Challenges and opportunities for animal production from temperate pastures

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Key points

1. Temperate pastures offer a major opportunity to reduce the feed costs associated with ruminant production.
2. Pastures offer unique opportunities for producing high value components in feedstuffs that are beneficial to human health.
3. The increased use of pasture will not automatically lead to improved environmental outcomes – difficult challenges exist in reducing nitrogen and greenhouse gas pollution.
4. Grazed pasture systems offer advantages in animal welfare, provided management avoids the problems associated with climatic extremes, and the toxins associated with some pastures.
5. To remain competitive with total mixed ration systems, and environmentally acceptable, pastures with higher intake characteristics that allow a reduction in stock numbers per hectare and greater per animal productivity must be developed.

Keywords: pasture, animal performance, environment, animal welfare, greenhouse gases

Introduction

A distinction can be made between pasture and feedlot systems using total mixed rations (TMR) for dairy cattle, beef cattle and sheep on the basis of the feedstuff they use. But it is important to realize that economic forces have moved farmers to use pastures more like feedlots. Pastures are often supplemented with a vast range of feedstuffs making pasture-based systems more like feedlot systems. For several decades, researchers in W. Europe and Oceania have concentrated on grazing management to increase milksolids per ha; while those in North America have concentrated on increased production per cow from improved crops such as maize (*Zea mays* L.), lucerne (*Medicago sativa* L.) and by-products (Fick & Clark, 1998). Re-integration of grass into a TMR feeding regime will be challenging.

The concept of high utilisation through high stocking rates, coupled with management of calving and drying off or weaning, and sale and purchase of stock, to coincide with the natural grass growth cycle is still profitable. However, individual animal performance is compromised, leading to lost opportunities for cost reductions and improved product quality. There are increasing problems related to nitrogen (N) leaching, soil compaction, methane (CH_4) and nitrous oxide emissions, and animal welfare and survival, as new strains of high yielding cows are introduced. Where pasture is the major feed source, long-standing issues related to variable milk and meat quality, and the cost of plant capacity to handle high peak milk and meat processing associated with seasonal calving and lambing have not been solved (Clark, 2002).

In all ruminant enterprises feed costs are the major expense. For example, in a USA dairy enterprise feed costs typically represent 45-55% of total cash costs (Moore, 1998). He calculated the average annual cost of Missouri pasture land to be US$131/ha, including opportunity costs of land, labour and capital and concluded that although pasture was a cheap feed source, its cost was often not realised leading to poor utilisation. Hemme (2003) reported costs of milk production of US$10-20/100 kg milk for pasture-based systems in Australia and New Zealand compared with US$25-55/100 kg milk for EU countries where pasture contributes much less to total cow diet.

Cheeke (1993) listed potential advantages of large-scale, industrial-style livestock enterprises (hereafter referred to as feedlots), including improved animal welfare, improved nutrition, effective waste management, consistent high quality products and better worker benefits. But what is the reality? Can smaller-scale, pasture-based enterprises compete with feedlots? This paper compares ruminant performance under pasture-based and TMR systems and examines opportunities for pasture-based systems to more fully meet consumer demands. It identifies specific environmental and animal welfare challenges to pasture-based systems and suggests ways to answer these challenges. Finally, it outlines a blueprint for developing new pastoral systems that are profitable, produce healthy food and are morally defensible.

Animal performance from pastures

Dairy cows

Kolver & Muller (1998) showed that early lactation cows fed only high quality perennial ryegrass (*Lolium perenne*) pasture in spring ate 19.1 kg dry matter (DM)/cow per day or 3.4% of bodyweight and produced 29.6 kg milk/day. This was 4.5 kg/day less DM intake (DMI) and 14.5 kg less milk compared with TMR-fed cows. They showed that metabolisable energy (ME) was limiting milk yield rather than amino acids or metabolisable protein.

The non-fibre carbohydrate of cool-season grasses is 15-22%, compared with 35% for a TMR, the difference due to grain in TMR. Grass has high crude protein (CP) about 25% but is highly degradable in the rumen. Beever *et al*. (1986) identified high protein degradability, low non-fibre carbohydrate (NFC) and high protein intake as reasons for low efficiency of N utilisation in grazing cows. Loss of rumen degradable protein (RDP) can account for 1.5-3 kg of milk yield.

Data from Kolver *et al*. (2002) in Table 1 show that although grass and a TMR may both have high ME contents, the ability of the two diets to generate milk yield differs. This is due to the lower neutral detergent fibre (NDF) and higher NFC in the latter, and also physical differences like water content and rate of breakdown that determine intake (Waghorn, 2002). The higher DMI and starch content in the TMR are able to support much higher milk yield than a solely pasture diet.

Table 1 Mean annual nutrient composition of grass and total mixed ration (TMR) diets fed to dairy cows and associated milk and milksolids yield (from Kolver *et al*., 2002).

Item	Grass	TMR
ME (MJ ME/kg DM)	11.7	11.8
Crude protein (%DM)	26.9	18.2
Degradable protein (%Protein)	57.8	56.2
Soluble protein (% protein)	30.8	33.1
Neutral detergent fibre (%DM)	42.5	34.3
Acid detergent fibre (%DM)	23.3	21.0
Non fibre carbohydrate (%DM)	16.1	36.3
Fat (%DM)	4.2	6.7
Milk (kg/cow)	5880	10100
Milksolids (kg/cow)	460	720

To achieve higher milksolids New Zealand farmers have utilised maize silage purchased off-farm and grazed all non-lactating dairy stock off-farm. These options have allowed extra milksolids to be produced from the farm. The full advantage from maize silage can only be obtained with increased stocking rate (Kolver *et al*., 2001), which increases labour, machinery, feeding facility and inventory costs. The combination of perennial ryegrass - white clover pasture supplemented with maize silage does not lead to increased milk production per cow at peak but achieves a modest increase in whole lactation performance by increasing days in milk. Some farms are now stocked at 4-5 cows/ha producing 400-500 kg MS/cow per year. In these systems 75% of feed is from perennial ryegrass - white clover and 25% from maize silage.

Beef cattle

Keane & Allen (1998) compared different beef production systems, viz. Intensive – bulls finished on silage and concentrates slaughtered at 19 months, Conventional – steers finished on silage and concentrates and slaughtered at 24 months, and Extensive - steers finished off pasture and slaughtered at 29 months (Table 2).

Table 2 Inputs and outputs and economic returns for intensive, conventional and extensive beef finishing systems (from Keane & Allen, 1998).

Item	Intensive	Conventional	Extensive	Significance
Carcass weight (kg)	384	363	366	NS
Kill out proportion (g/kg)	568	541	535	***
Live weight gain (kg/day)	1.18	0.73	0.72	***
Stocking rate (animals/ha)	4.0	2.1	1.47	N/A[1]
Concentrates (kg/animal)	1705	1218	256	N/A
Carcass weight (kg/ha)	1536	756	538	N/A
Gross margin – interest (€/animal)	336	269	403	N/A

[1] Not applicable

The Intensive system had higher kill out proportions and daily live weight gains than the Extensive, and the total carcass output / ha was much higher under the Intensive system, because of the greater use of N fertiliser and concentrates. However, the extra carcass weight could not compensate for the extra feed costs so that the Extensive system had the higher gross margin / ha. These results demonstrate how to produce acceptable carcass weight and quality from extensive pasture-based systems.

Sheep

There is evidence that individual Suffolk ram lambs can grow at close to 600 g/day from weaning to slaughter (Held *et al*., 1997) when they are well fed on a concentrate diet from weaning. However, Muir *et al*. (2003) reported a growth rate of 549 g/day for an East Friesian x Romney x Suffolk ram from birth to 52 kg live weight at 12 weeks of age on milk and a grass-clover pasture, and a group average of 437 g/day over the same period. However, lamb growth rates from pasture are often well below these figures presenting a challenge to achieve the growth potential of superior sheep genetics when pasture is the post-weaning feed.

Opportunities and challenges

Carpino *et al*. (2004) showed that Ragusano cheese made from milk from cows fed either a TMR or native Sicilian pastures differed in odor-active compounds with only 13 in the former compared with 27 (8 of them unique) in the latter. This work demonstrated how pasture feeding could produce unique cheeses with desired flavours. Of course the reverse is true, because plants such as chicory can impart undesirable flavours to milk, although these can be removed by plant breeding (Rumball *et al*., 2003). Carotenoid pigments may be used as a biomarker for grass-fed sheep (Prache *et al*., 2003) and presumably other species. Such a marker would identify carcasses as grass-finished and attract premiums in the some markets.

Cows grazing only pasture had 150 and 53% more conjugated linoleic acid (CLA) in their milk than cows grazing a diet with one-third and two-thirds pasture, respectively (Dhiman *et al*., 1999). CLA is the only known antioxidant and anticarcinogen primarily associated with foods originating from animal sources, and chemical induced tumours in rat mammary gland and colon tissue were reduced when isomers of CLA were fed (Ip *et al*., 1999). However, MacRae (2004) pointed out that CLA levels in butter, milk, lamb and beef of 4-7 mg/g total fatty acids (FA) were insufficient to reduce inflammation responses in humans. There is thus a major challenge to rumen microbiologists to substantially increase CLA production by rumen microbes.

It has been hypothesized that n-6 FA have a role in the inflammation processes associated with human coronary heart disease and cancer, and that n-3 FA can reduce inflammation by competing with the incorporation of n-6 metabolites into membrane cells (Gibney & Hunter, 1993). Present recommendations are to increase intake of n-3 FA towards the dietary optimum n-3: n-6 FA ratio of 0.4-0.5, assisted by increasing intake of linolenic acid derived from chloroplast lipids. Dewhurst *et al*. (2003) reported increased n-3: n-6 polyunsaturated fatty acid (PUFA) ratio in the lipid of animals fed fresh forages rather than concentrates.

High value proteins from cow's milk offer the opportunity of increased returns, but there is little evidence that pasture feeding will lead to quantitative or qualitative differences in these proteins. Some management systems such as once daily milking are likely to be practiced only where pasture is the major feed. Recent analysis of milk from cows milked once daily showed that higher absolute yields of lactoferrin are possible compared with milk from cows milked twice daily (Farr *et al*., 2002). Lactoferrin is valued for its iron-binding, anti-bacterial properties. However, there is no guarantee that high value milk proteins will come from cows, since the human lactoferrin gene has been cloned and is produced by recombinant DNA technology to fortify infant milk powders. Cow lactoferrin will have to compete with this product.

Animal breeding, especially of dairy cattle, has developed under the assumption that diets based on harvested forages and concentrates that meet all nutrient requirements will be fed. Such cows will not perform the same on pasture, and cows bred for pasture systems should be used (Kolver *et al*., 2004). Even cows bred for pasture feeding take longer to get back in calf and lose more condition after calving than cows bred thirty years ago. This indicates a need for continual focus on breeding for pasture-based systems if cows suited to such systems are to be available in the future. Failure to do so will erode the profitability, animal health and welfare advantages of such systems.

Long-term sustainability of pasture systems will depend on improved ability to convert forage protein into an animal product that will be bought by health-conscious consumers. Currently, 75% and 85% of protein fed to dairy and beef animals, respectively, ends up as waste N. Promising increases in milk production (Miller *et al*., 2001) and live weight gain from grazing lambs (Lee *et al*., 2001) have been reported from forages bred for higher levels of water-soluble carbohydrates (WSC). But these results may not be transferable to different environments. Recent work by Parsons *et al*. (2004) showed that perennial ryegrasses bred for higher levels of WSC had the same level of WSC as a control ryegrass when tested at warmer temperatures.

Pasture-based systems have failed to fully harness the beneficial effects of legumes. Research shows that legumes (e.g. white clover (*Trifolium repens*), red clover (*Trifolium pratense*), Lucerne and subterranean clover (*Trifolium subterraneum*)) are capable of increasing milk and meat production (e.g. Harris *et al*., 1998; Waghorn & Clark, 2004) (Table 3). Those containing condensed tannins (e.g. birdsfoot trefoil (*Lotus corniculatus*)) may be particularly beneficial (Waghorn *et al*., 1998), because they protect proteins from rumen degradation, and have anthelmintic and CH_4-reducing properties. Intensive grazing as a result of high stocking rates has led to decreased white clover content. Lower stocking rates will lead to less damage to clover stolons in spring and summer. Recent research suggests that legumes may have to be sown in strips within a grass-legume pasture to obtain high dietary levels of legumes (Marotti *et al*., 2002), and to allow protection from grazing at critical stages.

Although the application of molecular biological technology to pasture improvement is not discussed in this paper it will lead to future opportunities. In particular, Cisgenics® (the movement of heritable material only within species) offers a method to improve plants without resorting to transgenic technology, which may be unacceptable to either producers and/or consumers (Elborough & Hanley, 2004).

Table 3 Performance of cows in mid-late lactation and growing lambs fed a range of diets relative to ryegrass. Comparisons were made with forages given as sole diets and as supplements with ryegrass for cows (from Waghorn & Clark, 2004).

Cows	Supplement (% DM intake)	Response (% of ryegrass)		Lambs	Daily gain (% of ryegrass)
		DMI	Milksolids		
Ryegrass vs.				Ryegrass vs.	
White Clover	-	-4	+9	White Clover	+74
Lotus corniculatus	-	+18	+68	*Lotus corniculatus*	+55
Lotus corniculatus	75	11	48	*Cichorium intybus*	+47
White Clover	25	8	22	*Hedysarum coronarium*	+72
White Clover	50	22	29	Lucerne	+41
White Clover	75	25	33	Red Clover	+15
Cichorium intybus	40	1	9		

Environment

Nitrogen

The management of N presents major challenges and opportunities for pasture-based agriculture. The challenge is to avoid environmental damage as N moves from the farm into the environment. The opportunities exist because N capture in high value human food products can substantially improve farm profitability. Intensive grazing not only degrades the environment (EC, 1991), but also has specific problems absent from cropping enterprises. A good example is the aggregation of N into urine patches and subsequent large leaching losses (Scholefield *et al*., 1993).

Greenhouse gases

There are few comparisons of CH_4 emissions from grazing ruminants and those fed TMR diets. Robertson & Waghorn (2002) reported losses as a percentage of gross energy (GE) for pasture and TMR diets, respectively, of 4.9 and 5.0; 6.3 and 5.7; and 7.0 and 6.3 for cows in early, mid- and late lactation, with only the late lactation values being different ($P<0.05$). Dhiman *et al*. (2001) and Cushnahan *et al*. (1995) measured CH_4 losses of 8.2% and 7.8% of GE in lactating cows fed grass-dominant pasture. In a modelling exercise Benchaar *et al*. (2001) predicted that increasing intake and the proportion of concentrate in the diet would decrease CH_4 emissions by 7 and 40%, respectively. It may appear that increasing intake of grazing cows with concentrate supplementation is a simple way to reduce CH_4 emissions. However, van der Nagel *et al*. (2003) compared a TMR and pasture-based ration and showed that when the CO_2 emissions from cultivation, fuel and fertiliser were included in estimates of greenhouse gases (GHG) (CH_4 + CO_2) emissions, the TMR diet produced nearly twice as much GHG as pasture (1.53 vs. 0.84 kg CO_2 equivalents / kg milk). Currently, there are no animal–based interventions for reducing CH_4 emissions that fully meet requirements for product safety, welfare, cost and long term effectiveness. An obvious option of reducing stocking rate to decrease pasture consumption / ha and the proportion of feed used for maintenance is usually rejected on economic grounds. Carbon taxation, discussed later in the paper, could alter this perception.

Opportunities and challenges

Di & Cameron (2004) using a nitrification inhibitor (dicyandiamide (DCD)), marketed as eco-n^{TM}, showed that nitrate-N leaching was reduced from 85 to 21 kg N/ha per year for dairy cow urine applied at 1000 kg N / ha. This would reduce the annual average nitrate-N concentration under a urine patch from 25 to 7 mg N/litre, and reduce Ca and Mg leaching, but not ammonia volatilization. Annual pasture growth in the urine patch increased from 15.9 without eco-n^{TM} to 18.3 t DM/ha with eco-n^{TM}. This work needs to be verified under a wide range of commercial farming systems, and care needs to be taken that the potential benefits are not lost, e.g. extra pasture should be used to increase per animal intake rather than to increase stocking rate.

However, these and other options are tactical approaches. Urgently needed are strategic approaches that address both the N input into a farm system and its capture into food products. During an annual cycle, more than 300 kg N/ha can be released into long-term temperate grassland (Clough *et al*., 1998). If this release could be accurately predicted, artificial N inputs could be adjusted accordingly. These authors suggest the use of thermal units to predict N mineralisation. Lemaire & Meynard (1997) have developed a Nitrogen Nutrition Index to predict level and timing of N fertilisation. These tools coupled with decision support systems such as OVERSEER^{TM} (Monaghan *et al*., 2004) allow the inputs or processes that have the most impact on N pollution from farming to be identified and alternatives evaluated. Whitehead (1995) derived a general linear relationship between N intake and excretion in urine: thus 1.5% N in the diet leads to excreted N in urine at 45% of total N excretion, but 80% at 4% N in diet. Species with C_4 metabolism such as maize are usually more efficient at capturing carbon / unit of N than C_3 plants. The incorporation of maize silage with <1.5% N content into a pasture diet of 4% N will reduce N excretion at a given level of DMI. Maize is now used widely in dairying countries as either an integral part of TMR or as a supplement to grazed pasture. However, it does not necessarily follow that systems based on maize silage will decrease total N output from a system, especially where stocking rate, total herd DMI and total N consumed are increased. Peel *et al.* (1997) demonstrated the potential for dairy farm management of N outputs with a modelling exercise comparing three systems:

1. Conventional management following good practice and based on high output (economic optima for fertiliser, slurry broadcast, least cost minimum 18% CP in diet).
2. Reduced loss, high output system – tactical reduction in fertiliser, diluted broadcast slurry, incorporation of maize silage and no surplus RDP).
3. Minimal loss, reduced intensity – the same total output from a greater area – planned reduction in fertiliser, slurry injected, no surplus RDP.

All systems produced 6000 kg milk/cow. Nitrogen inputs were 472, 336, 266 kg/ha respectively, and N outputs (milk and meat) 72, 71, 58 kg/ ha, respectively, and total N losses were 175, 115, 57 kg/ha. Financial margins were reduced by 10% on the minimal loss system.

Table 4 shows that imposition of a carbon tax would make it economically feasible for New Zealand dairy farmers to reduce stocking rates by up to 30% (Clark & Lambert, 2002), but only if carbon taxation was greater than $NZ 44/tonne of CO_2. This would lead to a 25% reduction in CH_4 output / ha. It would also lead to important spillover benefits for nitrous oxide and nitrate leaching. However, individual farmers would lose $311/ha per year in economic farm surplus.

Table 4 The effect of stocking rate on milk yield, economic farm surplus (EFS) with and without a carbon tax and estimated CH_4 output (data from Macdonald *et al.* (2001) and CH_4 production calculated from Clark (2001)).

Stocking rate (cows/ha)	2.2	3.2	4.3
Milk (kg/ha/y)	12100	13800	14600
CH_4 (kg/ha/y)	233	309	385
EFS* ($/ha/y)	2661	2741	2325
EFS** ($/ha/y)	2430	2430	1940

*Economic farm surplus - details of calculation in LIC (2001).

**Net economic farm surplus - calculated as (EFS - cost of CO_2 tax (assumed at $43.70/tonne)) to give break even for optimum stocking rate for EFS (3.2 cows/ha) and the lowest stocking rate (2.2 cows/ha).

Animal welfare

Animals outside have freedom to move, and exposure to sunlight and fresh air – but this implies exposure to temperature extremes, wind, damaging ultraviolet radiation and high temperatures, unless adequate shelter is provided. In both indoor and outdoor environments there is exposure to deleterious organisms. Housing provides shelter from climatic extremes, but generates health issues of lameness, mastitis and physical constraint. It appears that a combination of the two approaches that uses low-cost shelter for certain climates, and times of the year, coupled with physical freedom at others would be beneficial.

Silanikove (2000) made the following recommendations to minimise heat stress in grazing animals. There should be shade/shelter available when ambient temperature exceeds 24°C and temperature-humidity index >70, water freely available, breed type limited and sufficient time given to acclimatise to hot conditions. Breed type is very important because the heat load on a cow producing 50 kg milk/day is much greater than on one producing 20 kg. In the former, it is possible to provide cooling regimes of fans and water sprinklers but these add cost to the system. Plant breeding offers options for reducing heat stress in hot environments by producing endophyte-free or endophyte modified tall fescue and perennial ryegrass (Woodfield & Matthew, 1999) with reduced levels of the vasoconstrictor, ergovaline.

Lacy-Hulbert *et al*. (2002) monitored cows of different genotypes on pasture and TMR diets for three years, and observed a higher incidence of coliform mastitis on the TMR fed cows. The TMR ration contained 23% starch and there is evidence that undigested starch in the large intestine encourages *Escherichia coli (E. coli)* growth (Huntington, 1997). Lacy-Hulbert *et al*. (2002) found coliform faecal count of cows on TMR to be 1000 fold higher compared with cows on pasture, consistent with research reviewed by Callaway *et al*. (2003).

A way ahead

If pastoral systems advocates believe they must produce at the same levels as feedlots then they will surely run into the same problems. The idea that genetic modification of plants and animals can deliver unlimited gains in productivity must founder on the rock of biological, chemical and physical limitations. There is a paradox here in that if we accept limits to production we may never discover the true potential of our systems, but if we push hard on genetic gains and management advances then we will create problems in pastoral systems at least as intractable as in feedlots. However, an acceptance that pastoral systems have limits, could mean that population growth slows more quickly and leaves more area for pasture-based as opposed to crop-based agriculture.

Currently, pastoral systems and feedlots compete on an even footing in the market place, with only organic produce commanding a premium. Pastoral systems based on sound scientific principles should be developed that allow them to capture at least the current premium paid by the consumer for organic product. The fact that a small but important group of consumers pays a premium for organic but not pastoral product suggests that they see no difference between pastoral and feedlot systems.

Pastoral agriculture can make an important contribution to a country's "clean and green" image, but it is difficult to quantify this in monetary terms. A New Zealand study (MfE, 2001) using contingent valuation methodology suggested that a "clean and green" image was worth several hundred million dollars to primary producers and the tourism industry. This estimate was based on interviews with overseas customers and tourists on their likely spending decisions should New Zealand's image be degraded. The effect of any improvement or degradation in environmental image will likely vary with country, depending on such factors as level of tourism and type and extent of exports. It is important not to overstate the case for pasture because all the 'problems' of feedlots can occur under pastoral systems if management concepts and practice are wrong. For example, environmental damage can occur under both systems and it is often a function of the absolute amount of the inputs coupled with spatial and temporal variation that exacerbates the effect of these inputs.

High intake pasture system

The challenge for pasture-based systems is to produce a year round diet that matches the energy, protein and mineral supply of a feedlot TMR, with equal intake potential, but under a low cost, predominantly grazing regime. Where year-round pasture growth occurs, total annual yield should be approximately 15 t DM / ha. A High Intake Pasture System diet (Clark, 2002) should be able to support 2 cows / ha at a live weight of 550-600kg with a production of 1.0 kg milksolids/kg live weight. The cow's annual DMI would be approximately 7.2 t DM (Table 5). Table 5 shows one scenario for a High Intake Pasture System that meets the above criteria. The scenario assumes a 50/50 split between autumn and spring calving to allow milk production for 365 days. In this scenario 25% of the farm area is sown in a tannin-containing legume (e.g. *Lotus corniculatus*) to obtain improved DMI and protein nutrition during the summer and autumn. Another 25% is sown in annual ryegrass for improved DMI and ME content in winter and early spring and this area is sown in maize for grain in spring to provide an energy dense feed throughout the year. Note that 50 % of the area is still sown in perennial ryegrass-white clover providing 53% of the cow's annual intake. This combination has the potential to provide feed for lactating cows throughout the year. However, it is still reliant on perennial ryegrass and white clover and is exposed to the deficiencies that this feed has for optimum dairy cow nutrition.

Table 5 An example of a High Intake Pasture System stocked at 2 cows/ha throughout the year

Forage	Proportion of area	Annual Feed Production adjusted for area (t DM/ha)	Proportion of cow's diet
Perennial ryegrass-white clover	0.5	7.7	0.53
Lotus corniculatus	0.25	2.4	0.17
Annual ryegrass	0.25*	1.8	0.13
Maize grain	0.25*	2.4	0.17
Total	1.00	14.3	1.00

*Annual ryegrass sown in autumn; maize sown in spring on the same area.

If establishment and management costs of High Intake Pasture Systems could be kept low then they would rival the conventional system for profitability with benefits for nitrate leaching and GHG emissions per unit milksolids, and animal welfare and survivability. The High Intake Pasture system offers advantages over a wholly ryegrass- white clover grazing system, decreasing the risk of dietary dependent disorders (e.g. facial eczema, bloat, endophyte toxicity, and hypomagnesaemia). It breaks the constraint set up by the natural growth cycle of perennial pastures so cows can be milked all year with longer lactations. The higher yields dilute the maintenance cost, and improve feed conversion efficiency from 13-15 kg DM/kg MS commonly achieved with pasture systems to 11.9 kg DM/kg MS, based on the above assumptions, closer to the 10-11 kg DM/kg MS for feedlot TMR (Kolver *et al*., 2001). The grazing process still poses a formidable challenge to the High Intake Pasture system which must be solved if this system is to come close to matching the per cow productivity of feedlot TMR.

Conclusions

Pastures offer a low cost feedstuff that can be profitably used in dairy, beef and sheep enterprises in most temperate regions. Their increased use may solve some of the environmental and animal welfare problems associated with feedlots using large amounts of concentrate feed from cropping enterprises. However, pasture systems can generate a different set of problems, particularly when trying to maximize pasture utilisation through high stocking rates and year-round grazing. From an economic and environmental perspective pasture research should develop plants and farm systems that allow high individual animal intake. The consequent lower stocking rate will allow improvements in labour productivity, animal health and welfare and overall profitability. The challenge is enormous and so are the benefits.

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