Challenges to achieving high production from dairy cows in Australasia

I.J. Lean[1] and C.T. Westwood[2]

'Bovine Research Australasia, 7 Broughton Street, Camden, NSW. 2570
[2] Department of Animal Science, University of Sydney, Camden, NSW 2570

Summary

High levels of milk production can be achieved in Australasia. Milk production is limited by availability of feed and balance of the diet, rather than by genetic merit or mammary efficiency. A critical examination of the limitations to current methods of describing nutrient requirements for dairy cattle will allow better diet formulation. In particular, longer term changes in metabolism that occur through better nutrition need to be considered when formulating diets for higher producing cattle. The efficiency of use of pasture energy and protein is impaired because pastures contain too little readily fermentable substrate and too much crude protein for optimal rumen and post–ruminal metabolism. High concentrations of rumen degradable pasture protein may reduce milk production by increasing energy requirements for maintenance and protein requirements.

The relatively low fibre content of young digestible pastures limits the use of starchy grain concentrates and raises the risk of subclinical and clinical acidosis. The risk of acidosis may be reduced and microbial protein production increased by supplementing cows with maize silage and by-product feeds rather than starchy grains. The rumen modifiers lasalocid, Monensin and Virginiamycin may have a role in improving milk production of cows given high-starch diets, through reducing the risk of acidosis and increasing the flow of protein out of the rumen.

Introduction

The increasing genetic potential for Australasian dairy cattle to produce milk suggests a need to re-examine nutritional strategies required for optimal production. Nutritional management of Australasian dairy cattle is largely based on feeding pasture with supplementation. The nutritional requirements and feed delivery systems required for high production are rarely addressed. This paper briefly examines commonly used energy and protein systems, addresses differences and limitations of these systems, and recommends strategies for achieving high levels of pasture-based milk production in Australasia. The concept of nutritional requirements is challenged and the concept of nutritional drive proposed.

Systems for Describing Nutritional Requirements

The major systems used for nutritional evaluation in Australasia are: ARC (MAFF 1975, ARC 1980, ARC 1984, AFRC 1993); NRC (1989); SCA (1990) and CamDairy (Hulme et al. 1986). All systems have major limitations that influence diet formulation and the capacity to predict responses to nutrients. These limitations may have contributed to a failure to challenge high producing cattle in Australasia. However, differences in estimates of nutrient requirements between systems are probably less important to prediction of milk yield responses than problems with the accuracy and timeliness of evaluating the feed value of pasture.

ARC

Technical Bulletin 33 (MAFF 1975) provided a simple model for evaluating the energy requirements of dairy cattle and despite the advances of AFRC (1993) remains a most practical means for evaluating energy requirements and predicting production responses. The fermentable metabolisable energy (FME) system (AFRC 1993) links the processes of fermentation and microbial protein production to the determination of ruminal microbial protein output. The FME system is misnamed., as it is, by definition, not fermentable, as metabolisable energy is the energy remaining after gaseous losses associated with fermentation. Disappointingly, the AFRC (1993) failed to address fully endogenous faecal protein requirements, and estimates of protein

requirements are substantially lower than those determined by NRC (1989) and CamDairy (Jones et *al.* 1996).

NRC

The NRC (1989) document provides a useful method for predicting responses to nutrients and can be effectively used in the field. The review of dairy nutrition associated with the document provides a fine précis of dairy nutrition. Advantages over AFRC (1993) include more realistic estimates of protein requirements, and an estimate of the energy losses associated with the detoxification of excessive concentrations of ruminal degradable nitrogen. A limitation is that protein quality is not taken into account.

SCA

The SCA (1990) document does provide some technical advances on earlier ARC documents, particularly in addressing problems of protein evaluation. The document, however, provides few other new insights and is not presented in a user-friendly format.

Camdairy

Computer models such as Camdairy (Hulme et *al.* 1986) provide a powerful, relatively 'user friendly' means of predicting production responses to nutrients and evaluating dietary manipulations. The algorithms used in Camdairy are unique, empirically derived equations that result in similar predictive responses to NRC (1989). The advantages of the computer model include ease of use, and the ability to formulate least cost and maximum profit rations using linear programming. The energy and protein estimates used are derived from independent analyses of data in describing responses to incremental increases in energy. The protein system used gives

similar responses to SCA (1990) and NRC (1989). An important limitation affecting the goodness of prediction of responses to energy is that the energy cost of detoxifiction of excess rumen degradable nitrogen is not taken into account. Other limitations include the underlying assumptions of the profit maximising model used which is of the type described by Dean et *al.* (1972) and Hulme et *al.* (1986). The assumption (Dean et *al.* 1972, Hulme et *al.* 1986) of diminished returns associated with phenotypic/ genetic merit must be questioned. These responses relate to milk production on a given day and do not account for the residual effects on future production responses, particularly in early lactation. Whole lactation responses to extra feed inputs differ considerably from those on a given day. The latter issues are pertinent to all current nutritional evaluation systems.

Cornell

The recently developed Cornell model (Fox et *al.* 1992, 1995) provides many theoretical advantages in the evaluation and formulation of diets. It does provide accurate estimates of the responses of pasture fed dairy cattle (Kolver et *al.* 1996) and addresses rumen fermentation and microbial protein production using a semi-mechanistic model.

Limitations to Systems of Nutritional Evaluation

Biochemical limitations

The energetic efficiency of milk production varies with the mix of precursors available for milk production (Baldwin 1987a,b,c). Table 1, derived from the work of Baldwin, demonstrates differing efficiencies of use of

Table la   Energetic efficiency synthesis of 1 kg milk from efficient precursors.

Milk Component (Precursor)	Percent in milk	Output (MJ)	Input (MJ)	Efficiency %
Protein (Amino Acids)	3.1	0.743	0.907	82
Fat (Fatty Acids)	3.7	1.478	1.607	97
Lactose (Glucose)	5.0	0.882	0.928	95
TOTAL OVERALL		3.104	3.373	92

Table 1 b   Energetic efficiency synthesis of 1 kg of milk from less efficient precursors.

Milk Component (Precursor)	Percent in milk	Output (MJ)	Input (MJ)	Efficiency %
Protein (Amino Acids)	3.1	0.743	0.907	82
Fat (Acetate)	3.7	1.478	2.111	70
Lactose (Propionate)	5.0	0.882	1.116	79
TOTAL OVERALL		3.104	4.139	75

metabolites for milk production, and shows that the theoretical energetic efficiency of milk synthesis may vary from 0.75 to 0.92, depending on the precursors used for milk synthesis. Use of fatty acids for milk fat formation is more efficient than use of acetate, and glucose is used more efficiently than propionate. Observed efficiencies of production also vary with factors such as processing of grains, use of rumen modifiers and amino acid composition of the diet. Estimates of dietary metabolisable energy availability (M/D) do not indicate whether the energy is in the form of starches, sugars or structural carbohydrates, and crude or even true protein. Moreover, amino acid estimates do not indicate which amino acids will be available to the liver and mammary gland.

Many of these limitations are addressed in the Cornell model (Fox *et al.* 1992, 1995). Differences between systems in the estimation of nutrient requirements are understandable, as the flux of different precursors into the body is not easily estimated from data normally presented on the composition of ruminant diets.

Homeorhesis – Homeostasis

A limitation to systems of nutritional evaluation is a failure to address the homeorhetic adaptations to lactation. Homeorhetic changes are the long–term adaptive changes that occur when an animal changes from being non-lactating to lactating or from being a non–ruminant to a ruminant (Bauman and Currie 1980). Current feeding systems evaluate nutrient needs on a given day and do not consider the impact of diet formulation on longer term adaptive changes (Broster *et al.* 1993). Further, currently used systems of feed evaluation do not consider carry-over effects of altered plane of nutrition on growth, body condition, mammary gland development and appetite. These responses may not be simply linear, but follow a recursive pattern, i.e. an increasing plane of nutrition now may allow increased production later, but this increased production may require additional or even an increasing supply of nutrients. This concept is exemplified by the strong association between a 1 litre increase at peak milk production and a 200 litre milk response over the whole lactation relationship (Brosher and Thomas, 198 1).

Protein or amino acids

Problems with model predictions of responses to protein or amino acid supplementation also indicate limitations with current systems. Limiting amino acids may substantively influence milk or total milk protein output, but responses have not always been highly predictable. This problem is specifically referred to in AFRC (1993), which acknowledges the failure of their model to adequately predict responses to fish meal supplementation.   The AFRC (1993) document also notes that the biological value of different proteins varies for different productive purposes. Rulquin and Verité

(1993) note that responses to supplementation with methionine and lysine for cows on grass silage have not always been good despite the diet being apparently low in these amino acids. The French PDI system (INRA, 1989) among others attempts to examine ruminant protein nutrition on the basis of potential absorbed protein (predicted from energy and protein) not amino acids. Polan (1992) argues that it will be some time before protein systems are perfected, but this should not delay the intelligent application of current knowledge of amino acid contents of feed in nutrition of dairy cattle. The potential for benefit from amino acid supplementation was demonstrated by Polan (1992) who calculated that the supply of as little as 2.66 g of lysine, if rate limiting, could result in an extra litre of milk. Unfortunately, the supplementation of diets of cows with additional amino acids that escape rumen fermentation has not always produced such impressive results.

Critical data needed for the development of a model capable of effectively predicting the responses of cattle to additional ammo acids are still lacking. Studies from the University of Sydney (Rajczyk *et al.* 1995) highlight a further challenge in examining responses. Similar total milk protein responses were found to diets formulated to provide additional high quality proteins, but groups of cows exposed to different protected proteins responded very differently in milk yield and milk protein content. Cows fed meat meal responded with markedly increased milk production, but little change in milk protein content, while cows fed fish meal had a 10 to 15% increase in milk protein content, but a lesser increase in milk yield. Protein yield responses were very similar.

There is also evidence (Orskov *et al.* 1987, Rajczyk *et al.* 1995) that production is driven, rather than requirements met. Specifically, additional protein supplementation will cause cows to become ketonaemic and even clinically ketotic as they mobilise body tissue to meet additional demands for milk protein, fat and lactose synthesis. If *cows are* fed ad *libitum,* however, feed intake will increase to match milk production (Rajczyk *et al.* 1995, Garvin *et al.* 1996). Therefore, rather than consider nutrition in terms of passive control *i.e.* meeting nutrient requirements, nutrition is an active process which determines the level of milk production by using feeding strategies that increase appetite.

Challenges to achieving high production

Realising genetic potential

Average milk production levels in the Australasian dairy herds remain well below those of the USA, although the genetic merit of bulls in Australia is very similar to that in the USA. A number of dairy herds are producing more than 8500 litres per cow per year, a production level that would be considered acceptable in the USA. Table 2a and 2b indicate the changes in feeding strategy

from 1991-92 to 1995-96, showing the potential for such production increase to be cost effective.

These herds do not necessarily have extreme genetic merit. The value of genetic merit needs to be critically evaluated in regard to the production system. In 1993 a difference of 30 kg in milk fat and protein was observed between the highest and lowest ABV bull offered by Australian Dairy Herd Improvement Scheme. Garvin *et al.* (1996) found a similar difference between the highest and lowest third of cows in genetic merit in the University of Sydney herds. If all of this difference in genetic merit were expressed, the response would be approximately 1.43 litres of 4% fat corrected milk per day of lactation. Subsequent trials at the University of Sydney have demonstrated that the predicted responses to ABV differences were observed (Garvin *et al.* 1996). A difference in production of 1.43 litres per day can be equated to an intake of less than one extra kg of feed, either provided by extra feed availability or by increased capacity to eat achieved through rearing heifers to achieve 20-25 kg of extra growth at calving. Genetic merit purchased at great expense has not been realised due to chronic underfeeding and poorly balanced diets in Australasia.

Utilising pasture energy

The energy density of the average diet of Australasian dairy cows in spring (Lean *et al.* 1995) can exceed that of typical Californian dairy diets fed in Tulare County (Trout *et al.* 1988) where average milk production exceeds 8,000 litres per cow per year. The high M/D of ryegrass (*Lolium* sp.) and clover pastures (*Trifolium* sp.) and the loss of energy associated with the use of conserved forages in California indicates the potential for high levels of milk production in Australia. If the energy content of pasture is 12 MJ of ME/ kg and the energy density of conserved forage is 11 MJ of ME/ kg, then the remainder of the diet fed in California will need

to have an energy density exceeding 12.5 MJ of ME per kg to provide the same overall energy density. Many grains and by-product feeds do not have an energy density of 12.5 MJ/kg. Clearly, factors other than estimates of energy density influence the potential for American dairy cattle to out-produce those in Australasia. It is possible that the relatively low non–fibre carbohydrate content of pastures may limit production of Australasian cattle. Fermentation characteristics of feeds are included in systems such as those of the AFRC (1993) and Cornell, and further investigation of carbohydrate needs for optimal rumen fermentation in pasture-fed cows is indicated.

To utilise pasture proteins

Pastures vary quite markedly in protein content and also in ruminal degradation characteristics. Ryegrass and clover pastures frequently exceed 30% CP in the spring and autumn (Verité *et al.* 1984; Van Vuuren *et al.* 199 1; Holden *et al.* 1994; Lean *et al.* 1995, Moller *et al.* 1995; Moller *et al.* 1996). Further, up to 50% of ryegrass CP may consist of rapidly soluble proteins and non protein nitrogen (NPN) [Wilman and Wright, 1983; Minson, 1990; Beever,1993] and the majority of ryegrass protein is rapidly degraded in the rumen (Cammell *et al.* 1983; Van Vuuren *et al.* 1991; Van Vuuren *et al.* 1992; Holden *et al.* 1994) (Table 3). Approximately 40–50% of the protein found in forages is chloroplast protein, which is extensively degraded in the rumen. Only 10–30% of the protein in fresh pasture materials entering the rumen will escape intact to the small intestine. Effectively, therefore, 70–90% of forage protein is effectively non-protein nitrogen (Satter *et al.* 1992). Such pastures frequently contain low levels of readily fermentable carbohydrates, ranging from 5 to 20%. Milk production may be optimised with a dietary soluble carbohydrate content of 30 to 3 5%. The protein content of ryegrass and clover, and high degradabilities of these feeds

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Table 2a Changes in milk production 1991/2 to 1995/6 from a south coast New South Wales dairy farm.

Production Comparisons	1991/2	1995/6	% Change
Milk production (Litres)	465000	790000	+70
Rolling Herd Average (Litres)	6332	10300	+63
Cow numbers	63	65	

Table 2b Changes in feed usage 1991/2 to 1995/6 by a south coast New South Wales dairy farm.

Feedstuff	1991/2 Tonnes	$	1995/6 Tonnes	$	% Change
Grain/ lupin	208	37804	170	38325	-18
Protein meals	6.5	2865	25	14654	+385
Whole Cottonseed	-	-	75	16332	-
Hay	117	26797	18	3919	-84
Totals	33	67466	285	73212	

results in high concentrations of urea and ammonia in the blood of cattle eating these pastures (Williamson and Fernandez–Baca, 1992).

Immature plants contain a higher content of degradable protein than older plants and the use of nitrogenous fertiliser to promote pasture growth will increase both the true protein content of pasture and the non-protein nitrogen (NPN) content (Reid, 1972; Whitney, 1974; Saibro *et al.* 1978; Wilman and Wright, 1983; Minson, 1990; Van Vuuren *et al.* 1991; Van Vuuren *et al.* 1992; Moller *et al.* 1996). The NPN includes nitrates, amines, amides and increases under cold, dull weather, particularly if nitrogen fertilised (Wilman and Wright, 1983; Minson, 1990; Beever, 1993). Under these same conditions the soluble carbohydrate content of plants falls (Hogan 1982). Efficiency of ruminal microbial protein production will be lower under these conditions. Variation in microbial growth efficiency (gMCP/MS ME) with soluble carbohydrates was reported by Corbett (1987) and confirmed by Dove and Milne (1994). A further impost on energy reserves is the need to remove excess ammonia absorbed from the breakdown of soluble pasture proteins and from the NPN in pasture. Calculations provided in NRC (1989) derived from stoichiometric analysis by Blaxter (1962) and studies by Tyrrell *et al.* (1970) suggest that the energetic cost of detoxifying urea is 3.02 MJ of ME per 100g of excess N. Danfaer *et al.* (1980) reported a decrease in fat–corrected milk of 1.4 kg/day when dietary crude protein content increased from 19 to 23%.

However, the cost of urea synthesis should not be considered solely as an energy cost, but also as a loss of absorbed amino acids because of the contribution of the second nitrogen atom from aspartate (Reynolds, 1992; Lobley *et al.* 1995). Aspartate may be synthesised from the deamination of glutamate, or by transamination of other amino acids. Arterio-venous studies of bovine liver metabolism indicate that increased amino–nitrogen uptake accompanies increased ammonia uptake and increased urea output (Huntington, 1989; Reynolds, 1992). While not all of the nitrogen in amino–nitrogen is destined for inclusion in urea, the results suggest that at high levels of urea synthesis, significantly increased inputs of amino acids are required to act as donors of the second nitrogen atom necessary for urea synthesis. In vivo studies of the net flux of cc-amino nitrogen across the liver suggest that if the hepatic uptake of a-amino nitrogen is excessive, as may occur when rates of urea synthesis are high, a net decline in the availability of α–amino nitrogen to extrahepatic tissues, including the mammary gland may result. A further consequence of increased hepatic uptake of a-amino nitrogen during urea synthesis is increased availability of carbon skeletons left after the transfer of the amino group from various amino acids to aspartate. These carbon skeletons may enter the tricarboxylic cycle for oxidation, or become available for gluconeogenesis. The very rapid breakdown in the rumen of soluble proteins increases the difficulty in formulating diets that will promote the efficient capture of protein.

Dry matter intake (DMI)

If Australasian *cows are* given *ad libitum* access to high digestibility feed and appropriate supplements, intakes may exceed 4% of body weight, specifically, 24-28 kg of feed on a dry matter basis (Lean *et al.* unpublished; Westwood *et al.* unpublished). These

Table 3   Degradation of pasture crude protein.

Reference	Forage	Estimated N degradation
Cammell *et al.* (1983)	*Lolium perenne* Early, mid and late season	> 0.95
	Trifolium repens Early season	*> 0.95*
	Trifolium repens Mid season	0.88
	Trifolium repens Late season	0.90
Beever *et al.* (1986)	*Lolium perenne* Early season	0.93
	Lolium perenne Mid season	0.89
	Lolium perenne Late season	0.95
	Trifolium repens Early, mid and late season	0.94
Van Vuuren *et al. (1991)*	*Lolium perenne*	0.92[1]
		0.79[2]
Van Vuuren *et al. (1992)*	*Lolium perenne*	0.92[3]
		0.96[4]

[1] Grass harvested 9 days after application of 700 kg N fertiliser per hectare
[2] Grass harvested at same time as 1, with zero application of N fertiliser.
[3] Harvested following application of 500 kg / ha N fertiliser.
[4] Harvested following application of 275 kg / ha N fertiliser.

intakes exceed the 15 kg of dry matter intake (DMI) cited as an acceptable level (Holmes and Wilson, 1984) of DMI for cows in Australasia. Cows with DMIs of 24 to 28 kg per day are capable of producing more than 10,000 litres per lacation. Feed intakes of 24–28 kg DMI per day, however, depend on the presentation of adequate amounts of pasture and other feeds which do not contain excessive levels of fibre. To achieve high per head production and efficient harvest of pasture, some supplementation of cattle will be essential.

An important factor influencing DMI for pasture fed cows is the interaction between pasture utilisation and per head production. It has been clearly shown that harvest of pasture and per hectare milk production is greater with stocking rates that reduce milk production per head (Holmes and Wilson, 1984). However, per head production efficiency was greater at higher levels of milk production, and there was no evidence of reduced efficiency of utilisation of energy for milk production in trials in which a balanced total mixed diet was given to cows at stage of lactation at differing levels above maintenance (Jones *et al.* 1996, Figure 1). In these trials, however, feed was made available as a total mixed diet. These data suggest that the capacity for the mammary gland to utilise substrates is greater than the capacity of the cow to supply substrate through appetite. There was no evidence of a curvilinear response with increased partitioning of energy to body tissue with increased feeding above maintenance in cows with a high potential for milk production.

It has been claimed that the intracellular water content of pasture is the single most important factor determining production level (Ulyatt and Waghorn 1993). Notwithstanding, high levels of milk production have been achieved by cattle primarily grazing pasture and high levels of DMI (approximately 5% of body weight) achieved by cows grazing clover-dominant pastures (Rogers et *al.* 1982). The grazing cow must eat much more feed to achieve high production than the cow fed on conserved pastures and concentrates, but
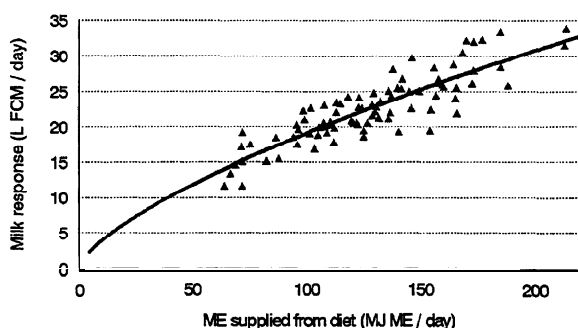
the magnitude of the depression in DMI resulting from by increasing intracellular water in plants is difficult to determine. A recent review of models by Ingvartsen (1994) of voluntary food intake in cattle contained only four models which included the DM content of the feed. These four models were developed for growing cattle fed silage and, it is unclear whether the inhibition of intake is related to wilting, stage of cutting or effect of ensiling, rather than intracellular water. The magnitude of depression, if any, of DMI resulting from intracellular water remains to be determined. Similarly, another recent review of voluntary feed intake (Ketelaars and Tolkamp 1992) did not address the issue of intracellular water as a limit to feed intake.

Formulating diets that overcome the limitations of the production system

The principles of maintaining high pasture harvest and achieving high production, in a cost-effective manner are detailed below.

Maintaining high dry matter intake

High DMI will be best achieved on most farms by ensuring that the quality of pasture is high. High quality pasture is achieved by setting relatively high stocking rates, by ensuring that pasture fertilisation strategies are appropriate and the grazing strategies, frequency of grazing and control of pasture residuals-which are key determinants of pasture growth and quality-are carefully managed. Further, legumes such as lucerne are rapidly digested, leading to modest rumen fill (Nelson and Satter 1992) and the potential DMI intakes. Stimulating DMI by supplying proteins limiting to production is a critical determinant of DMI.

In the USA, better dairy farmers ensure excellent access of cows to feed. In Australasia, the pasture system often deprives cows and heifers lower in the pecking order of adequate feed access. The use of strings (or groups) to provide better access for these cows is a strategy worthy of consideration. Access to feed can be improved by the use of strategic supplementation. Supplements and stocking rates should be manipulated to allow cows access to greater amounts of feed, while maintaining the same levels of pasture intake.

Stabilising the rumen

In the studies reviewed by Kellaway and Porta (1993) of supplementary feeding conducted in Australasia, concentrates were fed by the pulse-feeding of primarily starchy grains, rather than the feeding of diets which will provide rate limiting nutrients in a form unlikely to disturb rumen function. Starchy diets, particularly rapidly degraded sources of starch such as wheat depress rumen pH (Opanakankit 1995) and stimulate

Figure 1 Increase in milk production in response to ME (Jones *et al.* 1995).

insulin release (Chase *et al.* 1977). It is probable that the partitioning of energy to body tissues (improved condition) found in many studies has resulted from the supply of energy substrates when the first rate-limiting nutrient to production was amino acids. Maximum DMI will be achieved when adequate amounts of feed are available and the feed is not disruptive to rumen function.

Several rumen modifiers are available for use in lactating dairy cattle that can be used to reduce acidosis. The ionophore antibiotics Lasalocid and Monensin (Nagaraja *et al.* 1981; Newbold and Wallace 1988), and the antibiotic Virginiamycin can reduce the effects of acidosis *in vivo* and *in vitro* (Nagaraja *et al.* 1987; Zorilla–Rios *et al.* 1993; Clayton *et al.* 1997 unpublished). Monensin feeding increases the amount of dietary protein reaching the lower gut (Dinius *et al.* 1976; Hamoud *et al.* 1995) and there is a decrease in ammonia production in the rumen and bacterial protein reaching the lower gut (Poos *et al.* 1979). Much of the protein sparing effect appears to be mediated through the impacts of Monensin on Peptostreptococcus, important in deamination and sensitive to Monensin (Russell *et al.* 1988). However, these changes have not been reflected in significant changes in plasma urea nitrogen in studies with dairy cattle (Abe *et al.* 1994, Stephenson *et al.* 1997). Virginiamycin may also alter protein metabolism in the rumen (Van Nevel *et al.* 1984).

Studies of Australian herds have shown variability in milk production response with Monensin. Lowe *et al.* (199 1) found an overall increase in milk production of 1.1 litres of milk per day for treated cows. When the data from Lean *et al.* (1994) were pooled, there was no significant milk production increase, but we observed a significant increase in milk production in our most recent large trial (Beckett *et al.* submitted). In general, a 0.5-1.5 litre per day production response can be anticipated with monensin use. Recent studies using Virginiamycin in cows fed 10 kg of a wheat-based pellet demonstrated that Virginiamycin could stabilise rumen pH, reduce lactic acid production and increase milk production (Clayton *et al.* 1997). These fmdings support studies showing similar increases in milk production in dairy cattle fed Virginiamycin (Pasierbski *et al.* 1992) or Monensin. It remains to be determined whether variability in milk production responses that are observed with Monensin are also observed with Virginiamycin use and which dietary or management factors influence these responses.

Balancing the protein/energy axis

Dhiman and Satter (1993) found that cows given lucerne silage diets, with ample crude protein produced more milk when supplemented with protected protein rather than glucose and that supplementation of both protein and energy was most effective in increasing production. The principles of effective protein supplementation are to optimise the yield of protein from the rumen by supplying carbohydrates when possible, and not formulating diets with an excess of protein relative to energy, a ratio of 16 g of metabolisable protein per MJ has been suggested by SCA (1990) as optimal. If an excess of bypass protein is present, cows may initially mobilise too much body tissue (Orskov *et al.* 1987); and to consider the possibility of rate limiting amino acids when formulating diets.

While the energy density of pasture often equals or exceeds that of grain, the pasture frequently lacks sufficient fermentable substrate for the best use of pasture proteins by the cow. The difficulty is to supply fermentable substrates such as starch in a form that will not depress rumen function. Some by-product feeds and corn silage are examples of feeds that will allow this. These feeds can act as vehicles for other supplements in semi-mixed rations (SMR). The objective of SMR is to allow the incorporation of low–cost feeds and nutrients that are rate-limiting for production, while supplying additional DM that will allow cows to achieve high levels of milk production. In areas where by-products or corn silage are not available, the use of rumen modifiers to keep rumen pH stable and reduce the risk of acidosis is recommended.

While outstanding milk production can be achieved cost effectively in Australasia, the challenge remains to achieve a balance between supplying sufficient fibre to maintain effective rumen function, sufficient fermentable substrate for good microbial protein production and harvesting the maximum amount of pasture despite daily change in pasture quality.

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