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Improving animal performance using forage-based diets

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ABSTRACT

New Zealand livestock systems are based on ryegrass dominant pastures, but they are unable to maximise animal production. Limitations of ryegrass-based pastures are reviewed, and opportunities for using alternative forage species to complement pasture and improve animal production are discussed. Ryegrass pastures have low dry matter contents and high fibre concentrations which restrict feed intake so animal energy requirements are often not met. High crude protein (CP) concentrations in spring and rapid proteolysis in the rumen produces excess ammonia which must be excreted, whereas summer pastures contain insufficient CP. Chicory, red clover, lotus species, sulla, lucerne and maize silage are examples of forages that can complement ryegrass to improve animal performance. More information is needed to define digestion and fermentation of fresh forages in the rumen, but in vitro and in sacco techniques have been used to evaluate these parameters for grasses, legumes, herbs and silages. This information with feed composition data will be used in computer simulations to predict forage mixtures able to complement pasture at different times of the year. The challenge will be to complement the changing ryegrass pastures with other forages to improve animal welfare, productivity and profit.

Keywords: pasture; forage-diet quality; animal performance.

CURRENT PASTORAL SYSTEMS

New Zealand livestock production systems are predominantly based on perennial ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pastures. Ryegrass is well suited to our temperate climate and has good dry matter (DM) yields, moderate to good nutritive value and it withstands grazing in most environments. However, the quality and quantity of nutrients available to grazing animals is extremely variable because of changes due to season, maturity and management practices.

Nutrient requirements of most livestock species are well documented (NRC 1975, 1996, 2001) and highly productive systems in the Northern Hemisphere feed total mixed rations (TMR) to match animal requirements. Ryegrass-based pastures are not ideal for maximising production. The notable excesses, imbalances or inadequacies of ryegrass pastures that limit animal production will be discussed in this paper, along with options for complementing the ryegrass-based diet with high quality forages.

Ulyatt (1981) showed that white clover had a relative feeding value twice that of ryegrass for liveweight gain, and Burke *et al.* (2002) has shown sulla (*Hedysarum coronarium*) can provide performance equivalent to white clover. However all forages have disadvantages when fed as a sole diet. For example, the advantages of feeding white clover over perennial ryegrass for milk production are well known (Rogers *et al.*, 1982), but white clover swards are not a realistic option for New Zealand farming because of bloat in cattle and costs of maintaining a highly productive sward, as well as the metabolic costs of high protein diets (Danfaer *et al.*, 1980).

White clover rarely accounts for more than 15-20% of pasture, although Harris *et al.* (1997) reported that the optimum content of white clover for maximising milk production was 55-65%. Pastures do contain grass species other than ryegrass with cocksfoot (*Dactylis glomerata*) and tall fescue (*Festuca arundinacea*) found in many areas and kikuyu (*Pennisetum clandestinum*) and paspalum (*Paspalum dilatatum*) in warm, northern regions of New Zealand. Browntop (*Agrostis tenuis*) is common in hill country pastures but these grasses have a lower nutritive value than that of ryegrass (Ulyatt, 1981; Burke *et al.*, 2000).

LIMITATIONS OF PASTURE-BASED DIETS

Sheep and cattle industries have evolved around the seasonal pattern of pasture production with lambing and calving coinciding with spring pasture growth. However pasture growth does not meet requirements for deer which calve during summer and have high feed requirements when growth and nutritive value of ryegrass-based pastures is poor (Barry *et al.*, 1998).

The main limitations to pasture-based diets include:

1. Moderate energy concentrations and limited digestible intake.
2. Low dry matter content and excessive fibre in grass restricts feed intake.
3. Low concentrations of readily fermentable carbohydrates (soluble sugars, organic acids, pectin) relative to crude protein and fibre concentrations.
4. High crude protein (CP) and insufficient undegradable protein (UDP) concentrations require excess ammonia to be removed at a metabolic cost.
5. Quantities and proportions of volatile fatty acids (VFA's) arising from fermentation may not be optimal for rapid growth or milk production.
6. Forages required to complement ryegrass rarely persist in mixtures and specialist (e.g., separate) paddocks may be needed.

Mineral element deficiencies, excess potassium, and the incidence of endophyte and other toxins may limit animal performance, but are not discussed here.

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NUTRITIONAL IMPLICATIONS OF PASTURE FOR PRODUCTION

Seasonal changes in pasture digestibility and nutrient concentration on New Zealand dairy farms are well documented (Wilson & Moller, 1993) and recently Chaves *et al.* (2002) have defined nutrient composition and rates of digestion of ryegrass with advancing maturity (Table 1). Energy (primarily VFA's) is often the first limiting nutrient in a pasture-based system and coupled with low dry matter contents and recalcitrant fibre in ryegrass dominant pasture an animal is unable to consume sufficient feed to meet nutrient requirements for high productivity.

TABLE 1: Composition (% of DM) and *in sacco* degradation rates (k) of minced ryegrass harvested at increasing maturity.

Age (days)	DM (%)	Soluble Carbo-hydrate	Crude Protein	ADF[1]	NDF[2]	Lignin	k (DM)
21	19.1	6.9	22.5	23.5	42.1	2.66	0.067
31	19.2	6.6	17.2	26.1	48.0	2.38	0.058
53	19.5	5.2	14.6	29.3	48.6	2.50	0.071
74	22.9	9.9	10.0	30.0	50.9	2.62	0.044
88	20.7	10.1	9.1	30.9	51.3	3.02	0.044
105	31.6	7.3	5.0	36.1	61.9	4.35	0.029

[1]Acid detergent fibre (cellulose + lignin)
[2]Neutral detergent fibre (cellulose + hemicellulose + lignin)

Spring pasture is predominantly green leaf, with relatively low concentrations of fibre (NDF=40-45%) and high digestibilities (75–80%) and metabolisable energy (ME; 11.5-12 MJ ME/kg/DM). Concentrations of soluble carbohydrates are low (10-15% DM) relative to CP (25-30% DM) and consequently there is not enough energy in the diet for efficient microbial synthesis. High quantities of CP coupled with high degradability in the rumen (70-80%; Ulyatt & Waghorn, 1993) result in high concentrations of ammonia absorbed into the bloodstream. Animals divert energy from production to remove excess ammonia as urea (Danfaer *et al.*, 1980) and Beever (1993) suggest hepatic ammonia removal may further deplete amino acid availability for production in forage fed animals.

Spring pastures contain 12-16% DM, so large quantities need to be consumed to meet animal energy requirements. The soft flexible leaf requires little chewing or salivation to swallow, but the fibre needs to be broken into small pieces by chewing in order to pass from the rumen. Suggestions that fibre in spring pasture may not be effective for salivation (Waghorn, 2002) may be true during eating, but salivation associated with extensive rumination would facilitate buffering and maintenance of an optimal rumen pH.

In contrast summer pastures are maturing and the proportion of seedhead, stem and dead matter increases relative to leaf (Waghorn & Barry, 1987). Increased concentrations of neutral detergent fibre (NDF) (45-55% DM), lower concentrations of protein (<20% DM) and lower digestibility (<70%, <10.5 MJ ME/kg DM) (Wilson & Moller, 1993) are the most obvious pasture quality changes. Chaves *et al.* (2002) has defined relationships in ryegrass between increasing NDF concentration and reduced organic matter digestibility (r^2=0.89), CP content (r^2=0.94), and commensurate reductions in ammonia concentrations during *in vitro* fermentation (r^2=0.85; Figures 1a & b). The slow digestion of fibre and low CP content of mature pasture will limit intakes of energy and protein, so animal performance can only be sustained by substitution of mature pasture with rapidly digested forages with adequate concentrations of protein. Limited pasture availability will enable supplementation without substitution.

Pastures in autumn are of similar quality to spring pasture with high CP concentration relative to soluble carbohydrates. Fibre concentrations may be higher than spring (Wilson & Moller, 1993) and feed supply may be insufficient, so supplementation may be crucial to sustain productivity.

There are opportunities for incorporating high yielding quality forages into our pastoral system. Ryegrass-based pastures will remain the basis of our feeding systems because of their persistence and relatively high dry matter yields but there are several legumes and herbs (specialist forages) that have potential to complement pasture. In addition to maize silage, now commonly used in dairying, opportunities exist in the deer industry for feeding alternative forages that are of higher nutritive value than pasture (e.g., chicory or red clover) and have patterns of growth that are more in line with deer physiology and feed requirements (Barry *et al.*, 1998; Hoskin, 1998). Maturation of ryegrass during late spring reduces feed and nutrient intake and exacerbates the rapid decline in milk production that is characteristic of pastoral feeding. The Northern Hemisphere feeding systems for dairy cows are based on TMR which include expensive grain and protein supplements with silages and are not economically sustainable in New Zealand.

COMPLEMENTING RYEGRASS WITH SPECIALIST FORAGES

When pasture contains clover, sheep and young stock are able to select a diet with a higher nutritive value than the sward on offer (Hughes *et al.*, 1984), but intensive harvesting characteristics of our dairy systems prevent selection. Our cows eat much of the feed on offer, and increased use of urea has resulted in grass dominant swards. Farmers currently use supplements (pasture silage and hay) to meet shortfalls in feed supply rather than to complement pasture quality.

The research presented focuses on the choice of supplements best able to match the pasture on offer. Some experienced farmers achieve this, but use of modern feed analyses (e.g., Near Infrared Spectroscopy (NIRS; Corson *et al.*, 1999) with ration balancing models will provide a better match between cow requirements and forage systems. The challenges to researchers will be to develop nutritional criteria for forages in a similar manner to those developed in the USA over the past 30 years to create TMR from grains, silages and protein supplements, but we have an additional challenge in that ryegrass composition can change very rapidly. Work by Barrell *et al.* (2000) and Burke *et al.* (2000) have evaluated degradation parameters for specialised forages and Chaves

FIGURE 1a: Effect of increasing fibre (neutral detergent fibre; NDF) concentration on organic matter digestibility as ryegrass matures.

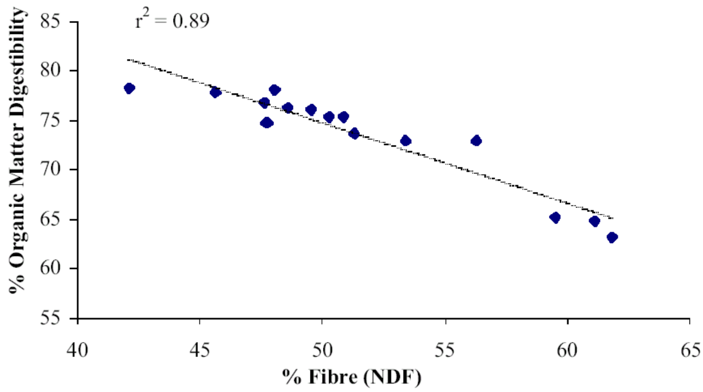
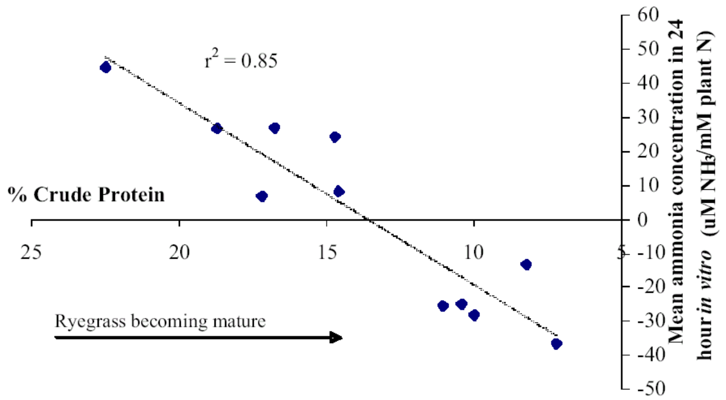


FIGURE 1b: Effect of ryegrass maturity on crude protein content and mean *in vitro* ammonia concentration.



et al. (2001, 2002) has defined ryegrass composition, to provide nutritional parameters for use in mixed forage ration formulations.

The superior nutritive value of legumes and herbs relative to ryegrass are well known (Ulyatt, 1981; Burke *et al.*, 2002; Table 2). Our challenge is to identify the reasons for high animal performance, and most importantly ensure that there is a sound basis for feeding other forage species with pasture, because ryegrass is the most economical feed for ruminants, despite some nutritional limitations.

LEGUMES AND PROTEIN DEGRADATION

Examples of forages that have good nutritional value when fed as a sole diet include lucerne (*Medicago sativa*

TABLE 2: Comparative feeding value, forage dry matter (DM) content, composition (% of DM), rate of degradation (k) and metabolisable energy concentration of fresh species.

Forage[1]	Feeding value[2]	DM (%)	Soluble Carbohydrate	Crude Protein	ADF[3]	NDF[4]	Lignin	k (DM)	ME[5]
White clover	100	15.0	12.1	26.9	19.0	25.6	5.8	0.195	11.5
Sulla	100	11.6	17.8	23.0	17.7	22.4	8.5*	0.121	12.7
Chicory	95	14.3	11.4	19.3	21.2	23.8	7.0*	0.260	12.5
Birdsfoot trefoil	87	16.2	13.0	22.2	19.6	28.2	7.2*	0.151	11.0
Lotus	84	16.3	12.2	21.5	22.2	33.1	16.9*	0.108	12.0
Grasslands Tama	83	15.2	16.4	21.3	16.2	36.5	2.9	0.098	12.7
Lucerne	82	23.9	8.6	29.9	21.4	29.5	6.1	0.131	10.9
Perennial ryegrass	52	18.8	9.1	15.5	25.5	48.7	3.5	0.114	11.0
Maize silage	-	34.7	41.7	7.6	24.5	40.5	4.4	0.042	10.7

[1]Latin names in text
[2]All values relative to white clover (Waghorn & Barry, 1987)
[3]Acid detergent fibre (cellulose + lignin)
[4]Neutral detergent fibre (cellulose + hemicellulose + lignin)
[5]Metabolisable energy (MJ ME/kg DM)
*Values elevated due to condensed tannin

L.), red clover (*Trifolium pratense*), chicory (*Cichorium intybus*), lotuses (Birdsfoot trefoil - *Lotus corniculatus;* Lotus – *Lotus pedunculatus*) and recently sulla. Grazed or conserved lucerne has a high protein content in the leaf, but this is rapidly degraded in the rumen and very little reaches the small intestine (Dhiman *et al.*, 1993), but lucerne silage is often the basis of TMR's. Adding a source of energy to the diet of sheep fed high protein lucerne increased liveweight gain and improved the efficiency of protein utilisation (Dellow *et al.*, 1988). They showed more ammonia-nitrogen was utilised by rumen microbes, more propionic acid was produced and absorbed amino acids were utilised more efficiently for protein metabolism when a source of energy was added to a high protein lucerne diet.

The improved performance of sheep and deer fed red clover (Jagusch, 1982) and/or chicory (Barry *et al.*, 1998) compared to perennial ryegrass was due to the high concentrations of soluble carbohydrates relative to structural fibre, rapid digestion, higher feed intakes and more efficient utilisation of metabolisable energy. The lower CP concentrations in chicory compared to red clover did not affect animal performance, possibly because rapid passage through the rumen prevented extensive protein breakdown. The high ratio of readily available carbohydrate to protein enabled rapid microbial growth and protein capture (Barry, 1998).

The breakdown for forage protein is a major disadvantage for ruminants. The importance of rumen UDP is a major factor in formulating TMR diets where UDP is 33-40% CP (NRC, 2001). However, the presence of condensed tannins (CT) in some high protein legumes (lotuses, sulla) will prevent excessive degradation of dietary plant protein in the rumen allowing protein to pass directly into the small intestine for absorption. Several studies have shown improvements in liveweight gain, reproductive performance, wool growth and milk production by feeding plants containing condensed tannins alone or with other forages.

HIGH-QUALITY LEGUME FORAGES

Animal trials with birdsfoot trefoil have shown that the condensed tannin (up to 4% DM) has improved wool growth, milk production, liveweight gain, ovulation rate and reduced the incidence of dags and flystrike in sheep (Waghorn *et al.*, 1998), and animal peformance has been superior to that of lucerne (Douglas *et al.*, 1995). Woodward *et al.* (1999) fed lactating cows on birdsfoot trefoil and reported milk production to be 51% greater than pasture with 42% of this increase attributable to the CT in the birdsfoot trefoil.

Sulla has high CP (18-23% DM), soluble carbohydrates (18-25%) and low fibre concentrations (22-23% DM). Deer grew faster when fed sulla than chicory (Hoskin, 1998) and newly weaned lambs have achieved growth rates of 340 g on sulla (Waghorn *et al.*, 1998). In contrast the CT in lotus has not always achieved improved performance relative to legumes without CT, because the type of CT provides excessive protection to protein against degradation with reductions in intake (Waghorn *et al.*, 1994). Nevertheless CT from one species is able to bind with and precipitate protein from another species both *in vitro* and *in vivo* (Min *et al.*, 2000; Waghorn & Jones, 1989). Research has shown that the presence of CT in a mixed forage improves protein utilisation and animal performance. This complementarity supports our hypothesis that single forages are unlikely to meet animal requirements for optimal performance and we must learn to complement pasture with feeds.

MIXED DIETS AND MAIZE SILAGE FOR DAIRY

Farmers mix chicory with red clover for high growth rates in sheep, and milk production responses have been achieved when chicory and turnips have been fed to complement mature pasture (Waugh *et al.*, 1998). Other examples of complementarity include birdsfoot trefoil with lucerne (Douglas *et al.*, 1995) but difficulties are often encountered with persistence of one or other species. Competition is also a problem with pastures where clovers have been virtually non existent since inexpensive urea has become available. Alternative feeding systems could include planting forages in adjacent strips, separate paddocks or cutting and carrying. Farmers in Northland have been feeding sulla because of its high nutritive value and lack of toxic endophyte and generally harvest, rather than graze, the sulla to minimise crown damage and encourage utilisation of stems as well as leaves. It is important to consider increased mechanisation with "new" forages, especially when farm products are achieving good returns.

The principal supplements currently fed with pasture involve substantial investment in planting and harvesting. For example, maize silage has been achieving significant growth in the dairying sector over the past 10-15 years. Maize silage (MS) provides a relatively cheap source of energy with the grain contributing 40-50% of the DM. Crude protein concentrations are low (7-8% DM), therefore MS can be complemented with high protein pasture to achieve a balance of dietary carbohydrate and protein. It is however crucial that pasture contain sufficient CP to accommodate the low protein in MS. Guidelines suggest that MS make up 20-35% of the diet in early lactation, 30-40% of the diet in late lactation and 60-70% of the diet during the dry period (Kolver, 2000). These guidelines are supported by Stockdale (1995). When MS is fed at levels greater than these guidelines protein will be limiting and milk production will be compromised despite adequate energy consumption.

The advantages of feeding maize silage with high quality pasture do not apply to mature swards where CP is 12-15% of the DM. Cows in mid lactation require 14-16% dietary CP and a protein supplement is required, rather than MS. Woodward *et al.* (2001) showed cows produced more milksolids (kg MS/cow/day) when pasture was supplemented with birdsfoot trefoil (1.29) than either MS (1.12) or pasture silage (1.11). This illustrates the importance of balancing pasture with a supplement to create a diet able to meet cow nutrient requirements, in contrast to making a guess as to which supplement is appropriate, perhaps based on cost alone. When cows in late lactation were fed pasture, milksolids production (kg/

cow/day) was greater when a mixture of MS and sulla were fed (1.02) compared to sulla alone (0.97), MS alone (0.86) or pasture (0.87). Voluntary intakes of cows fed the respective diets (15.5, 15.1, 14.5 and 16.9 kg DM/day) matched the production results. *In sacco* incubations of the forage mixtures supported a slow degradation of DM with pasture/MS (0.035 h^{-1}) relative to pasture/MS/sulla (0.057 h^{-1}) and pasture/sulla (0.101 h^{-1}; Burke, unpublished). The animal responses illustrate advantages of complementing mature ryegrass (although pasture quality was unusually high in this trial) with slowly degradable protein from sulla and energy from MS, and information derived from *in sacco* and *in vitro* incubations will help define optimal forage combinations for sheep or cows.

MIXED FORAGE DIETS FOR LAMBS

Lambs fed combinations of sulla with lucerne, and sulla with pasture had greater liveweight gains than lambs fed sole diets of lucerne or pasture, probably because of an increase in dietary soluble carbohydrates, low dietary fibre and protection of dietary protein. Sulla combined with white clover did not improve performance above either diet fed alone. The mixed diet contained only 23.9 % NDF and 23% CP in the dry matter but the high moisture content may have constrained intakes (Burke *et al.*, 2002). Sulla may not be an ideal supplement for lush, high protein spring pasture, however diets containing sulla resulted in lower rumen ammonia concentrations, lower acetate:propionate ratios and higher concentrations of propionic acid than diets without sulla (Burke *et al*., 2002).

The choice of diets fed to lambs (Burke *et al*., 2002) was based on *in vitro* incubations of individual forages and mixtures. It is essential that rapid screening methods be adopted to predict nutritive value of forages fed alone and as supplements to pasture in order to make best use of our soils, temperate climate and enable animals with high genetic merit to perform well. Both animal trials and *in vitro* and *in sacco* incubations have shown forages with CT are potentially useful supplements for pasture because they provide a source of slowly degrading protein that is particularly useful during summer. Sulla may be more favourable forage than the lotus species to supplement pasture because it can be fed with fibrous ryegrass-based pastures to dilute dietary fibre, supply soluble carbohydrates to the rumen bacteria, and any inhibition of protein breakdown by CT would be ameliorated through dilution by pasture. However, smaller supplements of the lotus species would provide a greater supply of UDP to the animal.

FORAGE MIXTURES FOR THE FUTURE

Research is defining mixtures of forages best able to supplement pasture at different times of the year, but the grazing livestock system is dynamic and no one combination is ideal for all livestock classes all year round. An optimal supplement will maximise nutritive value by encouraging high intakes of highly nutritious forages, with the overriding constraint being the profitable utilisation of ryegrass pasture.

Northern hemisphere TMR systems understand and address animal requirements during the season, therefore the New Zealand livestock industry should capitalize on this knowledge and use it within our grazing system. Unfortunately models are based on concentrates and do not apply to fresh forages so we need to know a lot more about digestion and fermentation in the rumen of the forage-fed grazing animal. Burke *et al.* (2000) and Chaves *et al.* (2001) have addressed this issue by defining the digestion and fermentation kinetics of individual and mixed diets using *in vitro* and *in sacco* methods. This information along with feed composition data from chemical or NIRS analyses will be used in conjunction with computer modelling programmes to predict which mix of forages will best complement pasture for animals in different physiological states to achieve defined levels of production. The Cornell model, CNCPS, has been tested against pasture fed dairy cows, but intakes are not predicted with sufficient accuracy (Kolver *et al.*, 1998). The fibre in pasture differs from that in TMR and this affects model performance.

In future, farmers will obtain comprehensive feed analyses including chemical composition, rates of digestion and prediction of metabolite yield during digestion. Our aim is to use this information in a ration-balancing model to predict the ideal mix of forages to complement ryegrass-based pastures and indicate the expected response.

Farmers will become more reliant on the strategic use of specialist forages that can be supplemented with and complement ryegrass pasture at different times of the year. Paddocks will be routinely planted in crops of species to provide high quality forages. For example a paddock of lucerne or sulla will provide a relatively cheap source of protein and energy that can be grazed during summer to complement mature pasture, but hay and silage can be harvested and fed when protein and/or energy is required. In winter, when cows have calved in autumn, pasture supply will limit milk production and maize silage may make up a large proportion of the diet, but the protein will come from lucerne/sulla/lotus silage fed with maize silage and pasture. Farmers will have the option to buy high quality feed as a silage from specialised growers. The success of these operations will depend on knowledge of feeding values, especially rates of fibre digestion to maximise intakes.

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