slow the digestion of the cell wall material and slow the outflow in the rumen, which would decrease the forage intake in the sheep. However the reduction in whole tract digestibility is not as great as the reduction in cell wall digestibility showing that there are some counteracting increases in digestibility in other areas of the digestive tract (Dixon *et al.* 1999). The authors also reported that the degree of substitution with high starch supplements is frequently larger than the extent of the depression due to the lower cell wall digestibility, demonstrating that there are other factors causing the substitution between the supplement intake and the forage intake.

3) The degree of substitution increases as the quality of the supplement increase. This can be attributed to the associative effects between the supplement that is of high quality and the forage of lower quality (Dove 2002).

4) It has been shown that substitution between supplement and forage may be greater as the level of supplement available is increased. However this is not a unanimous finding. Freer *et al*. (1988) found that as the amount of oat and sunflower meal supplement available to lambs was increased the level of substitution of the supplement over pasture hay increased. It continued to increase until the level of pasture hay consumption was at such a low level that high increases in supplement intake resulted in only small decreases in pasture hay consumption. However in Langlands (Langlands 1969) work, increases in the quantity of a wheat supplement fed to grazing sheep did not lead to greater levels of substitution.

5) The physical state of the sheep affects the level of substitution (Dixon *et al.* 1999). Sheep requiring higher nutrition, for example rapidly growing weaners and pregnant and lactating ewes, have a lower rate of substitution for a given forage and supplement. 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.

6) The frequency and method of feeding may influence the rate of substitution. McCrabb *et al.* (1990) found that substitution was greater in ewes fed the same total lupin supplement in two sessions a week compared to the same amount fed at a daily rate. However Hawthorne and Stacey (1984) found that there was no effect on the growth rates of lambs when feeding a total of 3.15 kg of lupins per week if it was fed daily, once, twice or three times a week.

The real challenge facing sheep producers feeding supplements to sheep grazing extensive systems is to achieve the desired production rates from the optimum level of supplementation that achieves true supplementation or complementation and make sure that the base forage is most efficiently utilised. High levels of substitution can be regarded as wasteful, as both the existing extensive feed source and the supplementary grain are under-utilised. If the additional energy supplied by supplementary grain is being used to fuel excess movement for grazing the existing feed base then the animal isn't getting the desired benefit from the supplementary grain. Similarly at high levels of substitution the intake of the base forage is reduced and the sheep are not utilising the base forage source. In this situation it may be more cost-effective to either confine the animals in a feedlot to maintain the desired growth rate or to reduce the level of supplementary feed, to increase the utilisation of the existing extensive feed base and accept a possible reduction in growth

One of the more common and well-suited uses of extensive feeding with a supplement is for the period of growth known as backgrounding. This is a period where sheep are grown at a slower rate in comparison to finishing growth rates for a reduced cost before they are intensively finished. This period allows animals to reach a target weight from which it can be intensively finished. It is during this phase that stubble and extensive supplementation with grain are used by producers to maintain the liveweight gain of their sheep as their annual pasture senesces.

One of the key factors that greatly influences the need and level of supplementation over the summer and autumn is the variability of the season and its effect on pasture production and crop yields. As a major dietary component of extensive grazing systems comes from the extensive forage base, be it pasture or stubble, the seasonal effect on the production of this forage base will greatly affect the quality and quantity of the feed available and consequently the requirement for supplementation.

Stubble

The use of stubble to grow and finish lambs is widely practised by producers in the agricultural zones of Australia and especially in Western Australia and South Australia where the growing seasons are shorter. Stubble provides valuable nutrition once annual pastures have senesced and their quality and quantity has diminished. The nutritive value of stubble comes from the residual grain with the actual stem being of little nutritive value (Brook *et al.* 1996). As the majority of the nutritive value of stubble comes from residual grain, the grazing quality of the stubble can be estimated by the amount of grain left in the stubble. The variation in the grazing quality of stubble from year to year is influenced primarily by the quality of the season. The reliability of stubbles as a summer and autumn feed is only as reliable as the season itself.

One of the benefits of grazing stubbles is that the residual grain that wasn't harvested is utilised. This grain would go to waste if it wasn't grazed and probably be sprayed out the following year after it germinated. Another added benefit of stubbles and other extensive systems supplemented with grain is that sheep can be introduced to specific grains at a low rate before they are exposed to it in an intensive feeding system. This is especially useful for cereal grains and other grains that contain high levels of starch. In stubbles the sheep have to select grain out of the stubble, which means that the rate of grain intake is not high enough to cause rumen imbalance.

Cereal stubble

With cereal cropping being one of the major cropping industries in Australia, it is not surprising that the utilisation of cereal stubbles as sheep feed is a common practice in the grain producing areas of Australia (Brook *et al.* 1996; Rowe *et al.* 1989).

Wheat stubble

There have been a number of studies that have included evaluations of the value of cereal stubbles for grazing sheep. In each study the growth response from the sheep grazing the stubbles has been variable. In the studies conducted on wheat stubbles, the liveweight change ranged between -176 g/day for animals grazing a stubble at 10 sheep per hectare (Rowe *et al.* 1986) and 65 g/day for animals grazing at 15 sheep per hectare (Mulholland *et al.* 1976). However it is difficult to compare these two studies. The wheat stubble used by Rowe and Ferguson (1986) had already been grazed by eight ewes per hectare for three weeks before the trial started. The trial of Mulholland *et al*. (1976) had significant summer rainfall that maintained the growth of green material in the stubble throughout the trial. The difference in growth rates for the two trials could largely be attributed to the difference in the feed base. In the former trial the ewes grazing the stubble before the trial had commenced would have consumed much of the residual grain thus reducing the total nutritional value of the stubble. In the trial of Mulholland *et al*. (1976) the green feed was heavily grazed. At some points in the trial the green herbage was above 1000 kg/ha and Mulholland *et al*. (1976) found that if the weight of the green feed was above 40 kg of DM/ha it made up 80% of the selected diet of the sheep. This level of green herbage cannot be expected in a modern stubble and therefore is not entirely representative. The comparative growth rates of all the studies on wheat stubbles can be seen in Table 6.

Table 6. The performance of lambs grazing wheat stubble at different stocking rates and for different grazing periods.

Breed	Sex	Age (months)	Feed source	Weight change (g/day)	Stocking rate (hd/ha)	Grazing days	Initial weight (kg)	Final weight (kg)	Reference
M	W	9	Wheat stubble	-27	10	113	29.5	26.5	(Rowe *et al.* 1989)
M		8	Wheat stubble	-98	10	51	29	24	(Morcombe *et al.* 1990)
M		9	Wheat stubble	-47	11.8	57	24.7	22	(Butler *et al.* 1986)
M	W	17	Wheat stubble	-29	10	84	31	28.6	(Coombe *et al.* 1987)
M	W	17	Wheat stubble	-55	20	84	31	26.4	
BL X M		17	Wheat stubble	32	13	110	30.8	34.3	(Mulholland *et al.* 1976)
BL X M		17	Wheat stubble	5	26	110	30.8	31.3	
BL X M		10	Wheat stubble	65	15	92	30.7	36.7	
BL X M		10	Wheat stubble	-11	30	92	30.7	29.7	
BL X M		16	Wheat stubble	13	15	77	36	37	
BL X M		16	Wheat stubble	-32	30	77	36	33.5	
BL X M		16	Weed free wheat stubble	-19	15	77	36	34.5	
BL X M		16	Weed free wheat stubble	-75	30	77	36	30.2	
			Wheat stubble	-48	10	34	24.2	22.5	(Rowe *et al.* 1986)
			Wheat stubble	-176	10	56	30.8	21	
M	W	24	Wheat stubble	-112	40	35			(Cottle 1988)
Dorset x (BL X M)	W	9	Wheat stubble	-134	40	30			

M – Merino, BL – Border Leicester, W – wethers

The variation in growth rates can be largely attributed to either differences in the quantity and quality of the feed base or differences in stocking rates or grazing period. However it is difficult to quantify these differences in the feed base as in nearly all of the trials the quantity and quality of the residual grain and other stubble components has not been measured. Rowe *et al*. (1989) did measure the quantity and quality of the stubble components at the commencement and end of their trial (Table 7). Sheep heavily selected the residual grain left in the stubble utilising 99.4% of the grain. The utilisation of the weeds in the stubble was also high at 75.4%. The selection of the leaf, chaff and stem components of the stubble was the lowest. The amount that the various components of the stubble were selected relates well to their protein content. The grain component that had the highest protein content and digestibility also had the highest utilisation. The overall digestibility and protein content of the stubble did decrease over the trial which is consistent with the findings of Jacobs (1984). The only increases in quality over the trial occurred in weed component, which increased in digestibility and protein content and the stem component that only slightly increased in protein content.

Table 7. 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	58.2	49.3	6.2	5.7
stem	1380	910	34.1	45.3	42.1	3	3.2

The liveweight loss of -27 g/day (Table 6) that Rowe *et al*. (1989) reported could be attributed to the low quantity of grain remaining in the stubble of their trial. Croker (pers. comm.) has recently measured the mean residual grain remaining in the stubble of crops harvested across the agricultural region of Western Australia in 2002 (Table 8). The average quantity of wheat grain remaining in these stubble was 94 kg/ha which is just over two and a half times the amount of grain remaining in the study reported by Rowe *et al*. (1989).

Table 8. Mean residual grain yields, remaining in the stubble of crops in WA for 2002 (Crocker pers. comm.).

Variety	Wheat	Barley	Lupins	Oats
Residual grain kg/ha	94	56	327	13

It is not possible to determine the variation in growth rates due to the differences in the quantity and quality of the feed base as the utilisation of the stubble components particularly the grain components has not be measured in any of the other trials (Table 6). However the variation in the wheat stubble from different seasons is evident in the growth rates of the sheep in the trial reported by Mulholland *et al*. (1976) where stubbles were grazed in consecutive years at the same stocking rates for a similar period by similar animals but the growth rates of the animals was very different. At the stocking rate of 15 per hectare, sheep grazed for 92 days and achieved an average growth rate of 65 g/day. In the following year sheep were grazed at the same stocking rate for a shorter period of 77 days only achieved an average growth rate of 13 g/day. This variation can be attributed to differences in the feed base between the years. The effect of an increase in stocking rate on the growth rates in sheep grazing wheat stubbles can be seen clearly in Table 6. It is not surprising to see that an increase in the stocking rate decreases the average growth rate. The degree in which the growth rates are reduced by a doubling of the stocking rate can be seen in Table 6 from the experiments of Mulholland *et al*. (1976) and Coombe *et al*. (1987). In these trials every unit increase in stocking rate caused between a 2-5 g/day reduction in the average growth rate.

The potential growth rates that can be gained from the stubble over a shorter period are much higher than the growth rates gained as the period of time on the stubble increases. It has been shown in a number of studies that as the sheep are introduced to the stubble their rate of liveweight gain decreases until it reaches zero and then there is an increasing rate of liveweight loss. This can be attributed to the fact that stubble has a fixed level of feed and as the animals selectively graze out the feed of higher quality (grain) the remaining feed can not support high growth rates and the rate of liveweight gain decreases rapidly. Stubbles have a finite use and once the quality feed has been grazed they are of little value as a feed source (Aitchison *et al.* 1988). The liveweight change of sheep grazing a wheat and barley stubble from the trial of Coombe *et al*. (1987) can be seen in Figure 3. The graph shows how the liveweight increases as the sheep are introduced to the stubble but as the period of grazing continues the liveweight then decreases.

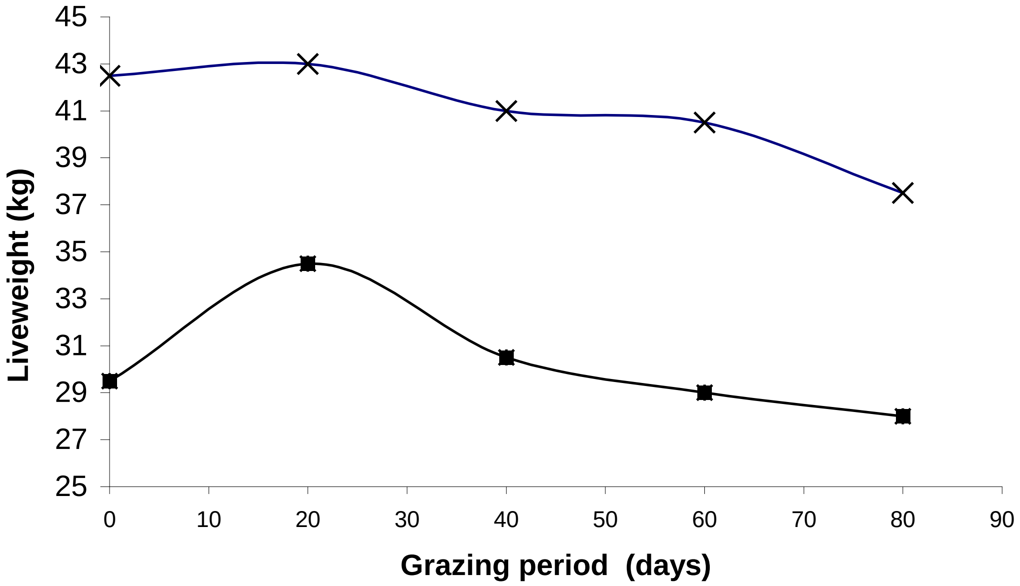

Figure 3. The liveweight change of sheep grazing a wheat (■) and barley (X) stubble (Coombe *et al.* 1987).

The grazing periods for the studies in Table 6 range between 34 days and 113 days. It is not possible to compare the growth rates of the studies that have significantly different periods as the growth rates are calculated on the difference between the initial weight and final weight over the period of time. If the growth rates from Figure 3 were compared for the period of the first twenty days to that of the first eighty days the resulting growth rates would be significantly different for grazing the same stubble. To use stubbles efficiently the growth rates of the animals need to be monitored and as the growth rates of the animals decrease they need to either be supplemented if they are to stay on the stubble or they need to be moved onto a new feed source.

Part of the study conducted by Mulholland *et al*. (1976) evaluated the effect of the weed component of a wheat stubble on the growth rate of sheep grazing that stubble (Table 6). 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 sheep per hectare and -75 g/day for 30 sheep per hectare. 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. The difference the weed component made was 32 g/day for the 15 sheep per hectare and 43 g/day for 30 sheep per hectare. The weed component in the experiment had a significant effect on the growth rates of the sheep. However during this trial the high amount of green herbage due to summer rainfall is not typical of all stubbles and therefore has to be considered when comparing the weed free and weedy stubble.

Barley Stubble

Similar to wheat stubbles there has been a number of studies done to evaluate the value of barley stubble for grazing sheep (Table 9).

Table 9. The performance of lambs grazing barley stubble at different stocking rates and for different grazing periods.

Breed	Sex	Age (months)	Feed source	Weight change (g/day)	Stocking rate (hd/ha)	Grazing days	Initial weight (kg)	Final weight (kg)	Reference
M	W	17	Barley stubble	-62	18	84	42.5	37.3	(Coombe *et al.* 1987)
M	W	17	Barley stubble	-115	36	84	39	29.3	
BL X M		17	Barley stubble	55	13	110	30.8	36.8	(Mulholland *et al.* 1976)
BL X M		17	Barley stubble	27	26	110	30.8	33.8	
BL X M		10	Barley stubble	65	15	92	30.7	36.7	
BL X M		10	Barley stubble	-16	30	92	30.7	29.2	
BL X M		16	Weed free barley stubble	0	15	77	36	36	
BL X M		16	Weed free barley stubble	-36	30	77	36	33.2	
BL X M		16	Barley stubble	52	15	77	36	40	
BL X M		16	Barley stubble	-52	30	77	36	32	

M – Merino, BL – Border Leicester, W – wethers

The extent of variation in growth rates for the sheep grazing barley stubble is similar to that of the sheep grazing wheat stubble. The highest growth rate of 65 g/day was reported by Mulholland *et al*. (1976) with the lowest of -115g/day coming from a trial of Coombe *et al*. (1987). However, as with the wheat stubble the two trials cannot be fairly compared. In the former, there was significant green herbage due to summer rainfall and the stocking rate was less than half that of the latter. Similar to the wheat trials, it is not possible to compare the differences in growth rate with respect to the quantity and quality of the feed base, as the critical measurements of the stubble components particularly the grain component were not made. Increases in the stocking rate again resulted in the decrease in the average growth rate with a single animal addition resulting in a decrease of between 2.1- 5.4 g/day in the average growth rate.

Removing the weed component in the barley stubble again reduced the growth rate of the sheep grazing the stubble (Mulholland *et al.* 1976). The difference in growth rates between the barley stubble with weeds and the stubble without weeds was 52 g/day for the stubble grazed at 15 sheep per hectare and 16 g/day grazed by 30 sheep per hectare. However the high green herbage levels in this trial would have exacerbated the differences in the growth rates between the weed free stubble and the stubble that contained weeds.

The liveweight change of sheep grazing barley stubble is similar to that of sheep grazing wheat stubble (Figure 3). The liveweight change follows the same pattern in the fact that as the animals begin to graze the stubble their rate of liveweight gain decreases until there is no gain and then as the stubble is grazed further an increasing rate of liveweight loss occurs. This response in liveweight can be expected for sheep grazing any stubble where there is not an increase in feed quantity or quality due to green herbage following summer rainfall.

Oat Stubble

It is not unexpected that the variation in the response of sheep grazing oat stubble is similar to that seen for sheep grazing both wheat and barley stubbles (Table 10, Mulholland *et al*. 1976).

The variation seen in the growth responses of the sheep grazing the oat stubbles can be attributed to the variation in the feed base in terms of the quantity and quality of the various stubble components, the variation in stocking rate and the differing length of grazing periods. As with the studies conducted on wheat and barley stubbles the failure to measure the quantity and quality of the various components of the stubble at the beginning and end of the trial means that it is not possible to determine what proportion of the variation in response is due to differing levels of feed base. It is anticipated that when significant differences in growth rates have occurred at similar stocking rates for similar grazing periods the variation in response is mainly due to differing levels in the quantity and quality of the feed base. The variation in liveweight change ranges from -71 g/day to 71 g/day (Table 10). This range in growth rates can be explained through two of the three reasons mentioned above. The animals that grew at 71 g/day were grazing on an oat stubble at a stocking rate of 15 animals per hectare. Whereas the animals that lost weight at 71 g/day were stocked at twice the rate and were grazing oat stubble that had been sprayed to kill the green weeds. In consecutive years Mulholland *et al*. (1976) maintained the stocking rate at 15 animals per hectare, the difference in growth rate was 71 g/day for a grazing period of 77 days versus 41 g/day for a grazing period of 92 days. If this variation was entirely due to grazing period, a 15-day increase in the grazing period relates to a decrease of 22 g/day in average growth rate. However the animals that obtained the 71 g/day had 2000 kg of dead DM/ha more than the animals that obtained the 41 g/day growth rate. This difference in dead material would suggest that not only the quality of the feed base was different but the quality may have varied as well. These differences in growth rates will be a product of not only a variation in grazing period but also differences in the feed base.

Table 10. 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)	Feed source	Weight change (g/day)	Stocking rate (animals/ha)	Grazing days	Initial weight (kg)	Final weight (kg)
17	Oat stubble	50	13	110	30.8	36.3
17	Oat stubble	-5	26	110	30.8	30.3
10	Oat stubble	49	15	92	30.7	35.2
10	Oat stubble	-43	30	92	30.7	26.7
16	Weed free oat stubble	6	15	77	36	36.5
16	Weed free oat stubble	-71	30	77	36	30.5
16	Oat stubble	71	15	77	36	41.5
16	Oat stubble	-13	30	77	36	35

The studies conducted by Mulholland *et al*. (1976) on the growth rates of sheep grazing oat stubbles investigated different stocking rates (Table 10). If the variation in growth rates was entirely due to the differing stocking rates it can be calculated that an individual increase in the stocking rate would equate to a reduction in the average growth rate of 4-6 g/day. However the length of grazing period must be taken into consideration when the effect of stocking rate is calculated. If the reductions were calculated from sheep grazing over periods a greater decrease in the average growth rate would be shown compared to that shown for the same sheep grazing over a much shorter period. As in the studies conducted on sheep grazing wheat and barley stubbles, the growth rates of sheep grazing a weed-free oat stubble were significantly lower than sheep grazing a oat stubble containing weeds (Table 10). Again the difference is heightened by the fact that there was considerable green material throughout the trial.

Conclusions

It is clear that the nutritive value of stubble is largely dependent on amount of residual grain that has been left within the stubble after the crop has been harvested. The other component of stubble that affects the nutritive value is the presence of weeds. When summer rainfall occurs the level of green herbage has a major impact on the subsequent growth rates of the grazing animals. To effectively compare the value of stubbles between studies it is necessary to measure the quantity and quality of all the components that make up the stubble, especially the residual grain component. For producers to effectively manage the grazing of their stubbles the level and quality of the feed needs to be assessed or at least estimated to understand how long and how many animals can be grazed. The factors that determine the growth rate of sheep grazed on stubble come from variation in the feed base due to seasonal variation, the rate at which animals are stocked and the period for which the animals grazing the stubble. In addition, further work is required to quantify the interactions between the stocking rate and grazing length to determine the best way to utilise stubbles ie. is it better to graze a smaller number of sheep for longer or is it better to graze a greater number of sheep for a shorter period.

Legume stubble

Lupin stubble

Lupin stubbles have been widely used as feed sources over the summer and autumn. As with cereal stubbles the nutritive value in lupin stubble is largely dependent on the quantity of residual grain. Lupins are high in energy and rumen degradable protein and contain a lower level of starch in comparison to other grains. Although lupin stubbles are regarded as safe because of the lack of starch, lupinosis can be a problem especially after significant summer rainfall.

Sheep grazing legume stubbles generally achieve better growth rates for similar yields of dry matter when compared to cereal stubble. This has been attributed to the fact that legume stubbles are generally higher in protein than the cereal stubbles. However, there may be other factors contributing to these higher growth rates. If sheep heavily select the grain component of a legume stubble rumen function will not be upset and feed intake not reduce, compared to the same scenario in cereal stubble, resulting in higher growth rates for sheep grazing lupin stubbles. Another factor that could explain the higher growth rates is the amount of residual grain left in the lupin stubble. In comparisons of the residual grain left in Western Australian stubbles, the residual grain from the lupin stubble (327 kg/ha) was three times that of the highest cereal, which was wheat at 94 kg/ha (Table 8). This high level of residual lupin grain has been seen in other studies where the residual grain in the lupin stubbles was 343 kg/ha, 316 kg/ha and 250 kg/ha respectively (Croker *et al.* 1979; Croker *et al.* 1994; Dunlop 1984). The better performance from sheep grazing lupin stubbles compared to cereal stubbles may simply be due to a greater amount of residual grain available to the sheep. Table 11 contains the growth rates of sheep grazing lupin stubbles from a number of studies. Unlike the studies on cereal stubble the quantity of residual grain remaining in the stubble has been measured throughout both of the studies.

Table 11. The performance of lambs grazing lupin stubble at different stocking rates and for different grazing periods.

Breed	Sex	Age (months)	Feed source	Weight change (g/day)	Stocking rate (hd/ ha)	Grain (kg/ha)	Grazing days	Initial weight (kg)	Final weight (kg)	Reference
M	W	5	Lupin stubble	56	25	343	79	22.6	27	(Croker *et al.* 1979)
M	W	5	Lupin stubble	11	50	386	79	22.5	23.4	
			Lupin stubble	35	9.1	197	91	26.5	29.7	
			Lupin stubble	58	8.3	316	83	30.2	35	
			Lupin stubble	80	9.4	183	87	31.5	38.5	
M	W	7	Lupin stubble	21			94	25	27	(Arnold *et al.* 1976)

M – Merino, W – wethers

Reasonable growth rates of 80 g/day for 87 days of grazing have been reported but there are some inconsistencies with regard to the reliability of the growth of sheep from lupin stubbles (Croker *et al.* 1994). Growth rates from the previous year were as low as 35 g/day in lupin stubble which had a higher amount of residual grain. It is not evident why this degree of variation in growth rates of the sheep from the two trials occurred. There is not a significant difference between the grazing period for both trials and no significant difference in stocking rate. This study involved the movement of the watering point throughout the stubble. This movement of the water source allowed more efficient grazing of the stubble and the growth rates obtained may not be representative of sheep grazing a lupin stubble with a similar stocking rate, for the same period of time, with a similar residual grain quantity that did not have the watering points moved.

The effect of increasing the stocking rate can be seen from the study by It can be seen that as the stocking rate is doubled from 25 to 50 sheep per hectare the growth rate decreases by 45 g/day from 56 g/day down to 11 g/day (1979).

The higher level of rumen degradable protein causes the water intake of sheep to increase significantly when they consume large quantities of lupin grain. The increased water intake allows the sheep to excrete the excess rumen degradable protein as urea through their urine. Croker *et al*. (1994) found that moving the watering source around in lupin stubbles increased the number of grazing days obtained from the lupin stubbles. As a consequence of this they obtained higher growth rates from the sheep grazing the stubbles and a better utilisation of the residual grain within the lupin stubbles. Moving the water point on several occasions also gave a more uniform grazing of the lupin stubble and reduced the risk of wind erosion by leaving a higher level of ground cover.

The consumption and utilisation of the various components of lupin stubbles being grazed by sheep can be seen in Table 12. The grain and leaf components of the stubble are highly utilised with the stem being utilised the least. The utilisation of the various components of the lupin stubble closely reflects the nutritional quality of each component. The grain and leaf component have the highest protein concentration and have high digestibility, where as the stem component has the lowest protein concentration and digestibility.

Table 12. The dietary selection of the various components of a 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

Conclusions

Although significant growth rates have been obtained from sheep grazing lupin stubble the high variation in growth rates obtained in the studies suggests that simply measuring the level of residual grain within the stubble is not reliable for predicting growth rates of sheep grazing a lupin stubble.

Grain supplementation on stubble

The feed quality of stubbles is principally determined by the quantity of residual grain left in the stubble. When sheep graze stubble they place heavy selection pressure on the grain component of that stubble and as the grazing period extends and the majority of the residual grain has been consumed it is generally, necessary for a grain supplement to be fed to stop sheep from losing weight. There have been a number of studies focusing on grain supplementation and alternative supplementation for sheep grazing stubble. As this review focuses on grain finishing systems only grain supplementation will be discussed. A summary of studies shows the range of responses to grain supplementation of sheep grazing stubbles (Table 13). However from the results of the studies it is not possible to establish which one of the three types of supplementation is occurring in each study. This is again due to the fact that the individual intake of forage and supplement has not been measured in any of the studies. Although the form of supplementation cannot be determined, the efficiency of the supplementation can be assessed as well as the efficiency when the supplement is increased. The most positive response demonstrated in Table 13 is in the study by Butler and McDonald (1986) who achieved an 155 g/day increase in the growth rate of nine month old Merino weaners grazing wheat stubble. This increase was achieved by offering 686 g/hd/day of an oat/lupin mix with 15.2% crude protein. In comparison, a study by Morcombe and Ferguson (1990) only reported an increase in growth rate of 40 g/day and 81 g/day when they supplemented Merino weaners with 500 g/hd/day of wheat or lupins. The lower growth rate maybe a result of a higher level of substitution but this is only speculation without the forage and grain intakes to support the notion.

Table 13. The growth responses of sheep grazing stubble fed grain supplements.

Breed	Sex	Age (months)	Feed source	Grain supplement (g/hd/day)	Weight change (g/day)	Stocking rate (hd/ha)	Grazing days	Initial weight (kg)	Final weight (kg)	Reference
BL X M		16	Weed free oat stubble	132 (68%wheat 12% urea 20% minerals)	29	15	77	36	38.2	(Mulholland *et al.* 1976)
BL X M		16	Weed free oat stubble	132 (68%wheat 12% urea 20% minerals)	-39	30	77	36	33	(Mulholland *et al.* 1976)
BL X M		16	Oat stubble	132 (68%wheat 12% urea 20% minerals)	32	15	77	36	38.5	(Mulholland *et al.* 1976)
BL X M		16	Oat stubble	132 (68%wheat 12% urea 20% minerals)	-6	30	77	36	35.5	(Mulholland *et al.* 1976)
M		9	Wheat stubble	none	-10	11.8	57	24.7	24.1	(Butler *et al.* 1986)
M		9	Wheat stubble	496 oats	70	11.8	70	24.7	29.6	(Butler *et al.* 1986)
M		9	Wheat stubble	618 oats + urea 12.4% CP	125	11.8	70	24.7	33.5	(Butler *et al.* 1986)
M		9	Wheat stubble	477 oats + urea 15.5% CP	105	11.8	70	24.7	32.1	(Butler *et al.* 1986)
M		9	Wheat stubble	824 oats + lupins 11.9% CP	140	11.8	70	24.7	34.5	(Butler *et al.* 1986)
M		9	Wheat stubble	686 oats + lupins 15.2% CP	145	11.8	70	24.7	34.9	(Butler *et al.* 1986)
M	W	9	Wheat stubble	none	-27	10	113	29.5	26.5	(Rowe *et al.* 1989)
M	W	9	Wheat stubble	150 lupins CP 31%	18	10	113	29.6	31.6	(Rowe *et al.* 1989)
M	W	9	Wheat stubble	300 lupins	55	10	113	28.9	35.1	(Rowe *et al.* 1989)
M	W	9	Wheat stubble	450 lupins	70	10	113	29.8	37.8	(Rowe *et al.* 1989)
M	W	9	Wheat stubble	600 lupins	112	10	113	28.9	41.6	(Rowe *et al.* 1989)
M	W	9	Wheat stubble	750 lupins	116	10	113	29.3	42.4	(Rowe *et al.* 1989)
M	W	9	Wheat stubble	150 oats CP 10.4%	11	10	113	28.9	30.1	(Rowe *et al.* 1989)
M	W	9	Wheat stubble	300 oats	13	10	113	29.4	30.9	(Rowe *et al.* 1989)
M	W	9	Wheat stubble	450 oats	52	10	113	28.6	34.5	(Rowe *et al.* 1989)
M	W	9	Wheat stubble	600 oats	75	10	113	29.4	37.9	(Rowe *et al.* 1989)
M	W	9	Wheat stubble	750 oats	79	10	113	28.9	37.8	(Rowe *et al.* 1989)
M	W	9	Wheat stubble	150 barley CP 11.6%	-4	10	113	29.5	29.1	(Rowe *et al.* 1989)
M	W	9	Wheat stubble	300 barley	21	10	113	30.2	32.6	(Rowe *et al.* 1989)
M	W	9	Wheat stubble	450 barley	60	10	113	28.4	35.2	(Rowe *et al.* 1989)
M	W	9	Wheat stubble	600 barley	57	10	113	28.9	35.4	(Rowe *et al.* 1989)
M	W	9	Wheat stubble	750 barley	75	10	113	29.3	37.8	(Rowe *et al.* 1989)
M		8	Wheat stubble	None	-40	10	112	29	24.5	(Morcombe *et al.* 1990)
M		8	Wheat stubble	300 pea CP 26.2%	4	10	112	29	29.5	(Morcombe *et al.* 1990)
M		8	Wheat stubble	500 pea	25	10	112	29	31.8	(Morcombe *et al.* 1990)
M		8	Wheat stubble	300 wheat CP 11.6%	-33	10	112	29	25.3	(Morcombe *et al.* 1990)
M		8	Wheat stubble	500 wheat	0	10	112	29	29	(Morcombe *et al.* 1990)
M		8	Wheat stubble	300 lupins CP 30.1%	16	10	112	29	30.8	(Morcombe *et al.* 1990)
M		8	Wheat stubble	500 lupins	41	10	112	29	33.6	(Morcombe *et al.* 1990)
M	W	7	Lupin stubble	None	21		94	25	27	(Arnold *et al.* 1976)

M	W	7	Pea stubble	None	16		94	25	26.5
M	W	7	Vetch stubble	None	5		94	25	25.5
M	W	7	Lupin stubble	250 lupins	90	50	94	25	33.5
M	W	7	Pea stubble	250 peas	69	50	94	25	31.5
M	W	7	Vetch stubble	250 vetch	59	50	94	25	30.5
M	W	7	Lupin stubble	500 lupins	117	50	94	25	36
M	W	7	Pea stubble	500 peas	85	50	94	25	33
M	W	7	Vetch stubble	500 vetch	80	50	94	25	32.5
M	W	7	Lupin stubble	750 lupins	122	50	94	25	36.5
M	W	7	Pea stubble	750 peas	112	50	94	25	35.5
M	W	7	Vetch stubble	750 vetch	85	50	94	25	33

The higher growth rates obtain from the supplementation of lupins and peas compared to cereal grains on wheat stubble would suggest that for young sheep wheat stubbles and cereal grain supplements lack the protein required by the animals for higher production (Butler *et al.* 1986; Morcombe *et al.* 1990; Rowe *et al.* 1986). In the trial of Butler and McDonald (1986) oats and a urea supplemented at 477 g/ day had a growth rate 35 g/day higher than the same sheep only supplemented with 496 g oats/day. In the trial of Morcombe and Ferguson (1990) the sheep grazing a wheat stubble supplemented with the same level of peas and lupins had a higher growth rates than the sheep supplemented the same level of wheat. At all the different levels of supplementation in the trial of Rowe and Ferguson (1986) the sheep supplemented with lupins had high growth rates than those supplemented with either oats or barley. In sheep grazing wheat stubbles a protein supplement may achieve higher growth rates than a cereal grain supplement.

The response of Merino weathers grazing a wheat stubble to incremental increases in lupin, oat and barley supplementation was assessed (Rowe *et al.* 1989). The supplementation of each grain increased by 150 g/hd/day (Table 14).

Table 14. The increase in growth rate for sheep grazing wheat stubble with each 150 gram increase in supplementation of lupins oats and barley (Rowe et al. 1989).

Supplement	Increase in supplementation (g/hd/day)	Growth response (g/day)
Lupins	0 to 150	45
Lupins	150 to 300	37
Lupins	300 to 450	15
Lupins	450 to 600	42
Lupins	600 to 750	4
Oats	0 to 150	38
Oats	150 to 300	2
Oats	300 to 450	39
Oats	450 to 600	23
Oats	600 to 750	4
Barley	0 to 150	23
Barley	150 to 300	25
Barley	300 to 450	39
Barley	450 to 600	-3
Barley	600 to 750	18

The growth responses indicate a decrease in feed efficiency with each increase at the higher end of supplementation. Although there are a number of discrepancies, this trend seems to be consistent with the concept that as more supplement is made available to grazing sheep the level of substitution increases. This is only conjecture as forage and supplement intakes need to be measured to determine whether this is truly taking place. The reduced efficiency at higher levels of supplementation can be seen again from the growth rates obtained by Arnold *et al.* (1976) (Table 15). The reduction in efficiency in the response to increases in supplements for both lupins and vetch is reduced to an increase of 5 g/day when the supplement is increased from 500 to 750 g/hd/day.

Table 15. The increase in growth rate for sheep grazing wheat stubble with each 250 gram increase in supplementation of lupins peas and vetch.

Supplement	Increase in supplementation (g/hd/day)	Growth response (g/day)
Lupins	0 to 250	69
Lupins	250 to 500	27
Lupins	500 to 750	5
Peas	0 to 250	53
Peas	250 to 500	16
Peas	500 to 750	27
Vetch	0 to 250	54
Vetch	250 to 500	21
Vetch	500 to 750	5

The major factors that affect the growth rate of sheep grazing stubble supplemented with grain are the quantity and quality of the grain supplement, the quantity and quality of the different stubble components and the interactive effect between the supplement and the forage.

Conclusions

The failure to quantify the level and quality of the stubble components in many of these studies means that it is very difficult to fairly compare growth rates between trials as one of the feed sources is unknown. The interaction between the forage and supplement cannot be established without measuring the individual intake of the grain and forage by the sheep grazing a stubble. As both of these are not measured the efficiency in which a grain supplement improves production cannot be realistically calculated and can only be estimated from the liveweight response to a level of supplement. Therefore if future research is to successfully measure the effect of a supplement on the liveweight response of a sheep grazing a stubble, both the stubble components must be measured as well as the intake of supplement and forage.

Grain supplementation on annual pasture

In many farming systems there is a period when the annual pasture is limiting and when stubbles are not ready to be grazed. It is in these situations that grain supplementation can play an important role to ensure that the growth rates of the sheep are maintained and the animals do not have significant weight lose. The idea behind feeding mature pastures is to utilise the bulk before it is lost through trampling, weathering and decay. Metabolisable energy and rumen degradable protein decrease as the pasture matures and decays. Therefore sheep grazing these pastures over summer and autumn need to be supplemented to maintain reasonable growth rates. As the mature pasture is grazed the animals selectively graze the high nutrient plant components similarly to sheep grazing stubbles. It is for this reason that it is important to increase the supplement offered as the period of grazing continues. This is evident in study by Freer *et al*. (1985) whereby the crude protein of annual senesced pasture fell from 9.43% to 6.5%. This decrease could be attribute to selective grazing and the deterioration of the pasture. There have been a number of studies conducted on the effect of various supplements on the growth of sheep grazing annual pasture (Table 16).

Table 16. The growth rates of sheep grazing annual pasture and fed various grain supplements.

Breed	Sex	Age (months)	Grain supplement g/hd/day	Weight change (g/day)	Stocking rate (hd/ha)	Grazing days	Initial weight (kg)	Final weight (kg)	Reference
M	W	7	none	40	24	77	29.2	32.3	(Gardner *et al.* 1993)
M	W	7	75 lupins	101	24	77	29.3	37.1	
M	W	7	150 lupins	113	24	77	29.1	37.8	
M	W	7	225 lupins	57	24	77	29.2	33.6	
M	W	7	300 lupins	121	24	77	29.1	38.4	
M	W	7	400 lupins	92	24	77	29.4	36.5	
M	W	7	80 barley	31	24	77	29.8	32.2	
M	W	7	160 barley	47	24	77	29.6	33.2	
M	W	7	240 barley	91	24	77	29.5	36.5	
M	W	7	320 barley	77	24	77	29.8	35.7	
M	W	7	480 barley	41	24	77	29.7	32.9	
M	W	7	430 silage	33	24	77	28.8	31.3	
M	W	7	860 silage	114	24	77	28.8	37.6	
M	W	7	1290 silage	95	24	77	29.4	36.7	
M	W	7	1720 silage	71	24	77	28.9	34.4	
M	W	7	2580 silage	55	24	77	29.3	33.5	
M X, Dorset Horn X BL	E/W		none	29	10	150	29.5	33.8	(Suiter *et al.* 1986)
M X, Dorset Horn X BL	E/W		ad lib oats	90	10	150	29.5	43	
M X, Dorset Horn X BL	E/W		ad lib oats and lupins (4:1)	105	10	150	29.5	45.3	
M	W	18	None	-28	10	113	51.3	48.1	(Thompson *et al.* 1990)
M	W	18	50 lupins	5	10	113	51.3	51.9	
M	W	18	100 lupins	24	10	113	51.3	54.0	
M	W	18	200 lupins	33	10	113	51.3	55.0	
M	W	18	300 lupins	33	10	113	51.3	55.0	
M	W	18	400 lupins	-24	10	113	51.3	48.6	
M	W	18	500 lupins	-29	10	113	51.3	48.0	
M	W	18	100 oats	1	10	113	51.3	51.4	
M	W	18	200 oats	17	10	113	51.3	53.2	
M	W	18	300 oats	2	10	113	51.3	51.5	
M	W	18	400 oats	-9	10	113	51.3	50.3	
M	W	18	500 oats	17	10	113	51.3	53.2	
M	W	18	100 lupins delayed	-15	10	113	51.3	49.6	
M	W	18	200 lupins delayed	18	10	113	51.3	53.3	
M	W	18	300 lupins delayed	38	10	113	51.3	55.6	
M	W	18	400 lupins delayed	21	10	113	51.3	53.7	
M	W	18	500 lupins delayed	88	10	113	51.3	61.2	

M – Merino, BL – Border Leicester

There is a wide range of growth rates from lambs fed varying levels of lupin supplements as they grazed on annual pasture (Table 16). With the highest growth rate coming from the study of Gardner *et al*. (1993) being 121 g/day for a lupin supplement of 300 g/hd/day. The lowest growth rate from the same trial is from the lupin supplement of 225 g/hd/day, which only achieved a growth rate of 57 g/day. This growth rate was lower than that achieved from the lupin supplements of 75 and 150 g/hd/day. However in the trial of Thompson and Curtis (1990) the growth rates obtained are much lower for similar levels of lupin supplementation. The highest growth rate obtained in this trial for lupin supplementation was 33 g/day, which was achieved at both 200 and 300 grams of lupins per head per day. The lowest growth rate came from the highest supplementation level of 500 g/hd/day, which achieved a liveweight change of -29 g/day, which was fractionally lower than that of the un-supplemented animals. This difference in growth rates could be attributed to varying levels of pasture quantity and quality between the treatments or the interaction between the grain supplement and the forage intake with the higher levels of supplementation increasing the rate of substitution. Gardner *et al*. (1993) believed that the unexpected differences in growth rates in their trial were due to variability with the pasture feed base and commented that "Different patterns in liveweight change indicated the importance of the amount and quality of the feed base in determining the response". Freer *et al*. (1985) found that on annual pasture providing a supplement of sunflower meal and oats up to 400 g/hd/day not only increased weight gain but also increased the intake of the annual pasture. However they found that supplying over 400 g/hd/day of the same supplement did not significantly increase the weight gain of these animals but consequently decreased the annual pasture intake of the sheep.

Freer *et al*. (1985) found that in all cases as the supplement levels of oats and sunflower meal increased above 400g the intake of the oaten hay, lucerne hay and annual pasture decreased. This shows a level of substitution of the roughage for the supplement. For the base feed resources of annual pasture or the two hays to be effectively utilised in this case the supplementation should not be greater than 400 g/hd/day.

The growth rate response to varying levels of oat supplementation has similar variability to that seen in the lupin supplements but at much lower growth rates. The highest growth rate achieved for oat supplementation on annual pasture was 17 g/day, which was achieved at both supplement levels of 200 and 500 g/hd/day (Thompson *et al.* 1990). The worst liveweight change in the same trial was -9 g/day that was the response to 400 g/hd/day oats.

Performance when supplemented with barley (Table 16) is not as variable as results of studies where other supplementary grains have been used. The highest growth rate that is obtained from the supplementation of barley is from a supplement of 240 g/hd/day (Gardner *et al.* 1993). The lowest growth rate from a barley supplementation was 31 g/day from a supplement of 80 g/hd/day (Gardner *et al.* 1993). The growth rate decreased as the supplement of barley increased with the highest barley supplementation of barley only producing a growth rate of 41 g/day. The resulting decrease in the growth rate of sheep grazing annual pasture as the barley supplement was increased above 240 g/hd/day was established as an insufficient utilisation of the pasture due to a lack of protein causing a reduction in the digestion of the pasture (Gardner *et al.* 1993). This theory by Gardner *et al*. (1993) supports the theory that there is an increase in substitution between supplement and forage as the availability of the forage increases. However a proportion of the variation that can be seen in all the growth rates on all types of supplement was attributed to variation in the feed base between treatments. This variation can be seen from the growth rates obtained for the supplementation of various quantities of silage. The highest growth rate obtained from silage supplementation was 114 g/day from 860 g/hd/day. The lowest growth response from the silage supplementation was 33 g/day at the supplementation rate of 430 g/hd/day. This growth rate was lower than the sheep grazing the annual pasture with no supplementation. This low growth rate is either caused by a high rate of substitution or a variation in the pasture base.

Conclusion

The interaction between the supplement and the forage and its effect on the growth rate of grazing sheep is relatively complex. The growth rate of sheep does not necessarily increase as the level of supplement available to the sheep increases. This is due to a number of factors that affect the utilisation of the forage when supplements of different quantities and qualities are fed. From the point of view of efficient production it is clear that to be able to determine the required amount of supplement the components of the feed base must be measured for quantity and quality and the liveweight response of the grazing sheep must be measured. To further investigate the relationship and impact of a supplement and forage, individual animal intakes of both the forage and supplement must be measured. From here a clearer understanding of how certain supplements affect forage intake and animal growth can be gained.

Supplementation with summer cereals

Under grazing conditions grain conversion efficiency (extra LWG/ kg grain offered) dictates the economic benefit of a supplementation program. Substitution rate affects grain conversion rate, and it depends greatly on forage availability and quality. To get good conversion rates it is necessary to restrict forage. Sheep develop better strategies of forage selection under forage restrictive conditions than cattle so the range of pasture management to prevent high substitution rates, might be very narrow. It is very easy to rapidly incur in poor grain conversion rates even when liveweight gain is good, without noticing it. Quantitative relationships between these variables are necessary to evaluate the economical viability of supplementation programs.

In a survey by Dixon and Stockdale (1999) studying the relationship between intake of forage when fed alone or when cereal grains were added to the ration, based on data from several experiments (grain varying from 6% to 69%) substitution rate was related to forage intake when fed in absence of the grain. For sheep they report an increase in substitution rate of 0.018 units per unit of increase in forage intake (g/$W^{0.75}$), higher than that reported for cattle of 0.0079.

Pereira and Bonino (1998) supplementing 10 month old Corriedale lambs with sorghum grain from June to September, on a grass-legume pasture (950 kg DM/ha, 10 lambs/ha) increased liveweight gain by 6% with respect to non-supplemented lambs, but grain conversion rate was 28.7:1. Under supplementation strategies grain conversion efficiency is probably more related to grain forge interaction and substitution rate than just to grain characteristics.

Intensive feedlot finishing

A feedlot can be defined as a confined area where no alternative feed source is available and all nutrients are supplied to the animal. In the classic sense of the definition, a feedlot is a specialised facility where the operator has strict control over the diet. In practice, there are a wide variety of grain feeding systems currently used by the sheep meat industry that fit the definition of ‘feedlotting’ but due to varying degree of control over the diet, may result in different growth rates and performance. The main methods of feeding are:

1. Loose total mixed rations fed in open troughs
2. *Ad libitum* access to balanced pelleted diet usually fed in self-feeder
3. *Ad libitum* access to loose grain mix (with minerals) fed in open trough or self-feeder with *ad libitum* access to roughage

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

Growth rates and feed conversion ratios indicated in extension literature have evolved over the past fifteen 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 17 are examples of those provided as a guide to performance in feedlots and are not related to particular feeding systems or equipment used in feedlots.

Table 17. Average production targets for feedlot finishing of lambs published in state agriculture department extension material.

Crossbred lamb		Merino lamb		Publication
Growth rate (g/day)	**Feed conversion ratio**	**Growth rate (g/day)**	**Feed conversion ratio**	
140-160	5:1	130-140	6:1	(Suiter 1990)
200	6:1	130	7:1	#(Hack *et al.* 1997a)
150-300	8:1 to 5:1			(Bell *et al.* 1998)
250-350	7:1 to 5:1	150-250	8:1 to 6:1	(Seymour 2000a)
250-350	7:1 to 5.5:1	220-320	7.5:1 to 6:1	(Milton 2001a)
250	6.5:1			*(Bell *et al.* 2003)
200-320	10:1 to 5:1			**(Bell *et al.* 2003)

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

Confinement feeding for purposes other than finishing

There has been an interesting evolution of feeding systems in response to poor seasons during recent years. The feeding systems are many and varied. Each producer has developed a system that makes use of resources available on their farm and is integrated into their farming system. The common theme between feeding systems is that animals are confined, usually in a small paddock, and all nutrients are supplied to the animal. Confinement feeding systems differ from production feedlots as they are used for purposes other than finishing eg. deferred grazing, feeding pregnant and lactating ewes, maintenance of dry stock and backgrounding lambs (Milton, pers. comm.; Bryant see appendix).

Confinement feeding systems are generally simple and low-cost. Profitability is hard to determine and often not a priority because it is difficult to put a dollar value on many of the benefits such as preservation of breeding stock, avoiding agistment and associated problems, preventing erosion, deferred 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.

For the remainder of review, only confinement feeding or feedlotting systems that focus on backgrounding and finishing of prime lambs are considered.

Loose total mixed rations

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 method are the high level of up-front capital investment to purchase the necessary feeding equipment and the ongoing labour required. The primary advantage is 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 eg. chaff cart residues, bakery waste, brewers grain.

There are very few examples in the scientific literature of 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 1970's and 1980's. The common slaughter weight of prime lambs at that time was approximately 35 kg and liveweight at feedlot entry was 20-25 kg. Loose mix feeding systems produced growth rates ranging from 100-240 g/day for crossbred lambs and around 160-205 g/day for Merino lambs and feed conversion ratios of 6.2:1 to 3.5:1 (Table 18). The relevance of this early data to modern feeding systems is questionable. Comparisons with modern production systems are unlikely to be valid due to improved genetics, production of increasingly heavy carcases and the evolution of intensive grain feeding systems that are now focused primarily on the finishing phase.

Table 18. Performance of lambs fed loose mix rations in feedlots and grown from 20-25 kg to 35 kg liveweight.

Growth rate (g/day)	Feed conversion ratio	Diet composition	Calculated Crude Protein of Diet (%)[1]	Calculated Metabolisable Energy of Diet (MJ ME/kg DM)[1]	Reference
Crossbred					
243	3.5:1	barley, oaten straw, lupins	14.7	11.4	(Tomes *et al.* 1976)
242	4:1	barley, oaten straw, lupins	18.9	11.9	(Tomes *et al.* 1976)
240	4.5:1	wheat, lucerne hay, meat meal	17.2	12.3	(Davis *et al.* 1976)
100*		barley, fishmeal, straw	16.0#	11.8	(Ikin *et al.* 1978)
143		wheat, pelleted lucerne	15.1	12.2	(Cotterill *et al.* 1979)
Merino					
162	4.2	oats, oaten chaff, lupins	18.5#	11.2	(McDonald *et al.* 1982)
205	5.4	triticale, pasture hay, lupins	19.5#	12.6	(Roberts *et al.* 1984)
171	6.2	oats, pasture hay, lupins	16.9#	11.4	(Roberts *et al.* 1984)

#measured crude protein reported in paper
*average growth rate during 6 weeks period from 23 to 27 kg

Key issues

Several key issues arise from experimental examination of the loose mixed feeding system. Not all of the issues are unique to this feeding system but the complexity of the system does create 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 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.

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

The producer has control over the nutritional composition of the loose mixed diet 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 common feed grains of the time (McDonald *et al.* 1982; Suiter *et al.* 1982). Lambs were fed in either indoor or outdoor feedlots on loose mixed rations consisting of 1.7% minerals, 9.9% oaten chaff and either 88.4% Swan oats, 88.4% West oats or 53.0% West oats and 35.4% 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 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 arguably 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 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 *et al.* 1987). Subclinical acidosis was considered to be a primary reason for poor performance during feedlot introduction in both of these experiments. Rapid introduction to intensive grain feeding becomes even more critical when the feeding system is targeted at finishing rather than growing lambs, as 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 the 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 brewers 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 *et al.* 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 *et al.* 2001). The nutritional specification of grain dust is similar to that of cereal grain (Knott *et al.* 2001). Chaff residues are readily accepted by sheep, although they tend to select the more digestible components when grazing chaff heaps (Roberts *et al.* 2001). Inclusion in feedlot diets is restricted by the relatively low nutritional value and the potential presence of toxins eg. annual ryegrass toxicity and phomopsins. The level of inclusion of grain dust is restricted by the potential risk of acidosis and the presence of chemical residues or mycotoxins (Knott *et al.* 2001).

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

Canola screenings and lentil screenings are suitable for inclusion in lamb feedlot diets at low to moderate inclusion levels (Stanford *et al.* 1999; Stanford *et al.* 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 ingredients and grain screenings, cost of gain in these examples was maximised at inclusion rates of approximately 33% canola screenings and 25% lentil screenings (Stanford *et al.* 1999; Stanford *et al.* 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 *et al.* 1990) but there has been relatively little evaluation of by-product feeds for lamb 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% 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 *et al.* 1997b). Other human food industry by-products have varying nutritional value for ruminants eg. citrus pulp, grape marc, brewers grain, distillers grain, molasses, malt mill run, bran, pollard (Cottle 1991; Hack *et al.* 1997b). 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 this feeding system 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 sheep's ability 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 commonly available as part of the farming system eg. chaff residues and grain screenings.

Pelleted diet in self-feeder

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 also be fed in troughs or trailed on the ground. The main disadvantages of pelleted feed are the cost of processing and a potentially 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, in fact, 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 UK researchers 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 *et al.* 1970a; Andrews *et al.* 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 1980's, researchers in WA 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 *et al.* 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 *et al.* 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 to successfully finish Border Leicester x Merino store lambs from liveweights of approximately 30 kg to ~37 kg during the 82/83 drought in NSW. 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% wheat-based pellets, 53% wheat, 4% hay, minerals and monensin (Donnelly *et al.* 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 19). Although there is a twofold variation in the range of reported growth rates, data from scientific literature generally supports the expected performance recommendations in extension material (Table 17).

Table 19. Breed and performance of first-cross lambs fed on pelleted diets with (metabolisable energy (ME) and crude protein specifications of diet indicated.

Breed (Sire x Dam)	Growth rate (g/day)	Feed conversion ratio	Initial liveweight (kg)	Final liveweight (kg)	Carcase weight (kg)	Diet specification		Reference
						Crude protein (%)	ME (MJ/kg DM)	
BL x M	336[a]	6	40.5	47.9	21.0	16	10.8	(Davidson *et al.* 2000)
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			
SM x M	359[a]	5.4	40.5	48.4	21.2			
WS x M	210	5.9	36.4	41.3		18	10.6	(Jones *et al.* 2000)
(T x PD) x M	220[x]	7	32	42.9	19.9	14.4	10.5	(Wiese *et al.* 2000b)
	242[x]	6.8	32	43.7	20.3	14.4	10.5	
	272[y]	6.2	32	45.2	20.5	14.4	10.5	
T x M	256[m]					15	11.8	(Holst *et al.* 1998; Hopkins *et al.* 1996)
PD x M	278[m]							
PD x M	296	5.1	35.2	43.5	19.4	15	11	(Wiese *et al.* 2003)
S x M	197[x]	7.7	33	44.6	20.7	15.9	10.8	(Pethick *et al.* 2003b)
	184[x]	8.2	33	44.1	20.4	16.2	10.1	
PD x M	190*	7	31.6	42.9	20.1	17.4	10.8	(Gardner *et al.* 1999)

BL – Border Leicester S – Suffolk
EF – East Fresian SM – South African Mutton Merino
M – Merino T – Texel
PD – Poll Dorset 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.

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 19). 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 was 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.*

2000b). 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 with 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 cryptorchids 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 six. 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.

The majority of current research has concentrated on finishing systems that produce 18-22 kg carcases eg. Table 19. More recently some focus has moved toward 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 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% commercial pellets, lucerne hay, lupins and cottonseed meal (Shands pers. comm.). The composite diet contained 11.3 MJ ME/kg DM and 19.0% 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% of lambs produced carcases in the desired range of 22+ kg and 8-20 mm GR depth.

Second-cross

Growth rates reported for second-cross lambs in pellet-based finishing systems are 300-350 g/day (Table 20).

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 cryptorchids 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 first-cross lambs (Table 19 and Table 20). The use of cryptorchids may have contributed to high growth rates in this experiment. These growth rates are in agreement with expected growth rates promoted in extension material (Table 17).

Table 20. Breed and performance of second-cross lambs fed on pelleted diets with (metabolisable energy (ME) and crude protein specifications of diet indicated.

Breed (Sire x Dam)	Growth rate (g/day)	Feed conversion ratio	Initial liveweight (kg)	Final liveweight (kg)	Carcase weight (kg)	Diet specification		Reference
						Crude protein (%)	ME (MJ/kg DM)	
T x (BL x M)	301[a]					15	11.8	(Holst *et al.* 1998; Hopkins *et al.* 1996)
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	(Gardner *et al.* 1999)
PD x (BL x M)	206		28.2	54.0	25.3	11.4	10.7	(Hegarty *et al.* 1999)

BL – Border Leicester PD – Poll Dorset
M – Merino 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.

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 to 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 limited number of reports for the performance of prime Merino lambs that are relevant to modern sheep meat production systems and each 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 21). Recent extension publications suggest expected growth rates of 150-320 g/day for Merino lambs in commercial feedlot finishing systems (Milton 2001a; Seymour 2000a). 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 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). 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 21. Performance of Merino lambs with metabolisable energy (ME) and crude protein specifications of diet indicated.

Growth rate (g/day)	Feed conversion ratio	Initial liveweight (kg)	Final liveweight (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 MJ	(Davidson *et al.* 2000)
243	6.1	37.0	47.2	19.9	15.0%	11.0 MJ	(Wiese *et al.* 2003)
160	8.7	30.3	39.2	17.9	17.4%	10.8 MJ	(Gardner *et al.* 1999)
148			40.9	18.2	17.9%	10.5 MJ	(Pethick *et al.* 2003a)
176	6.3	38	~50.3	23.6	15	11.9	(Pethick *et al.* 1996)

Of course, 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. There may also have been social interaction in addition to that created by the large group 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/hd/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 21).

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 *et al.* 1996).

Conclusions

Pelleted diets are generally expensive compared to purchasing unprocessed grain. However, there are advantages 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 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 eg. Q Lamb and Prime Merino Lamb Alliance. Although there is more data available for this feeding system 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 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, see attached appendix). In contrast, evaluations of this feeding system in the literature tend to report lamb performance when roughage intake is restricted. 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% 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% and 29% 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% 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% hay. Most recently, Davis *et al.* (2001) reported growth rates of around 260 g/day for second-cross lambs fed cereal based diets with hay at 12% 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 when prime lambs were fed hay on the ground compared to a covered hay rack, 77% more hay was required to achieve the same growth rate. The cost of feed to achieve the same liveweight gain was around 35% higher for the lambs fed on the ground due to the amount of hay that was wasted. Milling hay into smaller lengths has also been shown to reduce wastage. File (1976) estimated that 32% of lucerne hay and 43% of oaten hay was wasted when presented in a long form in hayracks. The author commented that poorly designed hayracks 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 to long in hayracks (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.

When grain and roughage are fed separately in a commercial scenario, there will be more variation in intake of feed components between individuals compared to a pellet 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 *et al.* (2003; 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. There were no significant differences between diets. 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 18 to Table 21).

In some cases, growth rate is 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 4, Brook *et al.* 1996; Holst *et al.* 1999).

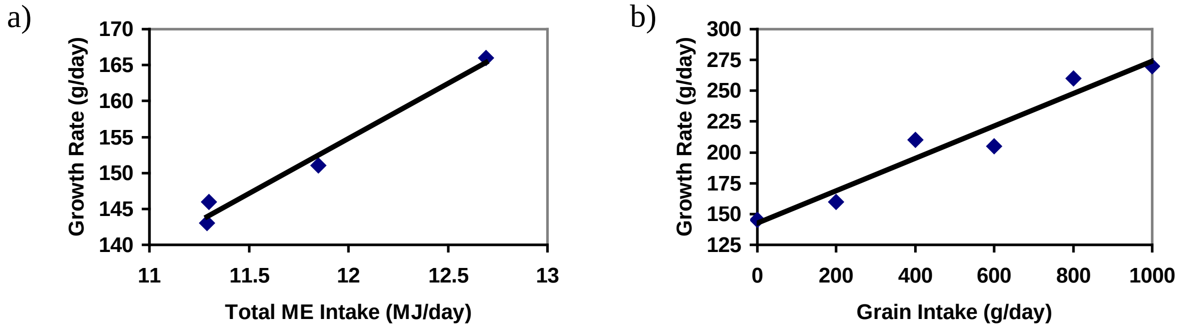

Figure 4. Relationship between energy intake and growth rate in mixed grain and roughage diets; a) calculated from Brook *et al.* (1996) and b) adapted from Holst *et al.* (1999).

Interactions between grain and forage

Interactions between grain and forage can affect both digestibility and intake of the dietary components (Dixon *et al.* 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 so 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.* 1999; Dixon *et al.* 1993).

The degree of interaction between grain and forages 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 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 on conserved fodder feeding systems are not as good as feedlot systems (Dixon *et al.* 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, there is a lack of conclusive data to support this concept. Further investigation of simple feedlotting systems with either *ad libitum* or limited access to forage is warranted.

Anecdotal reports of growth rate
There is little information available in the scientific literature for commercial scale monitoring of biological performance in modern finishing systems and the data is quite variable. Due to the lack of information in the scientific literature, anecdotal reports of animal performance and expected growth rates and feed conversion reported in extension material are a valuable source of performance information. Of the commercial producers who responded to a recent survey, 19% measured growth rate; 71% of this group indicated growth rates of 200-300 g/day, 21% indicated growth rates of 100-200 g/day and 7% indicated growth rates of 300-400 g/day (Bryant, see attached 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 1970's, producers indicated growth rates of around 100 g/day so it would appear that there has been some improvement in growth rates reported by producers for feedlot finishing systems over the last 30 years (Tomes *et al.* 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 as 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. The author evaluated a range of lupin inclusion rates and found no difference between the growth rates of animals offered 50%, 75% or 100% lupins. When lupin content of the diet was reduced to 25%, the growth rate was reduced to 119 g/day but all animals still met market specifications. This example illustrates the fact that 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 eight 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 is perhaps more meaningful to consider the performance of older sheep in a group feeding situation. Pethick *et al*. (2003) 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.

Role of intensive finishing systems in carcase manipulation
All finishing systems involve carcase manipulation as they involve change in both the size and composition of the carcase. Studies on carcase manipulations in feedlots can be categorised into (1) slimming of overfat lambs, (2) enrichment of carcase with specific nutrients (eg. antioxidants, omega-3 fatty acids, etc), (3) use of different growth paths to influence protein and fat deposition, (4) use of different feed ingredients (eg. grain versus silage), (5) use of different feeding levels and (6) use of anabolic agents to enhance protein deposition.

Slimming

Slimming overfat lambs is not a widespread practice in Australia. It has a couple of obvious limitations: (1) the cost is prohibitive unless the price incentive for leaner carcase is very high and (2) animals rarely lose solely fat without some loss of muscle tissue, especially over extended periods of slimming. Vipond *et al*. (1989) suggested 28 days as the optimum period of slimming.

Manipulation of carcase fat composition

Various studies have shown dietary manipulation of the fatty acid profile of lamb carcase largely under intensive feeding systems. An example is presented in Figure 5. Manipulation of the fatty acid composition of lamb meat (eg. n-3 enrichment) is only at an experimental stage. The concept of creating meat with healthier fat (intramuscular fat) is likely to increase in popularity in the future. Progress to commercial feedlot application will require further studies on product shelf stability, consumer acceptance and price incentives that compensate the added cost of specialty feeds.

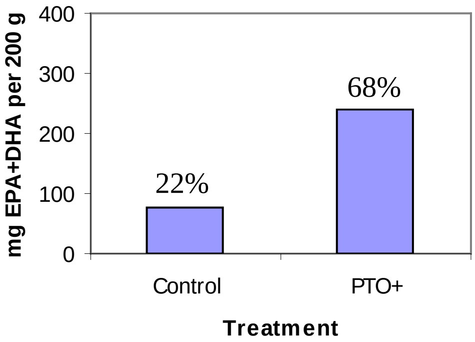

Figure 5. Levels of eicosapentaenoic acid (EPA) plus docosahexaenoic acid (DHA) in the intramuscular fat of unsupplemented or protected tuna oil (PTO) supplemented lambs. Percentages indicate % recommended daily intake (Kitessa *et al.* 2001).

Growth path

Various authors advocate the use of growth path to manipulate protein and fat deposition. The most common growth path contrast is that between animals on continuous growth (CG) versus those subjected to early restriction (RG) followed by realimentation period (also known as compensatory growth). Grain feeding usually forms a major part of the realimentation period. The conclusions from such studies have not been coherent. Hegarty *et al.* (1999) found that at similar slaughter weights, there was lower mass of fat in the carcase of RG than CG lambs. On the other hand, Ferrell *et al*. (1986) did not find any difference (with respect to growth path) in carcase composition within groups of lambs of similar liveweight that had been on three different growth paths (gaining 27, 5 or –6 kg over 42 days). Another study, Butler-Hog and Johnson (1986) found that lambs grown on restricted plane of nutrition followed by realimentation had more fat at all depots than those grown to similar liveweight on high plane of nutrition followed by restricted feeding. Why the discrepancy? One reason could be the age of restriction. Older lambs at any given carcase weight have more fat. For instance, Thornton *et al*. (1979) showed less fat in carcase of RG than that of CG immature sheep, but more fat in carcase of RG than CG mature sheep. They observed similar losses of fat and protein in immature sheep, but higher losses of fat (2462 g) than protein (466 g) in mature sheep during restriction. Furthermore, the degree of separation in growth rate between lambs under restricted and continuous growth may have an impact (eg. 202 g/day difference in growth rate between RG and CG resulted in a difference of 1.3 mm in fat depth at the shoulder whereas a difference of 47 g/day caused a difference of only 0.59mm (Chestnutt 1994)). Chestnutt (1994) also suggested that the effect of early dietary restriction on carcase fat at slaughter tends to depend on slaughter weight (later slaughter minimises effect).

Grain versus silage

Byers (1982) observed that at similar composition, both small and large cross-bred cattle were heavier on corn grain than on corn silage. In addition, it was observed that cattle fed high grain diets were fatter at lighter weights than those fed high corn silage. Byers suggested that this was related to the fermentation pattern of the two ingredients. There is no corroborating work in sheep.

Protein versus energy

Comparison of effects of escape energy versus escape protein on carcase composition showed reduction of kidney fat by escape energy, but no other difference in other carcase traits (McAllister *et al.* 1992). Data extracted from Hegarty *et al*. (1999) shows greater response of both fat and protein deposition in lambs to increased energy than increased protein (Figure 6).

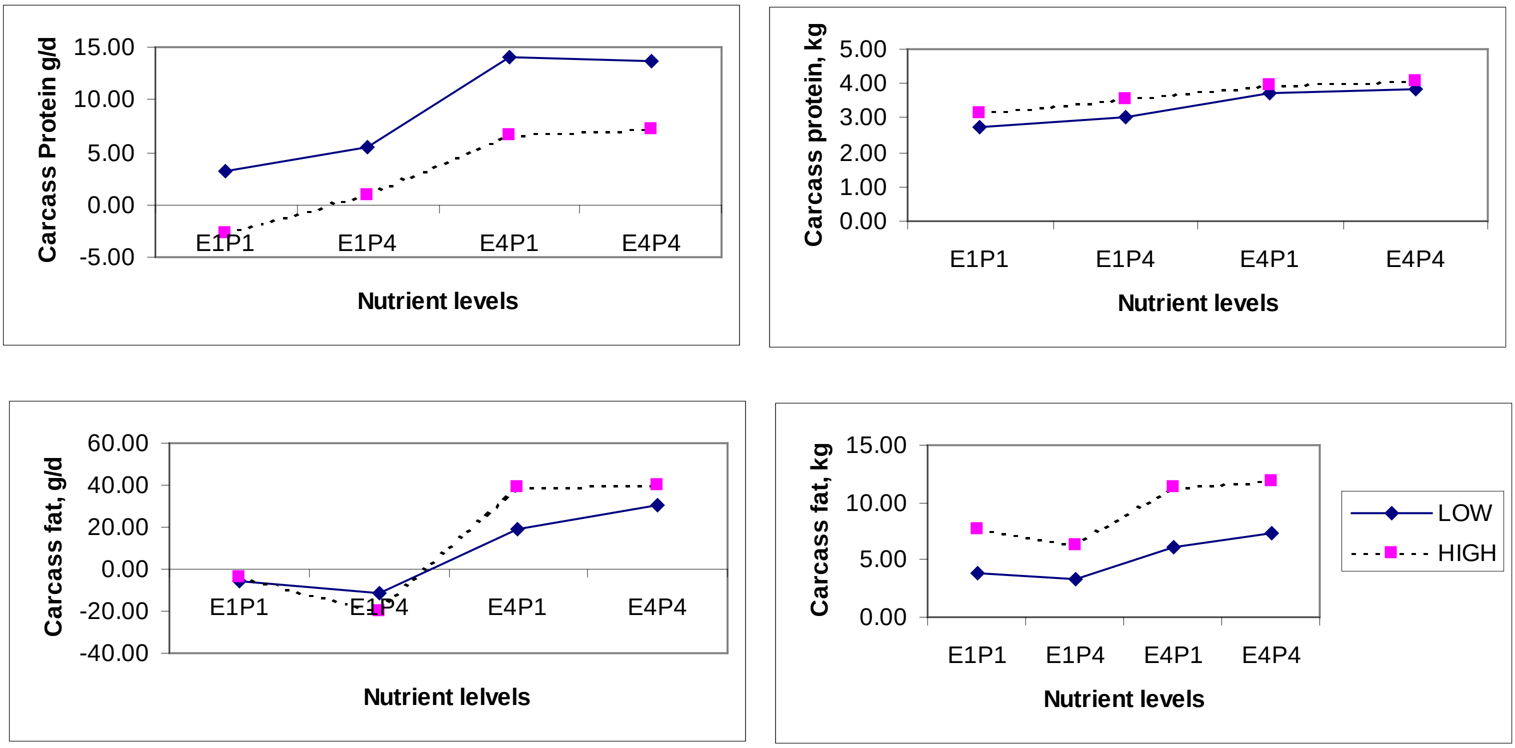

Figure 6. Response of protein and fat to different levels of energy and protein supply in sheep from different nutritional history (LOW: grown to and maintained at 35 kg; HIGH, grown to and maintained at 50 kg). E1, 500 g/d of pellets; E4 1500 g/d of pellets; P1, 0 g/d rumen protected casein; P4, 90 g/d rumen protected casein. Pellets: 123 g/kg DM crude protein and 10 MJ ME/kg DM. Adapted from Hegarty *et al.* (1999).

It appears that increased protein supply does not always lead to increase in protein deposition and production of leaner carcases. The nutritional history of the lambs altered the rate of protein deposition but it did not alter final weight of protein in carcase (Figure 6).

Feeding level

Some observations have shown relationship between feeding level and carcase composition. Feeding levels can be altered through use of high and low energy ingredients or full and limited feeding of the same ingredient. Examples from Byers (1982) showed 14-16% more empty body weight fat when steers were fed corn grain (high energy) than corn stover (moderate energy) at similar empty body weight. The same author showed energy level effects independent of ingredients when full fed steers were 20% fatter than those limited fed on shelled corn at similar slaughter weights. Limited fed steers even had 20% less fat at slaughter when their slaughter weight was 14% heavier. The author suggested that limited feeding reduces fat deposition to a greater degree than protein deposition, thereby effecting full fed animals to be fatter at similar final empty body weight. Obviously such advantages may be offset by increased cost of feeding as a result of unavoidable increase in duration of feeding to attain slaughter weight under restricted feeding.

Anabolic agents

Anabolic agents enable the deposition of more protein than fat at any rate of growth. The use of anabolic agents is not a common industry practice in Australian feedlots.

Conclusion

The success of any strategy in manipulating carcase composition will depend on knowing the growth pattern of the breed of sheep in question and the rate of growth possible under the proposed feeding regime. A hypothetical example is shown in Figure 7. Any strategy that aims to produce a lean carcase has to be able to (1) delay the point at which protein deposition plateaus while maintaining growth, (2) delay the onset of increased fat deposition, and/or (3) maximise the gap between rates of protein and fat deposition at a given target rate of growth. Under consistent feed supply (both in ingredient and quality), it is possible to determine what rate of growth a feedlot operator should aim for in terms of optimum protein deposition.

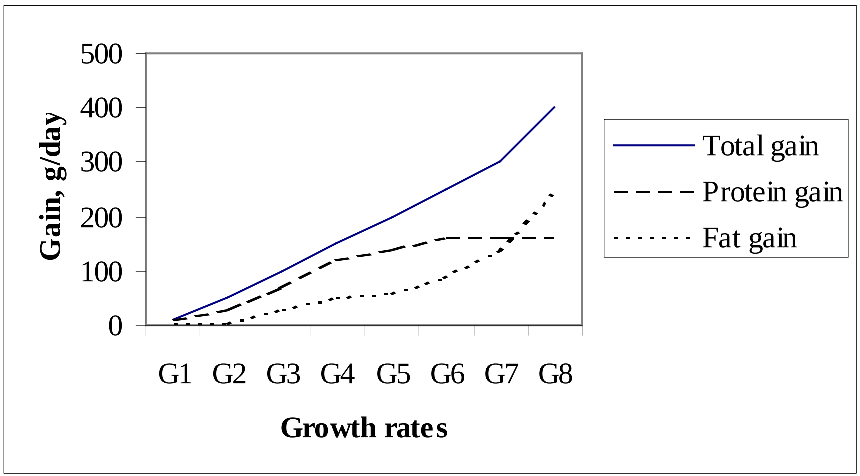

Figure 7. A theoretical schematic presentation of composition of gain at different growth rates (G1-G8). Adapted from Byers (1982).

<u>Use of maize and sorghum in growing and finishing diets for lambs</u>

This section of the review focuses on the use of maize and sorghum in lamb grain finishing systems. Data of animal performance is reviewed considering the different systems of feeding grain to lambs, varying from maize and sorghum whole grain diets in feedlot to supplementation of high roughage diets, where due to the lower relative importance of the grain in the diet and the strong interactions between grain and forage, more variation in animal response is expected. The primary aim was to cover Australian data on the use of these grains, but many of the topics where not sufficiently covered, so research from other parts of the world where these grains are frequently used in lamb growing and finishing systems were included.

The response to the inclusion of grain in growing and finishing lamb diets depends on the grain: forage ratio. Different feeding systems may be described varying the proportion of grain in the diet, including 100% whole-grain diets (Umberger 1997) to 30:70 ratio (Dulce *et al.* n/d). As the proportion of forage increases in the diet, forage quality and interaction between forage intake and grain digestion is more important. Associative effects between both components may affect efficiency of utilisation of nutrients.

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 (hay) is not incorporated into whole-grain diet or supplemented on the side. Table 22 summarises results of lamb performance when fed maize or sorghum in grain feeding trials, where grain constituted more than 70 % of the diet.

Table 22. Liveweight gain (LWG) and feed conversion ratio of lambs fed whole grain diets. Summary of trials.

Animals				Grain			Response				Ref
Genotype	Wt (kg)	Age (d)	N	Source	P	(%)	LWG (g/d)	FCR (kg/kg	DMI (kg/d)	Day on feed	
SX	15	35-49	64	Maize	W	90	345	2.52	0.87		1
				Barley			340	2.75	0.94		
				Wheat		*Ad-*	303	2.97	0.90		
				Oats		*lib.*	241	3.07	0.74		
CB	----	----		Maize			227	6.80	1.54		2
				Barley			217	6.34	1.37		
SAMM	19	56	60	Maize		90	202	4.97	0.99		3
				Triticale		*Ad lib*	192	5.71	1.04		
RxS	29	----	80	100 M	W: G	70	340	4.13	1.40	70	4
				75M: 25W			330	4.16	1.37		
				50M: 50W		*Ad*	320	4.25	1.36		
				25M: 75W		*lib*	290	4.46	1.29		
				100W			250	4.80	1.20		
----	S/d	36	143	Maize		100	195			166	5
				Wheat		100	172				
HX	38		80	M	DR	75	346	4.48	1.55	63	6
				M+SBM			346	4.42	1.53		
				M+FM		*Adj*	405	4.07	1.65		
				M+FM+ SBM			378	3.95	1.49		
HX	38		80	M	DR	74	477	3.51	1.67	98	7
				M +0.3%U			485	3.54	1.72		
				M+0.6%U		*Adj*	485	3.54	1.72		
				M+1%U			477	3.44	1.64		
CB	38		74	M+6%rup	DR	75	279	4.85	1.35	74	8
				M+7%rup			302	4.60	1.39		
				M+8%rup		*Ad*	306	4.85	1.46		
				M+9%rup		*lib*	302	4.76	1.44		
MX	20	60		Maize		85	375	3.24	1.22	63	6
				80M: 20S			326	3.61	1.18		
				60M: 40S			315	3.78	1.19		
----	----	----	454	Sorghum		100	223				9
				40S: 60W			204				
CB	----	----		Sorghum			300	6.48			2
				Barley			247	6.47			

Grain (%): percentage of grain in the diet, offered Ad-libitum or daily adjusted. LWG: liveweight gain, FCR: feed conversion ratio, kg feed/ kg gain, DMI: dry matter intake, T: Targee, P: Polypay. H: Hampshire, SAM: South African Merino , M: Merino, R: Rambouillet, S: Suffolk, X: crossbred, N: number of animal used, P: processing, W: whole, G: ground, DR: dry rolled, M: maize, W: wheat, S: sorghum, SBM: soybean meal, rup: rumen undegradable protein, U:urea

(Ref): references: (1) (Ørskov et al. 1974b), (2) (Lardy 1999), Average of various trials from North Dakota Sate University reported by this author, (3) (Brand et al. 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).

Research comparing lamb performance when offered different types of grains in the same trial is not very abundant. Most of data reported in Table 22 correspond to lamb performance when fed maize grain. Fewer data have been reported on the use of sorghum in finishing systems. None of these reports have been done under Australian conditions. The work by Mitchell and Roberts (1976) comparing different grains in whole-grain diets versus a pelleted stock feed as control using Dorset x Merino lambs (26 kg) is the only Australian reference that reports performance data for lambs fed sorghum or maize compared with other grains. These authors report lower liveweight gain for oats. Liveweight gain did not differ between sorghum, maize, barley and wheat based diets, but barley and sorghum based diets produced similar liveweight gain to the control group.

All data in Table 22 is for crossbred lambs from different genotypes. Expected liveweight gains will vary depending on this, however the data for performance in grain-feeding systems based on maize or sorghum generally falls within the expected range (Latif *et al.* 1980; Seymour 2000a). Feed conversion ratios are reported to vary between 7:1 to 5:1 (Seymour 2000a). 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 Owens (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* vs. 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 weekly adjusted feeding had lower liveweight gains (288 g/day) with respect to daily adjusted feeding (378 g/day) or ad libitum (387 g/day), mainly explained by a reduced intake of whole grain maize, with no differences in feed conversion ratio (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 22). 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, respectively).

Source of grain affected liveweight gain of early-weaned lambs fed a 90% concentrate diet until slaughter at around 35 kg liveweight. Lambs fed with maize performed better than on barley, wheat or oats (Ørskov *et al.* 1974b). Umberger (1997) reports that in whole grain feeding systems, compared to corn, lamb performance is reduced by approximately 10% when barley is fed, and suggests that as lambs prefer corn to barley these grains should not be fed together. Lardy (1999) analysing a large series of data from several trials at the North Dakota State University on lamb performance when fed different grains confirms this tendency (Table 22). On average, liveweight gains for lambs fed with corn or sorghum were 4% and 5% higher than with barley, respectively. However, feed conversion ratio was increased when fed corn, while no difference were observed for sorghum. This author also reports that carcase weights, dressing percentages 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 lambs feedlot diets report no differences in liveweight gain, grain or forage intake between treatments but lambs receiving maize tended to have better feed conversion ratio (13%) than those consuming triticale. Feeding values of triticale based on these parameter ranged from 65% to 94% that of maize diets, depending on triticale cultivar.

Given the high nutritive value of maize, but considering that this grain may be less frequent in some regions or its price much higher than for other grains or by-products, some research is require to quantify the effect of partially substituting it into rations. Dhakad *et al.* (2002) concluded in 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 offered to feeder lambs for a 166-day period, observing that as the proportion of wheat in the diet increased, feed conversion ratio was not affected but liveweight gain decreased. When substituting sorghum with wheat, as the amount of wheat in the diet increased from 0 to 60%, average daily 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% wheat.

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

Lamb performance fed maize or sorghum on high roughage ration

Table 23 reports lamb performance data when sorghum or maize were fed as part of a feedlot diet where forage representing more than 50% of the diet. The inclusion of a forage source affects feed conversion ratio. Reducing whole maize grain while increasing alfalfa proportion in lambs diet from 0 to 100% and maintaining an isoenergetic diet adjusted to animal requirements, did not affect liveweight gains but it increased feed conversion ratio from 4.5:1 when 100 % grain was fed to 7.8:1 when only alfalfa was fed (Fluharty 1999).

Table 23. Liveweight gain (LWG) and feed conversion ratio of lambs fed whole grain diets. Summary of trials.

Animal			Grain		Forage		Response			Ref
G	Wt (kg)	N	Source	g/day	Source	g/day	LWG g/day	FCR	FI (kg/day)	
	9.8	12	60M:40WB	115	Wheat straw	*Ad lib*	79 ab	6.0	174	1
			30M:70WB	112			88 b	5.7	194	
			1000 WB	106			68 a	6.5	128	
M x BL	19.3		Control	0	Oaten Chaff	*Ad lib*	75		639	2
			Maize	79[1]			81		418	
			Sorghum	87			88		497	
			Oats	92			112		560	
			Meat meal	100			148		661	
T	25		Control	0	Lucerne Hay	*Ad lib*	168	6.7		3
			Sorghum	250[2]			208	5.9		
			Wheat	250[2]			256	5.2		
T	25		Control	0	Pasture silage	*Ad lib*	-28			3
			Sorghum	250[2]			130	7.8		
			Wheat	250[2]			52	20		
SX	47	230	Maize (Whole grain)	100[3]	Alfalfa pellets	0[3]	347	4.5		
				80		20	365	4.6		4
				60		40	351	5.5		
				40		60	351	6.2		
				20		80	364	6.9		
				0		100	342	7.8		

[1] Grams/animal isoenergetic quantities (estimated based on NRC, 1996); [2] Grain adjusted to 1% BW ; during the experimental period; [3] Proportion of the diet
G: Genotype, M: Merino, BL: Border Leicester, T: Texel, S: Suffolk. N: number of animal used, LWG: liveweight gain, FCR: feed conversion ratio, kg feed/ kg gain, FI: forage intake. M: WB ratio maize to wheat bran.

Ref. 1. (Dhakad et al. 2002), 2. (Kempton 1982,) 3. (Dulce et al. n/d), 4. (Fluharty 1999)

How do maize and sorghum grains adapt to simple feeding systems

Simple systems of grain feeding have been proposed for cattle supplementation in Australia, looking for alternatives that reduce labour and costs, while not affecting liveweight gains or conversion rates (Rowe *et al.* 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 *et al.* 1999b; 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 gains. Low gains during the adaptation period may compromise the whole efficiency of the grain-feeding program depending on its duration. Maize and sorghum, given their lower rumen degradability appear to be safer grains compared with wheat or barley. Kreikemeier *et al*. (1986) suggest that when diets are based on grains of rapid fermentation, a mixture with slow degradable grains may be a method for overcoming acidosis. In their study they fed lambs on a 70% grain diet, and observed that increasing the proportion of whole dry corn with respect to wheat from 25% to 100% increased the intake during the 21-day adaptation period. Liveweight gain and feed conversion ratio showed a significant quadratic effect.

Mendoza *et al*. (1999) feeding different combination of high moisture corn and dry rolled sorghum grain in a 75% grain diet found that even when there was not any evidence of subacute acidosis the highest starch intake was registered for the mixture containing 33% high moisture corn and 67% dry rolled sorghum.

Conclusion

There is limited data describing the performance of lambs fed maize or sorghum grain under Australian conditions. Research from other countries shows that growing and finishing lambs fed summer cereal grains on high concentrate diets perform as well or better than with winter cereals in terms of liveweight gains and show better 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 sorghum fed to lambs is not as clear as for maize. Some evidence indicates processing may be used to manipulate fat carcase characteristics.

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

Maize and sorghum given their low rate of fermentation appear as safer grains that may adapt well to simple grain feeding systems where there is less control of grain intake.

ADAPTATION TO GRAIN FEEDING

The efficiency of grain feeding is limited by the rate of adaptation to both the feed and feeding system. There are several factors that influence the speed of introduction to grain either in a supplementary feeding situation or an intensive feedlot scenario. The sheep will have to physiologically adjust to the new diet and depending on the grain used, there may be a high risk of acidosis if this is not done correctly. The sheep have to adapt to novel aspects of the feeding situation such as the feeding equipment, the diet format and possibly the grain type. Finally, there will be 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 supplementary feeding situations. Acidosis has long been recognised as a significant impediment to successful grain feeding (Bigham *et al.* 1975; Ikin *et al.* 1978). Despite the management and intervention strategies that have been developed, it continues to be identified as the primary health problem in feedlots (Langman *et al.* 2000; Seymour 2000b). Advisers from Primary Industries and Resources South Australia carried out a survey of farmers lot feeding sheep in drought conditions and 19% of producers identified grain poisoning as the main causes of deaths (Langman *et al.* 2000).

Social and behavioural adaptation to grain feeding is equally important as 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 termed ‘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% shy feeders in a feedlot operation (Bell *et al.* 2003). Adaptation to diets continues to impact on grain finishing systems and it is an area that requires further investigation.

Physiological adaptation to grain feeding

What is acidosis?

The pH of blood is maintained at a range of 7.35-7.45 by its buffering system, of which the bicarbonate system is most important. The addition of relatively large amounts of acid or alkali to the blood is necessary for its buffering capacity to be exhausted and pH changed. Changes in the normal acid-base balance towards either acidosis or alkalosis can cause ill health. The common cause of acidosis is the excess loss of the bicarbonate ion and the production and absorption of large quantities of fixed acid such as lactic acid and acute carbohydrate engorgement in ruminants (Blood *et al.* 1983).

The introduction of starch to the rumen leads to rapid fermentation and production of volatile fatty acids (VFA). If the rate of production exceeds the rate of removal, the pH may fall below 6.0. This favours the rapid growth of starch degrading bacteria including *Streptococcus bovis and Lactobacillus* spp. The pH continues to fall and *S. bovis* can no longer grow and lactobacilli take over, fermenting the starch to produce more lactic acid and creating an ever lower pH (eg 5.5, Al-Jassim *et al.* 1999a). Acidosis can also occur in the hindgut (caecum and colon) as a result of starch passing through to the small intestine without complete digestion (Rowe *et al.* 2002).

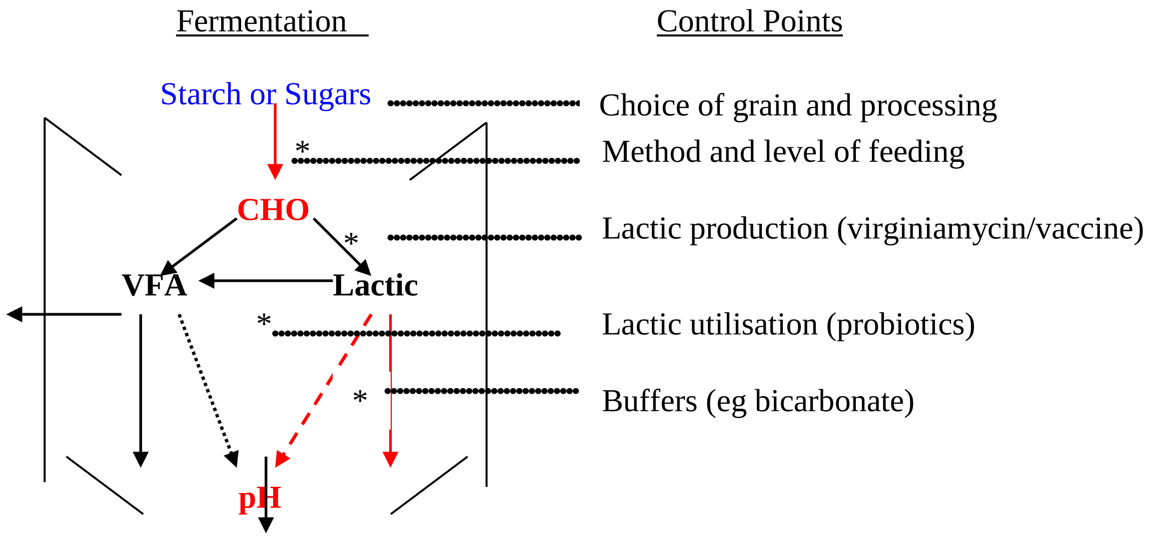

Figure 8. Principal control points for managing acidosis (Rowe *et al.* 2002).

It is recommended practice to introduce livestock to highly fermentable diets over a longer period of time or use management strategies such as ensuring gut fill with high fibre diets prior to introduction to grain and feed additives.

Rumen modifying antibiotics

Virginiamycin

Antibiotics have been used as supplements for growth promotion in most intensive production animals. It is generally appreciated that use of antibiotics contributes to lower animal production costs. These antibiotics have a diverse range of chemistry and primary antibacterial spectrums (Nagaraja *et al.* 1997) Antibiotics are included in feed in sub-therapeutic concentrations for two principal reasons:

1. To decrease the amount of feed needed, increase the rate of weight gain and thereby improve feed efficiency
2. To act prophylatically against a specific organism or group of organisms (Nagaraja *et al.* 1997).

Virginiamycin, a member of the streptogramin group, is used extensively through the sheep and cattle industries to reduce the risk of acidosis. Virginiamycin combined with the transfer of rumen fluid from well adapted animals has appeared to be effective for controlling lactic acid accumulation during the introduction of barley (Godfrey *et al.* 1993a). Similarly, the use of virginiamycin reduced the severity of acidosis in sheep fed grain (Godfrey *et al.* 1995b). The effectiveness of virginiamycin has been documented in the literature and its use within industry provides further support of the usefulness of this compound for managing acidosis during grain introduction.

Antibiotics from the streptogramin group impact on the physiology of the animal in several ways these include: (Godfrey *et al.* 1995a; Godfrey *et al.* 1993b; Godfrey *et al.* 1995b; Nagaraja *et al.* 1997)

1. Metabolic effect – they directly influence the rate and pattern of metabolic process of the animal
2. Nutrient sparing effect – the antibiotics alter bacterial populations, resulting in conservation of nutrients
3. Control of subclinical disease – the antibiotics suppress bacteria causing clinical of sub clinical infections
4. Modification of ruminal fermentation – the antibiotics alter the rumen's microbial population to improve fermentation efficiency

The future use of antibiotics may be restricted or potential applications altered and therefore avenues for strategic use or alternative acidosis controlling strategies need to be investigated. The report produced by the Joint Expert Technical Advisory Committee on Antibiotic Resistance (JETACAR, JETACAR 1999) raised concerns over the use of specific antibiotics for animal production. One of the recommendations of the JETACAR report was 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 draft report of the Australian Pesticides and Veterinary Medicines Authority has recently been released and recommends the following changes to the registration of virginiamycin for use in sheep production (Table 24, APVMA 2003).

The draft recommendations are currently open for comment within the industry. The recommended label changes in the report 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 producers commonly rely on use for the duration of the grain feeding programme, particularly within large operations. 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 24. An extract of the draft recommendations for the use of virginiamycin when grain feeding sheep (APVMA 2003)

Product, *Active ingredient* and poison schedule classification	Registrant	Claims on APVMA approved label	Recommendations	Proposed label amendments	Regulatory decision
49111 Eskalin wettable powder Spray-on feed premix *virginiamycin 400g/kg (individual sachets of 20g)* Schedule 5	Phibro Animal Health	For use in cattle and sheep rations to reduce the risk of acidosis when feeding grain	Label changes requires Schedule currently under consideration by NDPSC	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	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, also referred to as carboxylic polyether ionophore antibiotics, are a group of compounds produced by bacteria (Bergen *et al.* 1984). They are so named due to their ability to form lipid soluble complexes with particular cations across lipid barriers (Nagaraja 1995).

Incorporating ionophores into ruminant diets increases growth performance by altering rumen fermentation patterns (Table 25, Bergen *et al.* 1984; Elsasser 1984; Nagaraja *et al.* 1997). Altered fermentation patterns lead to control of acidosis and improved feed conversion (Bergen *et al.* 1984; Foreyt *et al.* 1981).

Table 25. The general response of beef cattle to ionophore antibiotics (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.↑	↑	↑

Feeding ionophores has been shown to increase the utilisation of nitrogen, by reducing proteolysis of dietary proteins and therefore reducing the amount of ammonia produced in the rumen (Boegart *et al.* 1991; Dinus *et al.* 1976; Ricke *et al.* 1984; Rogers *et al.* 1997). The net result is a more efficient utilisation of dietary nitrogen for protein synthesis in the rumen (Bergen *et al.* 1984). In addition, by limiting the intra-ruminal breakdown of dietary proteins, ionophores increase the flow of undegraded dietary protein and constituent amino acids to the small intestine, which is favourable for meat production (Schelling 1984). This can impact on the end product, for example, lambs that were fed 50 mg/day lasalocid had an increase in protein content and reduction in the fat content in the *longissimus dorsi* muscle (Krelowska-Kulas *et al.* 1992). This may have positive outcomes in meeting market specifications.

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, roughage diets that contain β-linked carbohydrates may not depress feed intake, but the weight gain of the animal is generally improved (Bergen *et al.* 1984). The chemical and physical properties of different fibre sources can also influence the digestibility and intake response when fed with ionophores.

The main ionophore for use in sheep is monensin, other antibiotics include lasalocid, laidlomycin, lysocellin, narasin, salinomycin and tetronansin (Mackie *et al.* 2002).

Probiotics
There is potential to reduce the susceptibility of sheep to acidosis, improve fibre digestion and control pathogenic gut bacteria through the introduction of naturally occurring organisms (probiotics) to the rumen (Mackie *et al.* 2002). Probiotics may be an important alternative management strategy for the control of lactic acidosis in sheep, especially considering the proposed restrictions for use of antibiotics.

The addition of a probiotic (Yea Sacc) alone to sheep on barley grain diet did not appear to cause any changes in the pattern of rumen fermentation and digestion compared to untreated animals (Godfrey *et al.* 1993a). However during acute grain feeding animals preceded by the inoculation of the rumen with 10^8 cfu of *S. rumiantium* subsp. *lactilytica* strain JDB201, ruminal lactate was undetectable and ruminal pH was stabilised for 24 hours (Wiryawan *et al.* 1995). Inoculation of the rumen with *S. ruminantium* subsp. *Lactilytica* strain JDB201 and *Megasphaera elsdenii* strain JDB301 was more effective than strain JDB201 alone maintaining ruminal stability for up to 4 days (Wiryawan *et al.* 1995). This result indicates that finding the right combination of probiotics to be included into a feeding regime may help in the initial adaptation period. Wiryawan and Booker (1995) also reported that when probiotics were used in combination with 0.75 μg/mL of virginiamycin lactate accumulation was prevented and fermentation *in vitro* was stabilised.

This may open avenues for reducing the use of antibiotics and increasing use of probiotics either in conjunction or alone when feeding highly fermentable diets.

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. Antibodies have been raised against *S. bovis, S. ruminantium, S. equis* and *L. vitulinus* for development of a vaccine (Brown *et al.* 2002). The authors were not able to indicate whether the antibodies stimulated protective immunity and inhibited lactic accumulation. However they documented that previous work indicated that *S. bovis* provided protection against lactic acidosis in sheep.

The use of an alternative such as vaccines may be a long-term option for the control of acidosis, however, there are potential issues that necessitate further work. For example, the length of rest period required between vaccinations and the actual grain feeding of the livestock is unknown. If a lengthy rest period is necessary, vaccination may not be a suitable strategy for most lotfeeding systems. It is not known whether vaccines against certain micro-organisms will negatively impact on the animal’s immunity and predispose them to other disorders within the feedlot environment. Further investigation of this management strategy is required before it can be applied commercially.

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. When intake is calculated for a group of sheep, the assumption is that all individuals are consuming an equal amount of supplement. This assumption is unlikely to be true. Individuals within a mob will display a wide variation in intake ranging from dominant feeders to non-feeders or shy feeders. Variation in intake between individual animals is increased by limited or excessive trough space, restricted supplement allowance, neophobia to feed or feed delivery device and increased group size in the feeding situation (Bowman *et al.* 1997). The influence of these factors will vary with the intensity of the feeding system.

When livestock are first exposed to a new feed or feed delivery device they often sample the feed cautiously before accepting it and take a number of days to reach a stable intake. This pattern of behaviour has been described as neophobia (Bowman *et al.* 1997). The first hurdle in becoming accustomed to grain feeding is overcoming fear of the feed delivery device (Chapple *et al.* 1987). Holst e*t al*. (1994) reported much higher variation in supplement intake between individuals when the supplement was offered in a self-feeder rather than trail fed. They observed that several animals were shy with the feeder upon initial exposure but some of these animals overcame the fear of the feeder in subsequent feeding periods. The necessity of training sheep to eat from unfamiliar feed delivery devices has been recognised for a long time. In a drought feeding leaflet published in 1958, CSIRO researchers described their 'no-choice' method of teaching sheep to eat from troughs (cited in Fels 1982). New mobs were confined in bare yards and lucerne chaff was offered in troughs with no other feed available. Sheep quickly learned to eat lucerne chaff from troughs and then progressed to accepting less attractive feeds placed in the troughs.

Once the fear of the feed delivery device has been overcome, the second phase in adaptation to grain feeding is acceptance of the grain. There is variation in the rate that sheep learn to eat new feeds. Green *et al*. (1984) observed that when sheep were first exposed to wheat they displayed a very distinctive pattern of feed acceptance over a period of days and that this process commenced on different days for different animals. Presumably, there is a point at which appetite or hunger overcomes the fear of sampling the novel feed. Young lambs take cues from their mothers when learning to detect food. Novel feeds are accepted more quickly when lambs have been exposed to the feed in the presence of older sheep (Green *et al.* 1984; Mulholland 1986).

Variation in intake is affected by competition for feed. This is more relevant for supplementary feeding where there may be a limited amount of grain offered, but is also relevant during feedlot introduction. When groups of sheep are mixed, there is a level of competition as they establish a social order (Fels 1982). If competition is aggressive due to limited trough space or feed availability, there may be a higher incidence of shy feeders.

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.

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