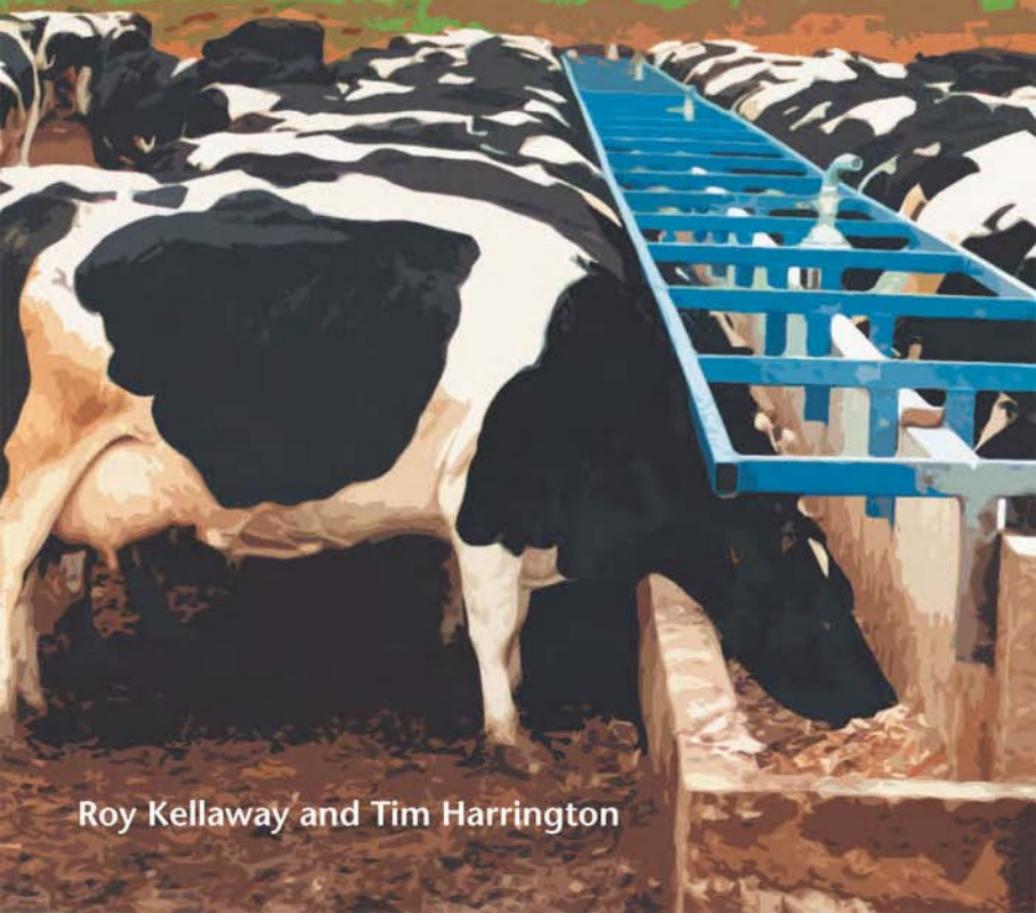Revised Edition

FEEDING CONCENTRATES
SUPPLEMENTS FOR DAIRY COWS

Roy Kellaway and Tim Harrington

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About the authors

Roy Kellaway

Roy is an animal nutritionist with more than 40 years' experience, including 29 years at The University of Sydney.

Since retiring from the university in 1997, he has worked as an agricultural consultant. One of his first assignments was to develop a plan for the future management of The University of Sydney dairy farms. He is currently an Honorary Associate Professor in the Faculty of Veterinary Science and still does some teaching in the Faculty.

During the past two years, Roy has worked with associates at the Epicentre at Massey University in New Zealand, producing a new version of the nutritional management software package called CamDairy. This software is now owned and operated by a leading Australian animal feed company.

Roy was also on the editorial board for the *Encyclopedia of Dairy Sciences,* published by Academic Press in 2003.

Roy was the principal author of the first edition of *Feeding Concentrates – Supplements for Dairy Cows.* He was asked by Ridley AgriProducts Ltd to update the book by incorporating research findings over the past 10 years.

Roy graduated from Wye College, University of London, with a BSc Hort. He also has a Diploma in Tropical Agriculture from the former Imperial College of Tropical Agriculture in Trinidad, a PhD from the University of New England and is a Fellow of the Australian Institute of Agricultural Science and Technology.

Tim Harrington

Tim moved to Australia with his family in April 2002 to take up the position of Ruminant Technical Manager with Ridley AgriProducts Pty Ltd, where he is responsible for providing technical, nutritional and commercial leadership to the industry and Ridley AgriProducts Pty Ltd.

Tim has over 18 years' experience in the UK feed and live-stock sectors and has worked for the Agricultural Development and Advisory Service (ADAS) and Associated British Nutrition Limited (ABN Ltd).

After completing an honours degree in Animal Science at Leeds University, Tim ran a research programme at Cambridge University on protein nutrition in ruminants. He started with ADAS as a nutritionist working with all classes of farm stock, before specialising in dairy cow work with a particular emphasis on nutrition, fertility management, and husbandry and business management. Tim also has considerable research experience, setting up and running studies in dairy cow nutrition, dry cow management, the manage-

ment of high yielding cows, laminitis in down-calving heifers, youngstock management, factors affecting the incidence of mastitis and forage conservation.

Tim joined ABN Ltd. as a nutrition consultant in January 1996 before becoming Dairy Product Manager later that year. He was responsible for developing and promoting the Bibby range of ruminant products and services throughout the UK and Ireland.

Foreword

The Australian dairy industry is a major agricultural industry, ranking third behind the wheat and beef industries, and worth some $3.7 billion dollars at farm gate prices in 2001/2002. It employs about 46 000 people in related manufacturing, processing and farm establishments. The compound annual growth rate of the Australian dairy industry has averaged five per cent over the past decade, and it is forecast to continue at similar levels into the medium term.

From an industry that historically was predominantly pasture-based, it has moved to be a major user of concentrates and prepared feeds. Milk production per hectare is maximised by grazing a high proportion of the pasture. This does not allow cows to eat as much as they like or to be selective, but it minimises pasture wastage, reducing the cost of the pasture eaten. The down side of this is lower production per cow.

Higher milk production per cow and per hectare can be achieved with supplementary feeding, but responses vary. This review focuses on why and how responses vary, with the objective to maximise milk responses when feeding concentrates.

Responses to supplementary feeding require a number of complex factors to be taken into account, but often they are assessed only on litres per kilogram (l/kg) of supplement.

A more realistic assessment of the benefits of feeding supplements would include the economic benefits arising from factors such as stocking rates, pasture management, body condition score management, impact on seasonality of milk production in relation to milk prices, processing demands and milk composition.

Ridley AgriProducts is a major Australian agribusiness company that specialises in meeting the requirements of livestock producers for leading edge, high quality nutrition products. Our focus remains on the commercial benefits to producers, and a thorough understanding of the determinants of profitability for Australia's dairy producers is crucial to achieving this objective.

I am very pleased that we have been able to bring together such knowledgeable and experienced dairy nutrition specialists for this publication. Roy Kellaway has contributed greatly to dairy nutrition and production research, and has had many years of practical experience at dairy herd management. Similarly, Tim Harrington, working over many years in the UK dairy industry in both research and the commercial sectors, brings a new perspective to the Australian industry.

The present review presents the most recent information on the use of supplementary feeding under Australian conditions and on the complex factors that determine their commercial benefit.

Ray Johnson
National Technical, Quality and R&D Manager
Ridley AgriProducts Pty Ltd
August 2003

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Preface

The first edition of this book in 1993 was commissioned by the Dairy Research and Development Corporation (now Dairy Australia) to achieve the following objectives:

- Clearly document results of research on supplementing pasture-fed cows with grains.
- Thoroughly review the issues and identify gaps in our knowledge that may require further research.
- Identify areas that require additional extension if there appear to be significant gaps in the knowledge of farmers using grains supplementation.

Some of the gaps in our knowledge, which were identified, have since been addressed and the results have been incorporated in this new edition.

Ridley AgriProducts P/L commissioned this new edition. A substantial amount of additional material has been included. The major conclusions and recommendations are similar to the original, and many gaps in our knowledge remain to be addressed. We hope that the material in this book will help guide research workers to the most relevant topics for research on concentrate feeding of cows. Also we hope that dairy farmers will find the summaries and recommendations from previous research to be helpful in making the best management decisions relating to concentrate feeding.

Roy Kellaway and Tim Harrington
August 2003

Acknowledgments

General summary

This review focuses on feeding concentrates to pasture-fed cows in Australia. Many of the experiments reviewed were carried out 20 or more years ago when average milk yields were much lower than current average yields. Experiments published up to 2003, with cows giving much higher yields, have now been included. Cows with a high genetic potential give larger responses to concentrate feeding than cows of lower genetic potential, provided that they are well grown.

Other feed supplements, such as silage and hay, are equally important in maintaining a balanced supply of nutrients throughout the year.

Maximising milk production per cow

Under grazing conditions, lactating cows optimise their milk production where they can be highly selective, whilst eating as much as they like. However, this leads to substantial pasture wastage, unless followers such as dry cows are used to graze the residual pasture.

Maximising milk production per hectare

Milk production per hectare is maximised by grazing a high proportion of the pasture. This does not allow cows to eat as much as they like or to be selective, but it minimises pasture wastage, reducing the cost of the pasture eaten. The down side of this is low production per cow.

The best of both worlds

High milk production per cow and per hectare can be achieved with supplementary feeding, but responses vary. This review focuses on why and how responses vary. This helps to determine how to maximise milk responses when feeding concentrates.

The most influential factors in deciding response to supplementary feeding are:

Cow factors

- Stage of lactation
- Genetic potential for milk production
- Feeding level in relation to milk production potential
- Heat stress

Feed factors

- Pasture availability and nutrient content
- Supplement availability and nutrient content
- Substitution rate of the supplement for pasture

After taking the above factors into consideration, is the cost of supplementary feeding justified by an adequate increase in production? The optimum amount of dietary energy and protein to *maximise profit* is determined by the interaction of cow and feed factors, as well as feed costs and milk prices.

Responses to supplements may occur:

- during the period of feeding (*immediate response* plus *cumulative response*);
- after the period of feeding the supplement (*residual response* or *carryover effect*).

The sum of the immediate, cumulative and residual responses is the *total response*. It is often double the immediate response. This should be taken into account in assessing the economics of supplementary feeding.

Responses to supplements are often quoted as litres of milk per kilogram (l/kg) of supplement or kilograms of supplement required to produce a litre of milk (kg/l). Milk and supplement prices are applied to this ratio to determine whether or not supplementary feeding is profitable, but this does not tell the full story.

A more realistic assessment of the benefits of feeding supplements would include the economic benefits arising from the following factors:

- Higher stocking rates are possible, increasing the milk income per hectare.
- When the stocking rate is increased pasture use is improved as the cows consume a greater proportion of what is grown. This reduces the cost per tonne of the pasture eaten.
- The growth of heifers and cows that have not reached mature size is promoted. This increases their appetite and milk production potential in future lactations, as well as in the current one.
- Cows fed supplements maintain better body condition score when pasture availability is low. This increases their ability to reach their milk yield potential and helps reduces the time to their first oestrus after calving.
- When milk prices are high, feeding supplements can increase net milk income.
- Feeding supplements when pasture availability is low can increase lactation length.
- Appropriate supplementation can increase milk protein content when the energy intake from pasture is low.

Recommendations to farmers

- Determine the cost of growing both the pasture and forage supplements fed to the dairy herd.
- Feed concentrates as a normal part of feeding management, where the basal forage is grazed pasture, hay or silage. This may not necessarily entail feeding concentrates all the time, but they should be fed whenever it is profitable to do so in terms of both the immediate and long-term benefits.
- Pasture is often deficient in nutrients, including protein, minerals and trace elements. Supplements can play an important role in cost-effectively filling the gap between nutrients supplied by the pasture and nutrients required at different stages of lactation.
- Feeding concentrates affects pasture management. It should be possible to increase grazing pressure or stocking rate, and at the same time increase the proportion of pasture actually eaten by the cows. This reduces the cost of pasture eaten.
- The best milk response to feeding concentrates is during early lactation, when cows calve down with a body condition score of 4.5–5.4 (on a scale of 1–8; thin to fat.)
- Cows of high genetic potential will give larger responses to concentrates than cows of lower genetic potential, provided that they are well grown.
- If cows are small and in poor body condition, many of the nutrients supplied by the concentrates will go into improving body condition. These cows will give a small milk response in the short term and a larger milk response over time.
- If young cows have not reached their potential mature size due to under-feeding, they will divert a lot of the nutrients from concentrates into increasing body size. These cows will give a small milk response to concentrates in the short term, but in the long term, their appetites and milk production are likely to increase.
- To maximise profit from feeding, consider the availability, nutrient content and cost of the pasture, conserved forages and concentrates available, as well as the likely milk potential of the cows and the milk price. All these factors can be considered simultaneously with an appropriate computer program. Regular use of such a program, and regular consultation with a nutritionist, will show how profits can be maximised from the resources available.

Note: Ban on animal by-products
Animal by-products including meat meal, meat and bone meal, blood meal and fish meal now are banned from inclusion in feeds for cattle. Data referring to their feeding value for cattle are included in Tables 4, 8, 9 and 16. They have been retained because they illustrate the feeding value of high quality protein supplements, which provide a high proportion of by-pass protein. It is now a challenge to find alternatives to these valuable feed sources.

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Milk composition

Summary

The effects of concentrate feeding on milk composition are referred to in various sections throughout this publication. This chapter is essentially a summary of points that are discussed more fully elsewhere.

- Maintaining high concentrations of fat and protein in milk when milk price schedules are component based is important. This can be achieved through appropriate use of concentrates. High levels of starch-based concentrates generally depress milk fat content and increase or result in no change in milk protein content. By maintaining adequate effective fibre levels in the diet, milk fat depression can be minimised.
- Problems with low protein content of milk can be overcome by increasing energy intake.
- Feeding fat supplements protected from degradation in the rumen can suppress milk fat content and modify the composition of milk fat to increase the content of conjugated linoleic acids, which have positive effects on human health and disease prevention.

Introduction

Milk payment schemes are generally based on milk component yield rather than volume. Although the exact formula for calculating milk price differs between purchasing companies, there is a common trend to place more emphasis on the protein content of milk, than fat content. This is due to changing perceptions of the nutritional value of milk for human consumption. However, there is little scope to alter the protein content of milk through dietary manipulation. While dietary changes can alter fat concentration by up to 3% units, changes in protein content are rarely more than 0.5% units (Sutton 1990).

Milk constituent concentrations change with stage of lactation. After calving both fat and protein contents of milk fall to reach minimum levels at around 2–3 months of lactation (Sutton 1990). They then increase slowly through to the end of lactation. The low concentrations of fat and protein at the time of peak yield can be a particular problem in the seasonal calving herds where all cows are at the same stage of lactation.

Milk fat content

Forage:concentrate ratio

A major factor affecting milk fat content is the level of effective fibre in the diet. The act of chewing fibre stimulates saliva production, which acts as a buffer in the rumen, preventing decline in rumen pH. The recommended minimum particle length for forages is 0.6–0.8 cm in order to stimulate saliva production (Sutton 1990). If rumen pH is depressed, there is a change in the volatile fatty acid (VFA) ratio, increasing the proportion of propionate to acetate. Previously it was thought that milk fat depression was due to this change in VFA proportions. Research in the past 10 years strongly suggests that milk fat depression is also the result of changes in the rumen bio-hydrogenation process and not just changes in rumen VFA patterns (NRC 2001).

Bacteria in the rumen hydrogenate polyunsaturated fatty acids in the diet. Fatty acid chains of mono- or poly-unsaturated fatty acids can be straight (trans) or bent (cis). Trans unsaturated fatty acids behave more like saturated fatty acids than unsaturated fatty acids, and are considered to be less desirable in the human diet than cis unsaturated fatty acids. Reduced fat synthesis in the mammary gland has been related specifically to the trans-10 isomer of linoleic acid (Griinari *et al.* 1998). This is produced when there are sufficient polyunsaturated fatty acids in the diet and when rumen pH falls below 6.0. Under these conditions, addition of buffers to the diet will increase rumen pH and increase milk fat content (Erdman 1988).

Reduction of milk fat content may be desirable for human dietary reasons, as well as to reduce the energy cost of milk synthesis. Abomasal infusions of conjugated linoleic acids reduced milk fat content by 52–55%, and increased the milk fat content of conjugated linoleic acids, with no effect on milk yield or protein content (Chouinard *et al.* 1999). The specific isomer trans-10, cis-12 conjugated linoleic acid is a very potent inhibitor of milk synthesis with a dose of 3.5 g/day eliciting a 25% reduction in milk fat yield (Bauman *et al.* 2001). Conjugated linoleic acids in milk have positive effects on human health and disease prevention (Parodi 1997) including suppression of carcinogenesis and reduction in atherogenesis and diabetes.

A measure of effective fibre, which is specifically related to maintenance of milk fat concentration, is effective neutral detergent fibre (eNDF), which is defined as the sum total ability of the NDF in a feed to replace the NDF in forage or roughage in a diet so that the percentage of milk fat is maintained (Mertens 1997). This ability may be attributed to the fibre fraction of a feed, or the oil fraction. For example, the effect of feeding whole cottonseed on milk fat percentage may be a result of both its fibre and fat contribution to the diet (NRC 2001).

Another measure of effective fibre is physically effective NDF (PEF) (Mertens 1997), that is the portion of NDF which is effective in stimulating salivation. Thus the PEF of long

grass hay is set to 1, with other forages having lower values. Mertens (1997) suggested that PEF could be estimated by the proportion of NDF retained on a screen with 1.18 mm or greater openings after dry sieving. Lammers *et al.* (1996) suggested that PEF could be estimated from particle size distributions in a three-screen sieve (>19 mm, 8 to 19 mm, and <8mm).

NRC (2001) concluded that more research is needed to identify other chemical and physical characteristics of feeds that influence their ability to maintain optimal ruminal function before specific values for effectiveness of various forage and non-forage fibre sources can be determined. Because of these problems, NRC (2001) chose not to recommend dietary levels of effective fibre.

NRC (2001) recommendations for minimum total NDF varies from 25 to 33% as the forage component of NDF in the diet varies from 76 to 45%. This recommendation applies to lucerne or maize silage diets. With grazed temperate pastures in a vegetative state, the fibre is likely to be less effective at stimulating chewing, so the minimum desirable NDF is 35 to 40% when the forage component of NDF is about 75%. Broster *et al.* (1985) and Sutton (1990) found that as level of intake increased, an increasing proportion of fibre was required to maintain a constant milk fat content.

Type of concentrate

Milk fat content can be greatly influenced by the type of concentrate fed and its degree of processing. Starch-based concentrates cause greater milk fat depression than fibrous ones, because starch fermentation can rapidly lower rumen pH. Some cereal grains, such as maize and sorghum, may have a lesser effect on milk fat content because they are degraded more slowly in the rumen (Herrera-Saldana *et al.* 1990).

Milk fat depression is made worse by fine processing of grain. This makes starch more readily available and so it ferments more quickly in the rumen.

In general, it appears that soluble carbohydrates, such as molasses, increase the content of milk fat. This may be due to an increase in the production of butyric acid in the rumen. The level of supplement given may influence this response (Ashwood and Cowan 1990; Sutton 1990).

Dietary protein

Changes in dietary protein levels have minimal effects on milk fat content. When the protein content of the diet is limiting, increased dietary protein may increase milk fat content through increases in roughage intake. Sutton (1990) comments that in experiments where an increased supply of undegraded dietary protein was given in conjunction with starch-based concentrates, milk fat content was markedly reduced.

Fat supplements

Fat supplements may either increase or decrease milk fat content, depending on their effects on rumen fermentation. High levels of saturated fats (>5–6 % of the overall diet) or even small amounts of unsaturated fats cause milk fat depression. Lower levels of saturated fats usually result in a constant milk fat content (Sutton 1990).

Fat supplements that have been protected from rumen degradation by protein encapsulation have consistently increased milk fat content. Other methods of fat protection, such as fat prills or calcium salts of fatty acids, have given variable results. This is due to the

highly variable level of rumen inertness of the fat (Ashes *et al.* 1995). Whole cottonseed generally increases fat content due to slow rumen degradation of fat, whereas other whole oilseeds such as soya, canola and linseed depress milk fat due to the high levels of polyunsaturated fatty acids.

Fat supplementation can also be used to manipulate the fatty acid composition of milk fat. A panel of researchers in the USA (O'Donnell 1989) recommended that, for human nutrition, the level of C18 mono and polyunsaturated fatty acids should be increased to about 80% and 10% respectively, of the total milk fat. The most effective way to consistently and substantially increase the proportions of C18 mono- or polyunsaturated fatty acids, or both, and to reduce the proportion of saturates is to feed oilseeds that have a low content of C16:0 in a form where the constituent C18 unsaturated fatty acids are highly protected from ruminal bio-hydrogenation, by encapsulation in a matrix of formaldehyde-treated protein (Ashes *et al.* 1992; Gulati *et al.* 1999).

Also of interest in human nutrition is increasing the intake of omega-3 fatty acids that occur in fish oils. Inclusion of these in rumen-protected supplements in the diet of lactating cows produced milk containing significant amounts of omega-3 fatty acids without depressing feed intake or fat and protein content of milk (Ashes *et al.* 2000; Kitessa and Gulati 2002).

A review of procedures for manipulating milk fat in dairy cows is given by Doveau *et al.* (1999).

Frequency of feeding

For high grain diets, frequent feeding of small amounts of grain often reduces the effects on rumen pH and causes less milk fat depression. Gibson (1984) summarised the results of 27 experiments and concluded that, when feeding frequency of concentrates was increased from one or two meals per day to three or more, the average increase in milk fat content was 7.3% and milk yield by 2.7%. No effect was found when cows given concentrates one or two times per day were already producing milk of normal fat content.

Buffers

Buffers act to neutralise the volatile fatty acids in the rumen to prevent the decline in rumen pH and consequent milk fat depression. Some trials in Australia have found little benefit in the use of buffers, with grain feeding levels up to 10 kg/day. However, in some overseas studies with maize silage diets, buffers have been successful in maintaining milk fat content at higher feeding levels of grain. In New Zealand, supplements of magnesium oxide given to hypomagnesaemic cows have produced increases in milk fat yield of 3–11% (Merrall 1983).

Milk protein content

Milk protein content varies with breed and stage of lactation. Channel Island breeds have a higher milk protein content than Holstein Friesians; there is significant variation within breeds, which allows for improvement through genetic selection. Milk protein content is highest at calving, reaches a nadir at the peak of lactation and increases gradually thereafter. For a particular breed and stage of lactation, the most important factor is energy intake. If energy intake is depressed through heat stress, poor quality forage, or limited

access to feed, milk protein will be depressed. Specific effects of dietary manipulations are discussed below.

Energy supplements

Increasing energy intake increases milk protein content through increased yields of microbial protein in the rumen. However, providing feed in excess of requirements has little further effect (Sutton 1990). Stockdale (1994) summarised results from 27 experiments in Victoria where a wide range of feedstuffs had been used. He reported that starch-based supplements, such as cereal grains and compounded concentrates, are the best way to improve milk protein content. This improvement is believed to be due to an increase in the proportion of propionate (glucogenic precursor) produced in the rumen and an increased microbial crude protein synthesis (Beever *et al.* 2001). An average increase in ME intake of 17.9 MJ metabolisable energy (ME) from concentrates gave a 1 g/kg improvement in milk protein content. When the extra energy was supplied by pastures or maize silage, an average of 29.5 MJ ME was required to improve milk protein content by 1 g/lg. On clover pastures with a high protein content, milk protein content was not increased by extra feeding. This could have been due to the energy cost of excreting surplus dietary protein, or because metabolisable amino acid supply relative to energy was already at a maximum.

Dietary protein

Generally, unless amino acid supply is deficient relative to dietary energy, additional protein in the diet has little effect on milk composition. While it may affect total milk and protein yields, protein content remains stable. However, there are some exceptions. Both abomasal (fourth stomach) infusions of casein and formaldehyde-treated casein given in feeding trials have reliably increased milk protein content (Ashwood and Cowan 1990). The amino acid balance in casein obviously matches that in milk protein.

Methionine and lysine have been identified as the amino acids likely to be first limiting for milk protein synthesis in maize-silage fed dairy cows, and perhaps histidine in grass-fed cows. The methionine and lysine contents of rumen bacterial protein are very similar to those in milk protein, so that any dietary adjustment, which enhances the production of microbial protein, provides an ideal balance of amino acids for milk protein synthesis.

Microbial protein can provide sufficient metabolisable protein for the production of over 40 litres per day of milk, provided that the diet is formulated to allow a high intake of metabolisable energy, with sufficient rumen-degradable protein and minerals for the requirements of the rumen microbes. When intake of rumen-degradable protein is insufficient, in relation to metabolisable energy intake, provision of dietary protein, which is digestible in the intestines, but undegraded in the rumen (UDP), is likely to increase both total milk protein and milk protein content. The extent to which it does so is dependent on the amino acid profile of the UDP.

The balance of methionine and lysine in most supplementary protein sources differs from that in milk protein e.g. sunflower is low in lysine, and lupins are low in methionine. Canola and cottonseed meals have a better balance of amino acids than lupins. When lupins were replaced by unprotected canola meal or cottonseed meal, there was no effect on milk protein content (Christian *et al.* 1999). However, when lupins were replaced by formaldehyde-protected canola meal, milk protein content was significantly increased by 1.5 g/l in cows fed a basal diet of grass silage and grain concentrate (White *et al.* submitted).

When 1 kg barley was replaced with 1.2 kg of 0.7% formaldehyde-protected sunflower meal, milk and protein yields increased, but there was no increase in milk protein content, even though the basal milk protein values were <30 g/l. (Hamilton *et al.* 1992). Other methods of protection with various protein sources also have not been successful. Ashwood and Cowan (1990) noted that where protein content of the diet was increased from very low levels (e.g. 9%) increases in milk protein content resulted.

It is still not possible to predict the type or magnitude of milk protein response to protein supplements.

Fat supplements

Trials involving fat supplements including vegetable blends, prilled fat, calcium salts of long-chain fatty acids, protected tallow, tallow, whole cottonseed, whole soybean and yellow grease have shown a reduction in protein content of milk (Ashwood and Cowan 1990; Chilliard 1993; Wu *et al.* 1993). Since fats cannot be used as an energy source by rumen microbes, a decreased yield of microbial protein usually results. For this reason, additional digestible rumen undegradable protein (DUP) is normally recommended in diets containing supplementary fats. Scott and Ashes (1993) recommended that to optimise the performance of cows fed diets supplemented with fat, the degree of protection or inertness should be as high as possible, and that a protected protein source equivalent to about 50–60% rumen degradable protein be included, so as to realise the synergistic benefits of including both protected fat and protein supplements in the diet.

Time of calving

When cows calve in late spring, the peak of lactation corresponds with periods of higher temperature and humidity, and a lower plane of nutrition from tropical pastures. These factors, which reduce energy intake, exacerbate the normal decline in milk protein content, which occurs at peak lactation (Barber *et al.* 2002).

Slug feeding versus total mixed rations

Slug feeding is a common practice on many Australian dairy farms. This occurs when medium to large amounts of grain (3–5 kg) are fed twice a day at milking time. This can increase the incidence of sub-clinical acidosis, thus having a negative effect on the digestive process, a decrease in nutrient supply to the mammary gland, and reduction in milk protein synthesis. Shabi *et al.* (1999) reported a 5.4% increase in milk protein content when maize-based concentrates were fed four times per day versus two times, with a subsequent reduction in the diurnal variation in ruminal pH and an increase in dry matter intake and organic matter digestibility.

Istasse *et al.* (1986) found an increase in milk protein content when concentrates were fed at 65% of the diet, as part of a mixed diet versus two times per day (31.9 and 33.2 g/kg respectively). However, Agnew *et al.* (1996) found no significant change in milk protein content when feeding concentrates at 2, 4, 6 and 8 kg/day, two times, four times or as part of a complete diet.

With total mixed rations, larger amounts of concentrates can be fed without causing ruminal acidosis and depressing milk protein content.

2

Strategies for concentrate feeding

Summary

- The most profitable strategy of feeding concentrates should be based on comparison of pasture and concentrate costs, their respective nutrient contents and the price received for milk. It is important to determine the cost of pasture actually eaten, as well as the variation that occurs in its nutrient content.

- In most cases, concentrate feeding allows an increase in stocking rate, which allows increased production both per hectare and per cow. Stocking rate and milk production per cow are major determinants of profitability. Feeding concentrates when there is a pasture shortage is useful in preventing underfeeding and decreased production. This also assists in allowing recovery of pasture growth.

- It appears that when feed is available to appetite, there is little difference in total milk yields associated with different systems of feed allocation. Under these circumstances, flat-rate feeding would be the simplest option. The flat rate for the whole herd is likely to vary with changes in pasture quantity or quality.

- Due to very limited information available on the mineral content of pastures, it is often prudent to include mineral supplements in concentrates.

Introduction

Kolver and Muller (1998) recorded milk production of 29.6 kg/day from cows grazing top quality pasture and 44.1 kg/day from similar cows fed a well-designed total mixed ration. The difference of 15 kg milk was attributed to dry matter intake (61%), energy for grazing and walking (24%), energy for extra urea excretion in cows on pasture (12%), energy for higher milk fat content from grazing cows (7%) and energy contributed from additional bodyweight loss from grazing cows (-4%).

These observations are helpful in designing feeding strategies which bridge the gap in milk production between an all-pasture diet and a total mixed ration. Feeding concentrates can increase dry matter intake of grazing cows. The energy cost of grazing and walking can be minimised with effective design of farm layout. The high content of protein in high quality pastures, which is in excess of the cow's needs, requires energy to excrete the surplus protein as urea. Feeding energy concentrates with a low content of protein can reduce the surplus of protein from pasture.

Before feeding concentrates, it is important to determine their most effective use for maximising profit. Questions to consider include:

- What feeding strategies can be used?
- What feeding strategy is the most profitable?
- How should stocking rates be changed?
- Should feeding continue throughout lactation or only when there is a pasture shortage?
- Should some cows receive more concentrates than others?

Usually it is assumed that pasture is the cheapest source of feed, and that the most profitable system is the one that allows the most efficient use of pasture. The optimum ratio of pasture to concentrate in the diet should be determined by their relative costs, their nutrient content, the price received for milk, the target level of milk production and the stocking rate.

A very important exercise for any dairy farmer is to calculate the cost of pasture consumed. This entails adding the costs of fertiliser, seeds, chemicals, pasture machinery, equipment maintenance and depreciation, electricity (direct costs, such as for irrigation), pasture labour and pasture land rates. An estimate of forage consumption from the farm can be made as follows:

Tonnes DM

Total annual milk production in litres/1000	A
Number of replacement stock x 2.3	B
Total purchased concentrates and forages	C

$$\text{Forage consumption per ha} = \frac{(A + B) - C}{\text{effective ha}}$$

Annual dry matter consumption by lactating cows (A), which includes an allowance for the dry period, is based on predictions from the computer program CamDairy (see Chapter 11). These show that the ratio of dry matter consumption per annum to milk production per lactation varies between 1.2 and 0.8 where the average lactation yield is 4200 and 8400 litres respectively. The average ratio of 1.0 is used in the above calculation.

Annual dry matter consumption by replacement stock (B) is based on predictions from the computer program GrazFeed (see Chapter 11). These show that, in order to achieve an average growth rate on pasture of 0.6 kg/day between three and 24 months, dry matter consumption is 4.6 tonnes or 2.3 tonnes per annum.

Costs of pasture production per hectare, including conservation, can then by divided by forage consumption per hectare. This is important information that can be used in benchmarking to help identify weaknesses in the system.

Kellaway (1991) calculated that, with irrigated annual pastures in NSW, the cost of pasture eaten was $118/t DM, a figure comparable with the price of cereal grains at that time. This was based on cows grazing 6.8 t DM/ha/year, which was only 40% of likely pasture production. When pasture use is improved to 10 t DM/ha/annum, the cost of pasture eaten would be reduced to $80/t DM.

DRDC (1996) reported benchmark studies on 89 dairy farms in western Victoria. They found that average pasture consumption was 5.4 t DM/ha/annum, the cost of which was $107/t. Dairy Farmers (1997) published a Farm Benchmarks guide that did not consider the cost of pasture eaten. Subsequently, Dairy Farmers did consider the cost of pasture eaten in an analysis of 56 northern coastal dairy farms in NSW for 1998/1999. They found that average pasture consumption was 7.5 t DM/ha/annum, the cost of which was $129/t DM (Dairy Farmers 2000).

Potential DM production under irrigation would greatly exceed the above estimates of pasture eaten. The more efficiently pasture is used, the cheaper it becomes. Farmers should aim for a minimum of 60% pasture grown being consumed to maximise profits. This can be achieved by increasing stocking rates. Optimum levels of utilisation are dependant on pasture types. With tropical pasture and mature temperate pastures, it is difficult to get cows to graze more than 60% of pasture offered due to the high stem content of the swards.

The nutrient content of cereal grains and other types of concentrate is usually much less variable than that of pasture. More information is available on the nutrient content of concentrates than on pastures. Only when the true cost of all potential feeds is known, together with their nutrient content, will it be possible to make rational decisions about the feeding management of dairy cows.

Kellaway *et al.* (1993) estimated the energy, protein and mineral content of pasture actually consumed by cows on a commercial dairy farm in NSW. Nutrient deficiencies of energy, protein, calcium, phosphorous, magnesium, sodium and copper were identified at certain times of the year, which could be met by strategic supplementary feeding of concentrates.

Follow-up studies were conducted on research stations in Victoria, results from which were collated by Wales and Jenkin (1997). Only one of the 12 papers cited reported on the mineral content of pastures and no studies were carried out on commercial farms. Relationships were established between pasture allowances, pasture type and differential selection in relation to energy, crude protein and neutral detergent fibre only (Wales *et al.* 1998).

Subsequently a study was carried out on commercial farms in western Victoria (Jacobs *et al.* 1999). Nutrient deficiencies of energy, protein, calcium, phosphorus and sodium were identified at particular times of the year. A study on commercial farms in northern Victoria (Stockdale *et al.* 2001) was restricted to energy, protein and fibre. These observations were combined with a large body of data from research stations to produce equations for predicting the energy, protein and fibre content of pastures from the season, month within the season, pasture mass and botanical composition. It would be valuable to validate these equations against independent data, and to develop equations for predicting the content of major minerals in pasture.

Clearly there is a need for more information on the cost of pasture actually eaten and the variation that occurs in its nutrient content including minerals. Ideally, this informa-

tion should be collected for each farm. Alternatively, the type of equations developed by Stockdale *et al.* (2001) should be extended to include major minerals and other geographical areas. Until such information is available, it is not possible to have an accurate basis for determining the cost effectiveness of feeding concentrates.

Apart from the major issue of the price ratio between pasture and concentrates and the differences in their respective nutritive values, the most suitable feeding strategy will vary depending on the reliability of pasture quality and quantity throughout the year, calving pattern and milk payment system.

Operation Milk Yield, carried out in Victoria in 1982–1985, examined two different concentrate-feeding strategies applicable to the seasonal calving pattern in that state. The first involved increasing stocking rate to increase production per hectare, and the second looked at the effects of feeding in mid- to late lactation to improve per cow production. Responses are discussed below.

On the tropical pastures in northern NSW and Queensland, where dairy herds are calved all year round, energy deficiency is more likely to be a problem throughout lactation. This may require concentrate feeding for the whole of lactation with or without an increase in stocking rate. Possible feeding strategies and their benefits are outlined below.

Technical review

Increasing stocking rate

To maximise intake by a high producing cow, she must be offered pasture in excess of three times her appetite. While this enables high per cow production, it is wasteful of pasture and results in low production per hectare. It is also detrimental to pasture quality, decreasing sward density and photosynthetic efficiency (Trigg *et al.* 1985). These effects were quantified on ryegrass/clover pastures by Dalley *et al.* (1999) who offered grazing cows 20–70 kg dry matter/cow/day. As herbage allowance increased, dry matter (DM) intake increased curvilinearly from 11.2 to 18.7 kg DM/day, herbage utilisation decreased from 54% to 26% and milk production increased from 25.9 to 29.1 kg/cow/day.

Increasing the stocking rate is one way of increasing use of pasture and maintaining pasture quality. However, although this increases production per hectare up to a point, production per cow is reduced. In this situation, concentrates can be added to the diet to maximise pasture use, while still allowing cows to be fully fed, therefore, maintaining or increasing production per cow.

Tables 1 and 2 (Chapter 5) show that when high quality pasture is offered to appetite, the response to concentrate supplementation is negligible. This is because supplementation causes a decrease in pasture intake, known as substitution. Increasing the stocking rate restricts pasture availability and allows worthwhile responses to be obtained.

Operation Milk Yield looked at the effects of increasing stocking rate in conjunction with concentrate feeding on four Victorian farms over three years. The benefits of this strategy were:

- increased production of milk and milk fat through:
  - increased cow numbers;
  - increased production per cow.

Combining both factors, the overall response was 1.8 litres milk per kilogram concentrate.

- Improved use of pasture. Increased stocking rates resulted in reduced substitution and less wastage of pasture, and maintenance of pasture quality.
- Increased lactation length. Concentrate feeding increased milk yields in late lactation and extended lactation length by an average of 14 days.
- Increased proportion of milk produced in autumn. In seasonal-calving herds, autumn corresponds with late lactation and is often a time when pasture quantity and quality are low. Premium milk prices are often paid. Concentrate feeding increased the proportion of milk produced in this period and substantially increased the milk income.
- Concentrate feeding gave greater flexibility in pasture management. This allowed grazing rotations to be extended without the problem of underfeeding.

The actual pattern of feeding concentrates varied between farms. Some farmers matched concentrate feeding with pasture availability from day to day. If the cows were not utilising pasture well enough, their concentrate rations were decreased. Other farmers fed at the beginning of lactation, when pastures were poor, ceased feeding in early to mid-lactation when abundant spring pasture was available, and fed again over summer and autumn.

In all cases where stocking rates were increased in conjunction with concentrate feeding, profitability per hectare was increased. The average return on extra capital was 62% (Australian Dairy Corporation 1987). In two instances where there was no intensification of production, income losses were sustained.

Increasing stocking rate is a successful strategy when feeding concentrates. It enables maximum use of pasture, while still allowing increased production/cow. It reduces substitution effects and increases response to concentrate. Computer programmes, such as CamDairy and UDDER, can calculate the economics of concentrate feeding at different stocking rates and concentrate prices. This enables the choice of an optimal stocking rate for each farm.

The extent to which stocking rate can be increased when extra concentrates are fed can be calculated. For example the ME intake of a 550 cow averaging 20 litres/day over a lactation is approximately 180 MJ ME per day or 55 000 MJ ME over a 305 d lactation. Importing an extra 75 tonnes of concentrate (average ME content of 12 500 MJ ME per tonne) onto a farm for 150 cows, and increasing concentrate intakes from 1 to 1.5 tonnes per lactation would equal 937 500 MJ ME. This extra energy that is imported onto the farm should support an extra 17 cows producing 20 litres/cow/day, provided that pasture production is not compromised.

Feeding concentrates in times of pasture shortage

In Victoria, many herds calve in late winter. Therefore, they are able to make good use of the abundant high quality spring pastures in early lactation. The term 'high quality' usually refers to digestibility or energy content, and does not necessarily imply a good balance of nutrients. Young vegetative pasture often has a surplus of protein in relation to animal requirements, and energy is wasted in its excretion. Over much of summer, autumn and

winter, both pasture quantity and quality may be inadequate. It could be beneficial to feed concentrates through mid- to late lactation to fill this gap in pasture supply. This strategy was examined on three Victorian dairy farms during Operation Milk Yield (1982–1985). The advantages of this strategy were:

- Increased production per cow in mid- to late lactation, with an average response of 1.2 litres milk per kilogram concentrate fed.
- Increased lactation length. Lactation was extended by an average of 23 days allowing cows to continue milking until better pastures were available following the autumn break.
- Increased proportion of milk produced in autumn when premium prices were paid.

Thus, feeding concentrates to seasonal-calving herds in mid- to late lactation increases yearly production through greater production per cow and increased lactation length. The profitability relies on the fact that milk prices are higher at this time. Over the trial, the average return to extra capital was 9%. Consequently this strategy was far less profitable than one in which stocking rates were also increased.

Feeding concentrates throughout lactation

Tropical pastures are energy deficient. To allow high levels of production it may be necessary to feed concentrates throughout lactation. Davison *et al.* (1985) noted that most Queensland dairy farmers fed high energy concentrates at a flat rate for the whole of lactation. This strategy can be combined with increased stocking rates to enable better pasture use. Cowan *et al.* (1977) calculated that pasture that supported cows at a stocking rate of four cows per hectare without any supplementation would support five cows per hectare when they were fed 4 kg/cow/day of concentrate. This intensification of production would decrease substitution, increase milk yields and allow good responses to concentrate.

Pattern of feeding

The greater the frequency of feeding concentrates through the day, the less the chance of disrupting rumen function and reduction in forage intake associated with depression in rumen pH. The ideal way of minimising this effect is to feed a total mixed diet. However, where it is more economic to operate a grazing system, cows are usually fed at milking time. McLachlan *et al.* (1994) found that milk production was 11% higher when feeding concentrates twice daily compared with feeding once daily.

The periods during which concentrate feeding may be beneficial have been established. Several experiments have examined whether the pattern of feed allocation within this period influences the response. These experiments compared three systems of feed allocation:

- Flat-rate feeding;
- Feeding biased towards early lactation;
- Individual feeding according to yield.

The distribution of supplementary feed throughout lactation influences the shape of the lactation curve (Broster and Thomas 1981; Johnson 1983). Cows fed according to yield have higher peak yields, and decreased persistency of yield compared with cows on a flat

rate of feeding. This is because reducing the feeding level in line with decreasing yields in late lactation has a compound effect that further depresses production (Broster and Thomas 1981).

> *The interesting point is that the difference in distribution of milk production throughout lactation results in little difference in total lactation yields. The lower peak yield seen with flat-rate feeding is compensated for by greater persistency of yield in later lactation* (Broster and Thomas 1981).

Ostergaard (1979) examined eight different feeding patterns over three levels of concentrate. He concluded that there was little difference in total milk yield when cows were fed the same total amount of supplement. Moisey and Leaver (1985) compared a flat rate of feeding, common for all cows, with a flat-rate based on cow potential. Again, no significant differences between treatments were observed. Johnson (1983) obtained similar results when comparing a graded system of feeding with flat rate feeding.

Davison *et al.* (1985) compared four patterns of maize allocation to cows grazing tropical pastures and found no statistically significant differences between treatments. However, there was a trend to increased production, above that of flat-rate feeding, when maize allocation was biased towards early lactation. However this trial involved only four cows per treatment.

On the basis of the above, it appears that pattern of feeding has little effect on total lactation yield. However, Leaver (1988) found that different feeding patterns only resulted in similar milk yields when conserved forage was offered to appetite. When restricted forage provided the basal ration it was preferable to allocate concentrates according to yield. *In conclusion, flat rate feeding is the simplest and cheapest system to implement. The flat rate for the whole herd is likely to vary with changes in pasture quantity or quality, or problems of access to pastures due to heavy rain or re-seeding.*

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Measurement of milk responses to supplementation

Summary

- Measurement of milk responses is used to determine the potential economic benefit of feeding supplements.
- Cows may respond quickly or slowly to supplementary feeding, depending on their genetic potential, their body condition, the quantity and quality of both the main feed supply and the supplement, and the stage of lactation.
- Milk responses to energy and protein supplements are often curvilinear, not linear.
- Immediate, cumulative and residual milk responses can be identified.
- Long-term experiments give a more realistic assessment of the benefits of supplementary feeding by taking into account long term effects on body condition and body weight, which affect milk production.

All these factors should be considered when assessing the economic benefits of feeding supplements.

Introduction

Many factors influence responses to supplementation and responses change over time. This chapter describes the various ways responses are measured and the terms that are used in describing them. This knowledge is basic to an understanding of the research referred to elsewhere in this publication.

Broster (1972) noted that the response to supplementation in terms of milk production was curvilinear, with 60–70% of the effect present after seven days and the full effect recorded after 12 to 14 days (Figure 1a).

When investigating response to supplementation of heifers in early lactation, Broster *et al.* (1975) again found a rapid build-up of response over the first two weeks of supplemen-

tation, with a further development of the response in the next six to eight weeks of feeding (Figure 1b).

B. A. Hamilton (personal communication) recorded a similar curvilinear change in response with time, to the feeding of 3 kg of cracked sorghum per day to cows in early
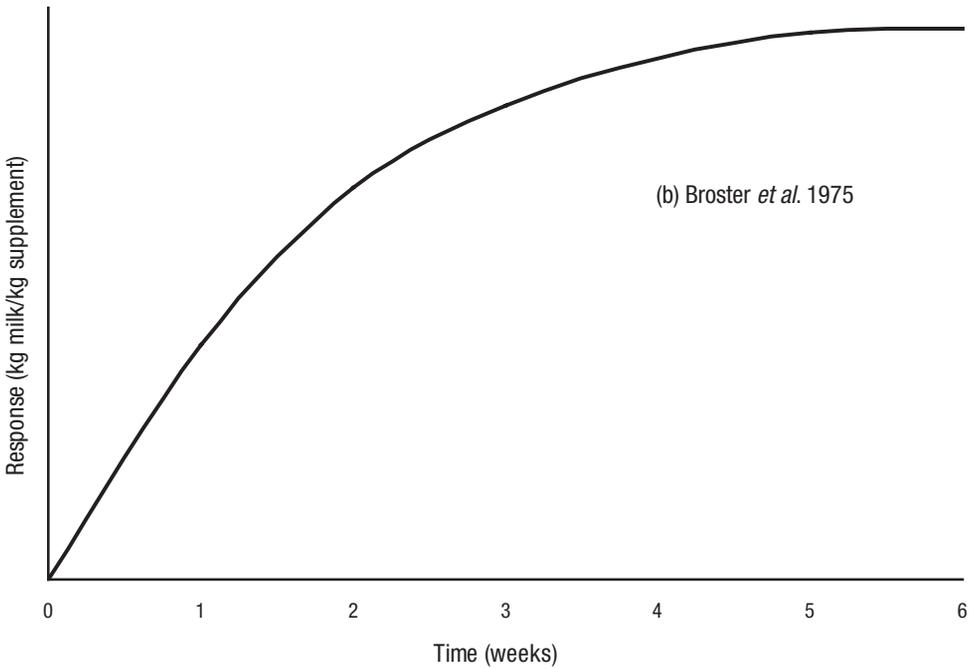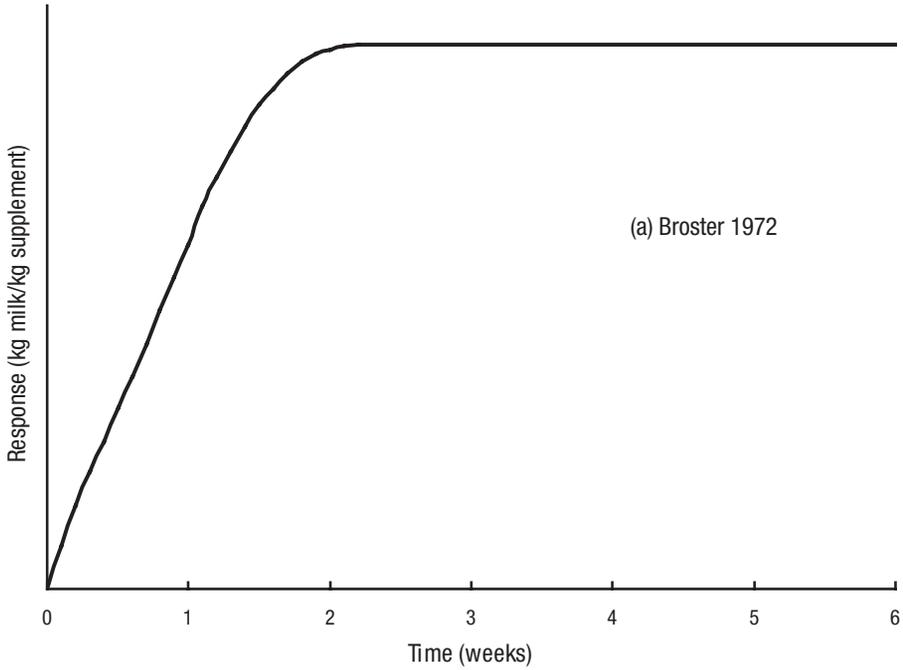
Figure 1(a) and (b). Representations of change in response in time in two experiments.

lactation. However, the build-up of response was much slower with only 30% of the maximum recorded response present within one week, 50% present after two weeks and the full effect developing over nine weeks (Figure 1c).
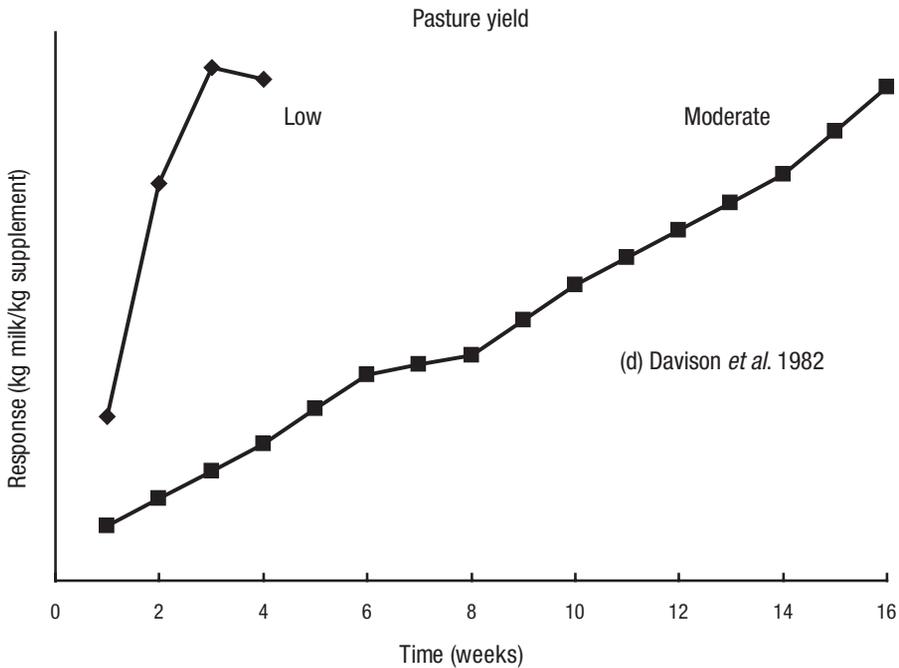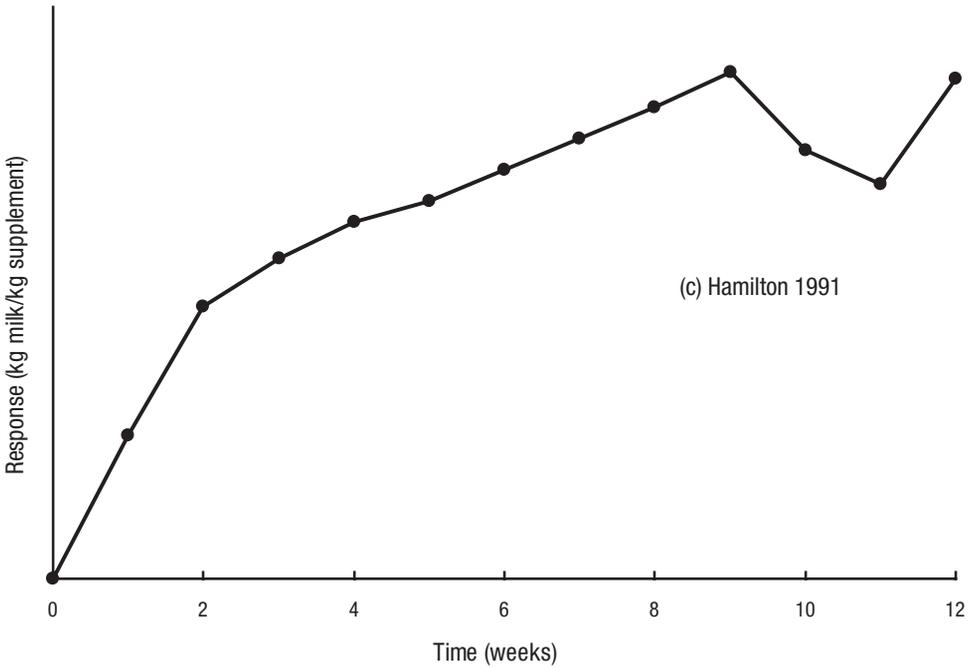
Figure 1(c) and (d). Representations of change in response over time in two experiments.

Davison *et al.* (1982) examined the change in milk response over time to supplements of molasses and grain at various levels of pasture allowance. Cows grazing pasture with less than 3000 kg DM/ha took four weeks to reach a response of 1.0 kg milk/kg supplement, while those on pasture of more than 3000 kg DM/ha took up to 16 weeks to achieve the same response (Figure 1d).

The factors that determine the variation in response shown in Figure 1 include:

- Body condition score;
- Stage of lactation;
- Length of time from the start of feeding to the time of measurement;
- Pasture allowance and quality;
- Quantity and quality of supplement fed;
- Genetic potential of the cow.

These factors can be incorporated into three major categories, which interact to vary the response:

- Net energy supplied by the extra feed;
- Balance of nutrients in the whole diet;
- Partition of nutrients between milk production and body condition.

The following definitions are important in discussing the milk production response to supplementary feeding.

Changeover period

The changeover period is a lag phase in the milk response when a supplement is introduced into the diet. This is due to:

- Changes in rumen microflora;
- Changes in hormonal responses;
- Changes in grazing behaviour;
- Time taken for the supplement to be digested and absorbed.

On the basis of experiments by Blaxter (1956) and Broster *et al.* (1975), Broster and Broster (1984) suggested a changeover period of 14–21 days, during which time the response builds up rapidly and stabilises. Leaver (1988) also considered that changes in rumen microflora were complete and a full milk yield response seen within two weeks.

These observations suggest that a changeover period of at least two weeks is desirable. However, the exact time required would be a matter of judgement based on the extent of the change being imposed. A much longer changeover period would be needed for a cow when first given 10 kg supplement per day compared to one fed 2 kg per day.

The immediate response

The immediate response is the increase in milk production recorded soon after introducing a supplement. It is the result of the total quantity of nutrients absorbed and the way in which these nutrients are partitioned between milk production and liveweight gain. The size of the immediate response is also influenced by the stage of lactation. It is greatest in

early lactation, when there is a natural tendency for the animal to partition energy towards milk production, and it decreases with time from calving because of increased partitioning to liveweight gain (Figure 2).
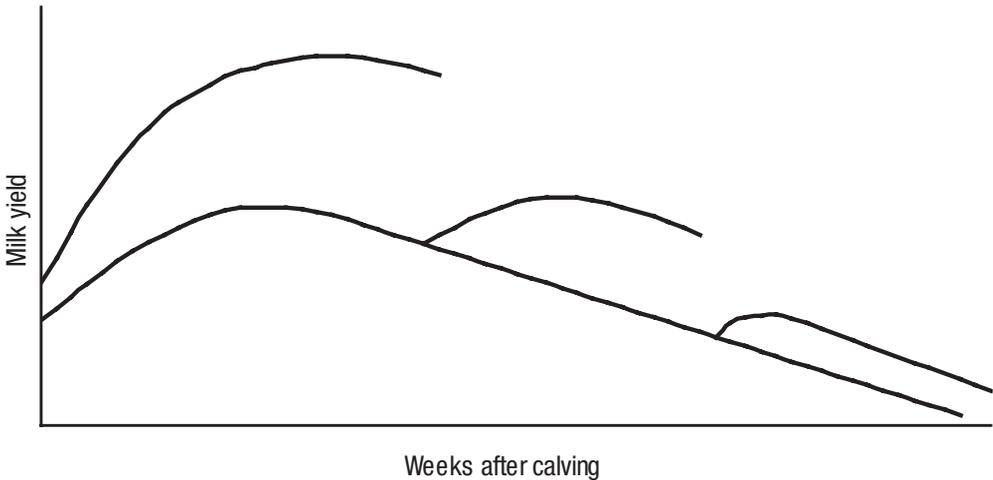
Figure 2. Stylised milk yield response to fixed increments of supplementary feed at various times during lactation (Broster 1983).

Considering that response changes with time, some consistency is required in measuring the immediate response. If we allow for a changeover period of two to three weeks, the immediate response can then be defined as *the average increase in milk production per kilogram of concentrate recorded in the next one to two weeks of supplementation*. This period should be long enough to achieve reasonable precision in measuring the response.

Cumulative response

As the period of feeding continues, the magnitude of the response may change, defined as the 'cumulative response' by Broster and Broster (1984). Usually the cumulative response is calculated as an average response over a given time. When measurements are taken over consecutive periods, the development of the response can be determined.

A number of suggestions have been put forward to explain the cumulative response:

- *Cumulative response may be due to an increase in body condition, from below average.* This would favour an increasing partition of nutrients from body tissue to milk production. Grainger *et al.* (1982) found that cows calving in body condition score 6 partitioned more body energy to milk than cows calving in condition score 3. B. A. Hamilton (personal communication) (Figure 1c) confirmed that when cows with condition score 4 calved there was a cumulative milk response to a supplement as liveweight and condition score improved.

- *Supplementation causes a decrease in pasture intake (substitution).* This means pasture can accumulate during a period of supplementary feeding because it is not being so heavily grazed. Consequently, pasture availability increases while the substitution effect lasts.

- *Substitution rate tends to decrease over time.* Cowan (1982), referring to the response curve in Figure 1d, suggested that at first there is a high substitution of concentrate

for pasture where pasture availability is high. This means that initially there is only a small response to supplementation, but this changes as the cows' appetites increase and they seek additional dry matter (DM), which leads to an increased response. A similar reduction in substitution rate with time was found in grazing studies in Victoria. However, this was attributed to progressive reduction in pasture availability as the season progressed (Stockdale 1999b). There were no differences in substitution rate between cows fed 5 kg concentrates per day for long or short periods.

- *Supplements can stimulate the development of secretory tissue in the udder in early lactation.* This leads to increasing milk response to the supplement.

Residual response or carryover effect

The terms 'residual response' and 'carryover effect' are interchangeable. They are used to describe *any additional milk production response that occurs after the supplementary feeding ceases.* This is likely to be a result of the following:

- Improved body condition allowing a greater proportion of energy to be partitioned towards milk production (Holmes and Wilson 1984).
- The availability of extra pasture that has accumulated during the feeding period because of substitution of concentrate for pasture (Rogers and Savage 1983).

In two recent experiments in New Zealand (Penno 2002), the carryover effect, measured in the four weeks after supplementary feeding ceased, was half the immediate effect. Clearly it is important to consider both the immediate and carryover effects when determining the economics of supplementary feeding.

Total response

The total response can be calculated in two ways:

- Total increase in production – measured throughout the whole lactation – of cows receiving supplementary feeding over those not receiving supplementary feeding. The total response is equal to the area under the response curve.
- Average response over the feeding period, plus the average residual response.

Marginal response

The marginal response is the increase in milk production from the last increment in supplementary feed.

It is widely recognised that responses in milk production to incremental increases in energy intake above maintenance are not constant. A curve of diminishing returns often applies, due to increasing partition of nutrients from milk production to body tissue.

The possibility of diminishing returns is ignored in major feed requirement systems (MAFF 1975; ARC 1980; NRC 1989; INRA 1989; AFRC 1993; NRC 2001).

This is unfortunate because, as Blaxter (1966) pointed out, prediction of the marginal response in milk production to marginal increases in energy is of critical importance in determining the most profitable level of feeding.

Curves of diminishing returns to energy are incorporated into the computer model CamDairy. The curves (Figure 3) are based on analyses of a large scale feeding trial in the USA, in which cows were fed metabolisable energy for production at levels from 30–210 MJ/day (Jones 2003).
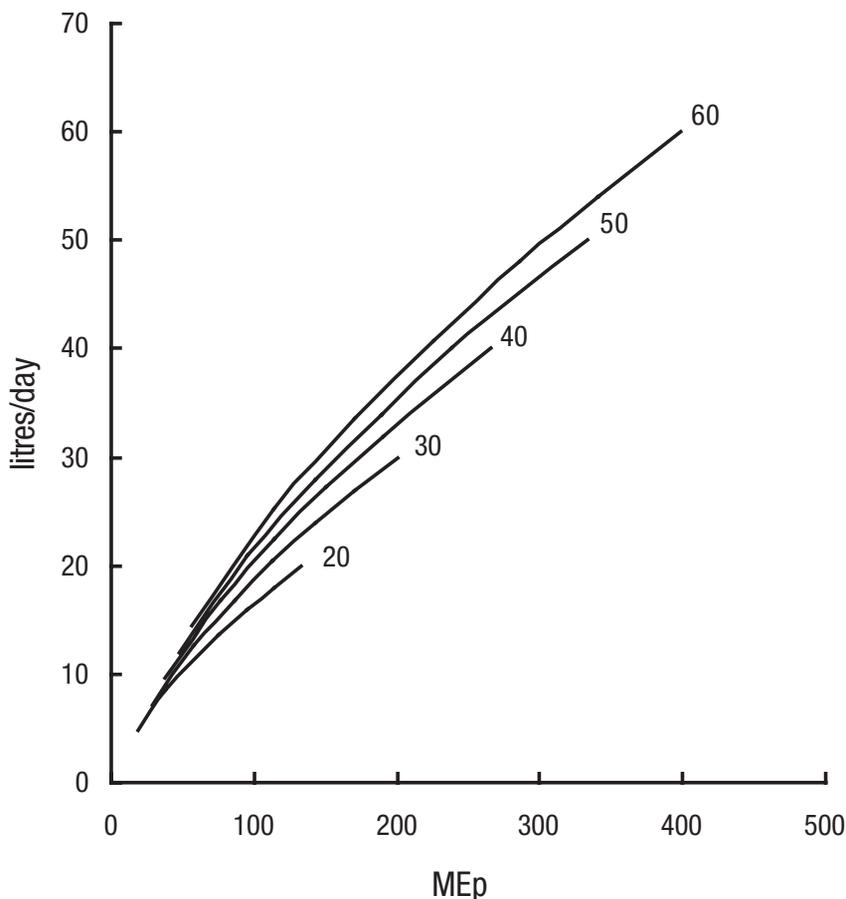
Figure 3. Relationship between metabolisable energy above maintenance (MEp) and milk production for cows with a range of milk production potential. Calculated from Jones (2003).

Short-term versus long-term experiments

The literature documenting milk responses to supplementation can be divided into two broad categories – short-term trials and long-term trials.

Short-term experiments are usually of a type known as the changeover design; its variation, the Latin Square design; or simply a continuous treatment over a period of one to two weeks.

In the main, short-term experiments have focused on mid-lactation. While they are suitable for measuring the immediate response in milk yield, they are usually too short to assess the cumulative and residual effects attributable to improved body condition and residual pasture.

Long-term experiments usually cover a whole lactation, or the greater part of it, and provide much more useful information than shorter trials. They allow the immediate, cumulative and residual effects of the supplement to be estimated, as well as any changes brought about over time by the treatment (Broster 1972).

In Australia, short-term experiments measuring immediate responses over varying periods have given average values of 0.5 kg milk per kg supplement (Rogers 1985). This is consistent with the 0.3–0.6 litre per kg response range reported by Davison and Elliott (1993) for short-term experiments of less than two months duration.

In contrast, long-term experiments – including both immediate and residual responses – have given average values of 1 kg milk per kg supplement (Cowan and Davison 1983). A direct comparison of long term versus short term feeding of 5 kg/day of concentrate in a single experiment confirmed that responses are greater in the long term than in the short term (Stockdale 1999a), which was attributed to poor body condition in long term unsupplemented cows. Davison and Elliott (1993) suggested that even long studies underestimate the responses achieved in whole-farm investigations.

Whole-farm input-output studies reveal responses of 1.0–1.4 litres milk per kg grain (Davison and Elliott 1993). Stockdale *et al.* (1997) propose that the improvement in response in the whole-farm studies compared with single lactation projects is primarily associated with the effects of supplementation on body condition and, hence, performance in subsequent lactations.

It appears that for set feeding systems (recipe farming), with continuous supplementation, whole-farm studies are likely to provide the most accurate prediction of response. However, where prices received for milk varies throughout the year and opportunistic or tactical supplementation is used, short-term studies can provide an appropriate guide to expected responses. The determination of long-term effects is nonetheless important as there is a trend to feeding increasing quantities of supplements over a lactation (Stockdale *et al.* 1997) in both year-round and seasonal production systems.

4

Energy supplements

Summary

- Supplements that provide extra energy to the cows' diet can increase milk production by 1.0 kg milk/kg supplement in the short term, and more than 1 kg milk/kg supplement in the long term, depending on pasture quality and availability.

- Energy supplements typically increase milk protein content and allow cows to gain more, or lose less body condition than unsupplemented animals.

- When high quality pasture is available to appetite, responses to supplementation are minimal. However, when animals are restricted in their intake of good quality pasture, or the pasture is of poor quality, much larger production increases to supplementation are possible.

- Although the cereal grains vary widely in their energy and protein contents, they produce similar responses when fed at low levels (less than 4 kg/cow/day).

- At high levels of grain feeding, the differences between grains become more important. The higher fat and fibre levels in oats may result in greater fat-corrected milk yields and milk fat content.

- Differences in fermentation rates between and within cereal grains may cause differences in substitution rates and milk responses when grains are fed at high levels.

- Fermentation of starch in the rumen probably is preferable to digestion of starch in the intestines.

- Molasses produces a response about 70% of that of the cereal grains for equal amounts on an as-fed basis.

- A wide range of by-products is suitable for inclusion in dairy feeds. Brewers' grains, citrus pulp and mill mix are regularly fed in dairies close to food processing centres. Whole cottonseed has a good balance of energy, protein and fibre and is widely fed.

- With the exception of oats, there are benefits to be gained from processing cereal grains before feeding.
- Grain processing increases its digestibility and improves starch utilisation.
- The optimal method of processing varies with the grain type.
- Sodium-hydroxide treatment may give production benefits, but problems in handling and storing treated grain can limit its use.
- Ammonia treatment of grain may be a better alternative, but it has yet to be investigated with dairy cows.
- Steam flaking can greatly increase the milk response when feeding sorghum, but it is unlikely to be cost effective.
- Pellets offer several advantages over concentrate meal, particularly at high levels of feeding when feed-mixing facilities are not available on the farm. In addition, the nutritional specification of the pellets can be adjusted to suit the forages available.

Introduction

In the pasture-based dairy industry of Australia, insufficient energy is usually the major limiting nutrient to milk production. Energy deficiencies due to insufficient pasture or pasture of low energy density are common occurrences. Energy-rich supplements, both forage and concentrate, are used to increase production by overcoming this deficiency.

Cereal grains are the main source of energy supplement. The price ratio of milk to cereal grain is an important factor in judging whether it is economic to supplement the dairy cow's diet in this way. For example, with a milk price of 28 cents/litre and a cereal grain price of 14 cents/kg, the milk response would have to be greater than 0.5 l/kg to cover the feed cost. On the basis of experiments reviewed in this chapter, milk responses frequently are larger than 0.5 l/kg, particularly in the long term.

Scientific measurement of the nutrient content of feeds

Energy content of feeds is expressed in terms of metabolisable energy (ME) in units of megajoules (MJ) per kilogram of dry matter (DM), thus MJ ME/kg DM, which is sometimes abbreviated to M/D.

In practice, energy is often defined in terms of digestibility. This may be expressed as

- Organic matter digestibility (OMD)
- Dry matter digestibility (DMD)
- Digestible organic matter in dry matter (DOMD).

The most accurate measure of digestible energy is DOMD, which can be converted to M/D, assuming a constant energy value for digested organic matter (19 MJ/kg) and constant energy losses of methane and urine as a proportion of digested energy (0.19). However, the energy value of DOM varies with its content of protein and fat, and urine and methane losses vary between feeds. The recommended equation for predicting M/D in feeds other than oilseeds and other high-fat feeds is:

$$M/D = 0.18 \text{ DOMD\%} - 1.8 \qquad \text{SCA (1990)}$$

Rogers and Clarke (1981) measured differences in digestibility of dry matter and nitrogen between sheep and cattle and they found that DMD was higher for sheep than cattle in five out of six pastures. However, in most cases the cattle were fed at more than double the rate for sheep per unit metabolic size. Since digestibility is depressed with increased intake (though the extent of the depression is less with feeds of high digestibility) this depression will have distorted the results of the experiment.

When cattle and sheep were fed at similar low levels of intake (1.26% of liveweight), estimates of energy digestibility were only slightly lower in cattle with diets containing 20, 45 and 70% concentrate (Colucci *et al.* 1989). This suggests that digestibility measurements with sheep may be applicable to cattle provided that sheep are fed at a maintenance level.

The intake of dairy cattle may be three to four times that required for maintenance. Whilst faecal losses increase with intake level, methane and urine losses decrease as a percentage of gross energy (Blaxter 1962). The resulting decline in metabolisable energy per unit change in feeding level is about 1% unit (Van Es 1975). The effect of this is a reduction of 0.5 M/D for an increase in feeding level from maintenance to four times maintenance. Many cows in Australia are fed at levels of intake that are only two to three times maintenance, so that the bias is smaller than 0.5 M/D.

On the basis of the evidence presented, it appears reasonable to apply values for energy content for feeds determined with sheep fed at maintenance, to dairy cows fed at up to four times maintenance, using a maximum correction factor of -0.5 M/D. This should be checked in feeding trials.

Routine measurement of digestibility *in vivo* is expensive. Cheaper and quicker laboratory methods are required. Kitessa *et al.* (1999) reviewed the range of chemical, *in vitro* and *in situ* techniques used to predict digestibility. They concluded that *in situ* digestion of feed samples in the actual rumen environment is probably the most accurate of the indirect techniques, but is unsuitable for routine application. The preferred procedure is pepsin-cellulase digestion *in vitro* provided that amylase is included or high temperature digestion is used for samples high in starch content. Prediction from chemical composition is not recommended. Measurements with the *in vitro* or *in situ* technique can be used to develop calibrations for analysis by near infrared spectroscopy (NIR), a technique that is unsurpassed for speed and repeatability.

The Department of Primary Industry at Hamilton in Victoria uses NIR to predict ME, crude protein, NDF and oil in concentrates, and ME, crude protein and NDF in forages. The mineral content of feeds should be analysed by wet chemistry methods for reasonable accuracy, and these are much more expensive than NIR. However, NIR calibrations can be developed to predict the content of major minerals in pastures, and this is under development at the Hamilton laboratory.

Whilst it is attractive to have a single assay to assess the nutritional value of grains, van Barneveld (1999) pointed out that so many factors affect the nutritional value of grains, that no single assay is adequate. For example, access by rumen bacteria to starch granules can be limited by grain protein in some grain species, and by grain fibre in other grain species. Also the lipid content of grain can have a negative effect on rumen fermentation.

There is a small but increasing demand for information on the fermentation characteristics of protein and carbohydrate fractions in feeds, in order to supply inputs for semi-mechanistic feeds models such as CNCPS (Fox *et al.* 1992). When input data on

fermentation characteristics is provided, this model has the potential to make more accurate estimations of feed energy and protein available to the animal than is possible from the more conventional feed analysis data cited in Table 4. Whilst some data has been collected on fermentation characteristics of pastures and concentrates in Australia (Wales *et al.* 1999a; Granzin 2003c), it has yet to be used to develop NIR calibrations for practical application.

Types of energy supplements

Traditionally, energy supplements have been based on cereal grains that include barley, sorghum, wheat, oats, maize, rye and triticale. Some feed suppliers sell mixtures of processed grains, with and without mineral supplements. Lupins have a similar energy content to cereal grains and about three times the protein content. Molasses is a very popular energy source for cattle grazing tropical pastures in northern NSW and Queensland. By-products such as brewers' grain, rice pollard and mill mix increasingly are being used in areas near food processing centres, and more recently there has been interest in the use of fats to provide high density energy supplements for lactating cows.

Technical review

Response to energy supplements

Energy supplements normally increase the absorption of volatile fatty acids from the rumen, provided that intake of forage is not unduly depressed by a substitution effect. During anaerobic fermentation of carbohydrates in the rumen, volatile fatty acids are produced, and energy is generated in the form of adenosine triphosphate. This energy is used for the maintenance and growth of rumen microbes. The microbes provide amino acids to the host animal when digested post-ruminally.

The rate of growth of rumen microbes is determined by the availability of substrates (ammonia, sulphur and minerals) and adenosine triphosphate. If there is an imbalance between the supply of substrates and adenosine triphosphate, ammonia is absorbed and excreted as urea. This can happen on high protein diets such as nitrogen-fertilised grasses or legume forages, particularly in the form of silage. In silages, some of the carbohydrates have already been fermented to volatile fatty acids that do not provide energy for rumen microbes. Thus silages provide less adenosine triphosphate in the rumen than the original forage. In the course of digestion of feeds, microbes are washed out of the reticulo-rumen and onto the lower digestive tract. As well as containing energy, they also contain protein, which can be digested. This is commonly referred to as microbial protein.

When there is a deficiency of adenosine triphosphate, feeding a readily fermentable carbohydrate source, such as a cereal grain, should increase the rate of adenosine triphosphate production in the rumen and increase the flow of microbial protein from the rumen provided the supply of other nutrients for microbial synthesis is adequate. Thus the energy supplement provides an increase in supply of both energy and protein to the animal.

This has been demonstrated by Cohen (1997), who found that when cows were fed white clover silage, a supplement of crushed barley grain reduced nitrogen losses in urine and faeces, and increased milk yields. Milk yield was increased more when the grain was fed hourly than when it was fed twice daily, presumably due to less disruption of rumen pH, which was not reported.

Numerous trials have been conducted to measure the responses to feeding energy supplements. These have included both short and long-term experiments, with cattle grazing tropical and temperate pasture, and have covered various stages of lactation. The Australian experiments are summarised in Tables 1, 2 and 3.

The majority of experiments have been short-term trials measuring only the immediate response to supplementation. Where experiments were carried out over whole lactations or where measurements continued after feeding ceased, it was found that responses were greater in the long term than the short term.

Table 1 shows responses to cereal grain supplementation of cows in early lactation grazing high quality temperate pastures. The greatest responses were obtained when pasture was restricted and, in this situation, the average immediate response was 0.6 kg/kg supplement. Where high-quality pasture was available to appetite there was no response (Robinson and Rogers 1983) or a negative response (Hodge and Rogers 1984) to provision of a supplement.

Residual responses were recorded by Thomas *et al.* (1980) and Rogers and Robinson (1981) following supplementation of cows in early lactation. This resulted in total responses, over the whole lactation, of 2.5 kg/kg and 1.1 kg/kg supplement, respectively.

Robinson and Rogers (1983) found no residual response when cows previously on restricted pasture were fed pasture ad lib following supplementation. Again, no residual response was noted by Hodge and Rogers (1984), Dobos *et al.* (1987) or Robinson and Rogers (1983, pasture to appetite) when there was little or no response during the feeding period.

Table 2 summarises the responses to cereal grain feeding for cattle grazing temperate pastures in mid-lactation to late lactation. In seven experiments on pastures of good or high quality the average immediate response was 0.6 kg milk/kg grain. In four experiments on pastures of poor quality (M/D < 9.0), the average immediate response was 1.1 kg milk/kg grain.

The effect of stage of lactation between Tables 1 and 2 is confounded with pasture quality, because all the experiments were conducted in Victoria with cows calving in spring on good quality pastures (Table 1). By mid-lactation, most cows were grazing poorer quality pastures (Table 2), with the exception of the experiment of Wales *et al.* (2000b). The effects of pasture quality and pasture allowance on response to supplementation are discussed more fully in Chapter 10. The presence or absence of a residual response in mid- to late lactation was not investigated in any experiment.

In addition to feeding cereal grain at 6.0 kg/day, Wales *et al.* (2000b) (Table 2) fed hay at 0.5–3.0 kg/day to test the hypothesis that energy supplied as barley grain to cows grazing high quality irrigated pasture would be used inefficiently because of a lack of fibre in the total diet. Their results did not support this hypothesis. Cows in the barley-only treatment were able to maintain pasture intake, and the feeding of hay resulted in the substitution of hay for pasture. Milk production and milk composition were not improved by the feeding of hay. A similar conclusion was reached by Wales *et al.* (2001) when a cereal grain pellet was fed at 5.0 kg/day. Peyraud and Delaby (2001) conducted a review of experiments on responses to concentrate feeds, by grazing dairy cows. They found that the average response was 0.66 kg milk/kg concentrate in experiments published before 1990 and 0.89 in experiments published after 1990. The difference they attributed to increase in genetic merit of

Table 1. Summary of experiments measuring the response to cereal grain supplements fed to cows in early lactation grazing temperate pasture.

Reference	Basal ration	Length of feeding period	Supplement		Immediate response (per kg supplement)			Length of experiment	Total response (per kg suppl.)		Residual response (per kg suppl.)
			Type	Amount fed (kg/cow/day)	Milk yield (kg)	Milk fat (g)	Milk protein (g)		Milk yield (kg)	Milk fat yield (g)	Milk yield (kg)
Thomas *et al.* 1980	Restricted, temperate pasture	5 weeks	Whole oats	4.2	0.69 P<0.05	7.5 NS	–	20 weeks	2.5 P<0.05	86.8 P<0.05	–
Rogers & Robinson 1981 (average over 7 expts)	Restricted, temperate pasture	~ 8 weeks	Crushed oats	3.0	0.54	17	–	Whole lactation	1.1	48	–
Moate *et al.* 1984	Limited, high quality ryegrass/white clover pasture	–	Crushed oats	2.2	1.0 P<0.05	23 P<0.05	–	–	–	–	–
Robinson & Rogers 1983	Restricted, high quality pasture (15 kg DM/cow/day) ad libitum weeks 6–10; 78% DMD	5 weeks	Pellets (72% DMD)	4.0	0.5 NS	0.6 NS	20 NS	10 weeks	–	–	0*
	Ad libitum, high quality pasture (45 kg DM/cow/day, 78% DMD)	5 weeks	Pellets (72% DMD)	4.0	0 NS	-29 NS	0 NS	–	–	–	0
Hodge & Rogers 1984	High quality ryegrass/white clover pasture ad libitum	–	Crushed oats	4.0	-0.2 NS	-15 NS	-5 NS	–	0	–	0
Dobos *et al.* 1987	Restricted high quality ryegrass/white clover pasture (75% potential intake)	6 weeks	Hammer milled wheat	3.0	0.1 NS	2.2 NS	3.2 NS	–	–	0	–
Wales *et al.* 2001	Restricted high quality ryegrass/white clover pasture (72% potential intake)	40 days	Pelleted cereal grain	5.0	1.0 P<0.05	29.6 P<0.05	42.8 P<0.05	40 days	–	–	–
					Average: 0.6 (restricted pasture)						*Ad libitum pasture weeks 6–10

Table 2. Summary of experiments measuring the response to cereal grain supplements fed to cows in mid- to late lactation grazing temperate pasture.

Reference	Basal ration	Length of feeding period	Supplement		Immediate response (per kg supplement)		
			Type	Amount fed (kg/cow/day)	Milk yield (kg)	Milk fat yield (g)	Protein (g)
Hodge & Rogers 1982	Limited pasture (50% ME req.) 64% DMD, 12.3% CP	3 weeks	Pellets 74% DMD, 17% CP	3.3 6.4	0.74 $P<0.05$	27 $P<0.05$	25 $P<0.05$
Hodge & Rogers 1984	Restricted ryegrass/white clover pasture (70% ME req.) 72% DMD, 13% CP + silage, 65% DMD, 11% CP	– –	Crushed oats	4.4	0.28 $P<0.05$	12	–
Rogers & Moate 1981	High quality ryegrass/white clover pasture	–	Crushed oats Crushed oats	2.2 2.2	0.41 $P<0.05$ 0.45 $P<0.05$	7 NS 22 $P<0.05$	– –
Robinson & Rogers 1982	Limited pasture (50% ME req.) 67% DMD, 18% CP + silage (7–12 weeks)	12 weeks	Pellets 11.6 M/D, 7.5% CP	4.0	0.52	22	–
Hodge et al. 1984	Limited pasture, 60% DMD, 16% CP	3 weeks	Whole oats	4.0	0.8 $P<0.05$	36 $P<0.05$	26 $P<0.05$
Stockdale 1999b	30–40 kg/day DM Ryegrass/white clover/paspalum M/D 8.8	5 weeks	75% barley/25% wheat pellet	5.0	1.2	–	–
Stockdale 1999b	30–40 kg/day DM Ryegrass/white clover/paspalum M/D 8.3	5 weeks	75% barley/25% wheat pellet	3.0	1.2	–	–
Stockdale 1999b	30–40 kg/day DM Ryegrass/white clover/paspalum M/D 9.0	4 weeks	75% barley/25% wheat pellet	5.0	1.0	–	–
Stockdale 1999b	30–40 kg/day DM Ryegrass/white clover/paspalum M/D 9.0	4 weeks	75% barley/25% wheat pellet	5.0	1.0	–	–
Wales et al. 2000b	Restricted ryegrass/white clover pasture in autumn. DMD 86 CP 13.4%	34 days	Barley	6.0	0.84 $P<0.05$	30.0 $P<0.05$	32.6 $P<0.05$

Table 3. Summary of experiments measuring the response to energy supplements fed to cows grazing tropical pasture.

Reference	Basal ration	Length of feeding period	Stage of lactation	Supplement Type	Amount (kg/cow/day)	Immediate response (per kg supplement) Milk yield (kg)	Milk fat (g)	SNF yield (g)	Length of experiment	Total response (per kg suppl.) Milk yield (kg)	Milk fat (g)	Residual response (per kg suppl.) Milk yield (kg)
Cowan et al. 1975	Green panic/glycine pasture (average responses over 4 stocking rates)	50 days	Early	Crushed maize	3.6	0.6 $P<0.05$	–	–	Whole lactation	2.3 $P<0.05$	–	–
Stobbs 1971	Tropical pasture	10 days	Mid	Sorghum	4.0	0.5 $P<0.001$	–	–				
Royal & Jeffrey 1972	Kikuyu dominant pasture	14 days	Mid	Crushed maize	2.7	0.5 $P<0.05$	18.5 $P<0.05$	52 $P<0.05$	–	–	–	–
Cowan & Davison 1978a	Restricted green panic/ glycine pasture	28 days	Mid	Crushed maize	3.0	0.8 FCM $P<0.01$	27 $P<0.01$	87 $P<0.01$	–	–	–	0.3 FCM (x) NS
	Ad libitum pasture	28 days	Mid	Crushed maize	3.0	0.3 FCM $P<0.01$	13 $P<0.01$	13 $P<0.01$	–	–	–	0 NS
McLachlan et al. 1991	Tropical grass/legume	56 days	Mid–late	Molasses 2% CP	2.7	0.3 (y) NS	15 $P<0.05$	26 $P<0.05$	56 days	0.3 N	–	–
				Molasses 2% CP + Maize 10% CP	2.6 + 2.5	0.4 $P<0.05$	20 $P<0.05$	39 $P<0.05$	–	0.55 $P<0.05$	–	–
Cowan & Davison 1978b	Restricted green panic/ glycine pasture	6 months	Early–mid	Maize	2.4	0.6 $P<0.05$	29 $P<0.05$	–	–	–	–	–
			Early–mid	Molasses	3.0	0.5 $P<0.05$	20 $P<0.05$	–	–	–	–	–
Chopping et al. 1980	N-fertilised irrigated couch & pongola grass pasture	36 weeks	–	Molasses	1.2	0.9 (z)	–	–	36 weeks	0.8	–	–
			–	Molasses	2.4	0.5	–	–	–	0.6	–	–
			–	Molasses	3.6	0.7 $P<0.01$	–	–	–	0.6 $P<0.01$	–	–
Chopping et al. 1976	N-fertilised irrigated pongola grass pasture	Whole lactation	–	Molasses	3.6	–	–	–	–	0.7	–	–
Rees et al. 1972	Tropical pasture (survey)	Variable	–	Barley equivalent	400 kg/cow/year	–	–	–	Whole lactation	1.1	–	–
Colman & Kaiser 1974	Restricted, N-fertilised kikuyu grass pasture	5–6 months/ year	–	Crushed oats	390 kg/cow/year	–	–	–	2 lactations	0.9	36	–
Reeves et al. 1996	Kikuyu	56 days	Mid	Crushed barley	0.0	–	–	–	–	–	–	–
			Mid	Crushed barley	3.0	1.4	36	–	–	–	–	–
			Mid	Crushed barley	6.0	0.6 $P<0.05$	8 $P<0.05$	–	–	–	–	–
	Kikuyu	12 days	Late	Crushed barley and HCHO sunflower	0.0	–	–	–	–	–	–	–
					3.0	2.0	76	–	–	–	–	–
					6.0	0.8 $P<0.05$	29	–	–	–	–	–
Wales et al. 1999b	Paspalum. Daily allowance 25 kg DM	5 weeks	Mid	75% barley 25% wheat pellet	5.0	1.22	44	–	–	–	–	–
	45 kg DM				5.0	0.96	28	–	–	–	–	–

(x) = high quality pasture; (y) = over first 4 weeks of feeding; (z) = over first 12 weeks of feeding

the cows, with the incremental increase in milk response averaging +0.1 kg/kg concentrate DM every ten years.

Trials with cattle grazing tropical pastures have involved both grain and molasses supplements. Short-term experiments produced an average immediate response of 0.7 kg milk/kg supplement (Table 3). For experiments covering whole lactations, the average response was 1 kg extra milk/kg supplement for the cereal grains, and 0.7 kg/kg molasses. Again, supplementation in early lactation (Cowan *et al.* 1975) resulted in a residual response that gave a total response over the whole lactation of 2.7 kg milk/kg maize fed.

Choice of energy supplement

Cereal grains

A detailed review of the chemical composition of cereal grains and changes that occur during gelatinisation was given by Evers *et al.* (1999). This type of information should be used to gain greater understanding of differences in feeding value of grains and provide a rational basis for the genetic improvement of grains for their animal feeding value.

The feeding value of cereal grains is shown in Table 4. In Table 4, the term dgP% refers to protein degradability in the rumen at a high level of intake, NDF is neutral detergent fibre and eNDF is effective neutral detergent fibre as a percentage of dry matter, which is the portion of NDF effective at maintaining milk fat levels.

It is evident from the data in Table 4 that the levels of energy and protein in the grains can vary widely and, in fact, can vary more within one grain type than between particular grains. This variation makes it difficult to determine the preferred grain in terms of milk response.

Oats are generally considered to have the lowest energy content of the cereal grains, largely due to the higher fibre content of this cereal. Of interest, too, is the fact that the relatively high oil content in oat and maize grains (Table 4) may help to reduce bloat.

All cereal grains are relatively low in protein and fibre contents, with oats having the greatest content of effective neutral detergent fibre of about 9%. Molasses has no crude fibre and a very low protein content of about 4%. Molasses has a very high content of potassium, which in excess can interfere with magnesium absorption.

Rates of fermentation

Slow rates of fermentation are likely to be beneficial by minimising substitution effects at high levels of grain feeding and by reducing the incidence of acidosis.

The fermentation of grain in the rumen and the digestion of starch in the small intestine are influenced by grain characteristics such as non-starch polysaccharides and the protein matrix (Bird *et al.* 1999). There are large differences between and within grains with respect to both susceptibility of grain to microbial fermentation and enzyme digestibility of starch.

Opatpatanakit *et al.* (1994) compared the fermentation rates of several cereal grain species. Their results indicated that the differences between species were large and that the grains could be ranked from the most fermentable to the least in the order: wheat > triticale > oats > barley > maize > rice > sorghum (Table 5). Similarly, Herrera-Saldana *et al.* (1990) found that maize and sorghum are fermented more slowly than the other cereal grains.

Table 4. Nutritive characteristics of some cereals, by-products and grain legumes fed to dairy cows.

Feed	Dry matter (%)	M/D (MJ/kg DM)	Crude protein (%)	Starch %	dgP (%)	NDF (%)	eNDF (%)	Ether extract fat (%)	Calcium (g/kg DM)	Phosphorous (g/kg DM)	Sulphur (g/kg DM)	Magnesium (g/kg DM)	Sodium (g/kg DM)	Potassium (g/kg DM)	Chlorine (g/kg DM)
Cereal grains															
barley	85–90	12.9–14.1	10.8–13.5	56	80	20	7	1.7–2.1	0.5–0.6	3.8–4.4	1.6	1.3–1.8	0.2–0.3	4.7–5.8	1.3
maize	86–90	13.1–14.5	8.0–10.0	70	30–60	13	4	4.2–4.3	0.2–0.3	2.7–4.2	1.2	1.0–2.0	0.1–0.3	3.7	0.6
oats	86–91	11.1–13.6	10.9–13.5	47	80	26	9	4.9–5.5	0.7–1.1	3.4–3.9	2.2–2.3	1.3–1.9	0.1–0.8	4.2–4.4	1.1
sorghum	86–89	12.7–13.4	7.9–13.0	73	60	11	4	3.3–4.3	0.3–0.4	2.8–3.6	0.9–1.8	1.4–2.2	0.1–0.5	3.8–4.0	–
triticale	90	13.8	17.6	–	–	8	2	1.7	0.6	3.3	1.7	–	–	4	0.9
wheat	86–89	12.6–14.7	11.3–16.0	66	80	12	3	1.8–2.0	0.3–0.7	3.6–4.3	1.2–1.8	1.1–1.6	0.1–0.5	4.2–4.9	0.9
By-products															
almond hulls	90	9.1	2.7	–	80	25	11	3.0–3.6	2.3	1.1	1.1	1.3	0.2	5.3	0.5
apple pomace (fresh)	21–25	8.4–10.6	6.0–7.6	3	20	18	0	4.4–5.1	1.3	1.1	0.2	0.7	1.2	4.6	–
bakery waste (dried)	90–92	14.2–14.7	10.3–12.0	–	80	10	0	12.7	1.0–1.4	2.6	0.2	2.6	12.4	5.3	0.5
bran (wheat)	86–89	9.7–11.2	16.0–17.1	20	80	47	10	4.4–4.5	1.0–1.6	8–14	2.5	5.0–6.0	0.4–1.3	15.6	0.5
brewers' grain (wet)	21–32	10.0–10.4	20.4–27.1	6	47–60	42	8	6.4–7.3	2.9–3.3	5–8	3.2	1.0–1.6	2.0–2.3	0.9	1.3
citrus pulp (wet)	18	12.1–12.5	6.7–7.3	0.2	80	23	8	9.7	18–21	1.2	0.8	1.7	0.9	7.9	0.5
corn gluten feed	88–91	13.4–13.6	21.7–26.2	15	70	45	16	2.4–7.5	3.6	8.2	2.3	3.6	1.5	8.2	2.5
corn gluten meal	90–91	14.2–14.7	39.4–68.9	53	45–80	14	3	2.4–5.2	0.4–1.6	1.4–5.4	3.9–7.2	0.6–0.9	0.6–1.0	0.3–2.1	0.7
hominy	90	14.0	11.1	–	70	21	7	4.2	0.03	0.65	0.12	0.26	0.01	0.82	–
molasses	75–76	11.1–12.7	4.0–5.8	0	80–100	0	0	0–0.1	11	1.0–1.1	4.7	4.3	2.2	32–38	31.0
Vegetables															
carrots	12–13	12.1–13.7	9.2–9.9	–	–	9	3	1.4–1.5	4	3.5	1.7	2	10.4	28	5.0
potatoes	21–24	11.7–13.2	9.0–9.5	57	80	8	0	0.4–0.5	0.3–0.9	2.4–2.8	0.9	0.7–1.4	0.6–1.0	21.7	2.8
potato meal	89–90	12.4–14.9	8.4–9.8	–	–	–	–	0.4–0.6	1.6	2.5	–	–	–	–	–
whole cottonseed	90–92	13.1–16.0	19.6–24.0	–	55	39	35	23	2.1	6.4	2.6	4.6	0.1	10	–

Table 4. Nutritive characteristics of some cereals, by-products and grain legumes fed to dairy cows *(continued)*.

Feed	Dry matter (%)	M/D (MJ/kg DM)	Crude protein (%)	Starch %	dgP (%)	NDF (%)	eNDF (%)	Ether extract fat (%)	Calcium (g/kg DM)	Phosphorous (g/kg DM)	Sulphur (g/kg DM)	Magnesium (g/kg DM)	Sodium (g/kg DM)	Potassium (g/kg DM)	Chlorine (g/kg DM)
Grain legumes															
beans	86–89	12.4–13.8	25.3–31.4	40	80	20	7	1.3–1.5	1.8–1.9	5.9–6.7	2.6	1.3–1.5	0.5–2.0	14.7	–
lupins	86	13.2–13.3	31.3–48.0	<1	78	24	0	5.3–7.2	1.9	3.1	2.2	1.5	0.5	8.2	–
peas	86–89	12.8–13.4	24.0–26.2	44	60	12	4	0.7–1.9	0.8–1.5	4.3–4.5	–	1.4–1.7	0.1–0.5	11.3	–
Protein meals															
canola meal	90–93	8.5–9.5	38.0–41.0	4	72	27	6	1–2	6–7	10–11	3.5–4.5	5.8–6.0	3	6	0.5
cottonseed meal (expeller)	90–94	11.7–12.6	41.9–44.3	2	50–64	28	10	4.6–5.0	2.0–2.1	10.4–11.6	2.8–4.3	5.8	0.5	14.6	–
cottonseed meal (extracted)	91–94	11.3–12.3	43.6–54.0	2	59	26	9	1.3–1.7	1.7–2.2	10.0–12.4	3.4–5.6	5.0–5.5	0.4–0.6	14–16	–
fish meal	90–93	10–13	64.5–71.2	0	20–60	0	0	4.0–10	40–80	27–44	5–8	1.6–2.7	4.3–16.1	7–9	–
linseed meal	88–90	11.6–11.9	38.4–40.4	–	56	25	6	11	4.3	9	4.4	6.6	1.5	15	0.4
safflower meal	91–92	8.8–11.7	22.1–46.9	–	–	56	13	1.4–6.7	2.7–3.8	7.8–14.0	1.4–2.2	3.6–11.1	0.5	8–12	–
soyabean meal	88–90	12.1–14.3	47.7–55.1	1	55–72	12	3	1.0–5.3	2.3–3.0	6.8–10.2	3.7–4.8	2.8–3.2	0.3 - 5.0	20–23	0.5
sunflower meal	90–93	6.3–11.9	25.9–49.8	0.3	76	18	4	1.1–8.7	2.3–4.4	9.8–11.4	3.3	7.5–7.8	2.4	10.6–11.4	–

Granzin (submitted) found that maize was fermented more slowly than barley, and later found that estimated rumen degradability of maize and sorghum were consistently lower than oats, wheat, barley and triticale (B. C. Granzin unpublished data). Fermentation rates of grains are influenced not only by their inherent characteristics, but also by their physical presentation i.e. particle size and any heat or chemical treatment given to the grains.

Table 5. Gas production (ml/g DM) and pH after seven hours of incubation of seven species of cereal grain (Opatpatanakit *et al.* 1994).

Species	Gas production		pH		Number of varieties	Number of samples
	Mean	Range	Mean	Range		
Wheat	251[a]	231–262	5.84[b]	5.66–5.99	12	35
Triticale	241[b]	236–247	5.68[a]	5.63–5.73	5	10
Oats	237[b]	227–246	5.93[c]	5.82–5.95	4	16
Barley	222[c]	204–229	5.84[b]	5.67–6.07	7	20
Maize	138[d]	127–159	6.73[e]	6.50–6.89	18	66
Rice	109[e]	99–121	6.55[d]	6.52–6.58	3	9
Sorghum	104[e]	100–116	6.64[d]	6.52–6.84	21	62

[a, b, c, d, e]: Different superscripts within the same column indicate significant differences (P < 0.05).

It is thought that the high proportion of non-starch polysaccharides in the endosperm cell walls of oats and barley account for the lower rate of fermentation of these grains compared to wheat and triticale. Non-starch polysaccharides reduce nutrient digestion by increasing the viscosity of digesta (Rowe *et al.* 1999). In maize and sorghum the starch granules are surrounded by a protein matrix in the endosperm that limits microbial access (McAllister *et al.* 1993) and slows down the rate of fermentation.

The composition and kernel structure of sorghum and maize are similar, despite the fact that sorghum is less digestible. This may be because of the higher proportion of peripheral endosperm and the high tannin content in sorghum. Peripheral endosperm is extremely dense, hard and resistant to water penetration and digestion (Rooney and Pflugfelder 1986). The low fermentation ranking of rice has been attributed to the relatively high content of lignin and silica in rice hulls.

The result of slower fermentation in the rumen is an increase in passage of starch from the rumen. Overton *et al.* (1995) found, when feeding 9–10 kg/day of maize or barley that the passage of starch to the duodenum was 3.6 and 1.4 kg/day respectively.

Site of starch digestion
The efficiency with which the carbohydrate component of grain is utilised is considered to be one of the major determinants of the nutritive value of supplementary grains (Theurer 1986). Black (1971) suggested that the efficiency of energy utilisation would be maximised if the intestinal digestible component of feed offered to ruminants escaped rumen fermentation and was digested in the small intestine. Strategies aimed at shifting the site of starch digestion from the rumen to the small intestine will only succeed if the starch is extensively digested in the small intestine.

In *in vitro* experiments, Bird *et al.* (1999) reported a weak positive correlation between the enzyme digestibility of starch and starch fermentation. However, two varieties of triticale appeared to lie outside this general trend. They had much higher enzyme digestibilities of starch relative to their starch fermentation. In fact, of the six grains tested, the enzyme digestibility was highest for triticale (Table 6).

In vivo studies are required to confirm the results of *in vitro* investigations and to identify varieties that can be efficiently utilised by dairy cattle. This will undoubtedly lead to improved selection of feed grains. Hogan and Flinn (1999) discussed *in vivo* methods used for assessing grain quality for ruminants. They recommended ranking grains on digestibility in the whole tract, conducting growth studies and then doing more detailed investigations on starch digestion in the stomach and intestines.

Table 6. *In vitro* fermentation and enzyme digestion of starch in finely milled samples of various cereal grains (Bird *et al.* 1999).

| Grain type | Number of cultivars | Starch digestibility (% of original) | | | |
| | | Fermentation | | Enzyme Digestion | |
		Mean	Range	Mean	Range
Barley	20	67	52–76	45	37–53
Wheat	7	48	35–63	43	37–47
Oat	4	72	70–77	61	57–66
Sorghum	20	44	35–51	28	23–33
Triticale	3	60	52–78	70	65–76
Maize	1	42		29	

The site of starch digestion can be manipulated, largely via processing and feeding management. For example, Huntington (1997) was able to show that there is an inverse relationship between the level of intake of starch and the rumen fermentation of that starch, most likely due to an increased rate of feed particle passage and reduced time for fermentation in the rumen as intake increases. However, steam-flaked maize appears to reverse this trend; as intake of steam-flaked maize increases so does rumen fermentation. Rowe *et al.* (1999) propose that this may be due to an increase in viscosity and a subsequent slowing of the rate of passage of digesta.

The benefits and disadvantages of fermentative and enzymatic digestion in different parts of the tract are summarised in Table 7. Nocek and Tamminga (1991) suggested that production studies yielded no clear evidence that post-ruminal starch digestion enhances milk yield or changes milk composition. In contrast, Granzin (submitted) recorded indirect evidence of greater post-ruminal digestion of starch from maize than from barley, in that rumen degradation rate of maize starch was lower and faecal starch content with maize was significantly higher. This was associated with similar milk yields from the two grains, but milk from maize-fed cows had significantly higher milk protein percentage in two experiments and significantly higher milk fat percentage in one experiment. It does appear that starch digested post-ruminally may be used more efficiently for milk synthesis than starch digested in the rumen.

This is primarily due to the energy losses associated with the formation of methane by bacteria in the rumen. Nevertheless, Huntington (1997) suggests that for dairy cattle, ruminal starch digestion is overall more desirable than intestinal digestion. That view is based

on a resultant increased supply of microbial nitrogen, the negative relationship between extra glucose supply and milk fat and, perhaps most importantly, the apparent poor digestibility of starch in the small intestine and the associated risk of acidosis in the large intestine.

In ruminants, there is evidence that the digestion of starch in the small intestine may be limited by the availability of amylase (Huntington 1997), not oligosaccharidase activity or monosaccharide transport. Although the nutritional manipulation of amylase secretion is poorly understood, it appears that protein/peptides entering the small intestine can stimulate amylase production and increase glucose absorption (Taniguchi *et al.* 1995).

Table 7. Significance of site of digestion in determining the nutritional value of grain (Rowe *et al.* 1999).

Digestion site	Positive features	Negative features
Rumen fermentation	Microbial protein and vitamins available for intestinal absorption	Acid fermentation and low pH leads to risk of acidosis and reduced fibre digestion
	VFA absorption provides metabolisable energy	Energy loss through heat, methane and hydrogen
Intestinal digestion	No fermentation energy losses	No microbial protein production
	Glucose absorbed which can increase fat marbling	
Hind gut fermentation	VFA absorption provides metabolisable energy	Acid accumulation and low pH leads to risk of acidosis and reduced fibre digestion
		Energy loss through heat, methane and hydrogen

Grains have been compared for production response in feeding trials (Table 8). Jeffery *et al.* (1976) fed supplements of wheat, sorghum, maize, oats and barley at 3 kg/day to cows grazing pasture. They found no significant differences in milk or fat corrected milk (FCM) production between treatments. However, small but significant differences in milk composition were found with cows fed wheat having the highest milk fat and protein contents.

A similar trial was conducted by Tommervik and Waldern (1969) in which they fed approximately 6.3 kg/cow/day of a pelleted grain ration containing 96% of wheat, sorghum, maize, oats or barley. Again, they found milk yields and fat-corrected yields were similar for all treatments. However, oats produced a significantly higher milk fat content and lower solids not fat (SNF) and milk protein contents. The higher concentrations of effective neutral detergent fibre and fat present in oats may account for these effects on milk composition.

The above results are supported by Ward and Wilson (1967) who found that protein and SNF content of milk varied inversely with milk fat.

Moran (1986) compared responses to rolled barley, oats and wheat fed at approximately 10. 5 kg/day. He also found no significant differences in unadjusted milk yields

Table 8. Summary of experiments comparing responses to different grain supplements and molasses.

Reference	Basal ration	Supplement type	Amount fed (kg/cow/day)		Stage of lactation	Milk yield (kg/day)	Milk fat yield (kg/day)	Milk fat (%)	Milk protein (%)	Length of feeding period
Jeffery *et al.* 1976	Tropical grass legume	Wheat	3.0		Varied	13.1	0.62	4.78[a]	3.83[a]	8 days
		Sorghum	3.0			12.6	0.55	4.44[ab]	3.69[bc]	
		Maize	3.0			13.1	0.55	4.39[bc]	3.74[ab]	
		Oats	3.0			13.0	0.56	4.49[ab]	3.71[bc]	
		Barley	3.0			12.5	0.51	4.23[bc]	3.75[ab]	
						NS	NS	P<0.05	P<0.05	
Moran 1986	17% oaten silage, 17% lucerne hay, protein & minerals (40% total ration)	Wheat	60% diet		Early	24.0	1.01[b]	4.19	3.84[a]	21 days
		Oats	60% diet			25.1	1.18[a]	4.72	3.12[b]	
		Barley	60% diet			22.9	1.03[b]	7.54	3.52[a]	
						NS	P<0.05	NS	P<0.05	
Cowan & Davison 1978b	Green panic/glycine pasture	Maize	2.4		Early–mid	11.8	0.44	3.80	–	6 months
		Molasses	3.0			11.8	0.43	3.70	–	
						NS	NS	NS		
Walker *et al.* 1996	Tropical grass	Cereal, grain & molasses	Grain	Molasses						
			8.0	0.0	Early	20.5[abc]		3.87	3.03	12 weeks
			6.7	1.3		22.7[a]		3.68	3.03	
			5.5	2.5		21.4[ab]		3.77	3.03	
			4.3	3.7		19.8[bc]		3.71	3.10	
			3.0	5.0		19.7[bc]		3.82	2.99	
	Irrigated, N-fertilised ryegrass	Cereal, grain & molasses	Grain	Molasses						
			8.0	0.0	Early	28.7[d]		3.28	2.97	12 weeks
			6.7	1.3		25.7[ef]		3.70	3.00	
			5.5	2.5		25.7[ef]		3.65	3.01	
			4.3	3.7		27.1[def]		3.40	2.97	
			3.0	5.0		25.0[ef]		3.90	2.94	
Granzin 2003	Ryegrass/prairie grass	Barley	4.5		Early	22.0[a]		3.58[a]	2.82[a]	10 weeks
		Maize	4.5			22.0[a]		3.93[a]	2.95[a]	
		Barley	8.1			24.7[b]		3.15[c]	2.83[a]	
		Maize	8.1			23.6[b]		3.77[d]	2.98[b]	
	Kikuyu	Barley	4.5		Early	20.1[a]		3.49[a]	2.70[a]	10 weeks
		Maize	4.5			20.1[a]		3.66[a]	2.90[b]	
		Barley	8.1			23.2[b]		3.30[b]	2.72[a]	
		Maize	8.1			23.9[b]		3.20[b]	2.92[b]	

[a,b,c,d,e,f]: Means with different superscripts within the same experiment differ significantly.

between treatments but oats gave a significantly greater milk fat content and fat-corrected yield. This agreed with the work of Moss and Prier (1981), who found increased fat-corrected milk yields when oats substituted for barley in concentrate rations supplementing hay.

Granzin (submitted) compared barley and maize fed at 4.5 and 8.1 kg/day on ryegrass/prairie grass in the first experiment and Kikuyu in a second experiment. He found no difference between barley and maize in either experiment in terms of milk yield, but milk fat percentage was significantly higher with maize in the first experiment, and milk protein percentage was significantly higher with maize in both experiments. Interactions between grain and level of feeding were not significant.

In conclusion:

- From limited evidence, the grains appear similar in terms of milk production responses.
- Again, from limited evidence, milk contents of fat and protein may be higher with maize than with barley at similar levels of milk production.
- Rates of rumen fermentation of starch differ between cereal grains; slow rates of fermentation are less likely to depress rumen pH.
- At high levels of feeding, slow rates of rumen fermentation could reduce forage substitution and increase milk responses.

By-products

By-products of the food, beverage and cotton industries are proving increasingly popular as feed supplements for dairy cows. They can provide significant feed savings when bought in bulk but facilities on farm are required for bulk storage, handling and feeding out. This may involve building concrete slabs or storage bays, and purchase of a front-end loader.

At present, by-products are used on a minority of Australian dairy farms and very little experimental work has examined their potential. Their use is expected to increase in the future, especially in feedlot situations.

Guideline feeding values of the more commonly used by-products are presented in Table 4. Actual values can vary widely indicating that by-products should be analysed regularly to determine their nutrient content.

Almond hulls are the outer covering of the almond seed and, without shells, contain about 82% of the energy content of barley grain. However, shells are often mixed with hulls that reduce their energy content.

Brewers' grains are the residues when malt is extracted from barley. Since most of the starch and sugar is removed in the brewing process, the residue contains higher levels of fibre and protein than the original grain, but is very low in potassium content. Brewers' grains tend to deteriorate during storage and losses occur from mould growth and fermentation in warm weather. Also there can be significant seepage losses during short-term storage.

Australian experiments involving the use of by-products have been summarised in Table 9. Two experiments have compared brewers' grain with cereal grains. Hodge *et al.* (1982) found no significant advantage to either oats or brewers' grain as a supplement for dairy cows, while Valentine and Wickes (1982) found an increased milk yield when feeding 7.2 kg brewers' grain compared with 3.9 kg rolled barley per day (both on a dry matter basis.)

These amounts were calculated to provide isoenergetic supplements but it appears the method of estimation of DM digestibility was inaccurate and that a greater energy intake by the cows fed brewers' grain was responsible for the increased milk production. On the basis of energy values, expected milk response from brewers' grain would be about 80% of that from cereal grains, provided that protein is not limiting. If protein is first limiting, the milk response from brewers' grain is likely to be similar to, or greater than that from cereal grains.

Citrus pulp is a mixture of peel, inside portions and cull fruits of the citrus family. In Australia it is normally supplied with a high content of moisture, which leads to significant leaching during short-term storage. Also, moulds can develop, particularly during hot weather, if stored for more than a week. It is relatively high in energy and fibre and low in protein.

Cottonseed hulls are low in energy, protein and minerals, but high in fibre. They are palatable and can be used to increase roughage in dairy diets. Cottonseed hulls may come from genetically modified plants, which when fed to cows could cause rejection of the milk by some factories.

Corn gluten feed, a by-product from the manufacture of corn starch and corn syrup, has medium protein and high energy contents; the protein is degraded rapidly in the rumen.

Corn gluten meal provides high levels of both energy and protein and the protein is degraded more slowly in the rumen.

Cottonseed (whole) is a good energy source due to its high oil content. It is also high in protein and fibre. The high oil content can depress fibre digestion in the rumen and reduce intake. Thus when Ehrlich (1993) fed 3 kg/day whole cottonseed, which was sufficient to increase the oil content of the diet to 7.1%, there was no effect on milk yield due to pasture substitution. NSW Agriculture has reported several cases of toxicity associated with feeding whole cottonseed to cows in Australia (D. F. Battese). The pathogenesis and contributory

Figure 4. A novel means of providing access to whole cottonseed from the dairy holding yard.

factors have not been clearly identified. It is prudent to introduce whole cottonseed into the diet gradually and to monitor closely any adverse changes in milk production and animal health. Cottonseed may come from genetically modified plants, which when fed to cows could cause rejection of the milk by some factories.

Hominy, a by-product from maize grain processing, is high in energy and low in protein. The oil content is variable and has a large effect on the energy content and the extent to which it can be included in diets. Ehrlich *et al.* (1992) found that hominy pellets were an effective replacement for sorghum grain.

Molasses is a very palatable by-product of the sugar industry. It is fed in large amounts in dairies close to sugar mills. Further afield it is fed in smaller amounts, to increase palatability and reduce the dustiness of concentrate mixes.

Cowan and Davison (1978b) fed isoenergetic amounts (amounts of the same energy value) of maize grain and molasses (1:1.3 as fed) as supplements for cattle grazing tropical pastures. Similar milk production responses in terms of milk yield, milk fat yield and fat content were observed. In most cases, molasses would prove the more economical of the two, however, it has no fibre, so may depress milk fat content at high levels of feeding. Also, if the protein content of the supplements had been balanced, the milk response from the molasses might have been greater than from maize.

Walker *et al.* (1996) assessed the use of molasses in the concentrate rations of high producing cows in early lactation (Table 8). They examined the production responses to concentrate mixes in which there was progressive substitution of cereal grain by molasses, while the rations were formulated to contain similar amounts of energy and protein. During summer on tropical pasture, milk yield was highest for cows fed a low level of molasses in the concentrate portion of their ration. Increasing the level of molasses maintained milk yields at levels similar to the yields from the control animals. As molasses is generally cheaper than grain-based concentrates in sugar-growing areas, it appears that there is substantial economic benefit to the inclusion of molasses in the concentrate ration of high-producing dairy cows grazing tropical pasture in summer.

However, the situation appears to be different for cattle grazing temperate pastures in winter. In the second half of their study, Walker *et al.* (1996) found that cows under these conditions produced significantly less milk when molasses was substituted for grain in the concentrate portion of their diet.

Milk permeate – a by-product from dairy factories – was investigated by Cowan *et al.* (1990) to assess its value as a supplement for lactating cows. Cows fed milk permeate could not consume sufficient to maintain their DM intakes, so milk production was reduced. However, the authors concluded that milk permeate could substitute for up to 1.7 kg of grain/cow/day and could increase milk fat content.

Palm kernel meal is the by-product residue following extraction of oil from oil palm fruit. Oil is solvent extracted or extracted using pressure (expeller). As a result, the residual oil content varies from 2.5% to 10%. It has a very high content of fibre. Davison *et al.* (1994a) found that milk yield and milk fat content were increased when a concentrate mix of barley grain and cottonseed meal was progressively replaced with palm kernel expeller meal.

Mill mix is a by-product of the wheat milling industry, which contains a mixture of bran and pollard. It is palatable, moderately high in energy and protein, and high in phosphorus.

Potatoes and potato processing by-products have a high content of starch, which can lead to acidosis. Whole potatoes should be fed from ground level or chopped to avoid choking. The oil and protein content of waste potato products, such as chips, can vary substantially.

Rice pollard is a by-product of the rice milling industry, and metabolisable energy contents of up to 16 MJ/kg DM have been recorded. This is due, in part, to high fat levels. The effectiveness of rice pollard as an energy source was examined by Moran (1982b). He substituted rice pollard for 50% of the oats in a concentrate for cows in early lactation and found no significant differences in milk, fat or protein yields between treatments. He concluded that, despite its higher ME content, rice pollard was not superior to rolled oats. However, on a cost basis, it may prove to be a useful feed supplement.

Responses to some by-products are summarised in Table 9.

Processing grains

It is generally accepted that some processing of cereal grains is required before cattle can effectively utilise the energy and nutrient content of concentrate feeds (Kaiser 1999). While increasing the degree of processing improves utilisation, it may also lead to digestive problems when high levels of grain are fed (above 4 kg/cow/day) and may accentuate fat depression in milk. The type and extent of processing required depends on a number of factors including the grain type, the proportion of grain in the diet, palatability and the risk of developing digestive problems.

In general, if whole, untreated grain is fed, a large proportion of it can pass undigested in the faeces. The feeding of oats, however, appears to be an exception to this rule: the whole grain is well digested by cattle and there is generally no significant benefit in terms of milk response to processing (Hodge *et al.* 1984; Moran 1986; Campling 1991; Mathison 1996).

The characteristics of starch granules and the endosperm matrix of cereal grains have important effects not only on digestibility, but also on the response to processing, and these must be considered when designing processing techniques.

The minimum level of processing required to ensure efficient grain digestion is cracking the seed coat to expose the endosperm. This must be achieved by mechanical or chemical treatments, as cattle have only a limited ability to chew small cereal grains. The main nutritional significance of the seed coat is the extent to which it dilutes the amount of starch in the diet. For instance, in oat grain, the hull represents around 25% of the dry matter whereas in sorghum it accounts for only 3–6% of the grain weight (Rowe *et al.* 1999).

The second level of processing involves grinding and rolling, to reduce particle size, which in turn determines the surface area, which is exposed to microbial and digestive enzymes. This ultimately influences the number of starch granules freed from the protein and non-starch carbohydrate matrix of the endosperm (Rowe *et al.* 1999).

When starch granules are tightly held within the endosperm matrix, it may be necessary to use gelatinisation and/or hydration (i.e. high temperatures with or without water) to disrupt the granules. Table 10 summarises the major types of grain processing, the effects on grain, and consequences for digestion, and these are discussed in more detail below. Experiments comparing the different methods of processing and their effect on milk production are summarised in Table 11.

Table 9. Response to by-products.

Reference	Basal ration	Supplement type	Amount (kg/cow/day)	Stage of lactation	Milk yield (kg/day)	Milk fat yield (kg/day)	Milk fat (%)	Milk protein (%)	Length of feeding period
Valentine & Wickes 1982	Pasture hay	Rolled barley Brewers' grain	3.9 7.2 (isoenergetic amounts)	Early–mid	13.3 16.4	0.58 0.60	4.39 3.73	3.36 3.28	6 weeks
					P<0.01	NS	P<0.01	NS	
Hodge et al. 1982	Limited pasture	Whole oats Brewers' grains	4.0 4.0	Late	8.48 8.97 NS	0.45 0.44 NS	5.30 5.00 NS	3.80 3.80 NS	4 weeks
Moran 1982b	Stall-fed lucerne hay	Rolled oats	50% ration	Early	26.5	1.10	–	–	2 weeks
	Maize silage, protein & minerals (50% ration)	Rolled oats (25%) and rice pollard (25%)	50% ration		26.4 NS	1.10 NS	–	–	
Cowan et al. 1990	Ryegrass pasture/cracked sorghum	Milk permeate		Early–mid	–	–	–	–	8 weeks
	1. 6kg/6kg		1. 0		1. 11.2	0.42	3.80[a]	3.26	
	2. 6kg/3kg		2. Ad libitum		2. 10.4	0.47	4.50[b]	3.21	
	3. 3kg/6kg		3. Ad libitum		3. 10.2	0.35	3.50 P<0.05	3.04	

[a,b]: Means with different superscripts within the same column differ significantly.

Table 10. Summary of the effect of various processing techniques for cereal grains (Rowe *et al*. 1999).

Treatment process	Disrupts seed layer and/or exposes endosperm	Reduces particle size	Separates starch granules and/or disrupts endosperm matrix	Disrupts starch granules and/or causes hydration and gelatinisation	Increases fermentation rate	Increases intestinal digestion	Improves overall digestibility in cattle
Dry rolling	+++	+			++	+	++
Grinding/milling	+++	+++			++	+	
Steam flaking	+++	++	+	+	+++	++	+++
Extrusion	+++	−	++	+	++	++	+++
Pelleting	+++	−	+	+	+	++	+++
Micronisation	+	+				++	++
Sodium hydroxide treated whole grain	+				+	++	+
Exogenous amylase						++	+

Cracking, dry-rolling and grinding

The aim of these processing methods is to break the seed coat, reduce particle size and increase the surface area for digestion. Rolling grains cracks the coat while retaining a relatively large particle size, limiting the rate and extent of digestion and fermentation. Conversely, grinding or milling can produce extremely fine particles which can be rapidly fermented or digested and can reduce the palatability of the grain if excessively dusty.

High faecal starch levels have been reported by Davison *et al.* (1994b) for rolled sorghum grain fed at 5 kg/day and indicate that for this grain there are substantial losses in feed energy when sorghum grain is rolled.

In general, sorghum and maize require fine grinding to maximise digestion, while rolling and cracking are preferable for the more digestible grains: wheat, barley and triticale. In addition, maize and sorghum, which contain starch that is more resistant to amylolytic action, can be pelleted, steam-flaked or micronised. Steam pelleting or flaking of sorghum grain has been shown to reduce faecal starch to less than 5% (Moore *et al.* 1992; Davison *et al.* 1994b).

Fulkerson and Michell (1985) conducted a study to look at the effects of hammer-milled wheat. The processed grain gave a marginal response of 29 g milk fat/kg supplement when compared to whole wheat. This was attributed to the increased digestibility of the wheat after processing. Calculated apparent digestibilities were 14.4% for whole wheat and 93% for hammermilled wheat. This figure for whole wheat was much lower than previous estimates.

Granzin (2003a) compared two milling and three rolling processing with maize to give a range of particle sizes from 538 to 2065 microns. When fed at 6 kg/day, fine rolling, with an average particle size of 1279 microns, gave significantly higher yields of milk and protein than the other processing methods.

Steam-flaking

With this treatment, the whole grain is heated with steam for 10–40 minutes and subsequently rolled to varying degrees (Rowe *et al.* 1999). This breaks the seed coat and endosperm, although the whole grain remains as one. The process gelatinises much of the starch making it more susceptible to enzymic attack.

Grains such as barley, wheat and oats, which have a naturally high fermentation and intestinal digestion when ground or dry-rolled, are not affected as much by steam flaking,

Table 11. Summary of experiments on effects of processing cereal grains.

Reference	Basal diet	Supplement type	Amount (kg/cow/day)	Stage of lactation	Milk yield (kg/day)	Response (kg milk/kg supplement)	Milk fat yield (kg/day)	Response (g fat/kg supplement)	Milk fat (%)	Protein yield (kg/day)	Length of Feeding period
Fulkerson & Michell 1985	Ryegrass/clover pasture (6.4kg) (54.6% DDM, 10.6% CP) & silage (8kg) (69.9% DDM, 14.3% CP)	Whole wheat Hammer milled wheat	2.1 2.1	Late	NG	NG	NG	0 NS 29 P<0.05	NG	NG	8 weeks
Hodge et al. 1984	Restricted winter pasture (60% DDM, 16% CP); 50% ME req.	Whole oats Crushed oats	4.4 4.4	Late	8.5 8.6 NS	0.73 0.75 NS	0.45 0.37 P<0.05	33 15 P<0.05	5.3 4.4 P<0.05	0.31 0.32 NS	3 weeks
Moran 1986	19% maize silage, 20% lucerne hay, protein & minerals (50% total diet)	Whole oats Rolled oats Alkali treated oats *	50% of diet 50% of diet 50% of diet	Early	24.2[a] 25.3[a] 26.4[a] NS	– – – –	0.94[ab] 0.92[ab] 1.05[a] P<0.05	– – – –	3.8[ab] 3.7[a] 4.1[b] P<0.05	0.67[a] 0.73[ab] 0.77[b] P<0.05	3 weeks
Valentine & Wickes 1980	Pasture hay	Whole barley	2.7 5.4	Early	11.1[a] 8.8[x]	– –	0.46[a] 0.40[x]	– –	4.24 4.45	0.36[a] 0.27[x]	
		Rolled barley	2.7 5.4		12.5[b] 12.2[y]	– –	0.55[b] 0.56[y]	– –	4.46 4.66	0.43[b] 0.43[y]	
		Alkali treated barley	2.7 5.4		11.6[ab] 11.4[y] P<0.05	– – –	0.51[b] 0.47[y] P<0.05	– – –	4.36 4.27 NS	0.40[ab] 0.39[y] P<0.05	
Shambrook & Moate 1982	Pasture (6 cows/treatment)	Whole wheat Crushed wheat Soaked wheat	2.7 2.7 2.7		12.5 12.8 12.1	– – –	– – –	– – –	4.31 4.74 4.43	– – –	
Sriskandarajah et al. 1980	Kikuyu grass ad libitum	Rolled barley Alkali treated barley *	4.0 6.0 4.0 6.0	Mid	9.3 10.1 10.2 10.6 P<0.05	0.36 0.39 0.60 0.47 P<0.05	0.34[a] 0.35[x] 0.37[b] 0.36[x] P<0.05	8[a] 12[x] 16[b] 10[x] P<0.05	3.66 3.55 3.71 3.47 NS	0.32[a] 0.34[x] 0.35[b] 0.35[x] P<0.05	24 days

Table 11. Summary of experiments on effects of processing cereal grains *(continued)*.

Reference	Basal diet	Supplement type	Amount (kg/cow/day)	Stage of lactation	Milk yield (kg/day)	Response (kg milk/kg supplement)	Milk fat yield (kg/day)	Response (g fat/kg supplement)	Milk fat (%)	Protein yield (kg/day)	Length of Feeding period
Hamilton 1989	N-fertilised kikuyu	Cracked sorghum	3.0	Early	18.0	1.27	0.53	37	3.37	–	12 weeks
		Steam-flaked sorghum	3.0		18.6	1.47	0.55	42	3.38	–	
					P<0.10	P<0.10	NS	NS	NS		
Davison & Ehrlich 1991	Tropical N-fertilised grass & temperate clover-based pastures	Cracked grain meal, 18.4% CP	5.0	Early	18.89[a]	–	–	–	3.39[b]	–	3 weeks
				Late	19.09[x]	–	–	–	3.56[y]	–	
		Pellet, 18.1% CP	5.0	Early	21.09[b]	–	–	–	3.26[a]	–	
				Late	16.95[y]	–	–	–	3.4$7^x$	–	
		Steam-flaked pellet 16.9% CP	5.0	Early	21.03[b]	–	3.24[a]	–	–	–	
			5.0	Early	21.03[b]	–	3.24[a]	–	–	–	
				Late	17.02[y]	–	3.49[x]	–	–	–	
					P<0.05		P<0.05				
Granzin 2003	Ryegrass/prairie grass	Maize – finely milled	6.0	Early	30.4[a]	–	0.98	–	3.24[a]	0.90[a]	5 weeks
		Maize – coarsely milled	6.0		31.1[a]	–	1.01	–	3.26[a]	0.93[a]	
		Maize – finely rolled	6.0		33.3[b]	–	0.93	–	2.80[b]	1.00[b]	
		Maize – average rolled	6.0		30.7[a]	–	0.92	–	2.99[bc]	0.92[a]	
		Maize – coarse rolled	6.0		29.8[a]	–	0.93	–	3.12[ac]	0.90[a]	

[a,b,x,y]: Means with different subscripts within the same column differ significantly, P<0.05.   * Sodium hydroxide NG data not given

as are maize and sorghum. Despite pre-treatment differences, the steam-flaking process appears to bring most of the grains to a similar level of digestibility and rumen fermentation (Huntington 1997).

With respect to the processing of maize, provided rolling is adjusted to break the seed coat but not to fully disperse the endosperm, the relatively intact grain may pass to the small intestine and still be digestible. This is because the steaming process results in starch that is readily hydrolysed by the small intestine amylolytic enzymes (Rowe *et al.* 1999). The processing of barley and wheat by high moisture rolling might also have the potential to deliver more starch to the small intestine in a similar manner.

Hamilton (1989) investigated the effect of steam flaking on sorghum grain. This process increased the digestibility of starch in sorghum from 72% (rolled) to 97%, and resulted in a 16% increase in milk yield. There were no significant differences in milk composition. In contrast, Davison *et al.* (1994a) found that milk yield and composition were similar when sorghum grain was pelleted with or without prior steam flaking.

Extrusion

Extrusion involves subjecting the grain to moisture, pressure and high temperatures (125–170°C) for relatively short periods of time (15–30 seconds). The temperature, pressure and duration of treatment vary considerably, but in general, the aim of extrusion is to achieve a high level of starch gelatinisation and disruption of the grain structure. However, the interaction between the degree of gelatinisation and the physical characteristics of the final feed is not well understood in terms of the ruminant digestive tract.

Micronisation

Micronisation involves soaking the grain, high temperature treatment and then rolling. It is a similar process to steam flaking, allowing the grain to remain partially intact while reducing its density and increasing its susceptibility to amylolytic digestion.

With respect to sorghum grain, most processing treatments increase fermentation in the rumen as well as digestibility in the small intestine (Rowe *et al.* 1999). Micronisation of sorghum, however, appears to have little effect on the extent of rumen fermentation, but increases intestinal digestion substantially. This may be related to a change in the grain that allows whole grain-sized particles to pass more directly to the small intestine carrying gelatinised starch within.

Chemical treatment

Chemical processing includes the use of hydroxides and formaldehyde to improve the digestibility of grains. Formaldehyde treatment is discussed in the protein supplements chapter.

Alkali treatment

The treatment of grains with an alkali, such as sodium hydroxide, is an alternative to mechanical processing. The process causes partial hydrolysis of the hemicellulose in the seed coat and gelatinisation (swelling) of the outer starch granules, thereby allowing rumen bacteria and digestive enzymes to enter.

Alkali-treated grain is digested more slowly than mechanically processed grain, so there is a lower tendency to develop acidosis. In addition, the reduction in fermentation rate is likely to promote a more favourable rumen environment for fibre digestion.

This is supported by the results of two studies where grain supplements were fed once daily with hay available to appetite (Ørskov *et al.* 1980; Sriskandarajah *et al.* 1980). Significant increases (23% and 19%) in hay intake were observed in both studies when cattle were given sodium hydroxide-treated barley rather than rolled barley. Sodium hydroxide treatment of grain has also been associated with an increase in the rate of passage of grain through the rumen (Kung *et al.* 1983) and a reduction in the proportion of starch digested in the rumen (McNiven *et al.* 1995).

Sodium hydroxide may be applied by either spraying on to the grain directly, by soaking the grain in sodium hydroxide solutions for up to 24 hours prior to feeding. Spraying appears to be the more practical of these two options (Ørskov and Greenhalgh 1977). The third, most commonly used method is to mix the grain with sodium hydroxide (30–50 kg/tonne) and water (50–150 kg/tonne) allowing it to stand for 24–48 hours prior to feeding.

Moran (1982a, 1986) compared whole oats, rolled oats and sodium hydroxide treated oats. As expected, the mechanical processing of oats produced no significant differences in the yields of milk or milk solids. However, chemical treatment did increase yields of milk, milk fat and milk protein by 9%, 10% and 16% respectively.

Although not significantly different, the alkali-treated oats were found to have a slightly higher level of digestibility and a lower neutral detergent fibre content than whole oats or rolled oats. The difference was attributed to a greater DM intake. The ratio of lipogenic to glucogenic volatile fatty acids in the rumen of cattle fed alkali-treated oats also favoured milk fat production. These factors combined to increase productivity with alkali-treated oats.

In studies examining the feeding of barley to dairy cows (Table 11), milk production with sodium hydroxide treated whole barley and rolled barley was similar and higher than that with whole barley (Valentine and Wickes 1980). In contrast, Sriskandarajah *et al.* (1980) found that milk production with sodium hydroxide treated whole barley was higher than with rolled barley, which they attributed to the slower rate of digestion of alkali-treated grain. Alkali-treated grain did not depress rumen pH and had a tendency to increase the acetate:propionate ratio, which minimised the depression of milk fat content compared to rolled grain. Cows fed rolled grain gained more weight, possibly due to reduced rumen pH causing a shift in the partitioning of nutrients towards liveweight rather than milk production. The authors concluded that significant productivity increases result from alkali-treatment of grain.

In a review of a number of studies, Kaiser (1999) noted that the greatest milk production response (23%) to alkali treatment was obtained when the treated grain was soaked in water for at least 24 hours, allowing the grain to swell (Ørskov *et al.* 1983). This may have led to improved mastication of grain, in turn leading to an increase in digestibility and subsequently milk production.

The importance of the level of sodium hydroxide application has been highlighted in a number of studies. The generally lower digestibility responses to sodium hydroxide treatment in mixed forage-grain diets, compared to 100% grain diets, has led to high application levels (>40 g sodium hydroxide/kg whole grain) being recommended in these situations (Kaiser 1999).

Despite the variability in the results of numerous studies, Kaiser (1999) concluded that there is sufficient evidence to indicate that digestibility, milk production and liveweight gain on diets containing sodium hydroxide treated grain are similar to those based on

rolled grain. The responses to sodium hydroxide treated barley have generally been less than those obtained with similarly treated oats and wheat.

At present, practical problems such as the risks in handling sodium hydroxide as well as corrosion concerns restrict use of this processing method. There are questions about the long-term effects on the animal of feeding large quantities of sodium hydroxide-treated grain, and the potential environmental problems of high sodium excretion (Kaiser 1999). There is a tendency for treated grain to solidify, so it generally requires turning several times in the first twenty-four hours and internal heating of treated grain can also be a problem. For these reasons, alternatives such as ammonia treatment might be more practical.

Ammonia treatment

Low and Kellaway (1983) compared whole and cracked wheat with ammonia treated wheat fed to young steers. They found that the ammonia treatment increased DM digestibility over whole wheat and resulted in a lower rate of digestion than seen with cracked wheat. Ammonia treated grain seemed to have the benefits of sodium hydroxide treated grain, but with fewer handling problems. In particular, it did not form a solid mass like sodium hydroxide treated grain.

There have been only two studies conducted to determine the effects of ammoniation of grain on milk production. With high moisture maize rolled prior to feeding, Britt and Huber (1976) observed no difference in milk production between grain treatments of 6.3 g ammonia/kg grain and a propionic acid control. However, treatment with 5.4 g ammonia/kg grain did not prevent mould growth, and on this diet, milk production was significantly lower than for the control. In contrast, Robinson and Kennelly (1989) reported that ammoniation of high moisture barley increased milk production with the best response being obtained at 13 g ammonia/kg DM. In this study, both the treatment and control grains were rolled prior to feeding and the response was partly attributed to a greater proportion of non-fibre components (starch) being digested in the small intestine.

In the review by Kaiser (1999), it was concluded that there is some evidence, primarily from work with growing steers, that ammoniated whole grain can successfully replace rolled grain in cattle diets. It is, however, pointed out that more studies are required to further define the treatment conditions required to achieve this objective. This is certainly the case with respect to dairy production.

Pelleting

Pelleting is a common commercial process where small particles are combined into a larger particle by means of a mechanical process in combination with moisture, heat and pressure (Rowe *et al.* 1999). The starch is partially gelatinised by the heat, steam and friction generated during processing.

It is generally accepted that concentrate pelleting decreases waste, reduces dust, minimises spoilage (Ørskov 1981), improves feed efficiency and provides a means for uniform distribution of protein and minerals. However, until the 1990s there had been no work undertaken to directly compare pelleting of dairy concentrates with alternative preparation methods.

Davison and Ehrlich (1991) compared a cracked grain meal with normal pellets and steam-flaked pellets, where all feeds contained the same basic ingredients. Results showed an average difference of 1.3 kg milk/day between meal and pellet groups. The advantage to

the pelleted ration was as high as 2.2 kg/day in early lactation and 0.86 kg/day in late lactation. They attributed this improved production to better utilisation of starch in pelleted rations, with lower faecal starch levels in pellet-fed cattle. Heat treatment may increase protection of protein in pellets to rumen degradation and stimulate greater pasture intake.

More recently (Gardner *et al.* 1997; von Keyserlingk *et al.* 1998) compared textured versus pelleted concentrates in dairy cow rations with respect to a number of production parameters. The concentrate mixture used in these experiments consisted of barley, corn, canola meal, distillers' grain, molasses, multiphos, limestone, cobalt-iodised salt and a vitamin and mineral premix.

In the pelleted formulation, all components were ground through a hammer mill prior to pelleting whilst the textured formulation consisted of steam rolled cereal grains (barley and corn) added to a pellet containing the canola meal and vitamin-mineral premix. The results are summarised in Table 12.

The initial study demonstrated that lactating cows fed a fat-depressing diet based on alfalfa cubes responded with a higher milk fat content when the concentrate portion of the diet was fed in a textured rather than a pelleted form (Gardner *et al.* 1997).

In the second study, where the basal diet used was a grass-maize silage forage mix, it was also shown that textured concentrates improved milk fat content relative to pelleted mixes. However, milk yield, protein concentration and protein yield were significantly higher for cows fed the pelleted concentrate (von Keyserlingk *et al.* 1998). Whilst the major impact of the form in which the concentrate was fed was on milk composition, there were other differences. The effective degradabilities and rumen disappearance of both dry matter and crude protein fractions were higher for the pelleted versus the textured concentrate. The improved availability of energy and protein to the rumen microflora did not result in a higher intake as would be expected (Nocek and Tamminga 1991), but did result in improved efficiency. Rumen pH was lower and the proportion of rumen propionate higher for cows fed the pelleted diet. Knowlton *et al.* (1996) and Arieli *et al.* (1996) similarly observed a decrease in rumen pH and an increase in rumen propionate with diets of higher degradability.

There are several potential advantages of feeding pellets over meal or a loose mix:

- Balanced proportions of proteins, minerals, vitamins and buffers can be incorporated into the pellets.
- The higher the level of concentrate feeding, the greater the likelihood that nutrient balancing will be necessary.
- Risks of excessive unpalatable and toxic substances associated with supplements, for example urea, are avoided by careful blending of ingredients.
- Pellets usually are less dusty than mechanically processed grains. This is particularly so when fat is added. The fat itself is a valuable source of energy when fed in controlled amounts.

In summary, it appears that a relatively small change in the processing of concentrates can have a substantial influence on the degradation characteristics of the concentrate and can alter the yield of milk components significantly. Pelleted formulations, when compared to textured concentrates, tend to improve degradability, lower rumen pH, increase milk and protein yields, and can depress milk fat yield and percentage, without affecting intake.

Table 12. Summary of experiments comparing textured and pelleted concentrate mixes.

Reference	Basal ration	Form of concentrate	Milk yield	Fat (%) (kg/d)	Milk fat (kg/d)	Protein (%)	Protein yield	Intake (kg/d) (kg/d)	Rumen pH	Effective Degradability[z]	Rate of disappearance from rumen[x] %	Efficiency (Mcal NEL kg-1 DM)[y]	VFA's (Acetate: Propionate)
Gardner et al. 1997	Alfalfa cubes	Textured	20.40	3.37[a]	0.69[a]	3.34	0.68	12.47 (Lucerne) 8.76 (Conc.)	–	–	–	0.86[a]	3.36
		Pelleted	21.01	2.78[b]	0.58[b]	3.31	0.69	11.97 (Lucerne) 9.53 (Conc.)	–	–	–	1.16[b]	3.05
Von Keyslerlingk et al. 1998	Grass-corn silage forage mix	Textured	27.7[c]	4.05[c]	1.11	3.13[c]	0.87[c]	13.0 (Silage) 9.6 (Conc.)	6.79[c]	68.88[c]	DM: 67.33 CP: 64.23[c]	–	4.45[c]
		Pelleted	29.3[d]	3.72[d]	1.08	3.26[d]	0.94[d]	12.4 (Silage) 9.5 (Conc.)	6.58[d]	74.49[d]	DM: 72.36 CP: 70.40[d]	–	3.70[d]

CP = crude protein

DM = dry matter

VFA = volatile fatty acid

[x] Rate of disappearance of textured and pelleted concentrates in nylon bags incubated in the rumen for 12 hours.

[y] Calculations based on 4% fat corrected milk, maintenance and body weight change.

[z] Effective degradability estimates were calculated using the equation $P = e+(fg/(g+k))^{e(-kLt)}$ where e = soluble fraction, f = degradable fraction, g = the fractional rate of degradation. The fractional rate of passage was set at 6.0%h-1.

[a,b,c,d]: Means followed by different letters were significantly different (P<0.05).

5

Protein supplements

Summary

Conditions under which milk production can be increased by feeding protein supplements are well defined, although it is not possible to estimate litres of milk per kilogram of supplement with great accuracy.

Results from feeding trials in Australia indicate that milk responses from protein supplements can be up to 1.5 litres per kilogram supplement greater than from equal weights of cereal grain. Usually the responses are much lower when energy is first limiting.

In most cases, milk production from Australian pastures is limited primarily by energy, especially on tropical pastures. Where energy is limiting, protein supplements give similar milk responses to equal amounts of cereal grains, and surplus nitrogen is converted to ammonia and excreted as urea. However, as energy supply from cereal grains is increased, the protein content of the diet becomes limiting for milk production. Protein supplements then allow increases in milk yield with only small changes in milk composition.

The conditions where protein supplements give greater milk responses than cereal grains are determined by:

- Stage of lactation
- Genetic potential
- Forage quality
- Degradability of the protein supplement
- Substitution rate.

In early lactation, cows in good body condition mobilise body tissue, supplying much more energy than protein, causing a potential protein deficiency.

Protein requirements per MJ metabolisable energy are much higher for milk production than for maintenance. As milk potential increases, the protein requirement per MJ metabolisable energy or per kg DM increases.

On low quality diets, protein digested in the small intestine per MJ metabolisable energy is less than on high quality diets. This means that supplements to a low quality diet should contain more protein per MJ metabolisable energy than supplements to a high quality diet.

When the supply of dietary protein is adequate for microbial protein synthesis (approximately 85 g rumen degradable protein/kg DM), responses to protein supplements are greatest when the rumen degradability of the supplement is low and their digestibility in the small intestine is high (that is, by-pass protein.)

Protein supplements often have a lower substitution rate than cereal grains, which results in higher DM intakes. The lower substitution rate is due to slower rates of supplement fermentation and increased forage digestibility. The increased forage digestibility occurs because of sustained release of ammonia, amino acids and peptides in the rumen by the protein supplement.

Protein quality can be improved by reducing degradation in the rumen. This can be achieved by heat treatment or by treating with formaldehyde. Optimal conditions for both processes have yet to be defined for most protein meals.

More accurate prediction of milk responses in the future will be achieved by:

- Generating milk response curves by feeding different levels of protein and cereal grain supplements to cows grazing different types of pasture.
- Improving the accuracy with which the following are predicted:
  - Efficiency of microbial protein synthesis
  - Protein degradability in the rumen
  - Substitution effects
  - Outflow rates from the rumen.

For very high yielding cows, there is likely to be increasing interest in assessing and adjusting the balance of essential amino acids estimated in metabolisable protein, using dietary manipulation, or supplementation with rumen-protected amino acids.

Introduction

Protein requirements in a diet are often expressed in terms of % crude protein. Usually the greater portion of dietary crude protein is degraded in the rumen to peptides, amino acids and ammonia. This rumen-degradable protein (RDP) is used by rumen microorganisms to produce microbial protein. Urea, as a dietary supplement, also provides ammonia in the rumen, which can be a valuable substrate for microbial protein production when the protein content of the diet is low (< 16% crude protein). The efficiency of microbial protein synthesis is dependent on the amount of energy produced from feed fermentation in the rumen, and the degree to which release of RDP is synchronised with the energy release. Surplus RDP may be absorbed as ammonia, converted to urea in the liver and excreted, which is an energetically wasteful process.

Microbial protein, together with dietary protein, which is not degraded in the rumen (UDP), passes to the small intestines where it may be digested and absorbed as metabolisable protein (MP). The proportion of UDP in a protein can be increased by chemical treatment (typically with formaldehyde) or by heat. Proteins so treated are known as 'escape' or

'by-pass' proteins, because more of the protein escapes degradation in the rumen. Optimal conditions have to be defined for the treatment of each protein source, as over-treatment reduces the digestibility of UDP in the intestines. When there is sufficient RDP in a diet, it can be advantageous to feed 'by-pass' proteins in order to increase MP absorption.

The amount of MP likely to be absorbed from a particular diet can be predicted from measurements on protein solubility and rumen degradability, together with estimates of rumen degradation rate, which is influenced by inherent properties of the feed together with its rate of passage through the rumen.

Estimates of MP absorption can be related to animal requirements with much greater accuracy than information on the crude protein content of feeds, or estimates of their RDP and UDP contents.

Estimates of MP can be made from measurements on feed protein degradation, which are usually made by incubating feed samples in nylon bags suspended in the rumen of animals fed a standard diet. This is known as an *in situ* procedure. It is expensive, but, as mentioned in Chapter 5, it can be used to develop calibrations for analysis by NIR, which is rapid and inexpensive.

Whilst some *in situ* data has been collected on fermentation characteristics of pastures and concentrates in Australia (Wales *et al.* 1999a; Granzin 2003b), it has yet to be used to develop NIR calibrations for practical application. Until this is done, it is necessary to stay with the imperfections of formulating diets on the basis of their crude protein content, together with imprecise estimates of the RDP and UDP contents of feeds.

Dietary and microbial proteins contain ten essential amino acids (EAA), which the animal cannot synthesise, and ten non-essential amino acids, which the animal can synthesise. Microbial protein has a balance of EAA, which is close to that found in milk protein. When UDP becomes a major contributor to MP, the balance of EAA in MP may be sub-optimal for milk production. The content of EAA varies between feeds, as does the extent to which individual feed amino acids survive degradation in the rumen and become available as UDP in the intestines.

Methionine and lysine have been identified most frequently as first-limiting EAA in MP of dairy cattle (NRC 2001). The average proportion of lysine in EAA in cereal grains is half that in bacterial EAA (NRC 2001). Supplementary amino acids have to be fed in a form protected from degradation in the rumen. Numerous reviews on the effects of feeding rumen-protected methionine and lysine were summarised by NRC (2001) who concluded that the content of protein in milk is more responsive than milk yield, particularly in post-peak lactation cows, and that increases in milk protein percentage are independent of milk yield. These responses occur when an imbalance in the EAA content of MP is predicted.

Thus it is likely that, at least for very high yielding cows, there will be increasing interest in assessing and correcting the estimated balance of EAA in MP by dietary manipulation, or by the provision of protected EAA supplements.

In early lactation, about 16–19% of crude protein is required in the diet, declining to 12–16 % in mid to late lactation. The level varies according to the rumen degradability of the protein, which determines the ratio of rumen degradable protein to undegraded dietary protein. Rumen degradability varies with intrinsic properties of the feed and the time it takes particles to leave the rumen – the fractional outflow rate (FOR %/hr). The fractional outflow rate varies with intake level and rate of rumen digestion. Progress is being made

towards standardising methods to predict the rumen degraded and undegraded fractions of proteins (White and Ashes 1999; Wales *et al.* 1999a). In the long term it will be desirable to predict the amino acid content of absorbed MP. Australian estimates of rumen degradability derived from *in sacco* and *in vivo* measurements are given in Table 13. *In sacco* refers to an experimental technique where as many as 30 bags of feed ingredients are hung in the rumen for varying lengths of time before being removed so the residues can be analysed to assess the activity that has taken place in the rumen. *In vivo* refers to experiments with animals as opposed to laboratory experiments.

The large differences between estimates of protein degradability on the same type of protein supplement may be due to differences in:

- Protein degradability associated with differences in level of heat treatment during processing.
- Methodology.
- Assumed fractional outflow rate.
- Basal diet of the animals.

With one exception, the pairs of *in vivo* and *in sacco* estimates of protein degradability agree reasonably well, which helps to validate the *in sacco* technique. However, the estimates in Table 13 are really only useful to give an approximate ranking of protein sources in terms of protein degradability. Wales *et al.* (1999a) reported data on protein degradability of 12 concentrate feeds. Unfortunately, 11 of these were of mixed composition, so it is not possible to determine degradability characteristics of the components, which would allow application of their findings. What is needed is data from a wide range of pastures, conserved forages and concentrates, on the proportions of protein, which are soluble, rumen degradable and rumen undegradable, together with the rates of rumen degradation of rumen-degradable fractions. When these data are combined with estimates of rumen outflow rate, it is possible to estimate amounts of metabolisable protein absorbed. This provides a much more accurate basis for determining dietary requirements for protein, which is often the most expensive supplementary nutrient.

The most widely accepted technique for making these measurements is to incubate feed samples in nylon bags suspended in the rumen of animals on a standard diet (Ørskov and Mehrez 1977) using procedures described by AFRC (1992). These measurements have been made on a wide range of feeds in Europe, and the results compiled by AFRC (1993).

Rumen degradation characteristics have been estimated on mixed pastures, both offered and selected, throughout the year in Northern Victoria (Wales *et al.* 1999a), as well as on concentrate mixes. Application of this information, which is expensive to acquire, should be based on calibrations using near infrared spectroscopy (NIR). Such calibrations have to be based on the feed characteristics of the feeds for which predictions are being made. Thus, predictions based on NIR calibrations developed in overseas laboratories are likely to be inaccurate when applied to Australian feeds.

With high levels of intake and rapid rumen fermentation and digestion, such as a lactating cow eating good quality pasture, the fractional outflow rate is high (0.08). With low levels of intake and slow rumen digestion, such as a dry cow eating poor quality pasture, the fractional outflow rate is low. The extent to which fractional outflow rate influences the degradability of proteins is illustrated in Table 14.

Table 13. Degradability (%dgP) of protein supplements *in sacco* (unless stated otherwise) with estimates of fractional outflow rates from the rumen (FOR).

Reference	Protein meal	%dgP	FOR	Ref	dgP	FOR
2	Lupin seed meal, fine	85	0.06			
4	Sunflower meal	83	0.05	5	71	0.08
2	Sunflower meal	80	0.04			
4	HCHO sunflower meal	48	0.05			
4	Peanut meal	79	0.05			
2	Canola meal	72	0.04	5	60	0.08
1	Meat meal	62	0.06			
2	Lupin seed meal, coarse	53	0.05			
1	Soyabean meal	52	0.06			
4	Soyabean meal	72	0.05			
1	Cottonseed meal	46	0.06	5	53	0.08
	HCHO cottonseed meal *			5	13	0.08
4	Cottonseed meal	59	0.05			
3	Cottonseed meal (*in vivo*)	35	0.07			
3	Cottonseed meal	38	0.07			
3	Cottonseed meal (*in vivo*)	48	0.05			
3	Cottonseed meal	44	0.05			
	Copra meal			5	20	0.08
	Palm kernel extract			5	40	0.08
	Whole cottonseed			5	86	0.08
1	Fish meal	38	0.06			
	Feather meal			5	10	0.08

1. Hennessy *et al.* (1983) 2. Freer and Dove (1984) 3. Amaning-Kwarteng *et al.* (1986) 4. Neutze (1991)
5. Moss *et al.* (1998)
* HCHO refers to formaldehyde treatment of the meal to reduce its degradability in the rumen.

Table 14. Influence of fractional outflow rate (FOR) from the rumen on percentage degradability of protein supplements in the rumen (ARC 1984).

	FOR		
	0.02	0.05	0.08
Cottonseed meal	81	70	63
Linseed meal	78	59	46
Soyabean meal	81	63	50
Fish meal	23	22	22
Sunflower meal	82	66	55
Dried lucerne	83	70	62
Barley grain	83	75	69
Brewers' grain (dried)	78	70	64
Canola meal	87	78	72
Ground peas	89	80	74
Groundnut meal	87	74	64

Clearly it is not possible to interpret estimates of protein degradability without knowing the fractional outflow rate assumed in the calculation. Unfortunately, often, the fractional outflow rate is not quoted.

Rumen degradable protein can be converted to microbial protein at the rate of about 8–11 g microbial protein/MJ metabolisable energy from non-fat sources. The rate increases with the quality of the diet. No microbial protein is produced from dietary fat, so when there is a significant amount of unprotected fat in the diet (3–6 %), microbial protein production is reduced. This increases the requirement for undegraded dietary protein.

When cows eat low quality pasture, especially when cereal grains are fed, there is likely to be a deficiency of rumen degradable protein, which reduces the yield of microbial protein/MJ metabolisable energy. When the dietary intake of rumen degradable protein is in excess of about 11 g/MJ metabolisable energy, the surplus is absorbed from the rumen as ammonia and excreted in urine as urea. High blood levels of ammonia and urea can reduce fertility. This can be a problem when cows are grazing lush pastures that receive high levels of nitrogen fertiliser or that contain a lot of clover.

Table 15. Comparison of nutrient requirements for lactation with the nutrient content of barley grain.

	Nutrient content of diet recommended for cow giving 45 l/day in early lactation (per kg DM) *	Nutrient content of barley grain (per kg DM)
Metabolisable energy (ME MJ)	11.4	12
Crude protein (g)	160	110
Protein degradability (% dg)	61	80
Neutral detergent fibre (g)	290	210
Calcium (g)	6.7	0.6
Phosphorus (g)	3.6	3.8
Magnesium (g)	2	1.4

 * NRC (2001)

An apparent association between bulk milk urea levels and impaired reproductive performance was reported by Moller *et al.* (1993). However, Trevaskis and Fulkerson (1999) found no such correlation. They pointed out that absorption of excess ammonia from the rumen is associated with increasing levels of urea in the blood and milk, but only up to the capacity of the liver to synthesis urea. When that capacity is exceeded, increasing absorption of ammonia may have adverse effects on fertility with no concurrent increase in milk urea levels.

Under grazing conditions, energy intake is usually the main constraint to milk production. When energy intake is increased by feeding cereal grains, other nutrients are likely to become limiting (Table 15).

When there is a nutrient imbalance, there is inefficient use of energy for milk production. The most obvious effect of this is that energy is used for body tissue instead of milk when dietary protein is limiting.

In well-fed cows in early lactation, with sufficient rumen degradable protein in the diet, the microbial protein produced is sufficient for about 16 litres of milk per day. For milk

production in excess of 16 litres, the undegraded dietary protein requirement is about 93 g/l milk. If the crude protein content of cereal grain is 110 g/kg with a rumen degradability of 80%, the undegraded dietary protein available is 22 g/kg grain. Thus 1 kg cereal grain provides:

- Sufficient energy for 2.3 litres milk (4.0% fat)
- Sufficient undegraded dietary protein for 0.2 litres milk.

A response of 2.3 litres milk/kg cereal grain is very rarely recorded due to:

- Substitution effects
- Imbalance of nutrients caused by feeding cereal grains
- Partition of nutrients between milk production and body tissue
- Diet digestibility decreases as intake increases albeit with some improvement in metabolisability
- Negative associative effects between feeds, e.g. decline in rumen fibre digestion with high levels of grain feeding.

The higher the level of grain feeding, the greater the likely nutrient imbalance so the lower the marginal milk response to the grain.

In early lactation, when well-fed cows in good body condition (condition score 6) mobilise body tissue, there is an imbalance in the nutrients mobilised, such that 1 kg liveweight loss provides sufficient energy for 6.3 litres of milk and sufficient protein for 2.9 litres of milk (Hulme *et al.* 1986).

Table 16. Effects of formaldehyde-protected (HCHO) casein on milk yield from grazing cows.

Reference	Pasture	Supplement		Milk yield (kg/day)	
Minson 1981	Ryegrass CP 290 g/kg	1kg casein		15.0	
		1kg HCHO casein		15.9	
Rogers *et al.* 1980	Ryegrass/clover	Nil		16.1	
		CP 180 g/kg	1kg casein		16.6
		1kg HCHO casein		18.1	
Stobbs *et al.* 1977	Rhodes grass CP 200 g/kg	Nil		12.3	
		1kg casein		12.7	
		1kg HCHO casein		14.7	

When cows graze high quality pasture with a high crude protein content, there may still be a deficiency of undegraded dietary protein, due to the high rumen degradability of the protein. This was demonstrated in three experiments in which cows responded to a supplement of formaldehyde-protected casein (Table 16). However, a subsequent study by Reeves *et al.* (1996) showed no response in milk production when formaldehyde-treated canola meal was included at 0, 20, 40 and 60% of the concentrate, which was fed at 3, 6 and 9 kg/cow/day.

The extent to which pasture intake is reduced by feeding a concentrate supplement is the substitution rate. The substitution rate of cereal grains often is greater than that of

protein meals, and this is associated with greater rumen degradability of cereal grains. For this reason, milk response to feeding protein meals often is greater than from feeding the same amount of cereal grain because pasture intake is greater. Another factor is that the energy content of protein meals is sometimes higher than that of cereal grains.

Stockdale *et al.* (1997) discussed research that involved protein supplementation for medium to high producing dairy cows (up to 35 litre per day). They concluded that protein deficiency is not often an issue in pasture-based dairy systems in Victoria. They suggested that this may be because, in most grazing situations in Victoria, there is little scope for cows to increase their intake of pasture. Also they suggested that, to date, the pasture-based system in Victoria has not been sufficiently challenged. Wales *et al.* (1999a) concluded that metabolisable protein is unlikely to limit milk production of cows consuming 17 kg pasture DM/day and producing up to 30 litres milk per day when milk production is determined by metabolisable energy intake. For cows giving 40 litres/day or more, protein deficiency is much more likely, and the provision of protein supplements with an appropriate balance of RDP and UDP is necessary to sustain the high milk yields.

Whilst protein deficiency may not often be an issue in pasture-based dairy systems in Victoria, an excess protein intake causes an imbalance of nutrients in the diet, and the wastage of energy involved in excreting protein surplus to requirements. The increasing use of concentrate supplements, particularly cereal grains, provides the opportunity to better utilise high levels of protein in pastures.

In summary, dietary protein is most likely to limit milk production from high-yielding cows in early lactation, particularly when they are fed cereal grains or maize silage, both with low contents of undegraded dietary protein. An excess of dietary protein can occur when good quality temperate pastures are the main component of the diet.

There is a potential for pasture intake to be greater when cows are fed protein meals than when they are fed similar amounts of cereal grains. Rumen degradable protein is most likely to be limiting when cows grazing low-protein pastures are fed cereal grain supplements. Otherwise the protein deficiency is most likely to be undegraded dietary protein.

This section reviews Australian work that mostly compares energy supplements with protein supplements. Of greater economic importance is the effect of protein supplements given to cows receiving energy supplements.

Types of protein supplements

Grain legumes and oilseeds are the major types of protein supplements. Grain legumes include lupins, peas and faba beans, with lupins being the most popular. Grain of common vetch is available in South Australia as an alternative to lupin grain.

Grain legumes have a similar energy content to the cereal grains but a much higher protein content (Table 4). Therefore, they can be used as an energy supplement to pasture when their price is competitive with that of the cereal grains (as is the case in Western Australia). Alternatively, they can be used to raise the protein content of the diet when this is limiting production. For example, autumn-calving herds in South Australia are fed lupins at 20–50 % of the concentrate with low protein basal forages such as hay (100–120 g crude protein/kg DM).

Grain legumes contain less starch and more fibre than the cereal grains. Typical starch values (g/kg DM) are:

- Barley   550–600
- Lupins   0–5
- Peas   460–485
- Beans   370–380

(Bartsch and Valentine 1986).

The extent to which rumen pH is depressed after feeding these grains is proportional to their starch content. It would be expected that depression of milk fat content would be lower with grain legumes than with cereal grains, with lupins being the least likely to cause disturbance of rumen function. *However, if cows are fed excessive quantities of grain legumes, there may be reproductive problems associated with ammonia or urea toxicity.*

Oilseed meals include canola meal, sunflower seed meal, cottonseed meal, soyabean meal, safflower meal and linseed meal. Other protein sources include whole cottonseed, corn gluten feed and meal. Their nutrient composition is given in Table 4.

These protein sources vary widely in their protein content and in the rumen degradability of that protein (Table 4). Cottonseed meal supplies substantial amounts of undegraded dietary protein. Information on animal by-products including feather meal, fishmeal and meat meal is included in Tables 4 and 13, even though their use is currently not permitted in livestock feeds in Australia. Proteins can be treated to increase their undegraded dietary protein content by protecting them from rumen degradation (that is, by creating by-pass protein). Examples of such treatments include addition of formaldehyde and heating.

Table 17. Comparison of different protein meals for dairy cows grazing pasture.

Reference	Basal ration	Supplement type	CP (%)	Amount of supplement, kg CP/day (kg as fed)	Milk yield (kg/day)	Milk fat (%)	Milk protein (%)
Etheridge *et al.* 1983	Good quality, irrigated pasture	Linseed meal	26	1.0 (3.8)	18.5	4.5	3.5
		Soyabean meal	37	1.0 (2.7)	18.9	4.5	3.5
		Sunflower meal	15	1.0 (6.7)	17.9	4.7	3.4
		Cottonseed meal	38	1.0 (2.6)	18.1	5.0	3.3
Level of significance					NS	P<0.10	NS

Etheridge *et al.* (1983) compared four oilseed meals in a grazing experiment (Table 17). They fed varying amounts of soyabean, linseed and sunflower meals and whole cottonseed, so that each supplied 1 kg of crude protein to the diet. No significant differences in milk production or milk compositional quality were found, although milk fat content tended to be higher in cows fed cottonseed. However, as there was no control in this experiment, it is not possible to determine whether, in fact, protein supplementation produced any response at all. Also, by feeding only one level of crude protein, differences in protein quality were confounded by differences in the amount of energy fed. Assessment of incremental

responses gained by feeding protein at several levels would have been more useful. The fact that similar milk yields were observed for the four protein sources does not indicate that there were no differences in protein quality.

Technical review

Processing protein supplements

Hough (1991) showed the benefits of processing lupin grain prior to feeding. Whole, rolled and urea-treated, ensiled lupins were included, the last as an alternative to mechanical processing of lupins, which can be very wearing on machinery.

Cattle fed rolled lupins produced 0.6 kg milk/kg grain more than cows fed whole or urea-treated lupins. Differences in milk composition were non-significant (Table 18). In this situation, urea-treated lupins were not a practical alternative to rolled lupin grain. The reason for the production response was the increased digestibility of lupin grain after processing.

Table 18. Effect of processing lupin grain on production of dairy cattle grazing pasture.

Reference	Basal ration	Supplement type	Amount of supplement, kg CP/day (kg as fed)	Milk yield	Milk fat	Milk protein	Response over whole lupins (extra kg milk/kg supplement)
Hough 1991	Ryegrass/ clover/ Kikuyu pasture, CP 11.7%	Whole lupins, CP 30%	2.0 (6.0)	21.0[a]	3.9	3.2	–
		Rolled lupins, CP 30%	2.0 (6.0)	23.2[b]	3.8	3.1	0.6
		Urea-treated, ensiled lupins, CP 30%	2.0 (6.0)	21.2[a]	3.8	3.1	0
				$P < 0.001$	NS	NS	

[a,b]: means with different superscripts differ significantly.

Valentine and Bartsch (1986) measured dry matter digestibilities of whole and hammermilled lupin grains and found hammer milling increased digestibility by 11% when supplementing oaten-hay based diets, and by 18% when supplementing oaten pasture-based diets. Most of this difference was due to the excretion of whole grain in faeces. They concluded that hammer milling is necessary to maximise digestibility and production responses from lupin grain.

Likewise, the method of processing used for the oilseed meals can have an effect on their feeding characteristics. Meals can be produced by mechanical means (such as screw pressing) or by using solvents. Screw pressing tends to leave a higher level of residual oil

than solvent extraction, and the resulting meals have a higher oil fraction and energy content than solvent produced meals, but a lower protein content. However, a greater proportion of undegraded dietary protein is present, because the heat produced in pressing increases the protection of protein from rumen degradation.

Response to protein supplements

Over five experiments, the immediate response to feeding lupins in early lactation ranged from 0.4–1.8 kg milk/kg lupins, with an average response of 1.0 kg milk/kg supplement (Table 19). Three of these experiments continued feeding throughout lactation and gave average responses over the whole period of 0.8 kg milk/kg lupins (Hough 1991). In the first experiment of Hough (1991) in Table 19, lupins were fed for 14 weeks only and milk yield responses measured for a further 24 weeks. The residual response ranged from 0.5–1.1 kg milk/kg lupins, which was very substantial. There were no significant differences in milk composition between supplemented and unsupplemented cows in any experiment. However, the majority of experiments recorded increases in both milk fat yield and protein yield when lupins were fed.

In most cases, changes in liveweight and body condition score were insignificant, but there was a tendency for less body condition to be lost at the higher levels of grain feeding.

The milk response to feeding oilseed meals was examined by Rogers and Robinson (1982) (Table 19). They fed 6 kg of cottonseed meal to cows on a basal diet of restricted temperate pasture and calculated an immediate response of 0.7 kg milk/ kg supplement. Adding cottonseed meal allowed production levels to equal that seen on the ad-lib pasture, so compensating for pasture restriction. No residual response was recorded when cows grazed on ad lib pasture for six weeks following supplementation.

During the dry period, protein supplementation is not normally considered necessary on all but the poorest of pastures. However, cows grazing white clover and phalaris pastures during the dry period responded to the feeding of 1 kg/day of formaldehyde-treated sunflower meal (Norpro[R]) (Rustomo et al. 1996). The supplemented cows produced heavier calves, produced more milk in the first 12 weeks of lactation, and had fewer services per conception.

Lupin and vetch grains have similar contents of energy and protein. When similar amounts were fed with barley grain, milk yield was higher on the lupin grain, whilst fat and protein contents of milk were lower (Valentine and Bartsch 1996).

Grain legumes versus cereal grains

Experiments comparing production responses to supplements of cereal grains and grain legumes are summarised in Table 20.

In two trials conducted in early lactation, with a basal ration of cereal hay, there were substantial increases in milk yield when cows were fed grain legumes compared to cereal grains (Bartsch et al. 1987). Increases ranged from 0.2–1.5 kg extra milk/kg protein supplement. Cows fed lupins produced more milk than cows fed peas or beans, and gave significantly higher fat and protein yields than cows fed barley.

In the first experiment, cows fed lupins ate 20% more hay than those fed barley and lost less liveweight (Bartsch et al. 1987). It was concluded that the milk response was a result of improved efficiency in utilising DM due to increased protein content of the diet.

Table 19. General responses to protein supplements.

Reference	Basal ration	Basal ration CP (%)	Supplement type	Amount of supplement (kg/cow/day)	Stage of lactation	Milk yield (kg/day)	Milk fat (%)	Milk protein (%)	Length of feeding period	Response in milk yield (kg/kg supplement)		
										Immediate	Period (weeks)	Residual
Hough 1991	Pasture, M/D 9.5	14.9	Rolled lupins; CP 38.3%, M/D 12.8	0.0	Early	22.3	3.8	3.0	14 weeks	–	38 weeks	–
				1.6		24.8	3.8	3.1		1.8		1.1
				3.2		25.2	3.8	3.1		1.0		0.4
				4.8		26.2	3.8	3.1		0.9		0.2
				6.4		27.9	3.8	3.1		1.0		0.5
						P<0.001	NS	NS		P<0.001 Average 1.2		NS
Hough 1991	Ryegrass/ clover ad libitum, M/D 9.1	11.7	Rolled lupins; CP 30.0%, M/D 12.9	0.0	Whole lactation	15.2	4.1	3.2	Whole lactation	Average response: Whole lactation 0.9		
				2.0		17.2	4.1	3.2		Early lactation 0.8		
				6.0		18.8	4.2	3.2				
						P<0.001	NS	NS		Mid–late lactation 1.0		
Hough 1991	Ryegrass/ clover/ kikuyu dominant pasture, M/D 9.0	15.7	Milled lupins; CP 35.1%, M/D 13.8	0.0	Whole lactation	15.4	4.0	3.3	Whole lactation	Average response: Whole lactation 0.9		
				4.0		18.9	4.0	3.3		Early lactation 1.0		
						P<0.001	NS	NS		Mid–late 0.9 lactation 0.9		

Table 19. General responses to protein supplements *(continued)*.

Reference	Basal ration	Basal ration CP (%)	Supplement type	Amount of supplement (kg/cow/day)	Stage of lactation	Milk yield (kg/day)	Milk fat (%)	Milk protein (%)	Length of feeding period	Response in milk yield (kg/kg supplement)		
										Immediate	Period (weeks)	Residual
Hough 1991	Ryegrass/ kikuyu/ clover pasture, M/D 8.5	14.9	Milled lupins; CP 32.7%, M/D 12.7	0.0 4.0	Whole lactation	18.0 20.5 P<0.001	4.1 4.2 NS	3.1 3.4 NS	Whole lactation	Average response: Whole lactation 0.6		
						P<0.001	NS	NS		Early lactation 0.7		
										Mid–late lactation 0.6		
Rogers & Moate 1981	High quality, temperate pasture	21.2	Whole lupins; CP 30.0%	0.0 2.0	Mid lactation	15.3 16.1 NS	4.14 4.07 NS	3.4 3.4 NS		0.4 NS		
Rogers & Robinson 1982	Pasture ad libitum Restricted temperate pasture	– – –	– Cottonseed meal	0.0 0.0 6.0	Early	20.0 16.7 20.7	4.39 4.55 4.17	3.39 3.12 3.10	6 weeks	N/A – 0.7	12 weeks	– 0.1

Table 20. Summary of experiments comparing grain legumes, protein meals and cereal grains as supplements for dairy cows.

Reference	Basal ration	Length of feeding period	Stage of lactation	Supplement type (CP%)	Suppl. CP %	Amount of supplement (kg/cow/day)	Milk yield (kg/day)	Milk fat (%)	Milk protein (%)	Liveweight (kg) or Liveweight change (kg/day)	Response (kg milk/kg supplement)
Bartsch *et al.* 1987	Cereal hay	12 weeks	Early	Rolled barley	–	5.5	15.5[a]	3.90	2.96	-0.82	–
				Rolled barley/ lupins (1:1)	–	5.5	22.1[b]	3.90	2.94	-0.37	1.2
				Rolled lupins	–	5.5	23.5[b] $P<0.05$	4.20 NS	3.07 NS	-0.23 NS	1.5 $P<0.05$
Bartsch *et al.* 1987	Cereal hay, ad libitum	6 weeks	Early	Crushed barley	–	8.0	20.3[a]	3.90	3.05	–	–
				Crushed lupins	–	8.0	24.9[c]	3.80	2.96	–	0.6
				Crushed beans	–	8.0	22.5[b]	3.70	3.04	–	0.3
				Crushed peas	–	8.0	21.8[b] $P<0.05$	3.80 NS	3.12 NS	–	0.2 $P<0.05$
Valentine & Bartsch 1990	Cereal hay, ad libitum, CP 7.5%	6 weeks	Early	Milled lupins	29.7	3.5/7.0	20.0[c]	4.08	2.84[a]	507	0.4x
				Milled peas	24.3	3.5/7.0	18.9[b]	4.28	3.01[c]	508	0.2
				Milled beans)	23.4	3.5/7.0	18.9[b]	4.19	2.94[bc]	503	0.2
				Milled barley)	9.6	3.5/7.0	18.0[a]	4.03	2.91[ab]	500	–
				Milled barley + Urea)	13.1	3.5/7.0	17.8[a]	4.18	2.95[bc]	502	N/A
Bartsch *et al.* 1987	High quality medic/ryegrass	–	Early	Crushed barley	–	7.0	25.9	3.60	3.44[b]	520	–
				Crushed barley/ lupins (1:1)	–	7.0	25.1	3.80	3.38[a]	515	-0.1
				Crushed lupins	–	7.0	25.0 NS	3.80 NS	3.30[a] $P<0.05$	517 NS	-0.1 NS
Valentine & Bartsch 1989	High quality medic/ ryegrass pasture	8 weeks	Early	Crushed lupins	31.9	3.5	24.6	3.69	3.04[ab]	537	0.3
						7.0	23.8	3.42	2.98[a]	538	0.2
				Crushed oats	11.5	3.5	23.7	3.78	3.13[bc]	526	–
						7.0	22.1	3.44	3.22[c]	544	
				Whole oats	11.5	3.5	22.6	3.69	3.09[abc]	533	N/A
						7.0	21.6 NS	3.73 NS	3.17[bc] $P<0.05$	542 NS	NS
Hough 1991	Ryegrass/clover/ capeweed pasture	14 weeks	Early	Rolled barley	10.8	1.6–6.4	Average 24.2	3.70	3.20	–	–
				Rolled lupins	32.4	1.6–6.4	Average 24.1 NS	4.00 $P<0.001$	3.20 NS	–	0.0 NS

Table 20. Summary of experiments comparing grain legumes, protein meals and cereal grains as supplements for dairy cows *(continued)*.

Reference	Basal ration	Length of feeding period	Stage of lactation	Supplement type (CP%)	Suppl. CP %	Amount of supplement (kg/cow/day)	Milk yield (kg/day)	Milk fat (%)	Milk protein (%)	Liveweight (kg) or Liveweight change (kg/day)	Response (kg milk/kg supplement)
Hough 1991	Ryegrass/clover/ kikuyu pasture, CP 15.7%	Whole lactation	–	Lupins	35.1	4.0	18.9	4.00	3.30	–	0.3
				Lupins/barley (1:1)		4.0	18.0	4.20	3.40	–	0.0
				Barley	12.9	4.0	17.8	4.20	3.50	–	–
							NS	NS	NS	NS	NS
Hough 1991	Ryegrass/clover/ kikuyu pasture, CP 14.9%	Whole lactation	–	Lupins	32.7	4.0	20.5	4.20	3.40	–	0.0
				Lupins/barley (1:1)		4.0	21.2	4.20	3.40	–	0.1
				Barley	12.7	4.0	20.7	4.20	3.30	–	–
							NS	NS	NS	NS	NS
Rogers & Moate 1981	High quality ryegrass/clover pasture, CP 20.6%	–	Mid	Whole lupins	30.0	2.0	16.1	4.07	3.39	–	0.0
				Oats	8.8	2.2	16.2	3.95	3.39	–	–
							NS	NS	NS	–	NS
Rogers & Moate 1981	High quality ryegrass/clover pasture, CP 20.6%	–	Early	Oats	8.8	2.2	16.7	3.92	3.15	–	–
				Oats + crushed lupins	30.0	2.2	16.7	3.96	2.99	–	0.0
							NS	NS	NS	–	NS
Moss et al. 1996	Rhodes grass/ ryegrass/maize silage	24 weeks	Early–mid	Barley	12.8	8.0	24.0[a]	3.73	3.31	–	–
				Barley + CSM	16.3	8.0	26.8[b]	4.01	3.23	–	–
				Barley + tSFM	16.4	8.0	27.1[b]	3.85	3.24	–	–
Moss et al. 1994	Rhodes grass/ ryegrass/maize silage	3 whole lactations		Barley/sorghum/CSM	13.0	6.0	20.3[a]	3.72[ab]	3.35	–	–
				Barley/sorghum/CSM	14.9	6.0	21.2[ab]	3.58[a]	3.10	–	–
				Barley/sorghum/CSM	16.5	6.0	22.1[bc]	3.55[a]	3.15	–	–
				Barley/sorghum/CSM	18.2	6.0	22.6[c]	3.34[a]	2.98	–	–
				Barley/sorghum/CSM	22.2	6.0	21.8[bc]	4.08[b]	3.28	–	–
Stockdale 1999c	Ryegrass/clover/ paspalum	3 x 5 week experiments	Early–late	Barley	11.0	5.0	22.9[a]	4.22	3.26	–	–
				Barley/lupins, 1:1	23.0	5.0	24.0[b]	4.21	3.21		
Wales et al. 2000	Paspalum	29 days	mid	Barley/wheat	11.6	8.0	21.3	3.25	2.98	+0.75	–
				25% canola	20.5	8.0	22.3	3.28	2.97	+0.75	–
				29% CSM	21.3	8.0	21.8	3.49	3.00	+0.75	–

a,b,c: means with different superscripts differ significantly   x: response above that of barley   y: response above that of crushed oats   CSM: cottonseed meal
tSFM: formaldehyde treated sunflower meal (Norpro[R])

No residual response from lupin feeding was observed when cows were fed on high quality pasture and barley after supplementation.

In contrast, on the same low-protein hay diet, very small differences were recorded in milk yield between cows fed barley grain or legume seeds (Valentine and Bartsch 1990), which was unexpected for cows in early lactation. In this experiment, no increase in hay intake was noted (Valentine and Bartsch 1990).

In one experiment, cows started on low quality tropical grass in the autumn and then went onto ryegrass and maize silage (Moss *et al.* 1996). Cows fed barley supplemented with either cottonseed meal or formaldehyde-treated sunflower meal gave significantly more milk than those fed barley alone, presumably because the forage mixture was low in protein.

In a study extending over three lactations, cows grazed tropical grass in the autumn and summer, and ryegrass/clover in the winter and spring. They were offered maize silage throughout the year, plus 6 kg/day of barley grain or a mix of barley grain and cottonseed meal in ratios to provide a range of protein contents from 13–22% (Moss *et al.* 1994). There was an 11% increase in milk yield and little effect on milk composition associated with an increase in protein content of the concentrate.

Similarly, when cows grazed temperate grass in the spring and tropical grass in the summer and autumn, inclusion of lupins with barley grain (50:50) gave 5% more milk than barley alone (Stockdale 1999c). The increase in milk production appeared to be due to the higher energy concentration of the lupin/barley grain mixture.

The remaining experiments compared legumes and cereal grains as supplements to high quality pasture. These trials produced no significant differences in milk yields between treatments. However, there were some differences in milk composition.

Bartsch *et al.* (1987) and Valentine and Bartsch (1989) found milk from cows fed barley and oats had a higher protein content than milk from lupin-fed cows. Also, there was a trend towards a lower fat content when cows were fed hammermilled grains, both lupins and oats, compared to whole oats.

Hough (1991) conducted three experiments supplementing pasture with lupins and barley. The first trial found no effect of grain type on milk production, liveweight change or body condition score change, but a significantly lower milk fat content in barley-fed cows.

In the second trial, cows fed lupins produced 1.1 kg/day more milk than cows fed similar amounts of barley. However, this increase was non-significant as it could be accounted for by the greater energy content of the lupins used. Again, there was no effect of grain type on milk composition, liveweight or body condition score.

The third experiment found similar results, and in addition, observed a higher DM intake in lupin-fed animals. Substitution rates of 0.4, 0.6 and 0.8 were calculated for lupins, lupin/barley mix and barley, respectively.

Rogers and Moate (1981) compared lupins and oats as supplements for cows in both early and mid-lactation. Crushed lupins were heated to try and reduce the rumen degradability of the protein. Although protein supplements increased yields of milk and milk protein above that of pasture alone, the response was not significantly different from that obtained with isoenergetic amounts of oats. It was also found that heating crushed lupins did not protect lupin protein from rumen degradation.

These experiments indicate that, with a low quality basal ration (cereal hay), protein levels were limiting milk production. The addition of protein supplements significantly increased milk yield, compared to a similar amount of energy supplement. However, when the basal ration was of high quality, the addition of extra protein had no effect on milk yields, suggesting that protein levels in the pasture were already adequate. In this case, the less expensive cereal grains provide the more economical supplement to pasture-fed cows.

Protein meals versus cereal grains

Experiments comparing response to supplements of cereal grains and oilseed meals are summarised in Table 20.

Three experiments compared responses from feeding barley or cottonseed meal to cows grazing temperate pastures.

Ernst and Rogers (1982) found yields of milk, fat and protein were significantly increased by feeding cottonseed meal rather than barley to cows in early lactation on limited pasture. These increases were accounted for by a greater pasture intake (approximately 2 kg/day) in cows fed cottonseed meal, due to a lower substitution effect.

Shambrook (1983) conducted a similar experiment with cottonseed meal and barley in mid-lactation and found no significant differences in milk, fat or protein yields, fat content, liveweight change or body condition score change. However, a significantly higher milk protein content was seen with barley-fed animals. A possible reason for this is that the higher energy content of barley may have allowed greater rumen microflora growth, resulting in an increased supply of microbial protein to the cow. As with the trial of Ernst and Rogers (1982), cows fed cottonseed meal had a higher DM intake than those fed barley. This was in the order of 0.9 kg extra pasture per day, again indicating a lower substitution rate with cottonseed meal. However, no extra response resulted from this, because of the lower digestibility and metabolisable energy content of CSM.

Paynter and Rogers (1982) stall-fed cows on pasture alone, or with isoenergetic supplements of barley or cottonseed meal, either to appetite or 60% of appetite. As with the previous experiments they noted higher DM intakes with cottonseed meal, and calculated substitution rates of 0.64 for barley and 0.39 for cottonseed meal. Both supplements increased milk yields over pasture alone, but their effects were not significantly different. Barley, however, gave lower milk fat content and increased liveweight gain.

Hodge and Rogers (1984), conducted experiments in both early and mid-lactation to compare responses to supplementation with oats (4.4 kg/day), a mixture of whole soyabean and maize meal (4 kg/day) and cottonseed meal/soyabean meal (4 kg/day). Cows in early lactation were on a basal ration of pasture ad lib, while those in mid-lactation were fed on restricted pasture and silage at 70% of their metabolisable energy requirement.

In both experiments, significant increases in milk and milk protein yields resulted from feeding protein supplements compared to feeding crushed oats. Soyabean and maize meal mixture resulted in decreased milk fat content. The authors conclude that, again, these responses probably were due to increased DM intake with the protein supplements rather than to an effect of the protein content. Protein supplementation in early lactation produced no residual response in the period following feeding.

Cows in mid-lactation grazing high quality pasture were supplemented with isoenergetic amounts of oats or a mixture of soyabean meal and sunflower-seed meal in a trial

reported by Rogers and Moate (1981). Milk yields were similar for the two supplements, indicating that the pasture supplied adequate protein levels and that protein in excess of this was, most likely, excreted in the urine.

In three successive experiments run from spring to autumn, Stockdale (1999c) found that milk yield was increased by inclusion of lupins in the supplement. In contrast, in an experiment run in summer, Wales *et al.* (2000a) found that inclusion of a protein supplement in the concentrate did not increase milk yield. They compared three pelleted supplements: barley/wheat, barley/wheat/canola meal, and barley/wheat/cottonseed meal. There were no significant effects of dietary treatments on milk production (21.8 kg/cow/day) or milk fat (34.1 g/kg) and milk protein (29.8 g/kg) concentrations. The metabolisable protein in the diet of the cows receiving the barley/wheat pellets was calculated to be sufficient to support at least 22 kg milk/cow/day and was not limiting milk production. The authors estimated that in most circumstances where the crude protein of cereal grain is above 90 g/kg DM, responses to protein supplementation are unlikely. Exceptions may be when such feeds as oats or rice grain are fed, both of which can have crude protein contents below 90 g/kg DM. This conclusion obviously depends upon the protein content of the pasture and the proportion of grain in the diet.

A series of trials have also been conducted on tropical pastures to assess the effect of protein supplementation. Kaiser *et al.* (1982) investigated the effects of protein supplements on cows in early lactation fed high levels of grain. Results indicated an increased response of 0.36 kg milk/kg protein supplement, when fed 8.1 kg wheat and soyabean, as compared to wheat alone. This indicates responses to protein may occur for grazing cows receiving high levels of grain feeding in early lactation.

Kaiser and Ashwood (1981) reported the effect of two different energy levels on responses to protein for cattle grazing tropical pastures. At low cereal grain intake levels (7.59 g DM/kg liveweight), the addition of soyabean meal had no significant effect on milk production for cows on pasture. However, at high intake levels (17.5 g DM/kg liveweight), soyabean supplementation significantly increased milk, fat and protein yields and fat content. Inclusion of protein had no significant effects on liveweight or body condition score change, or on milk protein content. With varying levels of soyabean, the average increase in milk production was 2.1 litres per day for the first 100 days of lactation. No residual response attributable to protein feeding was observed.

These results confirm that energy is the major limiting factor to milk production on tropical pasture. However, at high levels of energy intake, production responses to protein supplements can occur.

Royal and Jeffery (1972) fed varying amounts of concentrate containing crushed maize, soyabean meal, and a mixture of the two (Table 21). They found a significant linear relationship between milk production and DM fed as supplement, concluding that the response was due to greater energy intake and that the protein supplements were acting as energy sources.

Davison *et al.* (1991a) also confirmed that metabolisable energy intake is the major factor limiting milk production on tropical pasture. They fed combinations of maize and meat-and-bone meal at three levels of concentrate and two levels of protein (Table 21). Although milk yields were linearly related to the level of concentrate fed, there was no significant effect from the feeding of meat-and-bone meal. However, cows fed meat-and-

bone meal tended to lose less weight over days 1–100 and to gain more weight over the whole lactation.

Hamilton *et al.* (1992) supplemented cows grazing kikuyu pasture with barley and sunflower meal and found no benefit from extra protein in the diet. They postulated that where the crude protein level in the basal pasture is more than 153 g/kg there is no benefit in supplying extra degradable protein to the diet, but that additional undegraded dietary protein may allow production responses.

Davison *et al.* (1990) looked at the effect of basal pasture type on the response to a protein supplement. They fed meat-and-bone meal with both nitrogen-fertilised tropical grass pasture and tropical grass-legume pasture. Whilst it is now illegal to feed meat-and-bone meal, the experimental results remain relevant in demonstrating effects of feeding proteins of low rumen degradability. Results showed significant linear increases in fat-corrected milk production on nitrogen fertilised grass pastures with increasing amounts of meat-and-bone meal. In contrast, there was no significant effect of meat-and-bone meal on production from animals grazing grass legume pastures.

They concluded that the tropical N-fertilised grasses have proteins of high solubility that are rapidly degraded in the rumen and lost as ammonia. This causes a protein deficiency in early lactation which responds to meat-and-bone meal because it is more slowly degraded. However, the protein in grass-legume pastures is less soluble and so more is available for the animal's use.

Moss *et al.* (1992) also examined the effect of basal pasture type, comparing responses to various levels of protein on both tropical Rhodes grass and irrigated ryegrass pastures. They fed isoenergetic supplements of cottonseed meal and cereal grain (6 kg/day) ranging in protein content from 10–20%. On the ryegrass pasture (25–30% crude protein) no response to the protein supplement was seen. For the Rhodes grass pasture, where cows selected a diet of 13% CP, responses were observed to protein levels of 16 and 20% and were greatest in early lactation.

In this series of experiments, supplementation with oilseed meals produced responses to protein, above that seen with cereal grains, on three occasions:

- Early lactation
- Where a poor quality basal ration was provided
- Where high levels of cereal grains were fed.

These experiments confirmed that when energy is limiting production, little additional response is seen to a protein supplement. However, at higher levels of energy intake, protein may limit production, allowing good responses to protein meals. A number of trials indicated a lower substitution rate when protein meals were fed. This is because protein meals are degraded more slowly in the rumen than cereal grains. The extra pasture intake results in increased milk responses. No residual responses were observed after feeding oilseed meals.

Protecting protein from rumen degradation

Dairy cows require both rumen degradable protein and rumen undegradable protein. In some cases, levels of rumen degradable protein may be adequate, but addition of undegraded dietary protein may increase production. Significant increases in milk production

Table 21. Summary of experiments comparing the response to supplements of cereal grains and oilseed meals.

Reference	Basal ration	Basal ration CP%	Supplement type	Suppl. CP %	Amount of supplement (kg/cow/day)	Stage of lactation	Responses Milk yield (kg/day or kg/lactation)	Milk fat (%)	Milk Protein Protein (%)	Response protein-cereal (kg milk/kg protein supplement)	Length of feeding period
Ernst & Rogers 1982	Limited high quality pasture (66% appetite)	26.0	Barley CSM	10.0 36.0	3.5 3.5	Early	19.4 23.0 sig.	4.02 4.17	3.50 3.23	– 10.0	
Shambrook 1983	Limited pasture (50% appetite)	10.0	Barley CSM	10.0 36.0	3.5 3.5	Mid	14.04 14.19 NS	4.54 4.52 NS	3.43 3.29 $P<0.05$	– 0.0	
Paynter & Rogers 1982	Stall fed pasture (to appetite)	12.9	Barley CSM	10.8 37.5	30% diet 30% diet		19.44 19.93 NS	4.04 4.28 NS	3.17 3.05 $P<0.05$	– –	
	Stall fed pasture (60% appetite)	12.9	Barley CSM	10.8 37.5	30% diet 30% diet		17.20 16.65 NS	3.96 4.50 $P<0.05$	2.78 2.78 NS	– –	
Hodge & Rogers 1984	Ryegrass/white clover, M/D 11.2	14.4	Oats, M/D 12.1	11.9	4.4	Early	21.10	3.97	3.34	–	
			Whole soya/maize meal, M/D 14.0	25.7	4.0		23.90 $P<0.05$	3.82 NS	3.26 NS	0.7	
Hodge & Rogers 1984	Restricted ryegrass/white clover + silage, M/D 11.3 (70% ME req.)	13.1	Oats	11.9	4.4	Mid	12.7[a]	4.79[b]	3.50	–	
			Whole soya/maize meal, 60:40 CSM/SBM,	25.6	4.0		13.6[b]	4.34[a]	3.40	0.2	
			80:20	36.3	4.0		13.7[b] $P<0.05$	4.72[b] $P<0.05$	3.48 NS	0.3 $P<0.05$	
Rogers & Moate 1981	High quality temperate pasture	20.6	Oats SBM/SSM	8.8 45.0	2.2 1.4 + 0.6	Mid	11.70 12.00 NS	4.15 3.98 NS	3.25 3.27 NS	– 0.2 NS	
Kaiser et al. 1982	Kikuyu grass pasture forage oats	19.1 24.6	Wheat Wheat/soya, 79:21	16.3 23.3	8.1 8.1	Early	17.90 20.80 sig.	3.09 3.22 sig.	3.57 3.67 NS	– 0.36	100 days +

Table 21. Summary of experiments comparing the response to supplements of cereal grains and oilseed meals *(continued)*.

Reference	Basal ration	Basal ration CP%	Supplement type	Suppl. CP %	Amount of supplement (kg/cow/day)	Stage of lactation	Responses Milk yield (kg/day or kg/lactation)	Milk fat (%)	Milk Protein Protein (%)	Response protein-cereal (kg milk/kg protein supplement)	Length of feeding period
Kaiser & Ashwood 1982	Kikuyu pasture . ad libitum + high energy suppl.	18.8	Oats Oats/soya	12.4 12.4/50.9	8.2 7.76/0.42	Early	16.03 18.27 sig.	3.23 3.25	- -	0.27	100 days
	Kikuyu pasture ad libitum + low energy suppl.		Oats Oats/soya	12.4 12.4/50.9	3.5 3.08/0.42	Early	14.69 14.07 NS	3.58 3.89	- -	-0.18	
Royal & Jeffery 1972	Kikuyu dominant pasture		Nil SBM Crushed maize SBM/maize, 1.1:2.7		0.0 1.1 2.7 3.8	Mid	7.5[a] 8.4[b] 8.8[b] 9.4[c] P<0.05	5.09 5.09 4.82 4.86 NS	3.32[a] 3.45[ab] 3.4[4ab] 3.52[b] P<0.05	N/A	14 days
Hamilton et al. 1992	Kikuyu pasture	15.6	Barley Barley/SFM	14.6 14.6/40.9	3.0 2.0/1.2	Early	17.90 17.80 NS	3.41 3.40 NS	2.95 2.93 NS	- 0.0	56 days
Davison et al. 1991a	Tropical N-fertilised grass & grass legume	15–21 & 11–17	Maize M + MBM Maize M + MBM Maize M + MBM	10.4 52.4 5.5 8.0	3.0	Whole lactation	5,290 5,581 5,602 5,608 5,950 5,814 NS	3.23 3.40 3.30 3.36 3.25 3.31 NS	- - - - - -	0.3 0.0 0.0 NS	Whole lactation
Stockdale 1999c	Ryegrass/clover/ paspalum	15.2	75% barley/ 25% wheat 50% lupins/ 25% barley/ 25% wheat	11.4 20.9	5.0 5.0	Early to late	22.9 24.0 P<0.05	4.22 4.21 NS	3.26 3.21 NS	0.2	15 weeks
Wales et al. 2000	Paspalum	12.9	Barley/wheat 25% canola 29% CSM	11.6 20.5 21.3	8.0 8.0 8.0	mid	21.3 22.3 21.8 NS	3.25 3.48 3.49 NS	2.98 2.97 3.00 NS		

[a,b,c]: means with different superscripts differ significantly   CSM: cottonseed meal   SBM: soyabean meal   SSM: sunflower seed meal   M: maize   MBM: meat-and-bone meal

have been obtained when cows grazing high quality pastures were given abomasal (fourth stomach) infusions of casein (Rogers *et al.* 1979) or supplements of formaldehyde-treated casein (Rogers *et al.* 1980) (see Table 16). Methods of treatment to improve rumen protection of the more common protein sources have been investigated (Table 22).

Table 22. Treatment of proteins to increase protection from rumen degradation

Reference	Basal ration	Supplement type (CP%) (CP%)	Amount of supplement (kg/cow/day)	Stage of lactation	Milk yield (kg/day)	Milk fat (%)	Milk protein (%)
Hough 1991	Ryegrass/ clover/kikuyu pasture + 1.5kg rolled barley/cow/day	Lupin kernel	1.5	Early	24.0	3.9	3.1
		Formaldehyde treated lupins	1.5		23.7	3.9	3.0
		Formaldehyde treated lupins + protected methionine	1.5 + 0.3		24.3 NS	3.9 NS	3.0 NS
Hamilton *et al.* 1992	Kikuyu pasture (15.6%)	Barley + SFM (14.6 + 40.9)	2.0 + 1.2		17.8[a]	3.40	2.93
		Barley + SFM + 0.7% formaldehyde	2.0 + 1.2		18.9[b]	3.41	3.00
		Barley + SFM + 0.5% formaldehyde	2.0 + 1.2		18.4[ab]	3.38	2.97
					P<0.05	NS	NS

[a,b]: means with different superscripts differ significantly
SFM: sunflower meal

Lupins contain only a small amount of rumen undegradable protein. As mentioned earlier, Rogers and Moate (1981) heat-treated crushed lupins in an attempt to decrease protein degradation but were unsuccessful.

Sunflower meal, treated with formaldehyde, has been marketed as Norpro[R]. Moss *et al.* (1996) estimated that the rumen degradability of this protein source was 35%. They compared the product with cottonseed meal, for which the estimated degradability of the protein was 53%. Despite the large difference in rumen degradability, there was little difference in milk yield or composition when these protein meals were fed at similar levels of protein intake (Moss *et al.* 1996).

In contrast, Westwood *et al.* (2000) found that with two protein supplements differing in rumen degradability, average milk yield was 39.7 l/day when 45% of the protein supplement was undegraded dietary protein, and 36.0 l/day when only 15% of the protein supplement was undegraded dietary protein. This substantial response to undegraded dietary protein was no doubt related to the high level of production in early lactation. There was no effect on milk protein content.

Rustomo *et al.* (1996) fed 1 kg/day Norpro[R] to cows in the 8 weeks prior to calving. The supplemented cows gave birth to heavier calves, produced more milk and had fewer services per conception than unsupplemented cows.

Reeves *et al.* (1996) found that inclusion of 24% Norpro[R] in a mix with barley grain gave a milk response of 2. 0 l/kg compared with 1.4 l/kg from barley grain alone.

Dhiman and Satter (1996) reported that heat treatment is a safe and economical method to reduce protein degradation of protein supplements by rumen microbes. Chemical, *in vitro* and *in situ* evaluations of whole cottonseed exposed to different heat treatments indicated that heat treatment of cottonseed should increase the supply of protein to the small intestine.

Heat-treated cottonseed, untreated cottonseed and soybean meal were compared as protein supplements for lactating dairy cows. All cows showed similar feed intakes, however, those animals fed the heat-treated cottonseed produced significantly more fat corrected milk than cows on the other two treatments. This resulted in an increased feed efficiency for cows receiving the heat-treated supplement. In addition, cows receiving cottonseed (heated or unheated) had slightly higher body weight gains and body condition scores at the end of the experiment than those fed soybean meal.

A series of studies has been conducted in the USA to determine optimal processing conditions for soyabeans. Several procedures have been used to reduce microbial degradation of the protein in full-fat soyabeans and soyabean meal. Faldet *et al.* (1991) reported that heat treatment might have the greatest potential for safe and economic treatment.

Feeding heat-treated soyabeans was subsequently shown to produce more milk and milk protein than untreated soyabeans (Faldet and Satter 1991). The extent to which protein is digested post-ruminally is determined by the exact conditions of heat treatment (Faldet *et al.* 1992). Hsu and Satter (1995) reported that optimal heat treatment for soyabeans was 146°C for 30 minutes. This was based on a range of criteria, including *in situ* and *in vitro* protein degradabilities.

Dakowski *et al.* (1996) examined the effect of processing temperature on amino acid degradation in the rumen and digestion in the intestine of canola meal. Treatments included processing temperatures of 130, 140 and 150°C as well as moisture levels of 15 and 20% and the effects were measured with nylon bag and mobile bag techniques. For untreated canola meals, the effective rumen degradability of protein was about 73%. With the heat-treated meals, protein degradability decreased to 56% for moderate heat treatment, and to 15–23% for 140 and 150°C treatments.

Protein degradability was higher with 20% moisture than with 15% moisture. Intestinal digestibility of protein from canola meals that were pre-incubated in the rumen for 16 hours was, on average, 81% for samples heated to 130°C, 73% for untreated samples and 67% for samples heated to the highest temperatures. It was apparent that heat treatment at 130°C did not overprotect the protein and may have shifted the site of protein digestion from the rumen to the intestine.

It would be very worthwhile to define optimal conditions of heat treatment for the range of protein meals fed in Australia.

Hough (1991) compared untreated lupin kernels with formaldehyde-treated lupins, with and without addition of the first limiting amino acid, methionine. Formaldehyde treatment had no effect on milk production or composition.

Hamilton *et al.* (1992) investigated two levels of formaldehyde treatment on sunflower meal. Cows grazing tropical pastures were supplemented with cracked barley, untreated sunflower meal or sunflower meal treated with 0.5% or 0.7% formaldehyde. Untreated sunflower meal did not improve milk yield over barley alone, however,

formaldehyde-treated meal did. The highest production came from cows fed 0.5% formaldehyde-treated meal.

While these results show that production responses are possible to increased levels of undegraded dietary protein, they also emphasise that the level of formaldehyde treatment is important, as it influences protein digestibility in the small intestine.

Further work is required to determine optimal levels and conditions of formaldehyde treatment for different protein sources.

Expander treatment and traditional pelleting

Since the late 1980s, there has been increasing adoption by the compound feed industries of the annular gap expander method of processing feeds. Prestlokken (1999b) compared traditional pelleting with the expander method at temperatures ranging from 85–125°C using barley and oats.

Traditional pelleting (75–80°C) decreased ruminal degradation of protein, whilst expander treatment decreased it even further. The lowest effective protein degradabilities (30% for barley and 29% for oats) were achieved at maximum temperature. No negative effects of treatment on digestibility of protein were observed, indicating that the treatments shifted the site of protein digestion from the rumen to the small intestine. Expander treatment did not alter the level of any individual amino acids in either barley or oats. It was concluded that amino acids were not heat damaged during processing. This is consistent with the findings of an earlier experiment by the same author. The risk of over-protecting the protein by expander treatment, even at temperatures at high as 170°C, was minimal (Prestlokken 1999a).

Rumen-protected amino acids

In a New Zealand study with pasture-fed dairy cows, supplementation with protected amino acids (methionine and lysine) or protected protein did not increase milk production relative to that from cows fed a barley-based supplement (Salam *et al.* 1996). In fact, mid-lactation cows provided with protected amino acids produced less milk and less milk solids than cows receiving barley. This suggests that the absorbed amino acid balance was adversely affected by the treatment. The extent to which amino acids other than methionine or lysine may limit milk production and composition remains unknown. There was no indication that the milk protein quality was affected by additional dietary amino acids or protein. There was, however, an effect of treatment on liveweight change. All cows increased in body weight over the 13-week period post-calving and it was found that there was a tendency for cows to gain less weight during this period when given protein meal or amino acids (mean 28 kg) than when given barley (43 kg).

The role of protected amino acid supplements for cows in Australia has yet to be defined. In view of the specific effect of increasing milk protein, when there is an imbalance of EAA in MP, as discussed above, there may be increasing interest in the use of protected amino acid supplements for very high yielding cows.

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Fat supplements

Summary

Fat supplements include oilseeds, vegetable oils, tallow and processed and protected fatty acids and fats. They provide high-density energy sources that can increase milk and fat yields and the milk fat content, often with a decrease in milk protein content. They can help reduce the incidence of ketosis, and under certain circumstances, improve reproductive performance.

Whole cottonseed is used extensively in feedlot dairies and dairies with feed pads. There have been reports of toxicity associated with it, the conditions for which have not been defined. For this reason, caution should be exercised in feeding excessive amounts of whole cottonseed.

Figure 5. An inexpensive feed pad.

Calcium soaps of fatty acids and fat prills have given inconsistent responses, so that conditions for production responses are not well defined.

Polyunsaturated fats can be protected from rumen hydrogenation by encapsulation in formaldehyde-treated protein. This can be used to increase the proportion of unsaturated fatty acids in milk fat, if desired.

Introduction

Cows calving in good body condition (score 6) may lose 1 kg or more liveweight per day, providing sufficient energy for 5–6 litres of milk. This mobilisation of body tissue partly compensates for the low appetite of cows in early lactation. Feeding fat supplements is another means of compensating for low appetite in early lactation. Fats contain about three times the metabolisable energy content of cereal grains. Thus dietary fat supplements can be used to increase energy density in the diet and increase the amount of long-chain fatty acids absorbed in the intestines.

Energetically, it is more efficient for cows to absorb dietary long-chain fatty acids than for them to synthesise fatty acids in the udder. Indeed, the maximum efficiency of milk production occurs when fatty acids provide about 16% of dietary energy (Kronfeld 1976), or about 50 g/kg dry matter intake. Normally the crude fat or oil content of pastures is low (20–40 g/kg DM) (AFRC 1993) and that of grains is similar (Table 4). Oats (49–55 g/kg DM) and lupins (63–72 g/kg DM) are the exceptions. Brewers' grains (64–73 g/kg DM) and distillers grains (60–120 g/kg DM) are by-products with higher fat content. Recent analyses of ryegrass and tall fescue in NSW found oil contents of 45–80 g/kg DM, which were strongly correlated with contents of crude protein (Porter *et al.* 2001). Clearly it is not difficult to formulate a diet with 50 g oil/kg DM.

Possible effects of fat supplements on production and health are:

- Increase in total milk production due to increase in energy intake;
- Increase in milk fat content due to increase in supply of long chain fatty acids;
- Reduction in loss of liveweight due to reduction in energy deficit in early lactation, which may improve reproductive performance;
- Reduction in ketosis due to provision of lipogenic nutrients, which reduces the need for mobilising body fat.

The crude fat fraction (ether extract) contains non-fat components, some of which are not digestible.

Excess fat in the diet can inhibit digestion in the rumen and reduce intake, which counteracts the potential benefits of increasing energy density of the diet. The actual mechanism is unclear, but may involve physical coating of fibre by fat, changes in the rumen microbial population due to toxic effects of fat or decreased cation availability due to formation of insoluble complexes with long chain fatty acids (Palmquist 1984).

Fat supplements also may result in a decrease in milk protein content. The reasons for this are not well understood but it appears to be due to a decrease in casein synthesis in the mammary gland (Smith 1988). When fats are fed, there is often a decline in propionic acid production in the rumen (Khorasani *et al.* 1992). This could result in an increased utilisa-

tion of plasma amino acids for gluconeogenesis, thereby reducing the amino acid supply for milk protein synthesis.

While fat supplements may increase the yield of long-chain fatty acids in milk through direct transfer from dietary fat, the yield of medium chain-length fatty acids in the mammary gland is reduced. One reason that may account for this is a decreased supply of acetate and butyrate to the mammary gland due to reduced carbohydrate levels in the diet and the effects of fats on rumen fermentation. Enzyme inhibition at the mammary gland by long chain fatty acids may also play a part (Thomas and Martin 1988).

Excess dietary fat also depresses fat digestion in the intestines and reduces absorption of calcium and magnesium. When fat digestion is reduced, absorption of the fat-soluble vitamins is also reduced.

To minimise the adverse effects of feeding fat, supplemental fat should not exceed 4–5% of DM intake. Also it has been suggested that the minimum levels of calcium and magnesium in the diet should be increased to 10 and 3.5 g/kg DM, respectively (Palmquist 1984). Addition of calcium reduces the adverse effects of fat on rumen digestion, presumably through the formation of calcium soaps. Higher intakes of supplemental fat may be possible when the fat is inert in the rumen.

When cows are grazing temperate pastures with high levels of protein and oil, as reported by Porter *et al.* (2001), the oil content of any supplementary feed should be closely monitored so that the total oil content of the diet does not exceed 5–6% dry matter.

Types of fat supplement

Major sources of supplementary fat are:

- Tallow
- Vegetable oils
- Oilseeds
- Processed fats including:
    - Fat prills
    - Calcium salts of fatty acids
    - Protected fats.

The inclusion of tallow in the diet would restrict export of beef to the European Union. Tallow has to be melted before mixing in the diet, so that normally only feed manufacturers use it. Apart from increasing energy density, it improves pellet adhesion and palatability.

Oilseeds and processed fats can be mixed directly with other diet ingredients by the farmer or feed manufacturer. Of the oilseeds, most are used for production of oil for human consumption. Cottonseed is the exception. Due to its content of gossypol, it is used only for animal consumption.

NSW Agriculture has reported several cases of toxicity associated with feeding whole cottonseed to cows in Australia (D. F. Battise, personal communication). The pathogenesis and contributory factors have not been clearly identified. It is prudent to introduce whole cottonseed into the diet gradually and to monitor closely any adverse changes in milk production and animal health.

Whole cottonseed is widely used as a supplement for dairy cows due to its high content of protein, energy and fibre (Table 4). Gossypol in its free form in whole cottonseed may adversely affect reproductive function in many animal species. The relative insensitivity of female ruminants, in particular, to gossypol is related to their ability to detoxify it in the rumen by binding the free form to soluble proteins, or by dilution and slowed absorption (Risco *et al.* 1992).

Nevertheless, there is a risk of toxicity with its use. In a review, Arieli (1998) concluded that diets with 150 g/kg whole cottonseed might be fed for long periods of time without adversely affecting growth or development of replacing heifers. This recommendation is consistent with the findings of Coppock *et al.* (1987) that 3–4 kg/day can be safely fed to dairy cattle. Similarly, Emery and Herdt (1991) suggested whole cottonseed be included in dairy diets at less than 3.5 kg/day.

Actual safe levels vary with the gossypol content of the seed, which is likely to differ with the variety and growing conditions. However, the processing of whole cottonseed may reduce the chances of gossypol toxicity (Arieli 1998). High temperatures favour the formation of stable bonds between gossypol and other molecules, and bound gossypol is generally considered to be physiologically inactive.

Pelleting and the addition of iron sulphate have been shown to be means of decreasing the toxicity of gossypol in cottonseed products (Barraza *et al.* 1991). Cottonseed may also be detoxified by ammonia treatment (Rogers and Poore 1995). Heat treatment of whole cottonseed is usually aimed at reducing the degradability of protein in the rumen and increasing the amount of protein flow into the intestine. Arieli (1998), however, concludes that an additional benefit of such a treatment is a reduction in the negative effects of gossypol.

It has also been suggested that cyclopropane fatty acids in whole cottonseed may be toxic (Hawkins *et al.* 1985).

Of the processed fats, fat prills are fine particles of solid fatty acids that are relatively inert in the rumen, as are calcium soaps of fatty acids. In the acid environment of the abomasum (fourth stomach), calcium soaps dissociate and are then able to be absorbed in the small intestine and utilised.

Unsaturated fatty acids are much more reactive in the rumen than saturated fatty acids, and undergo hydrogenation. A method was developed in Australia to protect vegetable oil from rumen hydrogenation by encapsulating it in protein, then coating the protein with formaldehyde (Scott *et al.* 1970). Protection of the fat in this manner (by-pass) prevented deleterious effects on rumen fermentation, making it possible to feed much greater amounts of fat and to increase the proportion of unsaturated fatty acids in the milk (McDonald and Scott 1977).

Technical review

In some experiments, fat supplements have given substantial increases in milk yields and milk fat yields. In others, fats have caused loss of appetite, reduction in yields of milk and milk constituents and depression of milk fat percentage (Thomas and Martin 1988). In between these extremes, the effects of increasing dietary fat depends on the level and type of fat used and the form in which it is included in the diet.

Danfaer (1981) showed that increasing fat content of the diet from 25 to 45 g/kg DM increased the energy density of the diet, and milk production was increased by about 9% in early lactation and 4% in mid-lactation. Above this fat level, the response diminished.

Feeding whole cottonseed is widely practised in the USA and is becoming increasingly popular in Australia. In overseas experiments, cottonseed generally has increased yields of milk and milk fat but reduced milk protein content.

Ehrlich *et al.* (1993) investigated the response to whole cottonseed under Australian grazing conditions. Early to mid-lactation pasture-fed cows grazing pangola grass were unsupplemented or supplemented with 3 kg cracked sorghum or 3 kg whole cottonseed. Supplementation with whole cottonseed did not affect milk yield or composition. It was suggested this was due to a high substitution rate of whole cottonseed for pasture, associated with an oil content in the diet of 7.1% of dry matter. Excessive intake of oil in the diet may have reduced pasture digestion in the rumen and depressed pasture intake.

In a review of 31 experiments with formaldehyde-protected fat supplements, workers who provided adequate quantities of polyunsaturated oil in a protected form found large increases in the content of polyunsaturated fatty acids in cows' milk (McDonald and Scott 1977). Most of these experiments also showed increased milk fat content and an increase or no change in milk yield.

Subsequent experiments have confirmed that formaldehyde-protected oilseeds increase milk fat content and fat yield and increase the proportion of polyunsaturated acids in the milk (Ashes *et al.* 1992; Gulati *et al.* 1999).

Other research workers investigated the direct treatment of lipids with formaldehyde. Again, this treatment reduced the negative effects on rumen digestion and showed consistent increases in milk fat content and yields of fat-corrected milk (Smith 1988). At high levels of intake (>4 kg/day) even these 'protected' lipids can exert detrimental effects on rumen function (Smith 1988).

Kerr *et al.* (1982) investigated the effect of providing a formaldehyde-treated tallow-soyabean supplement at two levels to cows grazing tropical pastures over two lactations (Table 23). This protected fat supplement produced linear increases in milk fat yield without significant increases in milk yield. A response of 112 g milk fat/kg of fat in the supplement was obtained. The authors concluded that fat supplements provide a practical method for maintaining milk fat content.

The use of fat prills has been investigated in a number of Australian experiments, which are summarised in Table 24. Hodge and Rogers (1983) fed fatty acids at levels of up to 800 g/day on top of a basal diet of silage during late lactation. They found that while the supplemented cows had a significantly higher milk fat content, there was no increase in total fat production due to an accompanying decrease in milk yield.

King *et al.* (1990a, 1990b) assessed effects of fat supplements at different stages of lactation. Cows in mid-lactation were fed varying quantities of a fatty acid supplement up to 1020 g/cow/day. They found yields of milk and milk constituents increased linearly with increasing intake of long chain fatty acid. Marginal responses to feeding 1 kg of supplement were 3.3 kg milk, 0.33 kg fat and 0.07 kg protein. There was no effect of the supplement on DM digestibility.

Cows in early lactation were fed either 3.3 kg of a pelleted high-energy supplement or 3.8 kg of the supplement containing additional long-chain fatty acids (King *et al.* 1990b). A

response of 1.8 kg milk and 0.33 kg milk fat per kg of additional fatty acid was obtained. The fatty acids prevented the reduction in milk fat content that occurred in animals offered the starch-based pelleted concentrate. Substitution rates of 0.21 kg/kg and 0.37 kg/kg were calculated for pellets and pellets plus fatty acids, respectively.

Trigg (1986) conducted a similar grazing experiment, feeding 4 kg/day of a pelleted supplement with or without 15% fatty acids. Milk and milk fat yields did not differ significantly between treatments, nor did milk composition. Again, substitution rates differed substantially, being 0.17 kg/kg for the control against 0.47 kg/kg for the pellet with added fatty acids.

In an assessment of the magnitude of response to fat supplements over a number of experiments, King *et al.* (1990b) concluded that the type of basal diet is not important in influencing the response to fat supplementation. However, Davison *et al.* (1991b) concluded that pasture quality and quantity, especially the level of protein intake, affected the size of the response.

Cows in both early and mid-lactation, grazing predominantly kikuyu pastures, were fed 0.5 kg/day of rumen-inert fat. There was a trend to increased milk yield for cows in mid-lactation of 2.8 kg milk/kg fat, but this was not statistically significant. An overall response of 0.8 kg milk/kg fat was gained, but there was no significant effect on milk components.

The lack of response in early lactation was thought to be due to:

- Increased substitution of pasture when fat was fed, and
- Low protein intake preventing maximum utilisation of the supplement.

It was considered possible that when pasture intake was restricted due to flooding, fat comprised too high a proportion of the diet reducing the milk response.

Table 23. The effect of a protected fat supplement on the production of cows grazing tropical pasture.

Reference	Basal ration	Length of feeding period	Type of fat supplement	Amount of extra fat (g/cow/day)	Milk yield (kg/lactation)	Milk fat	Milk fat yield (kg/lactation)	SNF yield (kg/lactation)
Kerr *et al.* 1982	N-fertilised & irrigated	2 lactations		0	2401	3.7	88[a]	203
	pangola grass + grain or molasses		Formaldehyde-treated tallow	250	2545	3.7	94[ab]	210
	(2.75 kg/cow/day)		Soyabean oil	500	2616	4.0	105[b]	219
					NS	NS	P<0.05	NS

[a,b]: means with different superscripts differ significantly

King and Trigg (1985) fed early lactation cows varying amounts of fat prills up to 1320 g/cow/day. They found supplementation produced a general negative effect on dairy cow productivity during the first 45 days of lactation. This was due, in part, to a significant reduction in the digestibility of the ration when fatty acids were fed. A negative carryover effect was also observed during the 45 days after supplementation.

In this series of experiments, responses to fat prills proved variable. In one case, protein intake seemed to limit the response, while in another, fatty acids reduced diet digestibility and so decreased the response. In two experiments substantial increases in milk fat yield and fat content were seen, and in one trial fat prills prevented the reduction in milk fat content seen with starch-based concentrates. While it appears that fat prills may be beneficial in some circumstances, the conditions under which responses would be expected are not well defined.

Table 24. Effects of supplementation with fat prills.

Reference	Basal ration	Stage of lactation	Type of fat supplement	Amount of supplement	Milk yield (kg/day)	Milk fat (%)	Milk fat yield (g/day)	Milk protein (%)	Milk protein yield
Hodge & Rogers 1983	Silage	Late	LCFA	0	7.6	4.33	329	–	–
				Up to 800 g/day	6.7	5.03	336	–	–
Trigg 1986	Ryegrass/ white clover pasture	Early	Fat prills	4 kg concentrates	26.2	3.43	890	2.97	780
				4 kg concentrates + 15% fat prills	26.0 NS	3.54 NS	900 NS	3.00 NS	770 NS
					Response per kg fatty acids				
					(kg)	(%)	(kg)	(%)	(kg)
King *et al.* 1990a	Maize silage, lucerne hay, CSM, rolled grain ad libitum	Mid	LCFA	120–1020 g/cow/day	3.3	0.85	0.33	0	0.07
King *et al.* 1990b	Irrigated perennial pasture + 3.3kg pelleted concentrate/ cow/day (3.2% fat)	Early	Additional LCFA in pelleted concentrate (12.8% fat)	3.8 kg pellets (~500 g LCFA)	1.8 NS	0.87 P<0.05	0.33 P<0.05	0 NS	0 NS
Davison *et al.* 1991b	Kikuyu pasture + 4.5kg grain/ mineral concentrate/ cow/day	Early Mid	LCFA LCFA	500 g/day 500 g/day	0 2.8 NS	0 0 NS	0 0 NS	Overall response = 0.8 kg milk/kg fatty acid	

LCFA: long-chain fatty acids

CSM: cottonseed meal

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7

Mineral supplements

Summary

Recommended concentrations of minerals in the diet vary with liveweight, reproductive stage, level of milk production and degree of heat stress. Studies in the southern states of the USA indicate that there are good reasons to greatly increase mineral concentrations during the summer when cows frequently suffer from heat stress.

Low concentrations of calcium, phosphorus, sodium and magnesium have been identified in pastures selected by cows on three commercial dairy farms in NSW. Low concentrations of calcium have been found throughout Victoria, and low concentrations of phosphorus in Gippsland. Low concentrations of phosphorus have been identified in large numbers of barley grain samples collected throughout South Australia. Effects of these deficiencies on milk production and fertility have not been determined.

In Queensland, deficiencies of sodium and phosphorus in grasses and legumes are widespread and cows respond to supplementation with these minerals. In some cases, where high levels of grain are fed, calcium may be required, and on rare occasions, potassium.

Trace element deficiencies are often regional and seasonal. Their variability is dependent on pasture management practices.

Decreased availability of minerals due to interactions with other dietary constituents can affect the mineral status of cows, especially in the case of copper that commonly interacts with molybdenum and sulphur, but can also be affected by other trace elements. Areas of copper and selenium deficiency in Australia are reasonably well defined, but not absolute, so that local knowledge is important in determining the need for supplementation.

The trace element content of cereal grains has been shown to vary markedly. In the pig and poultry industries, this problem is overcome by routine incorporation of trace element supplements into the diet. This practice is likely to become increasingly common on dairy farms as feeding and production levels increase.

Introduction

Mineral requirements for cows have been calculated for each of the important macro-minerals and micro-minerals (trace elements). These requirements vary with the cows' liveweight, reproductive stage, level of milk production and degree of heat stress.

There are many interactions and antagonisms between minerals, which affect the efficiencies with which they are absorbed. For this reason, minerals are often fed at concentrations in excess of their calculated requirements, but care has to be exercised because all essential minerals have detrimental effects on animal performance when fed in excess.

Heat stress is a factor that is not considered in the major feeding systems (MAFF 1975; ARC 1984; AFRC 1993; NRC 2001). However, studies in the southern states of the USA have shown that cows suffering from heat stress increase their excretion of sodium in urine and potassium in sweat, and that by increasing the concentration of sodium and potassium in the diet, milk production can be increased (Huber *et al.* 1988). A major response to heat stress is a reduction in feed intake, the effects of which can be minimised by increasing the nutrient density of the ration. Increasing the proportion of concentrates, and increasing the concentration of protein and minerals, as shown in Table 25, can achieve this.

Table 25. Recommended nutrient concentrations (g/kg) for lactating cows in Florida producing 35 litres/day (D. Beede cited by Davison 1988) compared with NRC (1989) and NRC (2001).

	NRC (1989)	NRC (2001)	Florida Winter	Summer
Crude protein	160	152	165	180
Calcium	5.8	6.1	8.0	8.0
Phosphorus	3.7	3.5	5.2	5.2
Potassium	9.0	10.4	12.5	15.0
Sodium	1.8	2.3	5.0	6.0
Magnesium	2.0	1.9	3.5	3.8
Sulphur	2.0	2.0	2.5	2.5

Florida recommendations, in most cases, are substantially higher than those of NRC (1989) and NRC (2001), particularly in summer. The higher recommendations for summer are particularly relevant to Australia where heat stress is experienced on a regular basis, particularly in northern areas. In recent studies in north-eastern NSW during summer, salt was added to the diet of grazing, lactating cows to provide sodium at 2.1 to 6.7 g/kg dry matter (Granzin and Gaughan 2002). Cows suffered heat stress during 50% of the experimental period. The optimum level of sodium was found to be 5.4 g/kg, at which the production of fat-corrected milk was 11% higher than that at 2.1 g/kg. This optimum is close to the recommended level of 6.0 mg/kg in Florida during the summer (Table 25).

The level of heat stress experienced by dairy cattle could be greatly reduced by:

• Providing effective shade in paddocks and yards;
• Providing cool drinking water at all times;
• Increasing air movement in milking parlours; and
• Reducing distances walked in hot weather.

A combination of improved animal management and increased nutrient density of the diet should lead to substantial increases in milk production during the summer. Detailed information on procedures to minimise heat stress for dairy cows in Australia is given by Davison *et al.* (1996).

Cows obtain minerals from pasture, supplementary feeds, water and soil. The need for supplementation depends on the level of minerals present in feed and water, their availability to the animal and the occurrence of any mineral interactions. Minerals such as calcium, magnesium and sodium can be present in bore water in amounts that contribute significantly to requirements. Excessive concentrations, particularly of sodium, can reduce feed intake.

Mineral supplement feeding is well established in certain areas. On the basis of pasture analyses carried out in the 1970s, dairy farmers in the Hunter Valley of NSW regularly fed supplements containing calcium, phosphorus, sodium and copper (Bob Thompson, personal communication). Requirements for mineral supplements are likely to increase with the increasing use of concentrates.

Technical review

Macro-minerals

The macro-minerals of importance to the cow are calcium, phosphorus, sodium, magnesium, potassium and sulphur.

Stockdale (1991) suggested that the temperate pastures of northern Victoria contain an abundance of most macro-minerals and that it is only when a major proportion of the feed is obtained from concentrates that mineral supplementation may be required. In a later comprehensive review of minerals in dairy pastures in Victoria, Jacobs and Rigby (1999) concluded that calcium may be limiting in all regions during spring, when most cows are in early lactation, and phosphorus may be limiting in Gippsland. High levels of potassium in pasture are also likely to have implications in relation to absorption of magnesium. Kellaway *et al.* (1992) estimated the mineral content of pasture actually eaten on three commercial dairy farms in NSW over three years. They showed that concentrations of calcium and phosphorus frequently were sub-optimal for milk production on all three farms. Other mineral deficiencies identified were copper throughout the year, magnesium in August and September and sodium in January–March. The sodium deficiency was associated with pastures being dominated by sub-tropical grasses. Fulkerson *et al.* (1998) found that average concentrations of sodium, calcium, phosphorus, sulphur and zinc in kikuyu pastures were sub-optimal for milk production, and concentrations of zinc and copper were marginal in ryegrass pastures.

Temperate grasses generally have a lower content of magnesium than tropical grasses, and magnesium absorption can be impaired by high contents of potassium in the grasses (Minson 1990).

Cereal grains are low in most minerals, particularly calcium and sodium. High grain feeding levels dilute the mineral concentration in the pasture and may produce deficiencies requiring supplementation. Sodium is present in substantial amounts in the water supply in some areas.

It is often assumed that the phosphorus content of cereal grains is reasonably high and cows receiving significant amounts of cereal grains in their diet are unlikely to be deficient in phosphorus. Studies in South Australia (B. Cartwright, personal communication) indicate that this is a rash assumption. It was found that the median concentration of phosphorus in barley grain dropped from 4.1 to 2.8 g/kg between 1984 and 1990, possibly associated with the declining use of superphosphate.

Moate (1987) examined the effects of a phosphorus supplement on production of dairy cows grazing temperate pastures in Victoria. Over a period of seven weeks, cows in early lactation were fed 2 kg of a commercial pelleted concentrate, with and without a phosphorus supplement. There were no effects on yields of milk or milk constituents due to supplementation.

A second experiment, with cows in late lactation, compared pasture, a control pellet supplement and a supplement fortified with phosphorus. While both concentrates increased milk yield above that of pasture alone, there was no difference between them. These experiments indicate that phosphorus was not limiting under those conditions.

Before testing the effects of adding mineral supplements to diets, it would be useful to carry out preliminary diagnostic tests. These would be carried out on samples of soil, pasture, blood or milk, whichever is appropriate for the mineral of interest. When an apparent deficiency is diagnosed, this would seem to be the appropriate time to initiate experiments to determine responses to supplementation.

Tropical pastures often have lower mineral contents than temperate pastures. Deficiencies of both sodium and phosphorus are widespread in Queensland (Cowan and Davison 1983). The sodium content of tropical grasses varies widely between and within grass species (Minson 1990). Phosphorus content is decreased following the application of nitrogen fertiliser to the pasture and low calcium levels have also been recorded in some areas. Some tropical grasses, particularly Setaria spp., and Cenchrus spp., have a high content of oxalates which bind to calcium, reducing its availability (Barry and Blayney 1987).

Figure 6. Grazing Setaria grass on the Atherton Tableland.

As with temperate pastures, the use of concentrates low in mineral content may increase the requirement for mineral supplements. High levels of cereal grain will increase the need for sodium (and possibly phosphorus), while feeding molasses will increase the requirement for both sodium and phosphorus (Chopping 1988).

Milk yield responses of about 10% have been recorded to supplements of both sodium and phosphorus, given to cows grazing tropical grass-legume pastures (Davison *et al.* 1980, 1982).

Davison *et al.* (1980) provided a sodium supplement in the form of 40 g coarse salt per day to cows on a basal ration of panicum-glycine pasture and maize (1 kg/cow/day). Supplemented cows produced an extra 1.2 kg milk/cow/day over a 12-week period. This was attributed entirely to sodium, either directly or through its effect on increasing roughage intake, but may have been attributable in part to chloride.

Phosphorus supplements given with molasses to cows on similar pastures allowed an extra 1.1 kg milk/cow/day over the first 180 days of lactation (Davidson *et al.* 1980). In addition to this, phosphorus supplements may also have favourable effects on the reproductive status of the herd.

Cowan (1985) notes that local knowledge regarding sodium content of pastures is important in determining need for supplements, as sodium content can vary widely.

The experiment of Davison *et al.* (1980) was conducted in the Atherton Tablelands region, where sodium levels are very low. However, in other areas of Queensland, with different pastures, they may be somewhat higher and sodium contributions from the water supply should also be taken into account, though this, too, can vary widely.

In Victoria, sodium is often high in pastures because of salinity and the fact that ryegrasses are active importers of sodium (Jacobs and Rigby 1999).

Magnesium levels in pasture selected on commercial dairy farms in NSW were found to be low in August and September (Kellaway *et al.* 1992). This is a time of the year when high levels of potassium and nitrogen may reduce magnesium availability. Frequently, Causmag (magnesium oxide) is fed to cows grazing temperate pastures in spring. In New Zealand, supplements of magnesium given to hypomagnesaemic cows have produced increases in milk fat yield of 3–11% (Merrall 1983).

Micro-minerals

Cobalt, copper, iodine, iron, manganese, molybdenum, selenium and zinc are trace elements of importance in the cow. All are required in small amounts for optimal health and production and excessive amounts can be harmful. Often marginal deficiencies of these minerals will not produce any specific symptoms, but will show only in a lower-than-normal production. Copper and selenium are the micro-minerals most likely to require supplementation.

Caple and Halpin (1985) noted that 60% of copper supplements marketed in Australia were purchased in southern Victoria, while 20% were used in Queensland. They also surmised that, despite this supplementation, copper deficiency would continue to be a problem due to constantly changing methods of pasture management, introduction of new pasture species and the effect of antagonistic minerals.

Local knowledge should be sought as to the requirement for copper supplementation in any particular region. In some areas of southern Australia, seasonal copper deficiencies

are seen, especially in the more favourable seasons with lush spring pasture growth (Caple and Halpin 1985).

Copper levels in grain may require monitoring to determine the need for supplementation. Koh (1990) examined copper levels in South Australian barley and wheat grain and found 100% of wheat samples and 98% of barley samples had copper concentrations below the accepted dietary requirement for cows. Significant regional variations in the mineral levels in grain suggest consideration should be given to the development of a rapid method of routine feed analysis for minerals.

Selenium deficiency is widespread on Australian pastures, but is a particular problem in many of the southern dairying districts. A survey of cattle in the south-east of South Australia (McFarlane and Judson 1990) found low blood selenium concentrations in 40% of cows sampled. While production responses to selenium supplementation have not been recorded, these supplements are required in some areas during spring, to prevent white muscle disease (Caple and Halpin 1985).

A survey of selenium concentrations in South Australian wheat and barley grain found adequate levels in all samples of wheat in 1981 and barley in 1982, but low levels in 6% of barley samples taken during 1981. Again, values varied significantly between regions confirming the need for feed analysis to determine mineral contents of grain.

Marginal cobalt deficiency has been identified in many coastal areas of Australia as well as some inland areas (Caple and Halpin 1985). Cobalt supplements may be required for cattle in these areas during winter and spring. The need for supplementation is also influenced by the pasture management procedures being undertaken, especially liming.

Grainger *et al.* (1987) investigated the effects of a commercial cobalt supplement (Dairy Complex) on the production of cows grazing temperate pastures. While pasture cobalt levels were above the accepted dietary requirement for cows, the availability of the cobalt was unknown. The cows were fed pellets containing the supplement at two different rates over 12 weeks. No significant differences in yields of milk or milk constituents occurred between treatments. This indicates that, where pasture levels of cobalt are adequate, there are no benefits in further cobalt supplementation. However, where cobalt levels in pasture are deficient milk production responses will be seen (Caple and Halpin 1985).

Deficiencies of iron, zinc and manganese have not been identified in grazing cattle in Australia (Caple and Halpin 1985). However, levels of both zinc and manganese in grain can often be below the accepted dietary requirement (Koh 1990). If high levels of grain are being fed, attention should be given to balancing the levels of these micro-minerals in the diet.

Koh (1990) surveyed mineral concentrations in South Australian barley and wheat grains. While only 14% of wheat samples had manganese concentrations below the accepted dietary level, 100% of barley samples were manganese deficient. Low zinc levels were present in 73% of barley grain samples and 77% of wheat samples. Again, there was significant variability between mineral concentrations between regions. Feed analysis conducted on each batch of concentrates received would prove useful in this situation.

Dietary cation-anion difference

Summary

Feeding supplements of acid salts to cows in late pregnancy changes the dietary cation-anion difference (DCAD), or acid-base balance. This can reduce the risk of post-calving metabolic disorders, particularly milk fever. However, acid salts are unpalatable, which limits the amount that can be fed.

On pasture-based diets, it is feasible to feed sufficient acid salts to reduce the DCAD by 100–200 mEq/kg DM. This relatively small reduction has been shown, in some experiments, to reduce the incidence of clinical and sub-clinical milk fever and thereby improve productivity. It has been suggested that much of the response might be due to magnesium in the anionic salts stimulating absorption of calcium. Other experiments in Australia have shown no benefit from feeding anionic salts to grazing cows.

Introduction

Milk fever is caused by low concentrations of calcium in the blood, which impairs muscle and nerve function. The calcium concentration in the blood is regulated by the interaction of parathyroid hormone, 1,25-dihydroxyvitamin D and magnesium. An important determinant of milk fever is the acid-base status of the cow at parturition when cows were grazing high-quality temperate pasture (Ender *et al.* 1971). An increase in blood pH, which is metabolic alkalosis, is caused by an excess of dietary cations, which are minerals with a positive charge, including potassium, sodium, calcium and magnesium. Dietary anions such as chlorine, sulphur and phosphorus are acidic, and reduce blood pH, which leads to increased calcium absorption from the gut and increased calcium mobilisation from bone.

Metabolic alkalosis impairs the activity of parathyroid hormone and reduces production of 1,25-dihydroxyvitamin D leading to reduced absorption of calcium from the intestines and bone. American work (Beede 1992) indicated that acidification of the diet for three to five weeks before calving increases calcium uptake and reduces the risk of milk fever.

The dietary cation-anion difference (DCAD), or dietary cation-anion balance (DCAB) as it is sometimes called, refers to the proportions of specific ions in the diet (Oetzel 1993). The difference between cations and anions in the body determines blood pH, and the DCAD is used as a measure of the acidity or alkalinity of a diet (Pehrson *et al.* 1999). If blood pH is more acid, parathyroid hormone is more effective at activating vitamin D and increasing absorption of calcium.

Several different formulae have been used to define DCAD. The most common equations (Oetzel 2003) are:

DCAD (meq) = (Na + K + 0.38 Ca + 0.30 Mg) – (Cl + 0.60 S + 0.50 P)
DCAD (meq) = (Na + K) – (Cl + S)
DCAD (meq) = (Na + K) – (Cl)

To convert from feed analyses in g/kg dry matter to meq/kg dry matter, divide the weights by the following factors:

Cations		Anions	
Sodium	0.023	Chlorine	0.035
Potassium	0.039	Sulphur	0.016
Calcium	0.020	Phosphorus	0.017
Magnesium	0.012		

The first equation takes account of the bioavailability of Ca, Mg, S and P and should be the most accurate, but the coefficients of absorption are averages, which may not be applicable in all situations. Even though the negative charge of the phosphate ion suggests its use as a means of acidifying to the benefit of plasma calcium, high levels of phosphorus in the diet (>15 g/kg DM) have been shown to induce hypocalcaemia (McNeill *et al.* 2002). The second equation is the most widely applied, whilst the third equation only accounts for monovalent ions.

Research indicates that the desired DCAD range is dependent on the status of the cow, differing greatly between the dry and the lactating cow (West 1993).

DCAD and the lactating cow

Block (1994) suggests that it is logical to keep the DCAD highly positive (cationic) for lactating cows because these animals have a high metabolic rate and the cellular environment tends to be acidic. He suggests that the higher dietary sodium and potassium relative to chorine counteracts the acidic conditions with the alkaline effects of sodium and potassium.

The findings of Tucker *et al.* (1988) support this idea. They demonstrated that cows from three to eight months after calving fed an alkaline diet with a DCAD of +200 mEq/kg (calculated as mEq of sodium + potassium – chlorine) produced more milk than cows fed an acidic diet with a negative DCAD diet (-100 mEq/kg.)

West *et al.* (1991) reported similar results. In addition, Delaquis and Block (1991) demonstrated that cows in early and mid-lactation, but not in late lactation, responded to an alkaline diet with a higher milk yield. These results collectively indicate that an alkaline diet is appropriate for lactating cows but that the ideal DCAD value may change as lactation progresses and milk production and metabolic activity decrease.

In contrast, Roche *et al.* (2003) found that when they increased the DCAD from +210 to +1270 mEq/kg in the diet of pasture fed cows in early lactation, there was no significant effect on milk production, and a slight decrease in dry matter intake.

When cows are heat stressed, increased DCAD has also been reported to increase DM intake (West *et al.* 1992), which is thought to be, at least in part, due to an increase in blood-buffering capacity.

DCAD and the dry cow

Prevention of milk fever

The nutritional management of a dairy cow in the period pre-calving can have a major effect on subsequent milk yield by reducing the incidence of metabolic disorders post-calving (Johnson 1995). The role of DCAD, in particular, has been the subject of much research following Dishington's (1975) findings that alkaline diets predisposed cows to milk fever, whilst acidic diets prevented the same metabolic disease. This has been confirmed in numerous trials (Block 1984; Oetzel *et al.* 1988; Gaynor *et al.* 1989; Goff *et al.* 1991) in which the incidence of milk fever was reduced by feeding an acidic diet (with a negative DCAD).

Low DCAD diets induce a mild metabolic acidosis, as shown by reduced plasma bicarbonate (Fredeen *et al.* 1988b; Tucker *et al.* 1988) and decreased urinary pH (Fredeen *et al.* 1988a; Oetzel *et al.* 1991). When acidification is optimal, mean urinary pH is about 6.0 to 6.5; mean urinary pH values below 5.5 indicate over acidification (Oetzel 2003).

Acidic diets have minimal effect on intestinal absorption of calcium (Johnson 1995), but do increase the amount of vitamin D produced by the parathyroid gland. This increases the mobilisation of calcium from bones, increasing blood calcium levels (Oetzel 1993).

DCAD of pre-partum diets

Oetzel (1993) reported that diets fed to pre-partum cows in North America are commonly alkaline and have DCAD values of around +50 to +300 mEq/kg DM. This is consistent with the findings of Walker *et al.* (1998) in Australia and Wilson (1998) in New Zealand who found DCAD values of pasture-based dry cow diets, receiving up to 50% of their diet from grain or silage to contain between +200 and +250 mEq/kg DM. Negative DCAD values were found for sub-tropical forages, including kikuyu grass and Rhodes grass (McNeill *et al.* 2002).

Cows receiving diets consisting entirely of pasture are likely to be exposed to higher DCAD values in their feed than those fed supplements. Studies in Victoria showed that DCAD values in pasture were highest in the winter and spring (700–900 mEq/kg DM) and lowest in summer (200–350 mEq/DM) (Jacobs and Rigby 1999). These results indicate that North American recommendations to reduce DCAD concentrations to less than zero prior to calving (Oetzel 1993) may be virtually impossible to achieve for pasture fed herds.

Chloride and sulphur concentrations are relatively low in grasses (Cherney *et al.* 1998). Potassium concentration has the most significant effect on dietary DCAD for cows eating a pasture-based diet. Although information on grasses is scarce, there is evidence that the fertiliser potassium source may have an impact on the nutrients of importance to DCAD

and subsequently to the health and productivity of a particular herd (Cherney *et al.* 1998). High concentrations of sodium occur in some temperate pastures, particularly those grown under irrigation (McNeill *et al.* 2002). This combines with potassium to give high DCAD values. Thus it is undesirable to add salt to concentrates being fed pre-calving.

Use of supplementary anionic salts

Diets can be made acidic by adding mineral acids or (more practically) acid (anionic) salts (Oetzel *et al.* 1988), which are minerals that are high in chloride and sulphur relative to sodium and potassium. Either form of acidic supplementation lowers DCAD and may reduce the risk of milk fever. Anionic salts include calcium chloride, calcium sulphate, magnesium chloride, magnesium sulphate, ammonium chloride and ammonium sulphate.

Very large reductions in sub-clinical milk fever have also been documented (Oetzel *et al.* 1988) resulting in diminished lethargy, improved rumen contractions and increased appetite in early lactation. In fact, the prevention of sub-clinical milk fever with acidic salts may have a greater impact than prevention of clinical milk fever on the profitability of dairies (Oetzel 1993).

Wilson (1996) examined the effect of supplementing pasture-fed dairy cows with acid salts during late pregnancy. The objective was not aimed at reducing clinical cases of milk fever, as it was not a problem in the herd under investigation, but to test whether sub-clinical milk fever was limiting production.

The DCAD of the diet was estimated to have been reduced from +250 to +165 mEq/kg DM by adding a mix of magnesium chloride and ammonium sulphate. Despite all cows (control and treatment) receiving a 40 g calcium supplement daily, 40% of the clinically normal, control cows had sub-clinical milk fever (blood calcium less than 8 mg/100ml) at some time during the first 12 days of lactation. In contrast, only 15% of the cows receiving acid salts had sub-clinical milk fever, requiring less assistance at calving, having lower ketone levels in the blood and producing 14% more milk protein during the first month of lactation.

In a similar experiment, Walker *et al.* (1998) examined the effect of feeding a grain-based pellet formulated to reduce DCAD, compared with the feeding of a control pellet, on the post-calving milk production and health of pasture-fed cows. The DCAD of the control diet contained between +200 and +250 mEq/kg DM whilst the treatment diet DCAD was close to zero. Pre-calving feeding to reduce DCAD was shown to significantly increase milk yield when the incidence of metabolic disorders was low.

Concerns about the relevance of anionic salts in pasture-based systems were raised by Roche (2000) who suggested that apparent responses to anionic salts by pasture-fed cows might be due to the inclusion of magnesium in the anionic salt, which stimulates absorption of calcium. He suggested that a cheaper alternative to the feeding of anionic salts to grazing cows is to feed 10–20 g/cow/day magnesium oxide for two to three weeks pre-calving, and limestone at 150–200 g/cow/day plus 10–20 g/cow/day magnesium oxide post calving.

The possible confounding between effects of magnesium and anionic salts was avoided by Stockdale *et al.* (2002) who fed 21 g/day magnesium oxide to control cows and 125 g/day magnesium sulphate to cows receiving anionic salt pre-calving, on a diet of maize silage, grain, straw and canola meal. The DCAD of the control and anionic salt diets aver-

aged +52 and -54 mEq/kg respectively. Blood calcium levels were significantly higher 12 hr after calving with the anionic salt supplement.

On a pasture diet, Roche *et al.* (2003) fed anionic salts to peri-parturient cows in SE Australia to give DCAD ranging from -120 to +690 mEq/kg and reported no beneficial effect on reduction in the incidence of milk fever. They concluded that the DCAD concept is not a practical means of preventing milk fever in pasture-fed cows.

Palatability of anionic salts

The salts most commonly used to reduce the DCAD of diets are ammonium chloride, calcium chloride, ammonium sulphate and magnesium sulphate (Pehrson *et al.* 1999). These salts, along with magnesium chloride and calcium sulphate, have similar acidifying values (Oetzel *et al.* 1991). However, palatability is a recognised problem with all supplementary anionic salts, putting a constraint on the amount that can be added to diets.

Oetzel and Barmore (1993) demonstrated a dramatic decrease in acceptability when 2.3 Eq/day of acid salts were delivered in a concentrate mixture. In addition, differences in acceptability among the salts were noted, with sulphates tending to be more palatable than chlorides and pelleting failing to improve the palatability of the concentrate. The significance of this is that the maintenance of pre-partum DM intake is already difficult and yet critical to post-partum health and productivity in dairy cows (Grummer 1995). For this reason a reduction in dietary acceptability pre-partum is likely to have negative consequences.

In a comparison among anionic salts, magnesium sulphate caused the least severe depression in DM intake (Oetzel and Barmore 1993), but also tended to be the least acidic (Oetzel *et al.* 1991).

Effects of acidified fermentation by-products and anionic salts

Recently, additives referred to as acidified fermentation by-products have become commercially available to aid in the prevention of post-calving metabolic disturbances. They have been shown to be as effective as conventional acid salts in producing an acidic response in non-lactating cows (Vagnoni and Oetzel 1997), but it is not yet clear whether they are less likely to reduce DM intake than mixtures of salts (Vagnoni and Oetzel 1998).

Excessive anionic salt supplementation

Wilson (1998) suggests that, if supplementary acid salts are to be added to a diet, it is best to use a mixture of two or more salts. This is to avoid toxicity (of ammonium salts), copper deficiency (associated with excess sulphur), diarrhoea and lower diet digestibility (both consequences of excess magnesium). However, in Australia and New Zealand, the risk of complications may be lower given the pasture-based nature of the industry.

Under such circumstances, it is not practical to feed up to 200–300 g acid salts/cow daily as is often practiced overseas (in total mixed rations). This is both because of the unpalatability of the salts and the fact that silage supplements (convenient carriers that mask the disagreeable flavour (West 1993) frequently make up only a portion of the diet. Wilson (1998) suggests that it will usually only be possible, given the nature of the diets offered in Australasia, to reduce DCAD values by 100–200 mEq/kg DM by feeding acid salts.

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9

Buffers

Summary

Buffers and alkaline compounds can be used to reduce rumen acidosis associated with high levels of rapidly-fermenting starch in the diet. Alternative strategies to deal with rumen acidosis include changes in feeding management and inclusion of antibiotics to modify rumen fermentation.

On the basis of experiments in Australia, addition of bentonite to diets containing up to 10 kg/day cereal grains is unlikely to have beneficial effects on milk production or composition. Bentonite may reduce the incidence of pasture bloat, but not its severity. Its main role may be in feedlots, or under drought conditions where higher levels of grain are fed. In these conditions, bentonite may reduce the incidence of digestive upsets and increase the production of milk and milk fat.

Limited Australian work has examined the use of buffers other than bentonite. The current recommendation is to use a combination of 15 g sodium bicarbonate and 8 g magnesium oxide per kg diet when problems are encountered with high levels of grain. This combination provides synergistic effects because the buffers have different sites of action.

Introduction

When cows are fed high levels of cereal grains containing starch, rumen fermentation is rapid, leading to high concentrations of volatile fatty acids in the rumen. Saliva, produced during chewing, has a buffering action, which maintains rumen pH at a level suitable for fibre fermentation (6.0 to 6.9). However, there is much less chewing of grain than of forages, and therefore much less saliva production. The reduction in buffering capacity can lead to a reduction in rumen pH. This in turn leads to a change in the microbial population, with a reduction in fibre-fermenting organisms and an increase in starch-fermenting organisms, which produce lactic acid.

Lactic acid is stronger than the volatile fatty acids, leading to rapid reduction in rumen pH and inflammation of the rumen wall and the formation of abscesses (ruminitis). Pathogenic organisms can pass from the abscesses via the portal blood to the liver, causing liver abscesses, and to the feet, causing laminitis. At low rumen pH, rumen contractions cease, eructation (belching) stops, leading to bloat and death.

This sequence of events can be avoided by feeding strategies which include gradual introduction of high starch feeds to the diet, feeding a complete mixed diet of forage and concentrate, feeding smaller amounts of high starch feeds more often, and processing the high starch feeds to reduce their rate of fermentation in the rumen.

Two alternative or complementary strategies are to include buffers in the diet, or to include antimicrobial compounds, which selectively reduce the organisms responsible for lactic acid production. In this context, the term 'buffers' is used loosely to include chemical buffers, such as sodium bicarbonate and potassium bicarbonate; alkaline substances such as magnesium oxide, limestone, dolomite and calcium hydroxide; as well as sodium bentonite (a montmorillonite clay with a high cation exchange capacity). Alkaline substances can be harmful when fed in excess, by interfering with the normal process of acid digestion in the abomasum.

de Veth and Kolver (2001a) found, using *in vitro* studies, that the digestion of high quality pasture was optimised at pH 6.35, although dry matter digestibility was not substantially depressed until pH dropped below 5.8. They suggested that the minimum level of effective fibre required in the diet might be lower for cows grazing high quality pasture than for cows fed mixed forage/concentrate diets. In follow up studies on the effect of variation in rumen pH, which simulates ingestion of discrete meals of concentrates, de Veth and Kolver (2001b) found that periods of four hours, when pH dropped to 5.4, reduced dry matter digestibility by about 4 percentage units.

Figure 7. Strip grazing ryegrass gives efficient use of pasture and maximises cow production when the cows are given appropriate supplementary feeds.

There is now evidence that low rumen pH is not only associated with concentrate feeding but may also occur when cattle are grazing pastures of high digestibility. In fact,

under such grazing conditions the rumen pH can be below 6.0 for a considerable portion of the day and this is thought to be due to insufficient dietary fibre. Stockdale (1993) showed that for cattle grazing fresh Persian clover forage, which is rapidly fermented, that rumen pH was less than 6.0 for a considerable amount of time after the onset of feeding and that the pH drop was greater at higher feeding levels.

A depression in rumen pH below approximately 6.0 inhibits the rate of fibre digestion, which in turn reduces DM intake. Stockdale *et al.* (1997) suggested that if the period over which the pH is reduced were not long enough for total impairment of the fibre-digesting bacteria, fibre digestion would resume as pH rises. de Veth and Kolver (2001b) suggested that reasonable levels of fibre digestion were obtained provided pH was 6.3 for at least half the day. Low pH may also favour the production of a type of linoleic acid (trans-10 isomer) that reduces fat synthesis in the mammary gland. The fatty acids are diverted instead into the deposition of body fat. Addition of buffers that increase rumen pH can reverse this process.

Technical review

Overseas trials investigating the effects of buffers in high concentrate diets have found that buffers can:

- Prevent milk fat depression;
- Prevent decline in rumen pH;
- Increase the proportion of acetic acid in the rumen;
- Improve utilisation of high-energy concentrates in early lactation by preventing the digestive upsets and depression of dry matter intake usually seen with the abrupt introduction of concentrates to the diet.

Little work has been done to confirm these findings under Australian conditions with grazing cattle.

Sodium bicarbonate

An experiment conducted by Kaiser *et al.* (1982) looked at the effects of sodium bicarbonate in concentrate rations for cattle grazing ad libitum kikuyu pasture in northern NSW. Cows were given supplements of wheat or wheat and soyabean meal at 15.6 g/kg liveweight, with sodium bicarbonate added at 0, 22.4 or 44.8 g/kg DM. Addition of sodium bicarbonate produced a small significant increase in milk fat content but no change in milk yield. They attributed this to differences in the basal ration and the fact that they equalised sodium content between treatments. Nevertheless, even this small response may be of considerable economic benefit when the milk fat content is marginal. The usually recommended amount of sodium bicarbonate is 1.5–2.0% of the grain mixture or 0.75–1.0% of the total diet (Chalupa and Kronfeld 1983).

Dalley *et al.* (2001) fed 6 kg cereal grain to cows grazing highly digestible pasture in spring, with and without sodium bicarbonate at 1.7% total diet DM. They found no effect of the buffer on rumen pH, rumen volatile fatty acids, milk production or milk composition.

Magnesium oxide

Granulated magnesium oxide is a cheaper dietary buffer than sodium bicarbonate and can be mixed uniformly in crushed or whole grain supplements. Valentine *et al.* (1993) found that granulated magnesium oxide was effective in increasing milk fat yield in cows fed high levels of crushed barley as a supplement to a grass-legume pasture-based diet. The authors suggested that this might have been due to an increase in intake in response to an improvement in fibre digestibility. No production responses to the magnesium oxide supplement were achieved when conserved pasture and conserved cereal crops were fed as the main roughage component of the diet. The response to dietary buffers is, it seems, influenced by the amount and type of concentrate fed and the fibre level in the grazed pasture (Erdman 1988).

Sodium bicarbonate and magnesium oxide combinations

Different buffers have different sites of action:

- Sodium bicarbonate neutralises volatile fatty acids in the rumen, and alters the pH of blood.
- Magnesium oxide also has a strong neutralising action in the rumen. It also has a specific action on mammary lipoprotein lipase activity, stimulating the uptake of fatty acids by the mammary gland.

Sodium also has an indirect action by increasing dry matter and water intakes, mediated through a higher rumen fluid dilution rate and lower rate of starch digestion. In fact, in situations where sodium is limiting in the diet, there is evidence that this is the primary mode of action of sodium bicarbonate (Russell and Chow 1993) rather than its role as a true buffer.

Due to the different modes of action of sodium bicarbonate and magnesium oxide, a combination of the two may give synergistic effects. Also, as sodium bicarbonate may depress serum magnesium concentrations, the addition of magnesium as magnesium oxide is beneficial. Erdman *et al.* (1982) found a combination of 15 g sodium bicarbonate and 8 g magnesium oxide per kg diet to be effective in maintaining rumen pH and increasing milk fat levels.

Limestone

Limestone has no action in the rumen, but may act to regulate pH in the small or large intestine. This could result in improved starch digestion in the small intestine and increased fermentative digestion in the large intestine.

Sodium bentonite

Sodium bentonite is a binding agent used in many commercial dairy pellets. Overseas studies involving the use of bentonite have found that it can:

- Help prevent lactic acidosis and digestive upsets due to its buffering capacity;
- Increase the acetate: propionate ratio;
- Improve nitrogen utilisation by forming a complex with protein in the rumen, reducing its degradability (Kempton 1983);
- Reduce the incidence of feedlot and pasture bloat.

Several experiments in Australia and New Zealand have looked at the effects of sodium bentonite on dairy cattle production (Ecosearch 1985).

Trials conducted in Kyabram, Victoria, in Australia and Ruakura in New Zealand indicate a possible beneficial effect of sodium bentonite on the incidence of pasture bloat. In the first trial, cows were given sachets containing 75 g sodium bentonite twice daily by stomach tube. In the second trial, pasture was dusted with bentonite. In the latter, the daily bloat score tended to be lower in cows receiving bentonite (P<0.10) (Ecosearch 1985).

A third trial involved feeding bentonite at 3% and 6% of the diet to cows fed lucerne, ryegrass and clover in stalls. It was found that bentonite reduced the incidence, but not the severity of bloat and gave no production benefits (Ecosearch 1985).

Moate (1985) used twelve sets of identical twin cows in an experiment to assess the benefits of sodium bentonite. Cows were stall-fed on pasture and one twin of each set was given 600 g bentonite/day. There were no effects on milk production or rumen fluid parameters following supplementation with bentonite.

Of more interest is the effect of bentonite added to diets containing high levels of grain. Moate (1983) fed bentonite at 5% of the diet to cows receiving wheat at levels of 0.5%, 1.0%, 1.5% or 2.0% body weight. He found no significant effects of bentonite on milk yield or milk composition at lower levels of wheat feeding. However, at the highest level of wheat feeding (2% body weight), bentonite produced a significant increase in DM intake, resulting in increased milk fat and protein yields. Rumen pH was not affected by the use of bentonite.

The buffering capacities of bentonite and limestone were compared in a trial conducted in northern NSW, for cattle grazing kikuyu-based pasture. Cows received either 4 kg maize + 120 g buffer or 6 kg maize + 200 g buffer. There were no significant effects of either bentonite or limestone on milk production or composition at either level of maize feeding (Ecosearch 1985).

Similar results were recorded at Ellinbank, Victoria, when grazing cows were supplemented with 2 kg crushed oats and 5% bentonite. Bentonite produced no effects on milk yield or composition (Anon 1983).

Two experiments at Kyabram, Victoria, looked at the effects of 4.8% bentonite given at different stages of lactation and at varying levels of pelleted supplement (Lemerle et al. 1983). Cows in both early and late lactation were given between 1.8 and 9.6 kg pellet DM/day. Again, there were no significant effects of bentonite on milk yield, milk composition or rumen fluid parameters.

Field trials conducted in southern NSW confirmed these results. On nine farms, where levels of grain feeding varied from 2–6 kg/day, there was no effect of bentonite inclusion on the production of milk or milk constituents (Ecosearch 1985).

Effects of bentonite supplementation to a molasses diet also were examined in a trial with weaner cattle. Bentonite was added, at 0.5%, to diets containing 50%, 63% or 80% molasses. There was no significant effect on molasses intake or rumen fluid parameters (Ecosearch 1985).

Ehrlich and Davison (2000) evaluated the effects on milk production and milk composition of feeding sodium bentonite to cows fed higher levels of concentrates and producing more milk than those in previous bentonite studies. The cows were fed 8–10 kg of a sorghum-based concentrate and were producing over 25 kg milk/cow/day. Addition of 4%

sodium bentonite did not increase milk production or alter milk composition of cows receiving a forage: grain ratio of about 50:50.

These results are consistent with those of Hamilton *et al.* (1988) who fed 4 or 6 kg maize to cows grazing ryegrass-clover pasture in the day and kikuyu pasture at night to achieve forage: concentrate ratios of about 60:40. Feeding sodium bentonite did, however, significantly increase rumen pH and faecal protein, decrease faecal starch (although this was not translated into an increase in milk production) and tended to lower rumen ammonia (thought to reflect an absorption of ammonia by bentonite). It was concluded that in dairy diets, where the forage content is about 50% of the total diet and milk yields are 25–30 kg/day, sodium bentonite is not effective in improving milk yield or composition when sorghum grain is fed as a supplement.

Antibiotics

An alternative strategy to reduce the incidence of acidosis associated with high grain feeding is to include antibiotics to reduce the production of lactic acid in the rumen (Nagaraja *et al.* 1987).

Virginiamycin, sold as Eskalin[TM], is derived from *Streptomyces virginiae* and has been shown to reduce lactic acid production in the rumen and caecum of cattle and sheep (Godfrey *et al.* 1995; Courtney and Seirer 1996) by inhibiting the growth of gram-positive bacteria (Vannuffel and Cocito 1996), without a decline in production.

Thorniley *et al.* (1996) investigated the efficacy of using a single drench of virginiamycin to control acidosis in cattle. The additive was administered as an oral drench suspended in distilled water via a syringe at doses of 0, 1.3, 2.6 and 5.2 mg/kg liveweight. L-lactate was significantly reduced to the same level by all doses of virginiamycin within six hours of drenching. D-lactate production, on the other hand, was not significantly different to that of the controls, although there was a trend for the rumen fluid from cattle drenched with 5.2 mg/kg virginiamycin to have lower D-lactate production than the controls.

Clayton *et al.* (1999) found that the inclusion of virginiamycin in a grain concentrate pellet, fed at the rate of 10 kg/cow/day to dairy cattle grazing pasture and with access to whole cottonseed/brewer's grain mixture, stabilised rumen and faecal pH. There was also a reduction in the potential for lactic acid accumulation in the rumen fluid. Milk production was slightly improved in the cows receiving the virginiamycin treatment, but this response was dependent on the stage of lactation, with cows in late lactation showing the greatest response.

Under certain feeding conditions, the addition of virginiamycin has not always prevented the risk of acidosis. Al Jassim and Rowe (1999) reported the presence of virginiamycin -resistant rumen bacteria, *Lactobacillus vitulinus* and *Selenomonas ruminatum*, in grass-adapted sheep. Their work suggests that the use of a virginiamycin supplement for ruminants on green feed may not always reduce fermentative acidosis.

Clayton *et al.* (1999) found that there was a tendency for rumen pH to be higher in cows fed virginiamycin plus sodium bicarbonate than in those fed sodium bicarbonate alone. This response was obtained from dairy cattle being offered 10 kg/cow/day of a pelleted cereal grain based concentrate. There was no effect of treatment on body weight or body condition, however this was not unexpected given the short period of the study (28 days).

Following on from this work, Valentine *et al.* (2000) examined the effect of supplementing high concentrate diets of similar sodium content with virginiamycin alone or virginiamycin plus sodium bicarbonate. They found that the addition of virginiamycin or virginiamycin plus sodium bicarbonate to the diet had no effect on milk production or composition at any level of grain concentrate feeding.

There was also no effect on rumen pH or concentrations or proportions of volatile fatty acids in the rumen, indicating that the cattle used in the experiment adapted well to the high level of grain feeding. It was concluded that in situations where the cattle have prior adaptation to high grain diets, that the inclusion of feed additives such as virginiamycin or virginiamycin plus sodium bicarbonate is unlikely to improve milk production.

In September 2003, virginiamycin was listed as a Schedule 4 substance under the Australian Therapeutic Goods Administration Act, and so is available only on veterinary prescription. This change is in response to concerns about the development, in human pathogens, of resistance to antibiotics used in human medicine.

Tylosin, sold as Tylan[TM], is registered for the control of liver abscess, which is a consequence of rumen acidosis. When used in conjunction with monensin, sold as Rumensin[TM], it is as effective as virginiamycin in reducing the production of lactic acid (Nagaraja *et al.* 1987). Monensin does not have a registered claim relating to acidosis, but does have registered claims relating to reductions in ketosis, bloat and coccidiosis, and improvement in feed conversion efficiency. The improvement in feed conversion efficiency is related to an increase in the proportion of propionic acid produced in the rumen.

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Factors affecting response to supplementation

Summary

The major factors affecting response to supplementation are:

- Body condition score
- Substitution effect
- Level of concentrate
- Stage of lactation
- Genetic potential of the cow
- Pasture and concentrate quality.

Each of these is summarised below, then enlarged upon in the rest of the chapter.

Body condition score

Cows in poor body condition score give smaller responses in milk yield than cows in good body condition score, unless they are given ad libitum access to high-energy feeds. *Under Australian conditions, where energy concentration in the diet is frequently sub-optimal in pasture-based diets, cows should calve down with a condition score of 4.5 to 5.4 (Earle 1976), which allows them to mobilise body tissue to support milk production and achieve a satisfactory level of fertility.*

Substitution effect

Substitution of concentrate for pasture is a major factor contributing to the variation seen in milk responses to supplementation. Decreased rumen pH results from rapid digestion of grain starch. This appears to reduce the number of cellulolytic bacteria, so fibre takes longer to digest and pasture intake decreases. Depression in rumen pH may be overcome to some extent by feeding buffers or by feeding grain in smaller amounts at more frequent intervals.

Substitution rates are greatest at high pasture allowances and with starch-rich concentrates. Therefore milk responses to supplementation will be greatest at low pasture allowances where the substitution effect is less significant. Protein meals and whole grains result in lower substitution rates than processed grains. There are conflicting reports about the change in substitution rate at increasing levels of supplement.

With ample pasture, substitution rates range from 0.3–0.9 kg pasture/kg concentrate fed. Future work should identify the chemical and physical properties of concentrates that minimise substitution effects and develop methods for the accurate prediction of substitution rate over a wide range of conditions. This will allow the economics of concentrate feeding to be thoroughly evaluated.

Level of concentrate

Relationships between milk responses and amounts and types of concentrate are crucial to determining the most profitable use of concentrates. Major feeding systems in the UK and the USA assume linear relationships between amounts of concentrate fed and milk response. This is often incorrect.

Decreases in marginal response to concentrates are attributable to changes in substitution rate of the concentrate, and changes in partition of nutrients as cows approach their potential for milk production. As level of concentrate increases, there can be an increase in substitution rate and/or an increase in the partition of nutrients to body tissue. Either or both effects will cause the milk response to be curvilinear instead of linear.

Factors affecting substitution rates of concentrate have not been defined and quantified. Similarly, partition of nutrients is poorly understood, and has not been quantified in relation to the genetic potential of cows.

Stage of lactation

The stage of lactation affects the magnitude of the milk response because of changes in energy partitioning that occur as lactation progresses. Immediate and marginal milk responses to supplementation are greatest in early lactation, decreasing thereafter as the energy is partitioned towards body condition in preparation for the next lactation.

Genetic potential of the cow

Improvement in the genetic merit of the herd increases yields of milk, milk fat and milk protein by allowing cows to partition more energy to milk production and to increase their feed intake. This will result in greater marginal responses to supplementary feeding.

Pasture and concentrate quality

Responses are likely to be larger when pasture quality is poor than when pasture quality is good. When concentrates provide limiting nutrients, responses are larger than when the pasture has a good balance of nutrients. However, concentrates may induce nutrient imbalances, which then restrict milk responses to the additional energy.

Body condition score
Milk production

Two aspects of body condition score affect milk response. One is the cow's body condition score at the onset of supplementary feeding and the second is the way in which the supplement changes body condition score over time. The change in body condition score with time interacts with stage of lactation to determine whether changes in partitioning allow extra body condition to be expressed as increased milk production.

Farmers need to know the optimal body condition score at which to calve the animal and the best way of achieving this condition score.

Numerous experiments have examined the effect of the level of pre-calving feeding on subsequent milk production.

Broster (1971) reviewed previous literature and noted that improvement of body condition score in late pregnancy was instrumental in raising milk yield later. He quoted Davenport and Rakes (1969), who fed three levels of feed in the dry period to produce cows that were 'thin', 'moderately fleshed' or 'fat' at calving. The higher feeding levels led to increased milk production in early lactation and a greater loss of liveweight.

Rogers *et al.* (1979b) challenged the view held by Broster (1971) and New Zealand researchers (Murray 1972; Miller 1974) that the most important determinant of the milk response to pre-calving feeding was the rate of liveweight gain during late pregnancy. They conducted three experiments to compare cows gaining weight at different rates in late pregnancy, but calving in similar condition, with cows having similar rates of liveweight gain, but resulting in different condition scores at calving. *The results showed that body condition score at calving was the most important factor affecting milk yield.* Level of feeding and rate of liveweight gain prior to calving had little effect provided cows calved in the same body condition score.

Grainger *et al.* (1982) built on these results by investigating the effects on milk production of body condition score at calving, and different levels of feeding after calving. Cows were fed to reach target body condition scores, ranging from 3 to 6, four weeks before calving. They were then maintained at these levels through to parturition. After calving, cows were fed on two different feeding levels, either 8 or 14 kg DM/day.

The results (Figure 8) showed that cows at low body condition scores partitioned more energy towards body condition and, in fact, actually gained body condition in early lactation, at the expense of milk production. Cows in good body condition score (scores 5 and 6) lost body condition in early lactation, but gave good milk responses. At a feeding level of 14 kg DM/cow per day, an extra 8.5 kg of milk fat was produced for each unit increase in body condition score over weeks 1–20 of lactation. This is equivalent to a difference of 425 kg of 4% fat-corrected milk between body condition scores 3 and 5 over this period.

In a second experiment, cows of body condition scores 4 and 6 were fed one of three levels of intake post-calving to examine the effect of condition score on DM intake.

Pasture intake and body condition score at calving were inversely related. Over the first eight weeks of lactation, cows in body condition score 6 ate less pasture than those in body condition score 4.

In the first experiment, this effect of change in intake could have resulted in overestimation of the production responses of thin cows, especially at high feeding levels, as cows of different condition scores all grazed together.
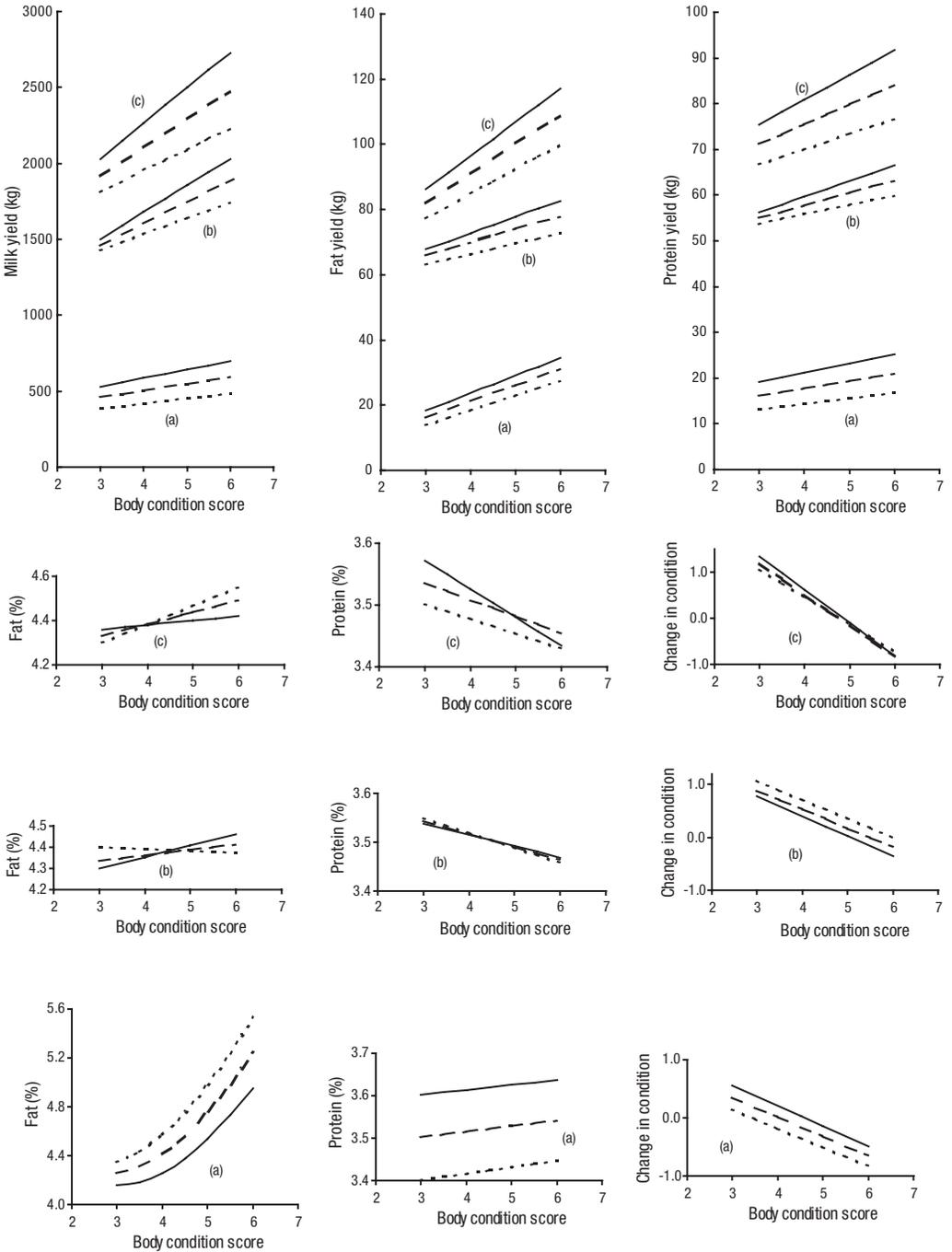
Figure 8. Effects of body condition score at calving and feeding level in first five weeks of lactation on milk production and changes in body condition score during weeks 0–5 (a), 6–20 (b) and 0–20 (c) of lactation. ------ 8kg DM/day; ------ 11kg DM/day; ——— 14kg DM/day. Grainger *et al.* (1982).

Garnsworthy (1988) gave conflicting reports on the effects of body condition score. He reviewed eleven trials in the UK and found that one demonstrated a significant negative effect of body condition score at calving on milk yield while the other ten showed no significant effects. However, eight of these involved only small cow numbers (<9 cows/body condition score). Of the other three trials, one showed a positive response to body condition score at calving which was significant below body condition score 4, and two showed negative effects.

Garnsworthy (1988) quoted the trial of Frood and Croxton (1978), where whole lactation yields showed a decreasing response through a range of body condition scores from 2 to 7. These lactation curves show that cows in poor body condition score at calving gave low, late peak milk yields with high persistency, while those in good body condition score gave high early peak yields with lower persistency. Therefore, in early lactation there was a benefit from good body condition. The effects on persistency were biased, as animals in low body condition score in mid- to late lactation were fed additional concentrates.

A common finding was that cows in high body condition score at calving had lower DM intakes in early lactation. This was a linear relationship resulting in a decrease in DM intake of 0. 8 kg/day for each unit increase in body condition score (Figure 9).
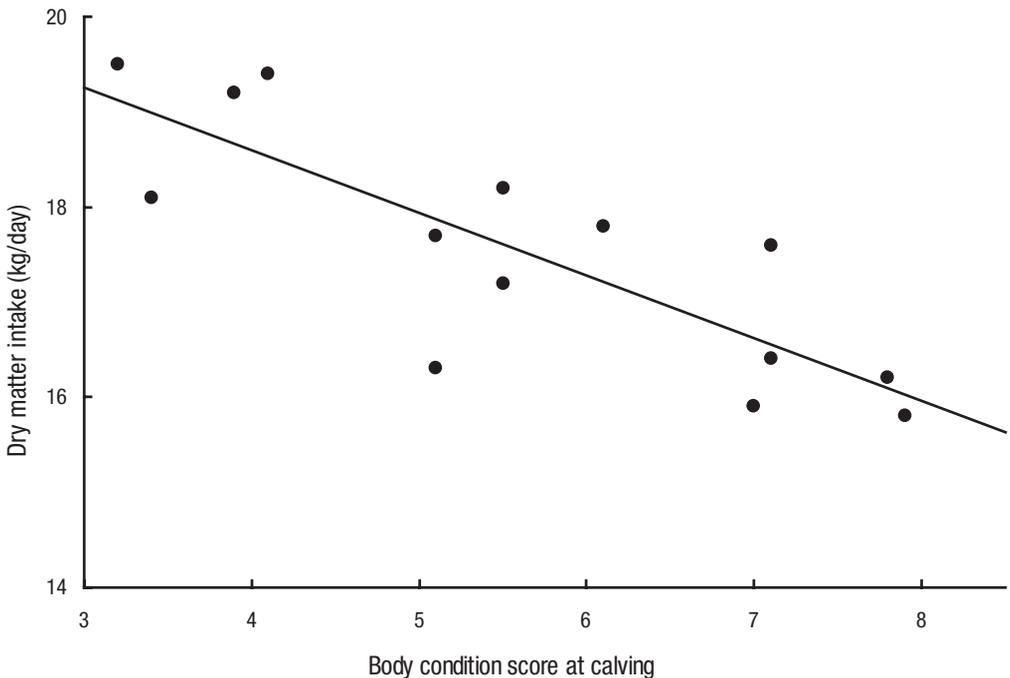
Figure 9. Effect of body condition score at calving on dry matter intake during early lactation. Garnsworthy (1988).

As in the work of Grainger *et al.* (1982), the UK trials noted that cows in high body condition at calving lost more liveweight in early lactation. Cows below body condition score 4 at calving gained weight in early lactation, while those above body condition score 4 tended to lose weight through mobilisation of body tissue.

Garnsworthy (1988) concluded that while animals in good body condition score produce more milk on a fixed intake (as in the experiments of Grainger *et al.* 1982), thin cows could match or exceed the milk yield of fatter cows, due to their greater appetite, if given access to ad libitum high quality feed. He pointed out that the energy concentration of the diet is important in allowing thin cows to reach their potential. Where the metabolisable energy concentration of the diet was less than 11.1 MJ/kg DM, positive milk responses to condition score occurred, whereas, if metabolisable energy concentration was greater than 12.1 MJ/kg DM, negative responses resulted.

This raises the question of whether it is possible under Australian conditions for the greater DM intake of thin cows to compensate for lower body condition score at calving. That is, whether the dietary energy from increased intake can equal or exceed the energy supplied by tissue mobilisation in high body condition score cows.

Table 26 is an attempt to use currently available data to answer the above question. The table is constructed using data from Garnsworthy (1988) for changes in DM intake, and adapts them to the size of cows used in the study of Grainger *et al.* (1982), using the body condition score data of Grainger *et al.* (1982) and relevant equations from Hulme *et al.* (1986). In compiling the table, the following conditions were assumed:

- A cow in body condition score 5 has a liveweight of 450 kg and an intake of 14 kg DM/day;
- One body condition score is the equivalent of 34 kg liveweight (Grainger *et al.* 1982);
- The energy content of pasture is 11. 5 MJ/kg.

Energy balances are compared over the first five weeks of lactation. The information from the table is interpreted in the following scenarios. The first compares cows at body condition scores 5 and 3 on a fixed intake. In the second, the cow in body condition score 3 receives a higher intake.

Table 26. Effect of body condition score (BCS) on maintenance requirement during the dry period (1), voluntary intake (2), change in body condition score in early lactation (3) and ME available from tissue mobilisation (4).

BCS	Maintenance during dry period (MJ/day)	Dry matter intake (kg/day)	BCS change in early lactation (per 5 weeks)	ME available from tissue mobilisation (MJ/day)
3	41.6	15.2	0.60	−17.8
4	44.4	14.6	0.23	−7.8
5	47.1	14.0	−0.15	4.6
6	49.7	13.4	−0.52	17.6

(1) 1 CS = 34 kg liveweight (Grainger *et al.* 1982)
     MEm calculated according to SCA (1990)
(2) Garnsworthy (1988)
(3) Grainger and McGowan (1982)
(4) Hulme *et al.* (1986)

Scenario 1

Intakes fixed at 14. 0 kg DM/day (as in Grainger *et al.* 1982)

At BCS 5

Intake ME = 14.0 kg DM/d x 11.5 MJ ME/kg DM x 35 days	=	5635
Tissue ME = 4.6 MJ/day x 35 days	=	161
Total	=	5796

At BCS 3

Intake ME = 14.0 kg DM/d x 11.5 MJ ME/kg DM x 35 days	=	5635
Tissue ME = -17.8 MJ/day x 35 days	=	-623
Total	=	5012

The difference in ME available for milk production is 784 MJ, which is the equivalent of approximately 157 litres of milk (where ME requirement for milk = 5 MJ/l.)

Scenario 2

Intakes vary (as in Garnsworthy 1988)

At BCS 5

Intake ME = 14.0 kg DM/d x 11.5 MJ ME/kg DM x 35 days	=	5635
Tissue ME = 4. 6 MJ/day x 35 days	=	161
Total	=	5796

At BCS 3

Intake ME = 15.2 kg DM/d x 11. 5 MJ/kg DM x 35 days	=	6118
Tissue ME = -17.8 MJ/day x 35 days	=	-623
Total	=	5495

Therefore, the extra energy available for milk production at body condition score 5 is 301 MJ, the equivalent of 60 litres of extra milk.

It is important to take into account, too, the extra energy costs involved in maintaining heavier animals throughout the dry period. Three possibilities are considered:

1   Maintain cow at BCS 3 throughout the dry period (65 days)

Metabolisable energy for maintenance (MEm) = 41.6 MJ/d x 65 days = 2704 MJ

2   Maintain cow at BCS 5 throughout the dry period.

MEm = 47.1 MJ/d x 65 days = 3062 MJ; = 13% increase over BCS 3

3   Increase the cow's condition in a linear manner over the dry period from
    BCS 3 to BCS 5.

Maintenance requirement/day = (41.6 + 44.4 + 47.1)/3 = 44.4 MJ/d

MEm = 44.4 MJ/d x 65 days = 2886 MJ; = 7% increase over BCS 3.

In options 2 and 3, the extra maintenance requirement of heavier cattle would decrease the carrying capacity or increase supplementary feed requirement by approximately 33 and 17 kg DM/cow, respectively. The cost of this supplementary feed is likely to be much less than the extra returns from 157 litres milk (scenario 1) or 60 litres milk (scenario 2), as outlined above.

This exercise demonstrates that when intakes are held constant or where feed is restricted, there is a distinct advantage in milk production to calving down in body condition score 5 rather than in body condition score 3. However, when thin cows are able to take advantage of their increased appetite in early lactation by being given access to ad libitum feed of high quality, the advantage of having cows in good body condition score will be much less. If a feed of very high energy density is provided, thin cows may even be able to match the milk yields of fatter animals. While this may be possible with unrestricted access to balanced complete diets, it is very unlikely with grazing cows.

The maximum energy concentration of the pasture-based diets in Australia is unlikely to exceed 11.5 MJ ME/kg DM on a regular basis. Diets of lower energy density would give an even greater advantage to cows calving in good body condition score than that shown in the above example.

On the basis of data available at that time, Cowan (1982), reached similar conclusions. He found that responses to pre-calving feeding were greatest when animals were restricted in their feed intake after calving because of low feed availability or feed of low energy density. When animals had *ad libitum* access to feed there was some compensation in intake in the thinner animals, particularly with diets of high-energy concentration.

It can be concluded from the above analysis that under Australian conditions, where energy concentrations of diets frequently are less than 11.5 MJ ME/kg DM, the optimal strategy is to calve down animals in body condition score 4.5 to 5.4 and allow them to mobilise body tissue to support milk production. At body condition scores greater than 6, dry matter intake is depressed, there is an increase in calving difficulties, reproductive performance is decreased and there is increased incidence of metabolic disease. Below body condition score 5, cows give lower milk production due to the partition of energy towards body condition.

Most research on the effects of dry cow nutrition on early lactation performance has been done with total mixed rations or with mixtures of silage and concentrates; this has limited relevance to most Australian conditions (Stockdale and Roche 2002).

In Victoria, Grainger *et al.* (1982) found that the differences in fat production, over 5 weeks, between pasture intake levels of 8 and 14 kg DM/day were 9.3 kg at body condition score 3 and 15.7 kg at body condition score 6. Cows in better condition at calving gave a greater response to extra pasture because of partitioning of energy towards milk production. Thus, the higher the cow's body condition score (within the range 3–6) when beginning supplementary feeding, the greater the apparent response to a supplement because of partitioning of body tissue energy towards milk production.

The second aspect of the effect of body condition score on response to supplementation is presented here but awaits further experimental work to more fully elucidate it. Supplements allow animals to increase milk production and also, to either gain more or lose less body condition score than unsupplemented animals.

Cows having a body condition score of less than 5 partition energy to liveweight gain. As their body condition score improves, they partition more energy to milk production, increasing the milk response to the supplement.

This idea is supported by the work of B.A. Hamilton (personal communication) (Figure 1c). The response curve shows a gradual increase in response over nine weeks. In conjunction with this curve, Hamilton calculated the proportion of the cow's energy

output that was directed to milk and to bodyweight. Initially, the cows were of body condition score 4 and partitioned energy towards liveweight gain. As body condition score increased, a change in partitioning of energy was recorded favouring increased milk production. Had these cows started in body condition score 5 or higher, their initial milk response would have been greater and less changeable with time, as more energy is diverted to milk production. This description fits the curve described by Broster (1972) for the response of UK animals to supplementation.

Further information on effects of body condition at calving on the performance of dairy cows in early lactation under Australian conditions is given by Stockdale (2001).

Reproduction

The purpose of this review is to focus on milk production rather than reproduction. However, it is pertinent to point out that body condition score has been shown to have a substantial effect on post-partum anoestrus. Grainger *et al.* (1982) found that the anoestrus interval decreased by 5.7 days for every unit increase in body condition score at calving up to 6.

Fulkerson (1984) found that the percent of cows submitted for service for the first time in the first 24 days of the mating season rose from 60% to 97% as cow body condition score improved from 3 to 5.5. There was no effect on non-return rates provided body condition score was 5.5 or over.

More recently, there has been a national project involving 40 000 cows in commercial dairy herds across Australia (InCalf 2001). A major outcome was that cows with a pre-calving body condition score between 4.5 and 5.4 (1–8 scale) had substantially better reproductive performance than thinner cows. The six-week in-calf rate was 52% when pre-calving conditions score was 4.5 or less, and 64% when pre-calving condition score was 4.5–5.4, with no advantage from higher condition score. There were no reproductive benefits where cows were in heavier body condition than this before calving. Cows with a condition score 6.0or more pre-calving had lower fertility. The target condition score is a herd average, which means that if an average of 6.0 is set, there will be many cows in excess of 6.0 and therefore likely to have reduced fertility. For this reason it is prudent to set the lower target of 5.4, as a herd average.

These effects are of substantial economic importance and should be considered when determining the economic benefits of supplementary feeding.

Exposure to heat stress can lower appetite and the rate of conception in dairy cattle. Inclusion of fat in the diet can increase energy density in the diet and maintain energy intake when appetite is depressed. Feeding a protected lipid supplement to heifers increased plasma progesterone levels, which could reduce early embryonic loss in heat stressed animals (Rough *et al.* 1998).

Substitution effect

When concentrates are fed to grazing animals, their pasture intake can be depressed. This may not be the case if a small amount of concentrate provides one or more nutrients that are limiting forage digestion. However, when it does occur, the result is an effective increase in energy intake that is less than the additional energy supplied by the concentrate. *This*

phenomenon is known as substitution and is a major factor contributing to the variation seen in milk responses to supplementation. The substitution rate is defined as the decrease in pasture intake per kg of supplement fed. Substitution rates based on a basal diet of silage ranged from 0.6–1.2 (Hulme *et al.* 1986). However, where ample pasture provided the basal ration, substitution rates have been in the range 0.3–0.9 (Cowan *et al.* 1977; Kempton 1983; Robinson and Rogers 1983; Meijs and Hoekstra 1984; Meijs 1986; Grainger and Mathews 1989; Stockdale 1999a). When pasture intake was controlled from low to high intakes, substitution rates were 0.0 to 0.95 (Stockdale 2000). When the substitution rate is less than 1, concentrate feeding increases the total DM intake.

The size of the substitution effect depends on:

- Pasture allowance
- Level of concentrate fed
- Digestibility of the forage
- Chemical and physical properties of the concentrate
- Duration of the change in feeding level
- Stage of lactation.

The substitution rate is greatest where there is pasture of high availability and digestibility and where large amounts of starch-rich concentrates are fed. As mentioned in Chapter 4, changing substitution rates with time (R. T. Cowan, personal communication) may explain the cumulative effect seen in Figure 1d.

Pasture availability is usually measured in terms of kg DM/ha, and pasture allowance is measured in terms of kg DM/cow/day. Wales *et al.* (1999b) found that substitution rates increased with level of both pasture availability and pasture allowance. Clearly, when pasture availability or pasture allowance are low, cows are less able to satisfy their appetite, and so there is less substitution when they are offered concentrates.

The reasons for substitution are not fully clear. In part, it occurs because the digestion of grain starch in the rumen lowers rumen pH, causing a decrease in the numbers of cellulolytic bacteria. This reduces fibre digestion, causes a longer retention time of the undigested matter in the rumen and so decreases pasture intake (Scharp 1983).

However, Mould *et al.* (1983) found that concentrate feeding resulted in negative effects on fibre digestion even when change in rumen pH was prevented. They suggested that when starch was present in the rumen, it may be preferentially degraded over cellulose. Thus facultative organisms in the rumen may prefer starch to cellulose when both substrates are present.

Other factors that may contribute to substitution are decreased grazing time (Mayne and Wright 1988) and rumen capacity.

Marsh *et al.* (1971) found that feeding of supplements caused a decrease in grazing time of 22 minutes/day per kg concentrate fed. This would have a greater effect on cows grazing at high pasture availability, where they have the potential for high pasture intakes. Cowan *et al.* (1977) obtained a similar result where it was found that during two months of a nine-month trial, grazing time was reduced by an average of 23 minutes/day for each kg of concentrate fed.

Stockdale *et al.* (1997) collated data from various Victorian studies that investigated the phenomenon of substitution in grazing dairy cows. The correlation between intake, expressed as total metabolisable energy consumption, and the level of substitution, was not very strong. Hence, it can be concluded that there are many factors, other than intake per se that are likely to be having an impact. The associative effects between forages and grains are discussed more fully by Dixon and Stockdale (1999).

Stockdale (2000) developed an equation to predict substitution from pasture intake, pasture type, season and concentrate intake. He found that substitution increased by 0.16 kg DM/kg DM for each increment of pasture intake, and grass dominant pastures resulted in more substitution than white clover. Substitution was highest in spring and lowest in autumn, and it increased by 0.03 kg DM/kg DM of concentrates offered.

Pasture allowance

Pasture allowance has a major influence on pasture intake. This is partly due to the relative ease with which cows can harvest the herbage as allowance increases (Stockdale *et al.* 1997). Pasture allowance has also been shown to be one of the major factors influencing the level of substitution when supplements are fed.

A number of experiments have investigated the effect of pasture allowance on substitution rate. Grainger and Mathews (1989) examined the pasture intake of cows at three levels of pasture allowance, when given no supplement or 3.2 kg grain-based pellets/day. They found a significant interaction between supplementation, pasture allowance and pasture intake. At a pasture allowance of 7.6 kg DM/cow/day, concentrate feeding did not significantly affect pasture intake. However, when pasture allowances were increased to 17.1 and 33.2 kg DM/cow/day, substitution rates of 0.25 and 0.69 kg/kg were calculated (Table 27).

Immediate milk responses to the supplement were 0.97, 0.69 and 0.28 kg milk/kg DM at low, medium and high pasture allowances, respectively. Responses were lower at high pasture allowances because substitution meant less metabolisable energy was provided for the same amount of supplement. This experiment was a Latin square design with treatment periods lasting one week. Milk responses may have been underestimated because of this short time period, which would not allow the cows time to adapt to the different feeding level.

Combining the data of their own and earlier experiments, Grainger and Mathews (1989) concluded that a significant linear relationship existed between pasture intake by the unsupplemented animal and pasture substitution rate (Figure 10a). For a 450 kg cow with a concentrate intake of 3.5 kg/day, substitution rates would vary from zero at 6 kg DMI/day to 0.75 kg/kg at an unsupplemented pasture intake of 17 kg DM/cow/day.

Subsequently, Wales *et al.* (1999b) also reported a linear relationship between pasture intake by unsupplemented cows and pasture substitution rate. In their case, the substitution rate varied from zero at 6 kg DMI/day to 0.53 kg/kg at an unsupplemented pasture intake of 17 kg DM/cow/day.

Robinson and Rogers (1983) fed 4 kg/cow/day of a pelleted grain-based concentrate to dairy cows grazing pasture that was either restricted (15 kg DM /cow/day) or offered ad lib (45 kg DM/cow/day). Substitution rates were 0.02 kg/kg for the low pasture allowance and 0.3 for high (Table 27). A milk response of 0.5 l/kg concentrate was obtained from cows fed
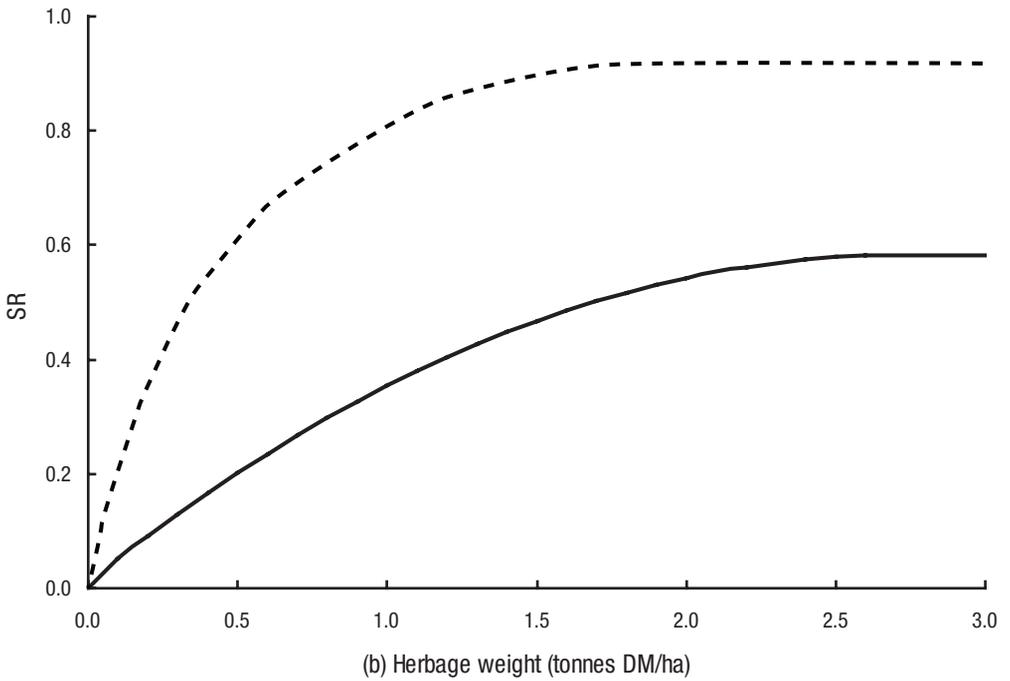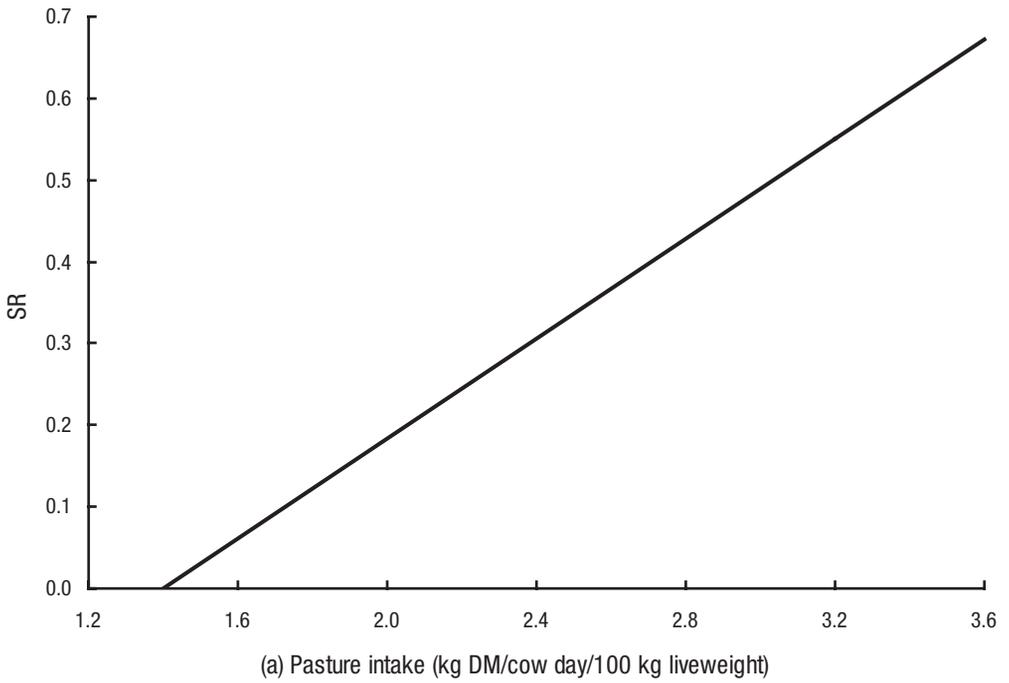
Figure 10. (a) Effect of pasture intake at zero concentrate intake on the pasture substitution rate (SR) of cows offered concentrates (Grainger & Mathews 1989); (b) Predicted substitution rates (SR) for a supplement of 80% digestibility on pastures averaging 70% (- - - - -) and 50% (———) digestibility SCA (1990).

concentrates on the low pasture allowance while those on ad lib pasture produced an extra 0.02 l/kg concentrate over unsupplemented animals.

Reductions in pasture intake resulting from supplementation are mainly due to reduction in grazing time, with little affect on the rate of biting or bite size (Stockdale *et al.* 1997).

These experiments show that as pasture allowances increase, substitution rates increase, and marginal responses to supplements decrease.

Pasture mass

Intake of grazing cows is greatly influenced by both pasture mass (t DM/ha) and pasture allowance (kg DM/cow/day). Thus at 3 t DM/ha, intake increased from 7 to 16 kg DM/day as pasture allowance increased from 20 to 70 kg DM/day; at 5 t DM/ha, intake increased from 10 to 22 kg DM/day as pasture allowance increased from 19 to 68 kg DM/day (Wales *et al.* 1999b).

Table 27. Calculated substitution rates (SR) at various pasture allowances and levels of supplementation.

Reference	Pasture type	Pasture allowance (kg DM)	Supplement type	Amount of supplement (kg/day)	SR (kg/kg)	Milk yield response (kg/kg supplement)
Grainger & Mathews 1989	Ryegrass/clover	7.6	Grain-based pellet	3.2	0.00	0.97
		17.1		3.2	0.25	0.69
		33.1		3.2	0.69	0.28
Robinson & Rogers 1983	Temperate pasture	15	Grain-based pellet	4.0	0.02	0.50
		45		4.0	0.30	0.02
Stockdale & Trigg 1985	Predominantly paspalum	15	Pellets	2.0	0.00	1.60
				4.0	0.00	0.80
				Ad libitum	0.23	0.70
				2.0	0.94	1.20
		26		4.0	0.43	0.80
				Ad libitum	0.30	0.50
Opatpatanakit *et al.* 1992	Ryegrass/clover	48.2	Rolled barley	4.0	0.64	0.10
		47.1		8.0	0.63	0.10
Robaina *et al.* 1998	Ryegrass/clover, year 1	18	Barley/lupin	4.4	1.14	0.73
		35		4.4	0.98	0.66
	Ryegrass/clover, year 2	21	Barley/lupin	4.2	0.21	1.13
		42		4.4	0.45	0.80
Wales *et al.* 2001	Ryegrass/clover	19	Grain-based pellet	5.0	0.18	1.00

SCA (1990) looked at the relationship between pasture mass and SR, and found a curvilinear response in substitution rate as pasture mass increased (Figure 10b). The curves shown represent predicted substitution rates for a supplement of 80% digestibility and pastures of 50 and 70% digestibility. The authors comment that while these curves agree well with published experimental results, more critical work is needed.

A number of experiments have investigated the effect of pasture mass on the level of substitution (Table 28). It is clear that, as pasture mass increases, so too does the level of substitution. At the same pasture mass, the substitution rate was higher with a daily allowance of 45 kg DM than with 25 kg DM (Wales *et al.* 1999b). Stockdale *et al.* (1997) suggest that taller pastures are trampled and fouled to a greater degree than are shorter pastures, thereby rendering them less palatable. If pasture utilisation is not maintained, supplements will become increasingly uneconomic as pasture mass increases.

Table 28 Effects of pasture mass and pasture allowance on substitution rate recorded for grazing dairy cows.

	Pasture Mass t DM/ha	Pasture Allowance kg DM/ day	Supplement	Supplement Intake kg/day	Substitution Rate
Stakelum 1986a	3.2 3.9		95% barley 5% molasses	3.7 3.6	0.32 0.44
Stakelum 1986b	3.8 4.8		95% barley 5% molasses	3.8 3.7	0.47 0.54
Robaina *et al.* 1998	4.5 6.3		70% barley 30% lupins	4.3 4.4	0.34 1.06
Wales *et al.* 1999b	3.0 4.7	25 45 25 45	75% barley 25% wheat	5.0	0.20 0.42 0.34 0.44

Level of concentrate

Stockdale and Trigg (1985) examined the effect of pasture allowance and level of concentrate feeding on milk yields of cows in late lactation. Two pasture allowances were used (15 and 26 kg DM/cow/day) and four levels of concentrate (0, 2 and 4 kg/cow/day and ad lib). Substitution rates were significantly greater at the higher pasture allowance. At low pasture allowances, substitution only occurred at the highest concentrate level, indicating that below this level, pellets were acting as a true supplement.

At the high pasture allowance, the substitution rate *decreased* with increasing levels of concentrate fed (Table 27). It was 0.94, 0.43 and 0.30 kg/kg at concentrate feeding levels of 2 and 4 kg/cow/day and ad lib., respectively. It should be noted that this trial involved only small cow numbers (four or less cows/level of concentrate).

Sarker and Holmes (1974) reported similar results, finding that substitution rate decreased as concentrate intake increased from 1. 6 to 6. 2 kg DM/cow/day. However, other experiments have produced conflicting results. Ostergaard (1979) and Faverdin *et al.* (1991), supplementing basal diets of silage, both concluded that substitution rate increased with increasing quantity of concentrates in the diet.

In grazing experiments, Meijs and Hoekstra (1984) found an increasing substitution rate with increasing levels of concentrate while Opatpatanakit *et al.* (1992) found no effect of concentrate level on substitution rate. They fed rolled barley at 4 kg and 8 kg/cow/day and obtained substitution rates of 0.64 and 0.63 kg/kg, respectively (Table 27).

Method/frequency of feeding

Agnew *et al.* (1996) investigated the effects of the feeding frequency of concentrates on the level of substitution in a non-grazing situation. The cattle received grass silage as their basal diet and the concentrate supplement offered consisted of a mix of wheat, barley, maize gluten, soyabean meal, white fishmeal and Molaferm molasses. The mixture was pelleted for cattle receiving supplements twice daily and four times daily. It was fed as a meal to cows receiving complete mixed diets, to prevent selection of concentrates from the forage-concentrate mix.

Estimated substitution rates were 0.50, 0.40 and 0.28 for twice daily, four times daily and complete diets respectively. The animals offered the concentrates and forage together in a mixed diet consumed significantly more (P<0.01) silage and concentrates than animals offered the concentrate portion separately, either twice a day or four times a day. This is consistent with the results of previous studies that compared complete diet feeding with separate feeding of forage and concentrates (Phipps *et al.* 1984; Istasse *et al.* 1986). The effect of the method of feeding on substitution rate, however, was not reflected in a change in milk yield or milk composition. The authors suggested that this might not necessarily be the case in situations where concentrates form a greater proportion of the diet (greater than 0.60 of total DM intake).

In the same experiment, Agnew *et al.* (1996) examined the combined effect of increasing both the level and frequency of concentrate feeding on milk yield and composition. The concentrate portion of the diet was offered at 2, 4, 6, and 8 kg/day by each of the three methods of feeding. Increases in milk protein concentration with increasing concentrate feeding level were significantly greater with twice and four times daily feeding than with complete diet feeding (0.59, 0.56, and 0.44 g/kg milk per kg additional concentrate DM respectively).

These responses were attributed to increased energy intake, rather than alterations in rumen fermentation pattern. Increasing concentrate level also had a significant effect on milk fat concentration with both the twice daily and four times daily treatments, whereas fat concentrations were unaffected when concentrates were offered in increasing proportions of a total mixed diet.

Digestibility of the forage

Leaver *et al.* (1968) found that the greater the digestibility of the forage, the greater the substitution effect. Cows grazing at high pasture allowances are more likely to have the opportunity to select pasture of higher digestibility and consequently will have a greater substitution rate (Mayne and Wright 1988).

Chemical and physical properties of the concentrate

Meijs (1986) found that supplement type had a significant effect on substitution rate, and that fibrous concentrates had a much lower substitution effect than starchy concentrates when fed at similar amounts. This observation may not be applicable to cows grazing highly fibrous tropical or mature temperate pastures.

Hulme *et al.* (1986) commented that the rate at which concentrates are degraded in the rumen is important in determining substitution rate. Those concentrates most rapidly degraded, such as processed cereal grains, have the greatest effect on substitution, while

Table 29. Effect of increasing the level of supplement on milk production parameters.

Reference	Basal ration	Supplement type	Amount of supplement (kg/cow/day)	Stage of lactation	Average basal milk yield	Average response to supplement (l/day)	Milk yield	Milk fat (%)	Milk protein (%)	Length of feeding period	Milk fat yield	Milk protein yield
Stockdale et al. 1987 (5 studies)	Stall fed, limited ryegrass/white clover pasture 6-7kg DM/day; Av. DMD, 73%; Av. CP, 18.5%	Pellets; Av. DMD, 81%; Av. CP, 25.7%	0–10 kg DM	Varying	9.9	1.3 (early), 1.1 (mid), 0.7 (late)	Linear increase	Decrease	Increase	<5 weeks	Curvilinear increase; peak at 6 kg	Linear increase
Moate et al. 1984	Ryegrass/white clover pasture; MD, 69%; DMD, 73%; CP, 2.8%	Crushed oats; MD, 69%; CP, 8.8%	0, 2.2, 4.4	Early	13.5	0.9	Curvilinear	Decrease	Increase (NS)	–	Decrease	Increase
Stockdale & Trigg 1985	Paspalum pasture; DMD, 58.7%; CP, 7.9%(allowance 15 or 26 kg DM/day)	Pellets; DMD, 80%; CP, 15.1%	0, 2, 4, ad l libitum (~6)	Late	8.0	0.9	Linear increase	Variable	Increase	22 days	Curvilinear increase; peak at 4–5 kg	Linear increase
Jeffery et al. 1976	Mixed tropical grass/legume pasture & oats mixture	Crushed maize	3, 4.3, 5.6, 7.0, 8.3	–	–	–	Linear increase (p<0.001) Quadratic effect (P<0.05)	No effect	No effect	14 days	Linear increase	Linear increase (P<0.001) Quadratic effect (P<0.05)
Stockdale & Trigg 1989	Stall fed ryegrass/white clover pasture; DMD, 69.7%; CP, 15.4%; NDF, 48% (3 levels of intake)	Pellets; DMD, 81.1%; CP, 16.3%; NDF, 16.1%	0, 2.2, 4.4	Early & late	11.1	1.2	Increase	Decrease	Increase	16–17 days	Increase	Increase
Stockdale et al. 1990	Stall fed, 7kg DM Good quality pasture; DMD, 70%; CP, 20.3%; NDF, 36.6%	Crushed wheat; DMD, 95% , CP 10.4%; NDF, 6.9% Pellets; DMD, 81%; CP, 16.7%; NDF, 14.1%	0, 4, ad libitum	Early	10.9	1.0	Linear increase	Decrease	Linear increase	35 days	Curvilinear increase, peak at 5–6 kg conc.	Linear increase
	Stall fed, 7kg DM Poor quality pasture; DMD, 62%; CP, 12.6%; NDF, 50.8%			–	7.5	–	Wheat, curvilinear, max. at 5 kg; Increase with pellets	No effect	Increase	35 days	Wheat, curvilinear, max. at 4.5 kg; Increase with pellets	Linear increase

Table 29. Effect of increasing the level of supplement on milk production parameters *(continued)*

Reference	Basal ration	Supplement type	Amount of supplement (kg/cow/day)	Stage of lactation	Average basal milk yield	Average response to supplement (l/day)	Milk yield	Milk fat (%)	Milk protein (%)	Length of feeding period	Milk fat yield	Milk protein yield
Moate 1982	Pasture hay; 1% liveweight	Crushed wheat	0.5%, 1.0%, 1.5%, 2.0% of liveweight	Mid	–	–	Curvilinear increase (NS)	No effect	Increase	21 days	Curvilinear increase	Increase
Cowan *et al.* 1977	Restricted green panic/glycine pasture	Maize/soyabean meal	0, 2, 4, 6	–	–	–	Linear increase in fat corrected milk	Linear decrease	No effect	–	–	–
Royal & Jeffery 1972	Kikuyu dominant pasture	Soyabean meal/ crushed maize	0, 1.1, 2.7, 3.8	Mid–late	7.5	0.6	Linear increase	No effect	Variable effects	14 days	Increase	Increase
Bartsch *et al.* 1985	Cereal hay ad libitum	Hammermilled lupins	6, 9, 12, ad libitum	Early	–	–	NS	No effect	No effect	63 days	NS	NS
Hough 1991	Pasture hay ad libitum; M/D, 8.1; CP, 10.8%	Rolled lupins; M/D, 12.8; CP, 36.6%	2, 4, 6, 8, 10	Early	–	0.7	Increase	No effect	No effect	14 days	Trend to increase	–
McLachlan *et al.* 1994	Panicum/setaria/ glycine	Cracked maize/ meat meal	0, 2, 4, 6, 8	Whole	12.8	0.9	Linear increase	No effect	No effect	36 weeks	Curvilinear increase, peak at 4 kg	Linear increase
Walker *et al.* 2001 Exp. 1	Paspalum M/D:8.6 CP: 11.9%	Barley/wheat	3,5,7,9,11	Mid–late	22.3	0.9	Linear increase	No effect[1]	No effect	5 weeks	–	–
Exp. 2	Paspalum M/D:8.2 CP: 11.9%	Barley/wheat	3,5,6	Late	19.4	0.4	Peak at 3 kg	No effect	Trend to increase	5 weeks	–	–
Reeves *et al.* 1996	Kikuyu M/D:10.4 CP:20.7%	Barley 0-60% HCHO canola[2]	0,3,6,9	mid	17.2	0.8	Linear increase	Linear decrease	Linear increase	3 weeks	Curvilinear increase; peak at 6 kg	Linear increase

[1] Depression at 11 kg; [2] No effect of HCHO canola inclusion

those that are degraded more slowly, such as protein meals or whole cereal grains, have less effect. Within the cereal grains, lower substitution rates are expected from maize and sorghum as they have been found to ferment more slowly (Herrera-Saldana *et al.* 1990).

Processing grains can influence substitution, because it improves starch digestion in the rumen. This enhances the effect of lowering rumen pH. Sriskandarajah *et al.* (1980) found substitution rates of 0.92 kg/kg and 0.48 kg/kg with rolled barley and whole alkali-treated barley, respectively. Ernst and Rogers (1982) fed supplements of rolled barley and cotton-seed meal and calculated substitution rates of 0.64 kg/kg and 0.39 kg/kg for each.

Stage of lactation

Phipps *et al.* (1987) found that substitution rate declined as lactation progressed. Earlier, Ekern (1972) had found similar results, but stage of lactation was confounded by level of feeding and cow potential, as cows were fed according to yield.

Synergistic effects

When there are nutrient deficiencies in pasture, which limit the rate of digestion of the pasture, or the rate of utilisation of absorbed nutrients, provision of supplementary nutrients often increase pasture intake. Typically this occurs on poor quality tropical pastures, which are deficient in one or more of energy, protein, phosphorus or sodium. Provision of supplements containing one or more of molasses, urea, di-calcium phosphate and salt often stimulate intake of the pasture. This is synergy rather than substitution. Synergy may be accounted for with a negative substitution rate:

Adjusted forage intake = basal forage intake – (basal forage intake x substitution rate)

Thus if the substitution rate is negative, the adjusted forage intake will increase.

Table 30. Trends in milk production parameters with increasing levels of supplement (Summary of Table 29).

Reference	Supplement type	Milk yield	Milk fat yield	Milk protein yield	Milk fat %	Milk protein %
Stockdale *et al.* 1987 Moate *et al.* 1984 Stockdale & Trigg 1985 Jeffrey *et al.* 1976 Stockdale & Trigg 1989 Stockdale *et al.* 1990 Moate 1982 Reeves *et al.* 1996 Walker *et al.* 2001 McLachlan *et al.* 1994	Cereal grains	Linear or curvilinear increase	Linear or curvilinear increase (one study showed a decrease)	Linear increase (one study showed no change)	Increase or no effect	Increase or no effect
Cowan *et al.* 1977 Royal & Jeffery 1972	Protein meals or cereal grains+ protein meals	Linear increase	Increase	Increase	Decrease or no effect	No effect or variable effect
Bartsch *et al.* 1985 Hough 1991	Lupins	Increase or no effect	Increase or no effect	Increase or no effect	No effect	No effect

Level of concentrate

Results from experiments where several levels of concentrate were fed are given in Table 29. These results are summarised in Table 30, which shows general trends in milk production parameters seen with increasing levels of concentrates, comprising cereal grains, protein meals and lupins.

Cereal grains

(a) Milk production

Experiments listed in Table 29 showed both linear and curvilinear increases in milk yields with increasing levels of concentrate. In some of the experiments, there was either insufficient replication or insufficient levels of concentrate to detect deviations from linearity in the response. As there were no consistent trends evident in marginal responses, only average milk responses are given and these are confounded with substitution effects.

In the experiment of McLachlan *et al.* (1994) there were eight cows per treatment and five levels of feeding over which the milk response to concentrate was linear. The average response was 1.1 l/kg in the first 150 days of lactation and 0.9 l/kg over the whole 250 days. This response is very similar to that recorded previously in this tropical environment with lower levels of concentrate.

It has been previously reported that the relationship between energy intake and milk yield is curvilinear (Blaxter 1962; Dean *et al.* 1972). Gordon (1984) in Europe found a curvilinear response between total concentrate intake over a lactation and total lactation milk yield (Figure 11). Similar curvilinear responses have been shown in several experiments in Australia (Walker *et al.* 2001) (Figure 12). These experiments indicate that the marginal milk response decreases as the level of concentrate increases.

Peyraud and Delaby (2001) summarised results of seven experiments which showed that the milk response to concentrates was 1.0 kg/kg concentrate up to 2.3 kg/day concentrate and 0.6 between 2.3 and 4.4 kg/day concentrate.

Declining milk response to increasing levels of concentrate may be due to:

- Increasing substitution rate;
- Decreasing digestibility of the diet;
- Increasing chance of nutrient imbalances;
- Increasing partition of nutrients to body tissue.

There is conflicting evidence on the effect of concentrate level on substitution rate, but most experiments indicate that the substitution rate increases with feeding level of concentrate (Faverdin *et al.* 1991). The effect of this would be progressively smaller increments of energy intake with equal increments in level of concentrate feeding.

Stockdale and Trigg (1989) proposed that the digestibility of the diet decreases as the feeding level increased due to a greater passage of undigested cell walls and starch. This was supported by increases in faecal starch content as concentrate feeding increased. However, as stated in Chapter 5, although increasing feeding level decreases digestibility, the net effect on metabolisable energy intake is very small (Van Es 1975). This is due to a reduction in energy losses from methane and urine as the feeding level increases (Blaxter 1962).
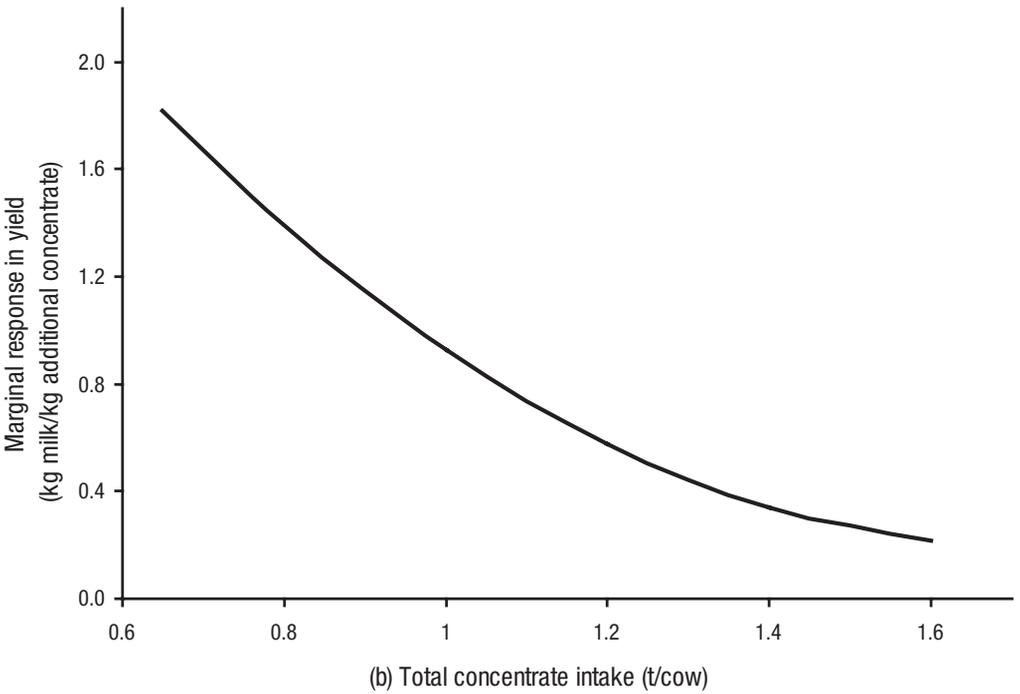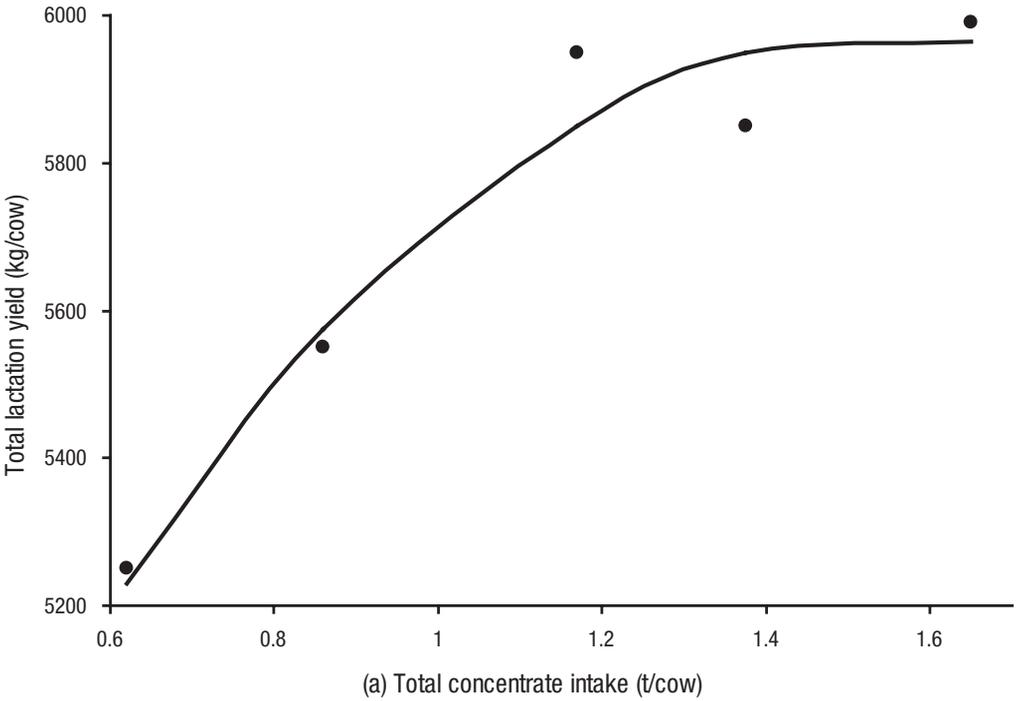
Figure 11 (a) and (b). The effects of level of concentrate supplementation on total lactation yield (a) and the marginal response in total lactation yield to changes in concentrate input (b). Gordon (1984).
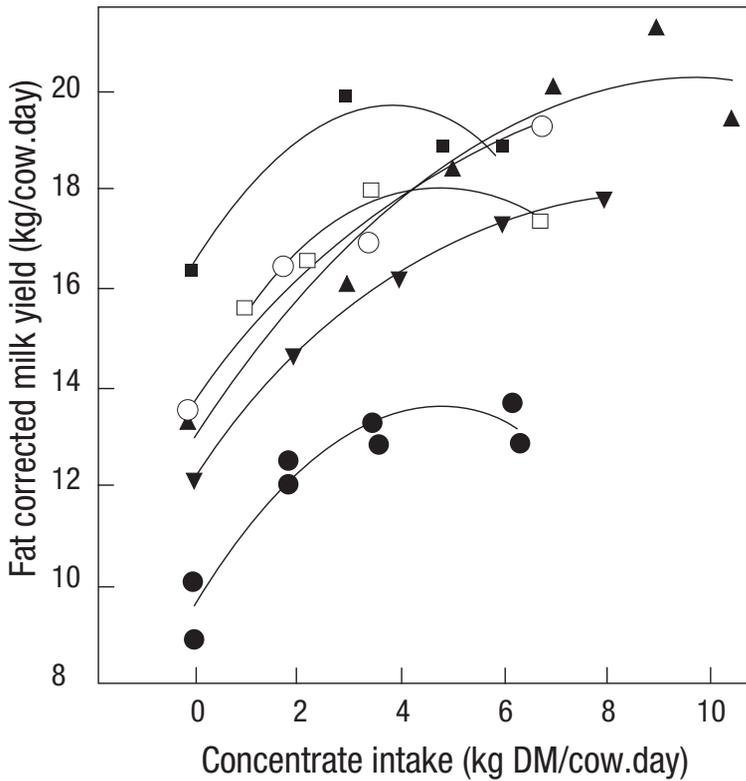
Figure 12. The relationships between 40 g/kg fat-corrected milk production and intake of cereal grain-based concentrates for experiments 1(▲) and 3(■); together with those of Stockdale and Trigg (1985)(●) from northern Victoria: McLachlan et al. (1994) (▼) from northern Queensland; and Robaina et al. (1998) (○) from southern Victoria and the relationship between milk production and intake of cereal grain-based concentrate from Davison et al. (1985) ( ). Walker *et al.* (2001).

With increasing levels of concentrate such as cereal grains, there is an increasing chance of nutrient imbalances that may become limiting for milk production, unless care is taken in diet formulation.

Curvilinear responses of milk production to level of concentrate, such as those of Gordon (1984) and Walker *et al.* (2001) shown in Figures 11 and 12, were attributable to possible changes in substitution rate and/or changes in the partition of nutrients.

In contrast, Jones (2003) examined the response between metabolisable energy above maintenance and milk production, an approach that avoided any bias due to substitution effects. He found a curvilinear response, which indicated that efficiency of energy use for milk production declined as metabolisable energy for production increased (Figure 13). This was not associated with increasing partition of nutrients to body tissue as energy intake increased. The asymptote of this curve will vary with the milk production potential of the cow, which is determined by

- Genetic potential;
- Liveweight;
- Body condition score;
- Nutrient intake.
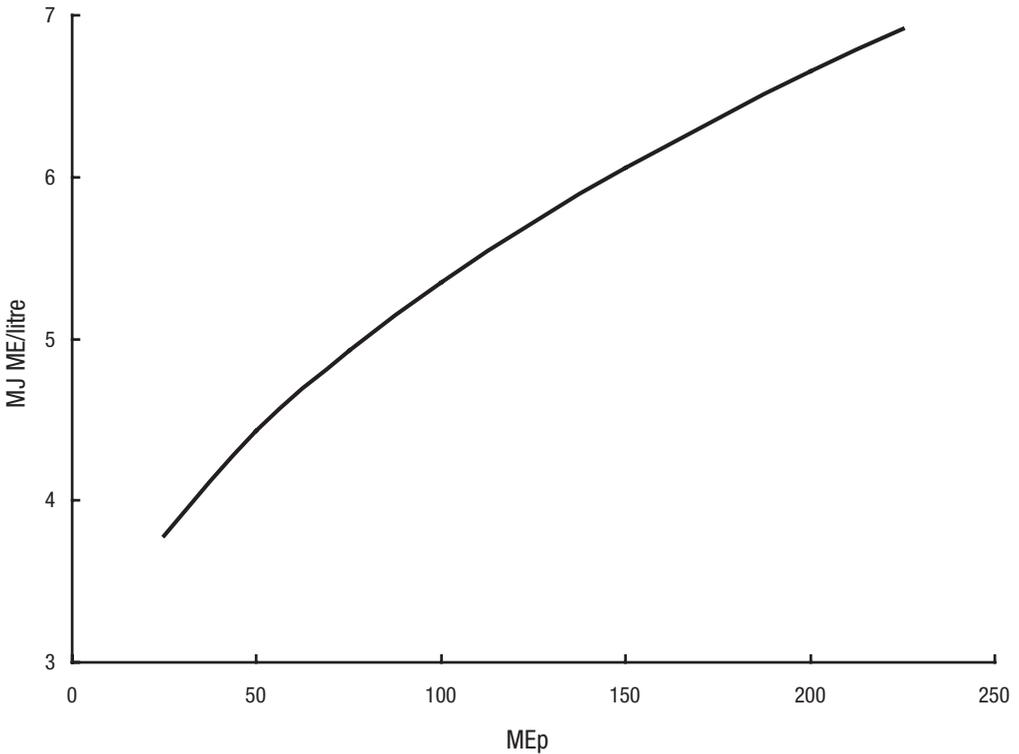
Figure 13. Effect of level of metabolisable energy for production on energy required per litre of milk. Jones (2003).

Genetic potential, liveweight, body condition score and nutrient intake determine the milk production potential of the cow. Maximum potential is achieved at the peak of lactation, when cows are well grown, in optimal body condition score and fed a diet that maximises intake of nutrients in the correct balance.

The experiments reported by Gordon (1984) and Jones (2003) were conducted over whole lactations with a wide range of energy intakes and large numbers of cows. The decreasing milk yield for each extra unit of metabolisable energy intake shown in both studies indicates that energy requirement per litre of milk is not necessarily a constant, as assumed in major feeding systems (MAFF 1975; ARC 1980; INRA 1989; NRC 1989; AFRC 1993; NRC 2001).

When the genetic potential for milk production exceeds either the cow's intake capacity or the feeding level that is permitted, energy requirement per litre may be constant. However, when the intake level of nutrients exceeds the cow's genetic capacity to produce milk, inevitably there will be increasing partition of nutrients to body tissue. This will bring about a decreasing milk response and an increasing energy requirement per litre of milk.

When the milk response to concentrate level is linear, as found by McLachlan *et al.* (1994), it is likely that the genetic potential of the cows for milk production exceeded the intake of nutrients possible from the tropical pastures.

The relationship in Figure 13 can be used to calculate energy requirement per litre of milk, as a function of metabolisable energy for production expressed as a proportion of metabolisable energy for production needed to maximise milk yield. If it is assumed that

the form of this relationship is similar for cows with different potential for milk production, a series of milk response curves can be generated as in Figure 3.

These curves facilitate more accurate prediction of milk yields from diet and cow information. They also facilitate the formulation of diets to maximise profits by applying costs of feed inputs to returns from milk outputs.

Importance of fibre digestion
Faverdin *et al.* (1991) calculated mean pasture substitution rates of 0.69, 0.63 and 0.51 for starch, high-quality fibre and low-quality fibre concentrates, respectively. It has been suggested that this marked effect may be attributed to effects on rumen fermentation that result in a diminished rate of fibre digestion in the rumen (Milne *et al.* 1981).

As the amount of grain feeding on dairy farms increases, it will become increasingly important to identify grain properties that minimise interference with fibre digestion. This will enable the selection of grains to maximise milk production, while minimising the likelihood of acidosis (Stockdale *et al.* 1997). Opatpatanakit *et al.* (1994) examined the effects of cereal grains on *in vitro* fibre digestion and found that wheat, barley, and maize had inhibitory effects, whereas oats and sorghum had synergistic effects on the neutral detergent fibre digestibility of both ryegrass and lucerne.

(b) Milk composition
Increasing the level of concentrate also affects milk composition. High levels of grain starch fermented in the rumen reduce rumen pH and increase production of propionic acid. Also they increase production of the trans-10 isomer of linoleic acid (Griinari *et al.* 1998), which has a specific effect in reducing fat synthesis in the mammary gland.

The decrease in milk fat yield to increasing levels of concentrate is curvilinear with three experiments showing peaks at 4–6 kg of concentrate DM intake (Stockdale and Trigg 1985; Stockdale *et al.* 1987; Stockdale *et al.* 1990; Reeves *et al.* 1996).

Propionate is a precursor for glucose synthesis, as are amino acids in dietary protein. Increase in availability of propionate reduces the amount of dietary protein converted to glucose, which makes more amino acids available for milk protein synthesis. The increase in milk protein content and milk protein yield is evident from the data in Table 29.

The digestive disturbances that lead to change in milk composition can be minimised by:
- Providing adequate fibre in the diet.
- Adding buffers to the diet (see Chapter 9).
- Feeding concentrates in smaller amounts, more often. An extension of this practice is to feed a complete mixed diet as in a feedlot dairy.
- Feeding long hay before feeding concentrates.

NRC (2001) recommend minimum fibre levels of 17–21% acid detergent fibre (ADF) and 25–33% neutral detergent fibre (NDF). This recommendation applies to lucerne or maize silage diets. With grazed temperate pastures in a vegetative state, the fibre is likely to be less effective at stimulating chewing, so it may be necessary to have a higher content of NDF when the forage component of NDF is about 75%. However, Wales *et al.* (2000b) found that when cows were grazing high-quality temperate pasture, and the diet NDF

content was 33%, of which 78% came from forage, normal rumen function was maintained.

The fibre particles should be long enough to stimulate rumination. This has been assessed in terms of physically effective NDF (peNDF) that is related to the proportion of NDF retained on a screen with 1.18 mm or greater openings after dry sieving (Mertens 1997) or to particle size (>0.6–0.8 cm) (Sutton 1990). The other term used in relation to NDF is effective NDF (eNDF), which is the ability of NDF to maintain the percentage of fat in milk. There appears to be little merit in distinguishing between peNDF and eNDF, the latter being in common usage.

In the two experiments where basal diets were high in fibre (Moate 1983; Stockdale *et al.* 1990), there was no change in milk fat content as level of supplement increased. Stockdale *et al.* (1987) found that milk fat content was not greatly affected by concentrate feeding until the ratio of lipogenic: glucogenic VFA's in the rumen fell below 4:1. For their experiment, this corresponded with a neutral detergent fibre content of 250 g/kg DM. Depression of milk fat occurred when concentrates comprised 40–50% of the diet (Stockdale *et al.* 1987). This level of concentrate is lower than that at which depression of milk fat occurred in UK experiments (Sutton 1990). This may be attributed to the lower fibre content of the Australian pastures, or the lower effectiveness of fibre to stimulate chewing, compared with the conserved forages fed overseas.

Milk protein yield and protein content generally increased as energy intakes increased (Table 30).

Protein supplements

(a) Milk production

Very few experiments have examined the effects of protein supplements on milk production. It would be expected that marginal increases in milk production would decrease with successive increments of protein concentrates as the cow approaches its genetic potential. However, protein supplements may have a lesser effect on depression of the marginal response for the following reasons:

- Substitution rate – in general, protein supplements are degraded more slowly in the rumen than cereal grains and cause less depression of rumen pH. Valentine and Bartsch (1987) found that rumen pH of cows given crushed barley grain decreased to a minimum value of 5.4. In contrast, rumen pH of cows fed hammermilled lupins or faba beans was maintained above 6.0. From 3–6 hours after feeding, rumen pH in cows fed cereal grains was significantly lower than that of cows given legumes (Valentine and Bartsch 1987). *These differences are a result of a lower starch content and higher fibre content in grain legumes compared to cereal grains and possibly a lower rate of starch degradation in lupins.* Bartsch and Valentine (1986) calculated starch values of 0.7, 47.8, 37.4 and 58.9% DM for lupins, peas, beans and barley, respectively.

Differences in rumen pH are likely to produce differences in substitution rates. Paynter and Rogers (1982) calculated substitution rates of 0.64 for rolled barley and 0.39 for cottonseed meal. In trials where cereal hay provided the basal ration, Bartsch *et al.* (1987) found that the substitution rate of cottonseed meal was lower than that of barley in one

experiment, but not another. In six grazing trials where cows were fed 5 kg/day of mixed cereal grains or a mix of 50:50 cereal grains and lupins, the substitution rates did not differ significantly (Stockdale 1996b). Further work is required to assess substitution rates of grain legumes with basal diets of pasture.

- Digestibility and intake – protein supplements can increase digestibility in the rumen, probably by providing peptides and amino acids, which increase efficiency of microbial protein synthesis (Maeng *et al.* 1976). This can lead to an increase in intake, as shown by Roffler *et al.* (1982).
- Protein content of the diet may limit milk production as energy intake increases.

(b) Milk composition
While there was no change in milk fat content with increasing levels of lupins, it is hard to draw conclusions, as the basal diets were high in fibre. However, *increasing levels of lupins would be expected to maintain a stable concentration of milk fat*, *due to their minimal effects on rumen pH.*

Increasing levels of lupins had no effect on milk protein precentage.

Stage of lactation

The marginal milk response to supplementation decreases as lactation progresses because more feed energy is partitioned towards liveweight gain (Broster and Thomas 1981) (see Figure 2). In early lactation, depending on body condition score, cows can mobilise body tissue and partition a larger amount of energy towards milk production. However, in late lactation, there is a natural tendency to partition energy towards body condition score in preparation for the following lactation.

The experiment by Stockdale *et al.* (1987) supported this premise. They found that marginal response in milk yield, to varying levels of supplement, was greatest in early lactation and decreased thereafter. Over five experiments with supplement intakes in the range 0–7 kg/cow/day, they calculated average marginal responses of 1.3, 1.1 and 0.7 kg milk/kg supplement in early, mid- and late lactation, respectively. The same effect was seen with milk fat yield. Responses decreased as lactation progressed. Stockdale and Trigg (1989) also found that, in general, responses were lower in later lactation, especially where pasture was restricted.

The experiments summarised in Tables 1 and 2 (Chapter 5) resulted in average responses of 0.6 kg milk/kg supplement in early lactation and 0.5 kg milk/kg supplement in mid- to late lactation for cows grazing temperate pastures. While this is in agreement with Broster and Thomas (1981), the results are confounded by variations in pasture and supplement quality and pasture allowance. Experiments where similar diets are offered to cows at different stages of lactation would give a better indication of the effect of stage of lactation.

Doyle *et al.* (2001) concluded that marginal responses to concentrates can be higher in mid- and late lactation than in early lactation under grazing conditions. However this conclusion was based on data where stage of lactation was confounded with pasture quality. Cows grazing poor quality pasture in late lactation will give a greater milk response to concentrates than cows grazing good quality pastures in early lactation.

Interaction between stage of lactation and pasture allowance

The experiment by Stockdale and Trigg (1989) looked at the interactions between stage of lactation, pasture allowance and marginal response. In early lactation, the marginal response was greatest at low pasture feeding levels, while in late lactation, marginal responses were constant, regardless of pasture allowance. These results are similar to those obtained by Grainger (1990) when examining the effect of feeding level on changes in pasture intake.

Cumulative and residual responses

The presence of cumulative and residual responses to supplementation will depend, to some extent, on the stage of lactation at which supplementary feeding occurs.

If supplementation is provided in early lactation, improvements in body condition score and residual pasture may allow increased responses during mid-lactation due to a preferential partitioning of energy towards milk production. Feeding in late lactation is more likely to result in improved body condition score, which may then allow increased production in the following lactation (Stockdale and Trigg 1985). Supplementation may also result in an increase in lactation length.

Responses to protein

Responses to protein supplements vary with stage of lactation. In early lactation, mobilised body tissue provides the cow with greater amounts of body fat than protein, resulting in potential protein deficiency. At the same time, potential milk production is greater than in later lactation. *For these two reasons, milk responses to protein supplements are more likely in early than in late lactation.*

Genetic potential of the cow

Cows of high genetic merit partition more feed energy to milk production, lose more body weight in early lactation and are thinner at drying-off than cows of lower merit (Wilson and Davey 1982; Broster 1983; Wilson 1983) (Table 31). These cows also have a greater feed intake than cows of lower merit, and a greater feed conversion efficiency (Bryant and Trigg 1982; Broster 1983).

If cows of high genetic merit partition more feed energy to milk production, there will be a greater marginal response to supplementary feeding. This has not always been recorded experimentally, perhaps because small differences in genetic merit or insufficient replication did not allow differences in marginal response to be detected.

Holmes *et al.* (1985) found that while high breeding index cows produced more milk fat than low breeding index cows, there was little difference between the groups in their marginal response to extra pasture. This was true of cows in both early and late lactation. Robinson and Rogers (1982) and Stockdale *et al.* (1987) examined the effect of initial yield on the response to pellet supplements. Both experiments found that cow potential, as reflected by initial yield, had no influence on the marginal response. However, high producers lost more weight and partitioned more energy towards milk production throughout lactation.

Other experiments have found greater marginal responses from high producing cows (Broster and Thomas 1981; Broster 1983). Grainger (1990) examined the effects of increasing pasture intake and found a significant positive interaction in early lactation between initial yield and marginal response. This supported the work of Grainger *et al.* (1985), where – although non-significant – higher marginal responses were obtained from high breeding index cows in three experiments.

Table 31 Effects of genetic merit (ABV) on response to three levels of concentrate feeding (0.34, 0.8 and 1.71 tonnes/cow/lactation), over five years (Fulkerson *et al*. 2000).

| Concentrate intake | Low ABV | | | High ABV | | |
	Low	Medium	High	Low	Medium	High
Milk – l/day	15.8	18.5	20.1	17.8	20.1	21.7
Milk fat %	3.74	3.76	3.71	3.86	3.87	3.89
Milk protein %	3.04	2.97	3.08	2.89	2.98	3.02
Extra milk – l/kg concentrate		1.47	0.92		1.75	1.06
Extra fat – g/kg concentrate		43.5	35.2		55.2	45.2
Extra protein – g/kg concentrate		42.0	31.0		60.0	38.0

The most comprehensive assessment of the effect of genetic potential on response to concentrates was reported by Fulkerson *et al.* (2000). They compared responses to three levels of concentrate feeding with two levels of genetic merit over a period of five years. The high genetic merit group, with over 66% North American genes had a mean Australian Breeding Value (ABV) of +752 litres milk. The low genetic merit group, with less than 20% North American genes had a mean ABV of +11 litres milk. Concentrates were fed at 0.34, 0.8 and 1.71 tonnes/cow/lactation. The results (Table 31) show that the high ABV cows were more productive at all levels of concentrate feeding, and gave larger responses to concentrate feeding than low ABV cows. Responses at the highest level of concentrate feeding were lower than those at the medium level. The superior performance of the high ABV cows was associated with days from calving to conception being extended from 91 to 99 days.

Pasture and concentrate quality

Analyses of several experiments in Victoria showed that the marginal response to concentrates increased as pasture quality declined (Stockdale 1998). *The more suitable a pasture is for milk production, the lower will be the response to a concentrate. Where pasture quality is low and concentrates are able to provide limiting nutrients to the diet, responses will be good.* Where high quality pasture provides adequate energy and protein to meet the cow's needs, high substitution rates will occur, producing only small responses. Where protein levels in the pasture are adequate for the level of production, protein provided in excess, relative to the energy supply, will be degraded to ammonia and excreted in the urine. On high quality pastures, fibre may become a limiting nutrient.

Concentrate quality has a similar effect on response. Concentrates that provide limiting nutrients give much greater responses than those supplementing already adequate levels. For example, concentrates of high protein content can give good responses when a protein deficiency exists, but at other times, provide only an expensive energy source. Cereal grains may induce a protein or calcium deficiency at high levels and so limit response in this way.

Stockdale *et al.* (1990) carried out a comprehensive trial on this subject. They stall-fed cows on approximately 7 kg DM/day of either good or poor quality pasture and supplemented with varying amounts of either crushed wheat or high energy pellets. Responses were found to hinge on the interaction between the supplements and pasture type.

For good quality pasture, similar marginal milk responses were obtained for both supplements (Figure 14). Milk fat yields were curvilinear, peaking at 5–6 kg of concentrate DM, then decreasing, and again were similar for both wheat and pellets. This depression in milk fat was a result of low dietary fibre levels (neutral detergent fibre <250 g/kg DM) limiting production.

On the poor quality pasture, responses differed between supplements. With pellets, milk fat yield was not depressed at high feeding levels, as adequate fibre (neutral detergent fibre >250 g/kg DM) was provided in the basal ration (Figure 14). With the crushed wheat supplement, other factors appeared to limit production. It is likely that the protein content of the diet was inadequate when wheat feeding exceeded approximately 5 kg DM/day. Other possibilities are that either calcium or phosphorus deficiency may have limited milk yields.

Rogers (1990) also looked at the effect of supplementing different basal diets. He fed oat grain as a supplement to both clover and ryegrass pastures. Much greater responses were obtained with a basal ration of clover (0.94 l/kg oats) than with ryegrass (0.36 l/kg oats). The reasons for these results are yet to be determined, but one possibility is that higher levels of calcium or magnesium in the clover may have been important.

Stockdale *et al.* (1999b) found that the best responses (as judged by marginal returns) to concentrates occurred when the pastures were dominated by paspalum and other poor-quality species that provided insufficient energy. The responses were greater than 1 kg milk/kg DM of concentrates eaten and were significantly higher than the responses when the pasture nutritive characteristics were highest (generally less than 0.6 kg milk/kg DM).

Despite variations in pasture allowance, size and body condition score of animals, stage of lactation, milk yield and type of pasture on offer, a substantial negative correlation was found to describe the relationship between marginal response and the metabolisable energy concentration of the pasture consumed by the cows. Interestingly, they also found that the relative changes in body condition score between supplemented and unsupplemented cows did not alter as the energy concentration of the pasture eaten increased.

Stockdale (1999b) examined the effects of feeding 5 kg DM of barley/wheat pellets to cows offered 30 kg DM/cow/day of either newly sown white clover-ryegrass or old, established paspalum pastures. The results proved contrary to other findings, in that the level of substitution was not significantly different between the two groups despite the difference in pasture quality. It is possible that the pastures were not sufficiently different in quality for any other conclusion to be made.

Stockdale *et al.* (1997) described a study that was conducted to examine the seasonal/annual productivity responses to high stocking rates, irrigation and grain supple-
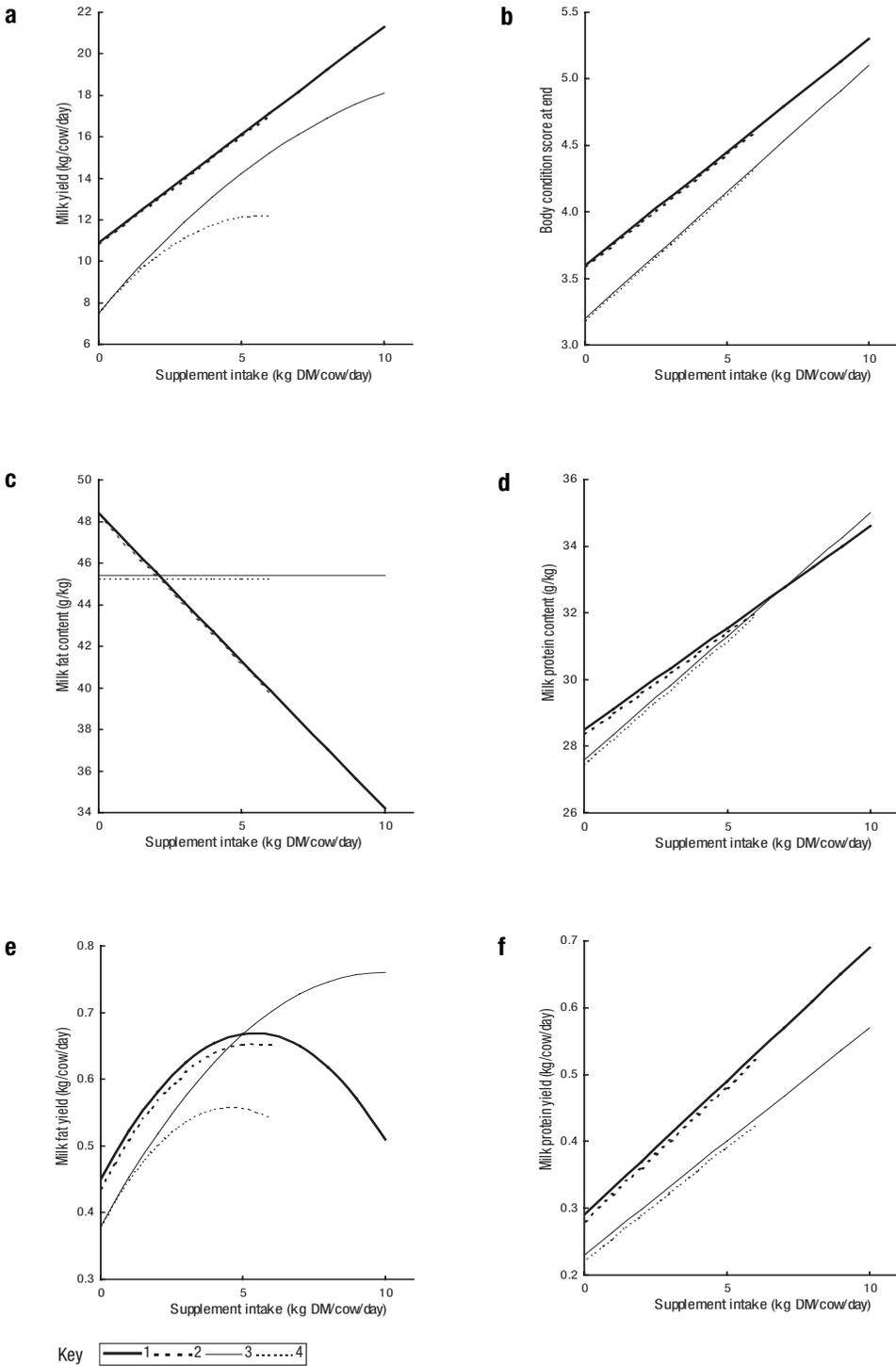
Figure 14. Effects of supplement intake on (a) daily milk yield, (b) body condition score at the end of the experiment, (c) milk fat content, (d) milk protein content, (e) milk fat yield and (f) milk protein yield. 1 – good quality pasture + pellets; 2 – good quality pasture + wheat 3 – poor quality pasture + pellets; 4 – poor quality pasture + wheat. From Stockdale *et al.* (1990).

mentation of farming systems based on ryegrass/white clover pastures. Two farmlets were stocked under dry land conditions at 2.4 cows/ha, with one having an input of 500 kg grain/cow/year and the other no grain at all. Another two farmlets were irrigated and stocked at 3.4 cows/ha with the same grain treatments as those for the dry land farmlets. The best responses to grain resulted in longer lactations in two consecutive years in the dry land situation. On the irrigated farmlets, grain did not result in an increase in lactation length and the responses to grain were poorer.

The quality of the basal diet and supplement interact to determine the magnitude of the milk response. Where supplements provide limiting nutrients to the diet, the best responses are seen. Fibre is most likely to be the limiting factor on high quality pasture, while protein is more likely to limit production on poor quality pastures. Cereal grains always have a low content of calcium and frequently have low contents of protein, phosphorus and sodium. Unless rations are balanced for all nutrients, milk responses are likely to be less than they might otherwise be.

Economic analysis of concentrate feeding

Summary

Concentrate feeding is most profitable when maximum use is made of pasture and when stocking rates are increased. The choice of concentrate and level of feeding depends on:

- The milk potential of the cows;
- Pasture availability;
- Pasture quality and cost;
- Concentrate quality and cost;
- Milk price.

The monetary value of other benefits should also be considered when assessing the profitability of supplementary feeding. These include:

- Extra body condition score;
- Improved reproductive efficiency;
- Extra pasture and improved pasture quality;
- Increased numbers of cull cows and calves;
- Lower overhead cost/l milk.

The total response to supplementation may be twice that of the immediate response and should be accounted for in economic calculations.

Introduction

The decision on whether or not to feed supplements, and the amounts to feed has to be determined by the change in profitability the feeding will bring about. The problem is to determine the overall change in profitability associated with feeding supplements. This is a complex issue, made more difficult by the fact that very few trials have examined this

aspect within the farming system as a whole. In most cases, simplistic calculations are made based on the return from milk above that of the concentrate cost. However, this assumes there is only a single benefit from concentrate feeding. It ignores the monetary value of other benefits, which include:

- Improved body condition score.
- Ability to carry more cows. This produces greater income through increased milk production; increased calf numbers, increased cull cows, increased pasture use and better quality pasture.
- Reduction in overhead costs per litre milk. When yields are increased, the overhead or fixed costs of milk production are less per litre of milk.
- Improved reproductive performance.
- Cumulative and residual responses to the supplement. In the short term, immediate responses to supplements may be low and appear uneconomic. However, over the long term, the total response (including cumulative and residual responses) may be twice the size of the immediate response.

All these factors should be included in computer models used for determining the economic benefits of supplementary feeding, but at present they are not. The CamDairy model considers feed costs, factors affecting conversion of feed to milk, and milk prices.

Cost of pasture

Kellaway (1991) calculated that, with irrigated annual pastures in NSW, the cost of pasture eaten was $118/t DM, a figure comparable with the price of cereal grains at the time. This was based on cows grazing 6.8 t DM/ha/annum, which was only 40% of likely pasture production. If pasture use had been improved to 10 t DM/ha/annum, the cost of pasture eaten would have been reduced to $80/t DM.

DRDC (1996) reported benchmark studies on 89 dairy farms in western Victoria. They found that average pasture utilisation was 5.4 t DM/ha/annum, the cost of which was $107/t. Dairy Farmers (1997) published a Farm Benchmarks guide that did not consider the cost of pasture eaten. Subsequently, Dairy Farmers did consider the cost of pasture eaten in an analysis of 56 northern coastal dairy farms in NSW for 1998/1999. They found that average pasture utilisation was 7.5 t DM/ha/annum, the cost of which was $129/t DM (Dairy Farmers 2000).

Potential DM production under irrigation would greatly exceed the above estimates of pasture eaten. The more efficiently pasture is used, the cheaper it becomes. Farmers should aim for a minimum of 70% pasture utilisation to maximise profits. This can be achieved by increasing stocking rates.

Operation Milk Yield, conducted in Victoria in 1982–85 (Australian Dairy Corporation 1987) found that feeding concentrates in conjunction with an increase in stocking rate was much more profitable than feeding only to increase production/cow. Increasing stocking rate resulted in a return to extra capital of 62%, compared with only 9% when concentrates were fed in mid- to late lactation to increase individual yields.

If pasture availability is not reduced through an increase in grazing pressure, supplementary feeding will be associated with high substitution rates, which greatly reduces the potential economic benefits.

Cost of concentrate

Concentrates have additional costs. Often these are not considered in simple economic analyses. For example, cereal grain may cost $150/t at source, but further costs are incurred before consumption, including transport, storage, processing and the labour involved in feeding out.

At present, there is limited nutritional information available on which to base the choice of cereal grain. The choice of grain should be based on $/t DM or preferably $/MJ metabolisable energy, with weighting factors for its substitution effect and content of other nutrients. *This will await research to measure differences in substitution rates, and the development of rapid feed analysis systems.*

By-products often provide cheap alternatives to cereal grains, although their nutrient content varies widely. For this reason, feed analyses should be carried out to allow assessment on cost per unit of dry matter, energy and protein, before making a decision to feed a particular by-product on a regular basis.

Responses to protein supplements have been variable and protein supplements are usually much more expensive than cereal grains. For these reasons, it is advisable to use the services of a nutritionist to calculate balanced rations with adequate protein at different stages of lactation. This involves knowing the protein content of the pasture and other ingredients of the diet. If high levels of grain are fed, or the pasture is of poor quality, protein supplements may be required.

Kellaway (1983) calculated response curves to different levels of dietary protein (Figure 15). He demonstrated that the most profitable level of protein to include in the diet varies with the price of the supplement, the milk production potential and the milk price

Response to the supplement

When pasture availability and quality are high, substitution rates are high, and minimal responses to supplementation are seen. Farmers should ensure that concentrates actually supplement the pasture, rather than substitute for it. This can be achieved by restricting pasture availability through increased grazing pressure, and by feeding concentrates with low substitution rates.

Greater milk responses to concentrate are generally seen in early lactation than in late lactation. This means it is generally more profitable to feed concentrates in early lactation, especially if cumulative or residual responses result during mid-lactation. It should be kept in mind that, although lower milk responses are observed in late lactation, improvement in body condition score may increase reproductive efficiency and milk production in the next lactation.

In the short term, milk responses have averaged 0.5 kg milk/kg concentrate fed. This value should not be used for economic analysis, since usually the response is doubled over the long term (1.0 kg milk/kg concentrate.)

Responses to supplements may be determined in terms of immediate, cumulative, residual, average and marginal effects as discussed in Chapter 3.

Milk price

The milk:concentrate price ratio largely determines the profitability of concentrate feeding. If milk prices are low and concentrate prices are high, it may be uneconomic to feed when
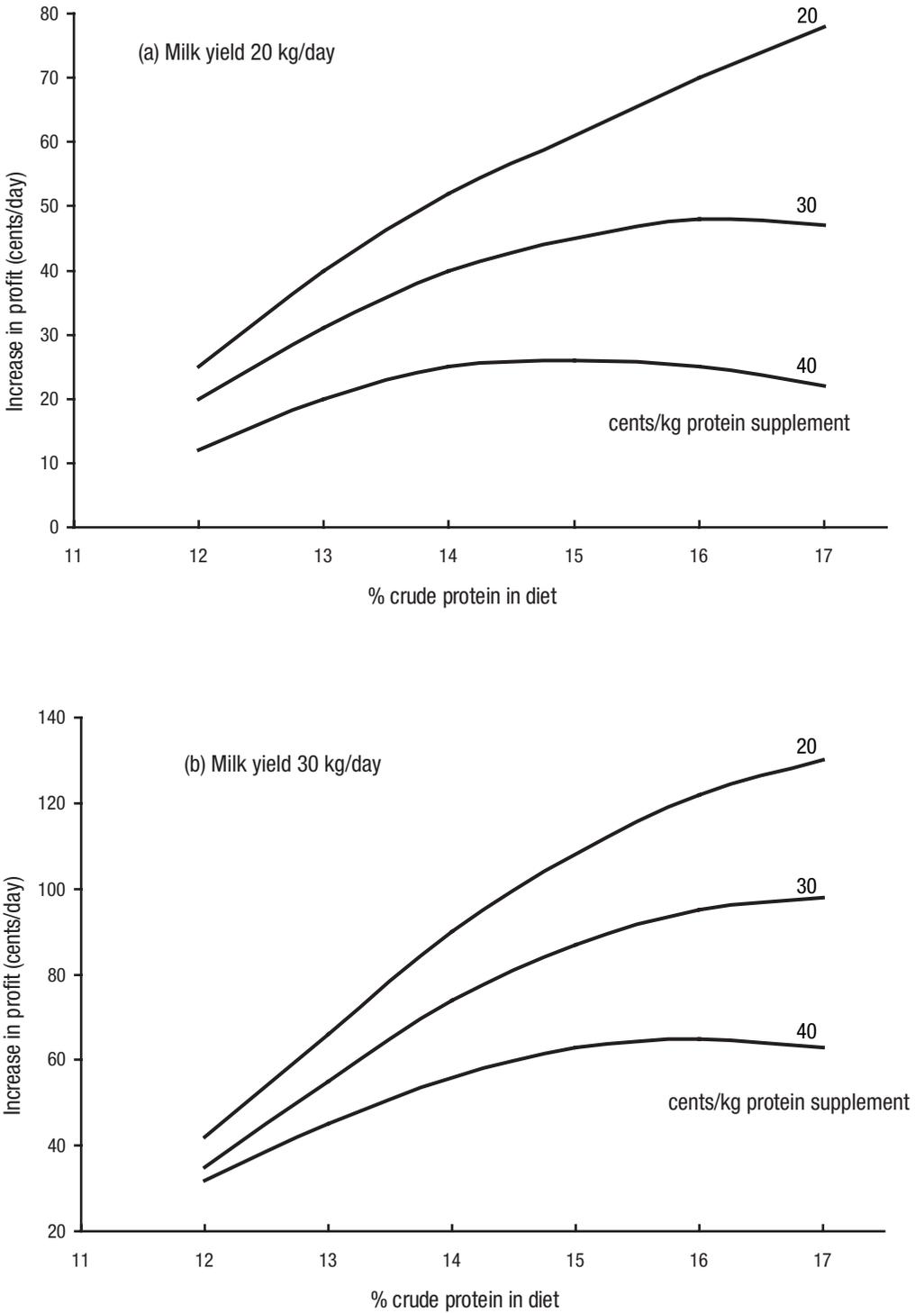
Figure 15. Effects of variation in price of protein supplement and milk production potential on optimum concentration of protein in the diet (a) Milk yield 20 kg/day; (b) Milk yield 30 kg/day. From Kellaway (1983).

evaluated solely in terms of milk response. However, feeding concentrate may have other benefits such as reducing grazing pressure on pastures, which are heavily stocked, and maintaining body condition when it might otherwise decline. These factors should also be taken into consideration. The premium price paid for autumn milk in the seasonal-calving herds of Victoria makes concentrate feeding more profitable at this time.

Concentrate feeding in the summer enables cows to continue milking until the autumn break. Surplus autumn pastures can then be used for milk production when the premium milk price is paid.

In a NSW dairy farm analysis in 1998–1999, the average manufacturing milk price was 25.5 c/litre and the average concentrate cost was 23.8 c/kg, giving a milk:concentrate price ratio of 1.07 (Dairy Farmers 2000). Experiments reviewed in this book indicate that short-term responses frequently are 0.5 l/kg or greater, and long-term responses often are double the short-term responses.

With a concentrate cost of 24 c/kg, the milk price would have to be 48 c/litre to cover the short-term response and 24 c/litre to cover the long-term response. The higher price appears unlikely in a de-regulated market. An average price in the region of 30 c/litre appears likely at the present time. This means that the economics of concentrate feeding have to be considered in terms of long-term effects, and careful consideration of the conditions under which responses to concentrates are likely to be greatest, which are:

- In early lactation;
- Cows of high genetic merit;
- Cows in good body condition score;
- Low pasture allowance;
- Low pasture quality.

The other major factor to consider is that when feeding concentrates, stocking rate can be increased, which has the effect of reducing the cost of pasture eaten.

Aids to economic analysis

As mentioned earlier, computer models are the obvious means of integrating information on the factors that determine profitability on dairy farms. For example, CamDairy (Hulme *et al.* 1986) can be used to predict performance and identify limiting nutrients. It also has an optimisation function to calculate diets that maximise profit. However, it does not predict long-term responses to current feeding practice. Nutrients considered include energy, protein, macro and micro minerals. For further information on CamDairy, see http://epicentre.massey.ac.nz.

The spreadsheet model Dairy$, which is available from the senior author of this book, is used to calculate indices of management efficiency, such as grazed pasture per hectare, as well as gross and net margins on the whole enterprise.

The model UDDER (Larcombe 1989), developed for conditions in Victoria, considers whole farm economics and does consider long-term responses to current management practices, including stocking rate, fodder conservation and calving pattern to determine the optimum strategy. However, the only nutritive characteristic of feeds it considers is digestibility. For further information, see www.udder4win.com.

Another model, which is specific for conditions in Victoria, is Diet Check (Heard *et al.* in press). It considers energy, protein and fibre only, and is used to predict performance and response to feeding supplements. It does not optimise the diet to maximise profit and does not consider long-term responses to current management practices.

A model developed for conditions in North America is the Cornell Net Carbohydrate and Protein System (Fox *et al.* 1992). It is a semi-mechanistic model, with a profit optimisation module, which requires information on the rumen degradability characteristics of carbohydrate and protein fractions in the feeds. Application of this model in Australia is limited by the paucity of data on Australian feeds, particularly grazed pastures.

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