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Improving the efficiency of pasture-based dairy production

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ABSTRACT

New Zealand dairy farmers have not achieved the increases in milk production that parallel those of other countries and this has led to a re-evaluation of the opportunities to use feed inputs to complement pasture diets for dairy production. An improved understanding of the chemical composition of pastures, a re-examination of pasture growth dynamics, and recent experimental evidence and farmer experience suggests that there is potential to increase milk production from pasture through strategic inputs of feeds to increase dry matter intake and improve the nutrient balance of the cow's diet. These modified pastoral farming systems would allow more of the genetic potential of New Zealand dairy cows to be exploited for milk production and increase the proportion of feed intake that is used for production. This review integrates knowledge of animal responses to non-pasture feed sources, with that for pasture management, and identifies opportunities to enhance the efficiency of pasture-based dairying.

Keywords: dairy production, pastoral systems, seasonal calving, ration balance.

INTRODUCTION

Milk production per cow has increased much more slowly in New Zealand than in Northern Hemisphere countries over the past 30 years (Ulyatt & Waghorn 1993). The reasons for this have been well documented in recent years (Bryant 1990, Edwards & Parker 1994, Parker 1995). Bryant (1990) indicated that for the highest producers of milksolids per hectare (ca. 10% of farms) limited potential existed to further increase milk production by introducing new pasture technology or manipulating sward management. The biological constraints to pastoral grazing, coupled with variable but generally declining real prices for milk that have restricted the use of purchased feeds, are reflected by the relatively small improvement in the national average per cow and per hectare milksolids (MS) production over the past 15 years (LIC 1994). Nevertheless, the industry continues to be the lowest (direct) cost producer of milk, on a farm gate price basis, in the developed world (Anon 1993).

The vital importance of maintaining international competitiveness in an industry that depends heavily on exports, and the lower cost of pasture relative to other feeds, suggests that future improvements to New Zealand dairy production should continue to be built around the well-established foundation of pasture efficiently grown and utilised *in situ* by cows of high genetic merit. The purpose of this paper is to examine the basis and shortcomings of current dairy farm practice and to suggest ways in which some constraints to milk production from pasture could be addressed.

THE CURRENT PARADIGM

The paradigm for seasonal-calving, high stocking rate pasture-based dairy production in New Zealand and southern Australia is well documented (Holmes and MacMillan 1982, Trigg and Bryant, 1982; Wilson and Davey, 1982: Holmes and Wilson, 1984: Bryant, 1990). In broad terms these systems are based around four strategic management decisions - stocking rate, calving date, conservation and supplementation, and drying off. These farm policy decisions largely determine the match between pasture growth (supply) and the feed demand of the herd (and replacements where these are grazed on the farm). Close synchrony of pasture supply and demand contributes to high utilisation of pasture grown and helps to maintain pasture quality. In general, supplementation of dairy cows has not been shown experimentally to be profitable, and except for pasture silage and hay, and some forage crops, limited use of bought-in feeds has been made. However, grazing off of herd replacements, and to a lesser extent the herd during the dry period, is a common means of increasing either the feed supply to the milking herd or herd size (Bryant 1990). The tactical application of nitrogen to increase pasture production, particularly in late winter - early spring to provide extra feed for freshly calved cows (Thompson *et al.* 1991), has been more widely adopted by dairy farmers in the last 5 years. Consequently, the diet of lactating cows is almost exclusively pasture and the diet balance reflects the sward composition, grazing and intensity and recent fertiliser history (Lawson *et al.* 1996, Moller *et al.* 1996a).

Stocking rates are high relative to the potential dry matter intake (DMI) of the cows resulting in DMI equivalent to 2.85% of body weight for a 450 kg cow producing 3750 litres of milk over a 300 day lactation, and the effects of this are manifested in several ways. First, the mature liveweight of cows is around 360 and 420 kg respectively for Jerseys and Holstens-Freisians (the dominant purebreeds farmed), considerably less than that of their counterparts farmed under Northern Hemisphere confined dairy sys-

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tems (Parker and Muller 1992). Second, the cow body condition score (CS) profile typically fluctuates between 5.0 (calving) and 4.0 (mid- to late- lactation), about 1 to 1.5 units less than for confined systems (Muller 1993), and the dry period, rather than late lactation, is generally used to ensure the target CS for calving is achieved. Third, lactation lengths are short (230-260 days vs. 305 potential) because of the combined effects of a concentrated spring calving, a normally abrupt cessation to milking (Parker *et al.* 1993), and unreliable and generally low summer and autumn pasture production. Consequently, it is estimated that only 25-30% of lifetime feed intake is directed towards milk production, compared to 35-45% in high producing herds in the North America, and in this respect the utilisation of pasture for milk production is relatively inefficient.

It is clear from comparative genotype studies involving New Zealand cows (e.g. Peterson 1989), and regional differences in milk production (LIC 1994), that the quantity and quality of feed supply is the single most important constraint to increasing milk output per cow and hectare. Hodgson (1989) defined the potential production of C_3 pastures in New Zealand under grazing, and Edwards and Parker (1994) used these data to estimate potential milksolids per hectare (ca. 1100 kg or 314 kg MS/cow at 3.5 cows/ha). Thus, the challenge to dairy researchers and farmers is to find economic ways to enhance feed supply in a manner that stimulates greater DMI by cows, provides an improved balance of nutrients to the rumen and small intestine, and reduces seasonality. To achieve these aims new approaches to milk production from pasture in New Zealand are required.

RETHINKING THE ROLE OF SUPPLEMENTS

Most of the supplementary feeding trials in Australia reviewed by Kellaway and Porta (1993) involved small cattle grazing relatively high quality pastures, and fed either crushed or uncrushed grains over a short period (a matter of weeks). Few measurements of responses to supplements over a lactation or multiple lactations have been reported. Responses in the short term (up to 12 weeks) experiments averaged 0.5 kg of milk per kg of supplement. Experiments by Hamilton (1991) and Davison *et al.* (1982) showed that responses were greater when measured over periods of 10 and 16 weeks, respectively. In long-term experiments, Cowan and Davison (1983) indicated that responses averaged 1 kg milk per kg supplement. Kellaway and Porta (1993) suggested that the lower milk production responses to supplements than might be predicted per unit of additional energy (Tyrell and Reid 1965) should be attributed to measurements occurring over too short a period to determine the full milk production response and because substitution of pasture resulted in very little additional feed intake; or the additional energy intake was portioned to body condition (or to growth where relatively undergrown young cows were involved) or a combination of these responses occurred.

Broster and Broster (1984) and Broster *et al.* (1993) found that the long-term effects of nutrition on milk production responses, may accumulate over single and multiple lactations and more closely approximate the responses that can be predicted from energetics. There is, however, considerable variation in the cumulative and residual effects of supplementary feeding, influenced by study design, levels of feeding and impacts on body weight. Cattle that are lower in body reserves prior to re-alimentation after a period of relative underfeeding are more likely to accumulate body condition at the expense of milk production (Broster *et al.* 1993). These cows will be more capable of responding to feed inputs with increased milk production subsequently, provided that body weight is not lost again by underfeeding. Bodyweight tends to stabilise to a level that is commensurate with the long-term plane of nutrition. Very few of the studies cited by Kellaway and Porta (1993) accounted for the longer term effects of nutrition on production. The failure to acknowledge the important role of homerohesis, the long term adaptive changes that occur when an animal changes from being non-lactating to lactating, are a major limitation of present nutritional evaluation systems and these are reflected by shortcomings in the study designs reported. Current systems for calculating nutritional requirements (e.g. AFRC 1993) do not consider the carry-over effects of an altered plane of nutrition on growth, body condition, mammary gland development and appetite. These responses may not be simply linear, but may follow a recursive pattern i.e. increasing plane of nutrition now, may allow increased production later, but this production may require further or even an increasing supply of nutrients. This concept is exemplified by comparing the 1 litre increase at peak production to the 200 litre response over the whole lactation relationship (Broster & Thomas 1981).

The degree of substitution of pasture for additional feed is a function of many factors including the appetite of the cow, pasture allowance (Grainger & Matthews 1989), formulation of the ration, type of supplement and processing of the ration (Kellaway & Porta 1993). Opatpatanakit (1994) reviewed many studies involving concentrate supplementation of pasture diets and found that at low levels of concentrate intake, substitution rates were likely to be high, but at higher levels of concentrate feeding, additional concentrate was associated with low substitution rates. This pattern of response implies that adaptation of rumen micro-organism to concentrate diets influences substitution rates. Studies show decreased fibre digestion (Stewart 1977) and decreased numbers of cellulolytic organisms (Henning *et al.* 1980) in the presence of rapidly fermentable starches. Opatpatanakit *et al.* (1995) observed a 12% higher feed intake for heifers fed lucerne hay and crushed sorghum grain vs. crushed wheat. The heifers which were meal-fed with wheat had a rumen pH <6 between 2 to 8 hours after feeding, conditions which are not consistent with optimal rumen function for fibre digestion and protein synthesis. Many of the diets reviewed by Kellaway and Porta (1993) would have similarly depressed rumen function and this probably contributed to the substantial pasture substitution cited. Further studies by Opatpatanakit *et al.* (1995) found that sorghum grain increased fibre digestion in *in vitro* studies. Clearly, the starch degradability characteristics of supplements for cows on pasture, and the way in which such feeds are fed to the cow, influences their productivity. In summary, trials on supplementary feeding in Australasia have generally not been designed to measure the effect of different supplementation diets on the rate of pasture substitution or long-term profit. Consequently, the effects of adding feeds to pasture diet on cow productivity and economic returns needs to be re-examined.

PASTURE AVAILABILITY

Pasture growth is seasonal and stocking rate is, therefore, rarely optimal to achieve high per cow DMI or to efficiently harvest pasture, when no feeds apart from pasture are utilised. A stocking rate set to provide sufficient grazing pressure to harvest peak pasture growth, normally results in excessive grazing pressure during periods of slower growth at other times of the year. Heavy grazing pressure (Brougham 1959, Michell and Fulkerson 1987) or frequent grazing (Bryant and Holmes 1985) can decrease pasture regrowth particularly where low post-grazing residuals (<1200 kg DM/ha) occur in the spring period (Matthews *et al.* 1995). While higher post-grazing residuals, and a greater plant leaf-area index created through supplement feeding may increase pasture growth (e.g. in late spring), relatively little quantitative data is available from which to estimate probable milk responses from spared pasture. The relationships reported by Brougham (1959) are still incorporated in dairy farm computer simulation models such as UDDER (Larcombe 1989), and these suggest that the use of additional feed inputs to allow substitution stimulates pasture growth. In this context substitution provides a means for management to manipulate grazing pressure, in order to stimulate appetite, increase pasture intake and promote milk production. Further research is required to clarify the work of Grainger & Matthews (1989) on the effect of substitution on post-grazing residuals and the subsequent fate of spared pasture.

PASTURE QUALITY

Moller *et al.* (1996b) showed that the average digestiblity of organic matter in New Zealand pastures exceeded 70% for much of the year. Digestibilities in this range match those of feedlot rations mixed from hay or silages and grains, but their energy density is usually lower than that of fresh pasture. In other words, well-managed pasture provides a high quality feed for dairy cows but it is unable to sustain high levels of milk production, even if supply constraints are removed (Ulyatt & Waghorn 1993; Muller 1993; Muller *et al.* 1995), and especially if the sward is dominated by grasses (Lawson *et al.* 1996). For example, the proteins contained in pastures are almost completely degraded in the rumen (Corbett 1987; Beever 1993; Holden *et al.* 1994). Concentrations of soluble protein in pasture that exceed the capacity of the rumen to produce microbial protein are associated with an energetic cost for detoxification of ammonia to urea (NRC 1989). The Cornell Net Energy and Protein Model of Fox *et al.* (1990) predicts that this factor, in combination with the negative effects on rumen function resulting from a decreased availability of soluble carbohydrates, would decrease milk yields by up to 11 litres milk per head per day, if the crude protein content of ryegrass increased from 20 to 35%. The work of Danfaer *et al.* (1980) also identifies a significant "protein penalty" on milk yield.

The fibre content in pastures also needs to be carefully examined. Grass pastures contain, typically, in the order of 44-48% neutral detergent fibre (NDF), while clovers, with a lower structural carbohydrate component, have approximately 36-40% NDF accounting, in part, for greater feed intake and higher production on all legume diets (Rogers *et al.* 1986). The relatively low fibre content of pastures, particularly in spring (Moller *et al.* 1996a), means that maintaining the optimal fibre density for rumen function is difficult when concentrates are fed.

The mineral content of pastures is quite often inconsistent with optimal animal productivity (Wilson *et al.* 1995). Anti-nutritional factors in pasture which may limit production and health include mycotoxins, nitrates, toxic metals and endophytes.

Efforts in plant breeding to develop pastures with characteristics more suited to dairy production would ultimately enhance the competitive advantage of pasture-based dairy industries.

IMPROVING AMINO ACID SUPPLY

Production responses to additional feed inputs could be expected to be associated with those nutrients that are most rate limiting to milk production. Although concentrations of protein in pastures, especially in immature fertilised ryegrass, are high relative to cow requirements (Moller *et al.* 1996a), specific amino acids are likely to be rate limiting to milk production (Muller *et al.* 1995). This was illustrated by Dhiman and Satter (1993) who found that the addition of protected soyabean meal to cows fed on alfalfa (lucerne) silage gave a much greater milk response than the feeding of isoenergectic amounts of starch-based concentrates.

There are problems with estimating responses to protein or amino acid supplementation with current nutritional evaluation systems (Jones *et al.* 1996). Thus AFRC (1993), acknowledges that responses to fish meal are not adequately predicted by their system and that the biological value of proteins for different productive purposes vary with differences in amino acid composition. For example, Rulquin and Verite (1993) note that responses of cows to supplementation with methionine and lysine on a grass silage diet are inadequate despite the diet being apparently low in these amino acids. The French PDI system (Jarrige, 1989), among others, attempted to examine ruminant protein nutrition on the basis of potential absorbed protein from energy intake. Polan (1992) argued that there will be some delay before protein systems are perfected, but this should not preclude the intelligent application of current knowledge of amino acid contents in feed to the nutrition of dairy cattle. Polan (1992), also suggested if that lysine was rate limiting the supply of as little as 2.66 g/d could result in an extra litre of milk. Critical data are still lacking to produce a model that effectively predicts the response of dairy cattle to amino acids (Muller *et al.* 1995). Studies at the University of Sydney (Rajczyk *et al.* 1994a, b) highlight a further challenge in examining responses, as similar total milk protein responses were recorded for diets formulated to provide additional high quality proteins, but groups of cows exposed to different protected proteins responded very differently in terms of milk yield and milk protein content.

Lastly, there is now good evidence (Orskov *et al.* 1987, Rajczyk *et al.* 1994a, b) that production is driven, rather than requirements met. Specifically, it has been shown that additional protein supplementation will cause cows to become ketonameic and even clinically ketotic as they moblilise body tissue to meet additional demands for milk protein, fat and lactose synthesis. Therefore, rather than consider nutrition in terms of passive control i.e. meeting nutrient requirements, nutrition can be an active process in which production is controlled by feeding strategies that determine appetite.

HEIFER REARING AND COW SIZE

Herd replacements in New Zealand are small relative to their genetic potential. Murphy (1993) suggested that improved heifer rearing provided an important opportunity for New Zealand dairy farmers to increase productivity. There is some evidence that smaller cows are more efficient under New Zealand conditions than larger cows (Holmes *et al.* 1993) but this needs to be re-examined in the context of the improved feeding strategies suggested here. Heavier cows fed close to maintenance will be less profitable than their lighter counterparts similarly fed. For example, an additional 100 kg of bodyweight should allow a heifer eating at 4% of her body weight on a diet with 11 MJ of ME (consistent with late spring pasture) to produce 7 litres of milk per day of lactation more than her lighter counterpart, but if DMI was at 2.8% of LW there would be no advantage in having a larger heifer. Consistently achieving DMI in excess of 3.5% of LW without supplements poses a management challenge, not only because of the biochemical structure of pasture (Ulyatt & Waghorn 1993), but also because of seasonal variation in the supply of pasture. These considerations also raise issues regarding the way stocking rates are expressed (Holmes *et al.* 1993). Recent work suggesting that Jersey cattle are more efficient milk producers from pastures than Holsteins (e.g. Oldenbroek 1994) implies that stocking rate should be considered on the basis of potential for feed intake rather than on a per head basis and within breed. Theoretically, fewer, but larger cows, could exert a similar grazing pressure with a greater feed conversion efficiency than more cows at a lower body weight relative to their genetic potential. This would also reduce the variable costs of milk production. Farmer experience indicates that the appropriate use of feed inputs to complement pasture should result in higher stocking rates and larger cows than at present, and hence greater milk output per farm, and optimum utilisation of pasture (Edgecombe & Edgecombe 1994, Phillips 1995).

RISK MANAGEMENT

Recent changes to dairy farm management in New Zealand involving greater use of concentrates, pasture conservation, crops and nitrogen fertiliser all help to reduce production risk. Traditional grazing methods are constrained by the need to maintain feed ahead of the cows, a reserve of cow body condition or the flexibility to sell (or dry off) cows. The reactive use of supplements for cows or nitrogen in response to pasture shortages was viewed as an unbudgeted expense and often inefficient because pasture management was either compromised or insufficient time was available for the maximum response to be obtained (Field & Ball 1978). Strategic supplementation to mitigate the impact of variable pasture growth on production and profit requires the early identification of surpluses and deficits, through formal feed budgeting. An aggressive conservation strategy coupled with the use of nitrogen fertilisers, to maximise late spring-early summer production pasture when water and sunlight are normally not limiting, can facilitate improved summer and autumn feeding of cows. The last third of lactation has been identified as having the greatest potential to increase the milk yield of New Zealand cows (Edwards & Parker 1994). The use of nitrogen fertiliser to stimulate pasture production, may increase the protein and nitrate content and decrease the soluble carbohydrate component of the pasture (Behaeghe and Carlier 1973; Moller *et al.* 1996b) and this factor should be considered when balancing pasture diets.

Underfeeding freshly calved cows in early spring, contributes to low levels of peak milk production, poor persistence and substantial body weight loss (Holmes & Wilson 1984). Consequently, autumn pasture production is often used to recover body condition in cows dried off early rather than to produce additional milk. Feeding to achieve higher levels of peak milk production, coupled with an increased supply of highly digestible nutrients in the summer period (e.g. through crops, silages or concentrates) should allow herds to produce milk for 270-280 days. Modeling studies suggest that additional expenditure incurred during early lactation for feed can be recouped by greater late lactation milk yields (Uribe *et al.* 1996), but as noted by Clarke (1995) where crops are grown high yields are necessary to ensure DM costs are below the breakeven level.

SUMMARY

The limitations of pasture based systems have been identified, and this suggests that a new paradigm is required for the management of pasture-fed dairy cattle that integrates pasture management knowledge already established in New Zealand with well-proved principles of ruminant nutrition for supplementary feeding. Under this paradigm, cows and replacement are fed more closely to their genetic potential than at present; supplementary in-

puts are evaluated in the context of whole farm performance over the long term; longer average lactations (270-280 days) increase the efficiency of feed conversion to milk, and inefficiencies that extend beyond the farm gate due to seasonal changes in milk flow and quality are reduced. Improved measurement of pasture and feeds quality, coupled with planning, is required to ensure the diet balance improves ruminant metabolism, stimulates appetite, and maintains grazing pressure. Together, these actions should increase milk output and farmer returns.

REFERENCES

AFRC, 1993. Energy requirements of ruminants. An advisory manual prepared by a technical committee on response to nutrition. CAB International, Wallingford, U.K.

Anon, 1993. International benchmaking in the Australian dairy industry. Boston Consulting Croup Report to the Australian Dairy Research and Development Corporation.

Behaeghe, T.J. and Carlier, L.A. 1973. Influence of nitrogen levels on quality and yield of herbage under mowing and grazing conditions. *Vaxtoidling* **28:** 52-65.

Beever, D.A. 1993. Ruminant animal production from forges: present position and future opportunities. Pp 158-164, *In:* Grasslands of our world. Ed. Brougham, R., SIR Publishing, Wellington.

Broster, W.H. & Broster, V.J. 1984. Long-term effects of plane of nutrition on the performance of the dairy cow. *Journal of diary research* **51:** 149-196.

Broster W.H., Broster, V.J. & Clements, A.J. 1993. Feed utilization by the dairy cow over multiple lactations: A review. *Livestock production science* **34:** 1-21

Broster, W.H. & Thomas, C. 1981. The influence of level and pattern of concentrate input on milk output. Pp 49-69, *In:* Recent Advances in Animal Nutrition - 1981, Ed. Haresign, W., Butterworths, London.

Brougham, R.W. 1959a. The effects of frequency and intensity of grazing on the productivity of short-rotation ryegrass and red and white clover. *New Zealand journal of agricultural research* **2:** 1232-1248.

Bryant, A.M. 1990. Present and future grazing systems. *Proceedings of the New Zealand Society of Animal Production* **50:** 35-38.

Bryant, A.M. & Holmes, C.W. 1985. Utilisation of pasture on dairy farms. Pp 48-63, *In:* The Challenge: Efficient Dairy Production. Ed. Phillips, T., Australian and New Zealand Societies of Animal Production.

Clarke, D.A. 1995. Summer milk - pastures and crops. *Proceedings of the Ruakura Farmers' Conference* **47:** 10-16.

Corbett, J.L. 1987. Energy and protein utilisation by grazing animals in temperate pastures, use and management. Pp 341 - 355, Eds: Wheeler, J.L., Pearson, C.J. and Robards, G.E., CSIRO/Australian Wool Corporation, Melbourne.

Cowan, R.T. & Davison, T.M. 1983 The supplementation of dairy cows at pasture in Queensland. Pp 69-81, *In:* Recent Advances in Animal Nutrition in Australia 1983. Ed: Farrell, D.J. & Vohra, P., University of New England Publishing Unit, Armidale.

Davison, T.M., Cowan, R.T. & Chopping, G.D. 1982. Milk responses to supplementation under tropical pasture feeding systems. *Proceedings of the Australian Society of Animal Production* **14:** 100-112.

Danfaer, A.; Thysen, I. and Ostergaard, O. 1980. The effect of level of dietary protein on milk production. I. Milk yield, liveweight gain and health. Research Report 492, Copenhagen, Bereting fra Statens Husdyrbrygs Forsog.

Dhinan, T.R. and Satter, L.D. 1989. Protein as the first limiting nutrient for lactating dairy cows fed high proportions of good quality alfalfa silage. *Journal of dairy science* **76:** 1960-1971.

Edgecombe, F. & Edgecombe, G. 1994. High production from higher levels of supplements. *Dairy farming Annual, Massey University* **46:** 44-49.

Edwards N.J. & Parker W.J. 1994. Increasing per cow milk solids in a pasture-based dairy system by manipulating the diet: A review. *Proceedings of the New Zealand Society of Animal Production* **54:** 267-273.

Field, T.R. & Ball, R. 1978. Tactical use of fertiliser N. *Proceedings of the Agronomy Society of New Zealand* **8:** 129-133.

Fox, D.G., Sniffen, C.J., O'Connor, J.D. Russell, J.B. and van Soest, P.J. 1990. A model for predicting cattle requirements and feedstuff utilization. Cornell University agriculture experiment station publication No. 34 (128): 1-123

Graham, N.J., Burnside, E.B., Gibson, J.P., Rapitta, A.E. and McBride, B.W. 1991. Comparison of daughters of Canadian and New Zealand Holstein sires for first lactation efficiency of production in relation to body size and condition. *Canadian journal of animal science* **71:** 293-300.

Grainger, C. & Matthews, G.L. 1989. Positive relations between pasture substitution rate and pasture allowance for cows receiving concentrate. *Australian journal experimental agriculture* **29:** 355-360.

Henning, P.A., Van der Lindin, Y., Matteyse, M.E., Nauhaus, W.K., Schwatz, H.M. and Gilchrist, F.M.C. 1980. Factors affecting the intake and digestion of roughage by sheep fed maize straw supplemented with maize grain. *Journal of agricultural science, Cambridge* **94:** 565.

Hodgson, J. 1989. Pasture production. *Dairyfarming Annual, Massey University* **41:** 76-81.

Holden, L.A.; Muller, L.D.; Varga, G.A. and Hillard, P.J. 1994. Ruminant digestion and duodenal nutrient flows in dairy cows consuming grass as pasture, hay or silage. *Journal of dairy science* **77:** 3034 - 3042.

Holmes, C.W. & MacMillan, K.L. 1982. Nutritional management of the dairy herd grazing on pasture. Pp 224-275, *In:* Dairy production from pasture. Ed: Phillips, T., Australian and New Zealand Societies of Animal Production.

Holmes, C.W. & Wilson, G.F. 1984. Milk production from pasture. Butterworths, New Zealand.

Holmes, C. W.; Wilson, G. F.; Kuperus, W.; Buvaneshwa, S. & Wickham, B. 1993. Liveweight, feed intake and feed conversion efficiency of lactating cows. *Proceedings of the New Zealand Society of Animal Production* **53:** 95-99.

Jarrige, R. 1989. Ruminant Nutrition INRA, John Libbley Eurotext, Paris.

Jones, B.B.; Kellaway, R.C. and Lean, I.J. 1996. Protein requirements of dairy cows. Report to Australian Dairy Research and Development Corporation (59 pages).

Kellaway, R. & Porta, S. 1993. Feeding concentrates: Supplements for dairy cows. Dairy Research and Development Corporation, Glen Iris, Victoria.

Larcombe, M. 1989. The effects of manipulating reproduction on the productivity and profitability of dairy herds which graze pasture. PhD Thesis University of Melbourne: 173-182.

Lawson, J.H.; Stockdale, C.R.; Wales, W.J. & Doyle, P.T. 1996. Implications of selection of nutrients from pasture for balancing diets in dairy cows. *Large Herds Australia Conference Proceedings:* 91-101.

LIC 1994. Dairy industry statistics 1992/93. Livestock Improvement Corporation, Hamilton.

Matthew, C.; Hodgson, J.; Matthews, P. & Bluett, S. 1995. Growth of pasture: Principles and their application. *Dairyfarming Annual, Massey University* **47:** 122-129.

Michel, P. & Fulkerson, W. J. 1987. Effect of grazing intensity in spring on pasture growth, composition and digestiblity, and on milk production by dairy cows. *Australian journal of agricultural research* **27:** 35-40.

Moller, S.N.; Edwards, N.J.; Parker, W.J.; Hodgson, J. & Wilson, G.F. 1996. Effect of rate and timing of spring nitrogen appellations and harvest interval on the concentration of crude protein and fibre fractions in ryegrass - white clover pasture. *Proceedings of the New Zealand Society of Animal Production* **56:** 275-278.

Moller, S.N.; Parker, W.J. and Edwards, N.J. 1996. Within - year variation in pasture quality has implications for dairy nutrition. *Proceedings of the New Zealand Grassland Association* **57:** 173-177.

Muller, L.D. 1993. Limitations of pastures for high production by diary cows - a US perspective. Pp 33-58, *In:* Improving the quality and intake of pasture-based diets for lactating diary cows. Eds. Edwards, N.J.; Parker, W.J. Occasional Publication No. 1. Department of Agricultural and Horticultural Systems Management, Massey University.

Muller, L.D.; Kolver, E.S. & Holden, G.A. 1995. Nutritional needs of high producing cows on pasture. *Proceedings of the Cornell Nutrition Conference:* 106-120.

Murphy, A. 1993. An international perspective of dairying in New Zealand.Pp 572-573, *In:* Grasslands for our world. Ed. Brougham, R., SIR Publishing, Wellington.

NRC, 1989. Nutrient requirements of dairy cattle (sixth edition). National Academy Press, Washington D.C.

Oldenbroek, K. 1994. The role of dairy cattle production in the industrialised countries. *Outlook on agriculture* **23:** 123-128.

Opatpatanakit, Y. 1994. Cereal grains/forage interactions in ruminant diets. PhD Thesis, University of Sydney: 31-33.

Opatpatanakit, Y., Kellaway, R.C., Lean, I.J., Annison, G. & Kirby, A. 1995. Effects of cereal grains on fibre digestion in vitro. *Australian journal of agriculture research* **46:** 403-413.

Parker, W.J. 1995. Overcoming the limitations of pasture systems. *The University of Sydney Dairy Research Foundation Symposium Proceedings* **13:** 131-144.

Parker, W.J.; Gray, D.I.; Lockhart, J.C.; Lynch, G.A. and Todd, E.A. 1993. Drying off management and the use of management aids on seasonal supply dairy farms. *Proceedings of the New Zealand Society of Animal Production* **53:** 127-131.

Parker, W. J. & Muller, L. D. 1992. Dairy farming in Pennsylvania - lessons for New Zealand. *Dairyfarming Annual, Massey University* **44:** 142-148.

Peterson, R. 1988. Comparison of Canadian and New Zealand sires in New Zealand for production, weight and conformation traits. Research Bulletin No. 5, Hamilton, New Zealand, Livestock Improvement Corporation Limited.

Phillips, R. 1995. My experience with ration balancing. *Dairyfarming Annual, Massey University* **47:** 70-72.

Polan, C.E. 1992. Protein and amino acids for lactating cows, Pp 236-247, *In:* Large Dairy Herd Management. Ed. Van Horn, H. H.; Wilcox, C. J., American Dairy Science Association, Champaign.

Rajczyk, Z.K.; Lean, I.J. and Gooden, J.M. 1994a. The effect of dietary protein on mammary blood flow and milk production. *Proceedings of Nutrition Society of Australia* **18:** 127.

Rajczyk, Z.K.; Lean, I.J.; McKean, K. and Gooden, J.M. 1994b. The effect of dietary protein on milk composition. *Proceedings of Nutrition Society of Australia* **18:** 178.

Roger, G.L.; Robinson, I. & Moate, P.J. 1986. Milk production of dairy cows grazing white clover and perennial ryegrass. *Proceedings of the Australian Society of Animal Production* **16:** 427.

Rulquin, H. and Verite, R. 1993. Amino acid nutrition of dairy cows: Productive effects and animal requirements. Nottingham Feed Manufacturers Conference (Butterworths).

Stewart, C. D. 1977. Factors affecting the cellulolytic activity of rumen contents. *Applied environment microbiology* **33:** 497-502.

Thomson, N. A.; Roberts, A. H. C.; Judd, T. G. & Clough, J. S. 1991. Maximising dairy production by using nitrogen fertiliser and calving early. *Proceedings of the New Zealand Grassland Association* **53:** 85-90.

Trigg, T.E. & Bryant, A.M. 1982. Nutrition of the grazing cow during early lactation. Pp 219-236, *In:* Dairy production from pasture. Ed. Phillips, T., Australian and New Zealand Societies of Animal Production.

Tyrell, H.F. & Reid, J.T. 1965. Prediction of the net energy value of cow's milk. *Journal of dairy science* **48:** 1215-1219.

Ulyatt, M.J. & Waghorn, G.C. 1993. Limitations to high levels of dairy production from New Zealand pastures. Pp 11-31, *In:* Improving the quality and intake of pasture-based diets for lactating diary cows. Eds. Edwards, N.J. and Parker, W.J. Occasional Publication No. 1. Department of Agricultural and Horticultural Systems management, Massey University.

Uribe, J.V.; Parker, W.J.; Dake, C.G. & McDonald, A. 1996. A whole farm approach to feed planning and ration balancing using UDDER and CAMDAIRY. *Proceedings of the New Zealand Society of Animal Production* **(in press).**

Wilson, G.F. & Davey, A.W.F. 1982. Nutrition of the grazing cow: mid and late lactation. Pp 219-236, *In:* Dairy production from pasture. Ed. Phillips, T., Australian and New Zealand Societies of Animal Production.

Wilson, G.F.; Moller, S.; Parker, W. & Hodgson, J. 1995. Seasonal differences in pasture composition and nutritional implications. *Dairyfarming Annual, Massey University* **47:** 46-56.