New Zealand Society of Animal Production online archive

This paper is from the New Zealand Society for Animal Production online archive. NZSAP holds a regular annual conference in June or July each year for the presentation of technical and applied topics in animal production. NZSAP plays an important role as a forum fostering research in all areas of animal production including production systems, nutrition, meat science, animal welfare, wool science, animal breeding and genetics.

An invitation is extended to all those involved in the field of animal production to apply for membership of the New Zealand Society of Animal Production at our website www.nzsap.org.nz

The New Zealand Society of Animal Production in publishing the conference proceedings is engaged in disseminating information, not rendering professional advice or services. The views expressed herein do not necessarily represent the views of the New Zealand Society of Animal Production and the New Zealand Society of Animal Production expressly disclaims any form of liability with respect to anything done or omitted to be done in reliance upon the contents of these proceedings.

This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.

You are free to:

- **Share** — copy and redistribute the material in any medium or format

Under the following terms:

- **Attribution** — You must give appropriate credit, provide a link to the license, and indicate if changes were made. You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.
- **NonCommercial** — You may not use the material for commercial purposes.
- **NoDerivatives** — If you remix, transform, or build upon the material, you may not distribute the modified material.

http://creativecommons.org/licenses/by-nc-nd/4.0/
**HIGH-ENERGY FORAGES AND FORAGE MIXED RATIONS**  

**CONTRACT PRESENTATION**

**CONTRACTORS:** W. C. MCNABB AND D.R. WOODFIELD

1. Can forages match concentrate diets for dairy production. G.C. Waghorn  
2. Improving animal performance using forage-based diets. J.L. Burke  
3. New opportunities to improve forage based production systems. D.M. Marotti  
4. Genetic modification to create novel high quality forages. N.J. Roberts

---

**Can forages match concentrate diets for dairy production?**

G.C. WAGHORN

AgResearch Grasslands, Palmerston North, New Zealand

**ABSTRACT**

Comparisons have been made between concentrate based total mixed rations (TMR) and grass dominant pasture for dairy production. Limitations to further improvement in cow performance have been indicated by the very high reticulo-rumen fill in New Zealand cows fed pasture, exceeding 22% of live weight, relative to United States cows fed either TMR or forage diets. The importance of high concentrations of structural fibre in ryegrass dry matter, moisture content of fresh forages and the very rapid eating associated with high utilization of pasture on New Zealand dairy farms will limit increases in feed intake and cow performance. Responses to ryegrass supplementation with high quality forages have been summarised together with suggestions for future research and farming systems to improve performance and profitability of cows fed forage diets.

**Keywords:** lactating cow, rumen fill, intake constraints

**INTRODUCTION**

The high milk production by cows in North America and Europe, relative to pasture fed cows in New Zealand is well known (Ulyatt & Waghorn, 1993). The reasons for high cow performance is partly due to a focus on individuals rather than a whole herd but mainly because cow nutrient requirements are met by offering rations formulated to balance requirements; total mixed rations (TMR). These grain and silage based diets have achieved an average production per cow of about 8000 kg/lactation in the United States compared to about 3500 kg/lactation for New Zealand cows. However, simplistic comparisons between dairying systems are not easy, because of differences in cow size, lactation length, reproductive performance, calving interval, attrition and veterinary intervention as well as nutrition. Genetic merit for milk production does not seem to be a major constraint to performance of New Zealand cows (e.g. Ulyatt & Waghorn, 1993). The principal limitation is nutrition and this paper will address some nutritional factors which limit productivity of cows grazing pasture.

New Zealand dairy farms have focused on an efficient harvest of a high proportion of the pasture offered, because this system has been low cost and profitable. Generations of management for high pasture utilization have resulted in cows which eat fast; the fastest eater gets the most pasture and the slowest has less to eat. The slow eater has a lower quality diet because it comprises less leaf, more sheath and stem and an increased likelihood of fungal endophyte and soil contaminants. Supplementation with maize or pasture silage has helped alleviate the nutritional stress placed on our cows (especially slow eaters, or those milked last) but we cannot predict the potential for forages to achieve high cow productivity unless feed is available ad libitum. A significant characteristic of TMR is that the feed never runs out—cows are given as much as they can eat. Ad libitum feeding is the first requirement for forage evaluation, but this can make comparisons between pasture and TMR difficult because few grazing studies provide true ad libitum intakes. Fortunately a series of trials at Dexcel (Hamilton) have involved grazing treatments where pasture allowances have been 60 kg DM/cow/day and the extensive measurements of heifer and herd performance (Kolver et al., 2000; Kolver, 2001) have provided data to illustrate some shortcomings of grass relative to a TMR (Table 1). The TMR contains about 50% concentrate (corn or barley grain with protein, vitamin and mineral supplements). These data are complemented by production data from recent trials in Hamilton and from the United States (Table 1) where pasture diets are being revisited because of costs, margins and reproductive problems associated with highly productive cows fed TMR.

Several factors stand out in a comparison between pasture and TMR.

1. Cows eat much more TMR than pasture. On an equal body weight basis, those fed TMR consume 15-50% more dry matter (DM) than pasture, with greatest
There are several characteristics of grass that prevent high intakes and digestion of grass leads to a different range of metabolites compared to grain based TMR. This paper will address constraints to intake and provide evidence that rumen-fill, and the need to physically break grass into small fragments to pass out of the rumen are major limitations to cow productivity. The importance of feeding the bacteria vs. using bacteria to digest recalcitrant fibre will be indicated because more than 70% of the cow’s energy is bacterial waste—the VFA. Comparisons with TMR diets suggest forages should support bacteria which produce propionate at the expense of acetate and proteinolysis to ammonia should be limited if high productivity is to be attained. The changing quality and digestion characteristics of maturing grass (Chaves et al., 2002) must be acknowledged and forages other than grass need to be evaluated (Burke et al., 2000, 2002) to indicate options for overcoming some of the limitations identified here.

### The reticulo-rumen

The reticulo-rumen (rumen) is the first compartment of the ruminant stomach. It is a storage vat, enabling feeds to be degraded by bacteria (with protozoa and fungi) and is maintained between pH 6.0-6.8 through copious salivary secretions during eating and rumination. Under forage feeding systems, a high proportion of forage entering the rumen is long (5-20 cm) although chewing during eating will rupture 50-60% of plant cells so that during eating will rupture 50-60% of plant cells so that 47% (grass)-61% (Lucerne) of DM will be reduced to a size able to pass through a 2 mm aperture in order to reach the oesophagus. There are several characteristics of grass that prevent high intakes and digestion of grass leads to a different range of metabolites compared to grain based TMR. This paper will address constraints to intake and provide evidence that rumen-fill, and the need to physically break grass into small fragments to pass out of the rumen are major limitations to cow productivity. The importance of feeding the bacteria vs. using bacteria to digest recalcitrant fibre will be indicated because more than 70% of the cow’s energy is bacterial waste—the VFA. Comparisons with TMR diets suggest forages should support bacteria which produce propionate at the expense of acetate and proteinolysis to ammonia should be limited if high productivity is to be attained. The changing quality and digestion characteristics of maturing grass (Chaves et al., 2002) must be acknowledged and forages other than grass need to be evaluated (Burke et al., 2000, 2002) to indicate options for overcoming some of the limitations identified here.

### The reticulo-rumen

The reticulo-rumen (rumen) is the first compartment of the ruminant stomach. It is a storage vat, enabling feeds to be degraded by bacteria (with protozoa and fungi) and is maintained between pH 6.0-6.8 through copious salivary secretions during eating and rumination. Under forage feeding systems, a high proportion of forage entering the rumen is long (5-20 cm) although chewing during eating will rupture 50-60% of plant cells so that 47% (grass)-61% (Lucerne) of DM will be reduced to a size able to pass through a 2 mm sieve (Waghorn et al., 1989). Much of this DM will be soluble, accounting for 35-40% of DM in ryegrass of all ages (Chaves et al., 2002) and 40-50% of legume DM (Burke et al., 2000). Bacteria have immediate access to soluble DM, including access through damaged cell walls and succulent forage such as lucerne leaf will have been completely degraded in as little as three hours (Kelly & Sinclair 1989). However the remaining 40-50% of grass DM imposes a severe limitation on further feed consumption because it comprises tough fibre which must be reduced to a size able to pass through a 2 mm aperture in order to reach the omasum, abomasum and intestines.

The need to reduce feeds to this very small size (indicated by the consistency of faeces) which limits the intake of grasses. Fibre in grass is a tough lignified matrix of cellulose intertwined with hemicellulose and held together with lignin (Wilson, 1993). Lignin is not
degraded by bacteria and cellulose and hemicellulose are only degraded by adherent bacteria. Hence the rate of fibre degradation can only be increased by increasing the available surface area for bacterial colonisation, and this is achieved largely by chewing during eating and rumination. Ruminants are able to live on forages with high concentrations of fibre but the rate of degradation is slow and the time required for the fibre to be physically reduced in size is the principal cause of low feed intakes and low performance of cattle fed grass dominant pasture.

**Fibre, chewing and clearance**

If forages are to match concentrate based diets, it is essential to clear residual fibre quickly. This could be achieved by more chewing during eating or development of a brittle fibre easily broken into fragments able to exit the rumen. The relatively ineffectual chewing during eating may be a consequence of our dairy management and the moist, soft and flexible nature of ryegrass leaves. Generations of breeding for efficient pasture harvest appears to have resulted in fast eaters more intent on tearing and swallowing grass than chewing it. Bolus formation for swallowing will be relatively rapid with long flexible leaves and the high moisture content of our pastures. It is surprising that as much as 50% of cells are ruptured during eating.

Contrast this with TMR. About 50% of the material needs no chewing, and one dilemma faced by ration balancers is to encourage efficient rumen fermentation rather than outflow. About 50% is roughage – either chopped hay or silage. The diet is about 50-60% dry matter (Table 2) and a rapid DM intake is possible with relatively little eating time. However lactating cows consuming a TMR spend about 300 minutes per day eating (in 10-12 bouts) and a further 450 minutes ruminating (12-13 bouts) (Dado & Allen, 1994; Shaver et al., 1988b). The cow carries out 40-50000 chews per day (Dado & Allen, 1994) to consume 44 kg of feed, half of which needs no chewing, and the remaining forage has been chopped to 1-2 cm lengths, so very considerable mastication and incorporation of saliva will have occurred with the TMR diet. Dado and Allen (1994) reported 90-103 kg rumen fill (15-17% of live weight) for cows fed TMR (Table 3). A cow eating pasture will swallow at least twice as much feed, and although a high proportion of the DM is soluble, the remaining fibre is long and requires extensive breakdown, but chewing records for lactating cows grazing (or fed) pasture do not appear to be available for comparison.

High-fibre TMR contain 35% neutral detergent fibre (NDF) and are avoided in early lactation because of constraints to intake. Contrast this with normal values for grass (40-55% of the DM; Tables 1 and 4) and the excessive NDF in grass is reflected in rumen digesta volumes. The NDF component in grass differs in structure and ruminal function to that of lucerne and maize; it is flexible, not scratchy and associations with “effective fibre” should be treated with caution.

Table 3 summarises United States and New Zealand rumen volume data from cows fed either pasture or TMR.

<table>
<thead>
<tr>
<th>Origin</th>
<th>Diet Description</th>
<th>DMI kg</th>
<th>Milk kg</th>
<th>Digesta kg</th>
<th>Digesta % LW</th>
<th>DM %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>USA</strong></td>
<td>40:60 concentrate : forage (cows 583 kg)</td>
<td>23.3</td>
<td>38.0</td>
<td>67</td>
<td>11.5</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td>Immature lucerne</td>
<td>20.0</td>
<td>32.1</td>
<td>74</td>
<td>12.7</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>Mature lucerne</td>
<td>17.9</td>
<td>29.7</td>
<td>90</td>
<td>15.4</td>
<td>14.4</td>
</tr>
<tr>
<td></td>
<td>Corn silage</td>
<td>23.7</td>
<td>36.5</td>
<td>67</td>
<td>11.5</td>
<td>16.3</td>
</tr>
<tr>
<td><strong>USA</strong></td>
<td>High and low forage TMR (cows 594 kg)</td>
<td>22.8</td>
<td>37.0</td>
<td>90</td>
<td>15.2</td>
<td>14.3</td>
</tr>
<tr>
<td></td>
<td>Low forage, 25% NDF</td>
<td>18.7</td>
<td>31.4</td>
<td>103</td>
<td>17.3</td>
<td>13.0</td>
</tr>
<tr>
<td><strong>USA</strong></td>
<td>Pasture alone and with concentrate (cows 650 kg)</td>
<td>19.8</td>
<td>30.4</td>
<td>71</td>
<td>11.0</td>
<td>15.7</td>
</tr>
<tr>
<td></td>
<td>Pasture+10 kg concentrate</td>
<td>13.9</td>
<td>21.8</td>
<td>77</td>
<td>12.0</td>
<td>15.1</td>
</tr>
<tr>
<td><strong>USA</strong></td>
<td>Forage or silage with concentrate (cows 672 kg)</td>
<td>21.9</td>
<td>24.1</td>
<td>75</td>
<td>11.1</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>Lucerne silage+7.6 kg concentrate</td>
<td>19.2</td>
<td>23.3</td>
<td>59</td>
<td>8.8</td>
<td>12.2</td>
</tr>
<tr>
<td></td>
<td>Pasture+6.7 kg concentrate</td>
<td>17.7</td>
<td>23.8</td>
<td>61</td>
<td>9.1</td>
<td>13.2</td>
</tr>
<tr>
<td><strong>NZ</strong></td>
<td>Pasture fed cows (423 kg)</td>
<td>13.1</td>
<td>NA</td>
<td>71</td>
<td>16.7</td>
<td>8.8</td>
</tr>
<tr>
<td><strong>NZ</strong></td>
<td>Cows fed grass with silage, period A (cows 558 kg)</td>
<td>16.3</td>
<td>15.8</td>
<td>123</td>
<td>22.5</td>
<td>12.4</td>
</tr>
<tr>
<td></td>
<td>Grass</td>
<td>16.5</td>
<td>15.8</td>
<td>120</td>
<td>22.5</td>
<td>10.3</td>
</tr>
<tr>
<td></td>
<td>Grass+silage</td>
<td>16.9</td>
<td>16.8</td>
<td>114</td>
<td>20.2</td>
<td>12.3</td>
</tr>
<tr>
<td></td>
<td>Grass+slulla silage</td>
<td>15.2</td>
<td>16.4</td>
<td>112</td>
<td>19.0</td>
<td>11.4</td>
</tr>
<tr>
<td><strong>NZ</strong></td>
<td>Cows fed grass with silage, period B (cows 533 kg)</td>
<td>13.6</td>
<td>13.0</td>
<td>92</td>
<td>16.9</td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td>Grass</td>
<td>15.0</td>
<td>14.2</td>
<td>110</td>
<td>19.9</td>
<td>10.4</td>
</tr>
<tr>
<td></td>
<td>Grass+silage</td>
<td>14.4</td>
<td>14.3</td>
<td>102</td>
<td>19.2</td>
<td>10.7</td>
</tr>
<tr>
<td></td>
<td>Grass+slulla silage</td>
<td>10.3</td>
<td>12.3</td>
<td>99</td>
<td>19.7</td>
<td>11.1</td>
</tr>
</tbody>
</table>

**Abbreviations:** NDF, neutral detergent fibre; LW, live weight.

Principal observations are smaller rumen pools (% of live weight) with TMR than pasture fed with concentrates or as a sole diet in USA cows, and the very high values recorded with New Zealand cows fed pasture based diets. Care has been taken to select equivalent data sets, with rumen measurements taken 2-4 hours after feeding and between about 60-150 days of lactation. Only a few data are available for New Zealand cows but the mass of rumen contents must represent a limit to both productivity and to future selection for improvements in productivity of cows grazing grass.

The digesta in cows (Woodward & Waghorn, unpublished) were packed so tight as to prevent penetration (by hand) to the ventral rumen. This mass of packed digesta is supposedly mixed and must be reduced in size to that of faeces in order that more food be eaten. In contrast, rumen contents from cows fed TMR are viscous and mobile, probably easily regurgitated for rumination and much of it is small enough to exit from the rumen without further chewing. Intake and outflow for cows fed TMR may be regulated by intestinal and other metabolic feedback, but for pasture, control is almost certainly through rumen distension and chewing.

Forages for high intakes

Burke et al. (2000, 2002) have evaluated grasses, legumes, herbs and silages by measuring chemical composition, products of digestion using in vitro techniques and rates of microbial degradation with in sacco bags in the rumen. Data from that work show very low structural fibre concentrations in sulla (Hedysarum coronarium), chicory (Cichorium intybus), white clover (Trifolium repens) and birdsfoot trefoil (Lotus corniculatus) ranging from 22.4-28.2% NDF in the DM. These forages had very rapid rates of in sacco degradation (0.12-0.26 h⁻¹) relative to perennial ryegrass which ranged from 0.067 h⁻¹ with young leafy material to 0.038 h⁻¹ at 60 days of age (Chaves et al., 2002).

Feeding trials with lambs (Ulyatt, 1981; Douglas et al., 1995; Burke et al., 2002) have provided an equal ranking for either white clover or sulla fed alone or mixed and Lotus corniculatus, all of which are superior to lucerne, Lotus pedunculatus and all grasses (Burke et al., 2002). Trials with lactating cows by Woodward (Harris et al. 1997, 1998; Woodward et al., 1999) have confirmed the superior feeding value of some of these forages relative to pasture (Table 4) but it will be necessary to determine rumen volumes and to measure outflow rates in order to understand limitations to performance. Whilst the chemical composition and digestion kinetics suggest potentially high intakes, the DM content of these forages are low; chicory, 8-10%; sulla, 12-14%; Lotus species, 12-16% and white clover, 16-18%. Verité & Journet (1970) demonstrated reductions in voluntary feed intakes when forage DM% was less than 16% for cattle, later confirmed by John & Ulyatt (1987). Wilting is able to increase intakes of wet material, supporting the importance of bulk (Ulyatt & Waghorn, 1993) and increasing the DM contents of these low fibre forages may be a viable challenge for molecular biology.

Optimal fermentation

TMR diets are associated with high ratios of glucogenic VFA (propionate (P)) at the expense of acetate (A) and butyrate. In vitro incubations (Burke et al., 2000) have shown A:P ratios of only 2.2 for sulla and 2.3 for white clover in contrast to values over 3.5 for most grasses (Burke, unpublished). These findings have been confirmed in trials with young lambs where rumen A:P ratios were 2.6 in lambs fed sulla, compared to 3.3 with white clover, 3.4 with lucerne and 4.1 when pasture was fed (Burke et al., 2002).

Although few forages contain high concentrations of readily fermentable or non structural carbohydrate, many

---

**TABLE 4:** Lactation responses by New Zealand cows to pasture supplements or feeding high quality legumes. All data from cows in the second half of lactation.

<table>
<thead>
<tr>
<th>Dietary* treatment</th>
<th>DM (kg)</th>
<th>Milk (kg)</th>
<th>MS (kg)</th>
<th>% MS to supplement</th>
<th>Composition of supplement or diet</th>
<th>DM %</th>
<th>CP</th>
<th>NDF</th>
<th>ME</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Pasture</td>
<td>10.4</td>
<td>0.87</td>
<td>–</td>
<td>–</td>
<td>Pasture</td>
<td>22.8</td>
<td>24.3</td>
<td>48.5</td>
<td>9.7</td>
</tr>
<tr>
<td>Pasture+turnips</td>
<td>11.3</td>
<td>0.99</td>
<td>+14</td>
<td>–</td>
<td>Turnip</td>
<td>9.0</td>
<td>16.0</td>
<td>21.1</td>
<td>(12.0)</td>
</tr>
<tr>
<td>Pasture+chicory</td>
<td>10.8</td>
<td>0.93</td>
<td>+7</td>
<td>–</td>
<td>Chicory</td>
<td>7.5</td>
<td>22.9</td>
<td>19.8</td>
<td>11.4</td>
</tr>
<tr>
<td>2 Pasture</td>
<td>8.8</td>
<td>0.81</td>
<td>0.72</td>
<td>–</td>
<td>–</td>
<td>19.7</td>
<td>55.9</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Pasture+turnips</td>
<td>13.0</td>
<td>0.90</td>
<td>+25</td>
<td>–</td>
<td>Turnip</td>
<td>10.8</td>
<td>12</td>
<td>23</td>
<td>–</td>
</tr>
<tr>
<td>Pasture+sorghum</td>
<td>12.0</td>
<td>0.77</td>
<td>+7</td>
<td>–</td>
<td>Sorghum</td>
<td>14.2</td>
<td>9.6</td>
<td>65.0</td>
<td>–</td>
</tr>
<tr>
<td>3 Ryegrass</td>
<td>10.9</td>
<td>9.0</td>
<td>0.84</td>
<td>–</td>
<td>Grass</td>
<td>21.0</td>
<td>14.3</td>
<td>61.8</td>
<td>9.5</td>
</tr>
<tr>
<td>Ryegrass+25% WC</td>
<td>11.1</td>
<td>1.11</td>
<td>1.01</td>
<td>+20</td>
<td>WC</td>
<td>15.0</td>
<td>24</td>
<td>34</td>
<td>11.5</td>
</tr>
<tr>
<td>Ryegrass+50% WC</td>
<td>11.5</td>
<td>1.19</td>
<td>1.09</td>
<td>+30</td>
<td>WC</td>
<td>11.9</td>
<td>55.9</td>
<td>–</td>
<td>10.0</td>
</tr>
<tr>
<td>4 Pasture</td>
<td>11.3</td>
<td>1.17</td>
<td>0.90</td>
<td>–</td>
<td>–</td>
<td>11.9</td>
<td>55.9</td>
<td>–</td>
<td>10.0</td>
</tr>
<tr>
<td>Grass+75% WC</td>
<td>14.6</td>
<td>1.54</td>
<td>1.15</td>
<td>+28</td>
<td>Diet</td>
<td>18.4</td>
<td>20.9</td>
<td>38.4</td>
<td>11.5</td>
</tr>
<tr>
<td>Grass+75% Lotus</td>
<td>13.0</td>
<td>1.67</td>
<td>1.28</td>
<td>+42</td>
<td>Diet</td>
<td>17.9</td>
<td>22.4</td>
<td>75.4</td>
<td>11.8</td>
</tr>
<tr>
<td>5 Ryegrass</td>
<td>14.7</td>
<td>10.2</td>
<td>0.85</td>
<td>–</td>
<td>Ryegrass</td>
<td>22.4</td>
<td>18.2</td>
<td>52.9</td>
<td>10.6</td>
</tr>
<tr>
<td>Lotus–CT</td>
<td>16.7</td>
<td>13.8</td>
<td>1.13</td>
<td>+33</td>
<td>Lotus</td>
<td>14.1</td>
<td>25.6</td>
<td>30.4</td>
<td>11.4</td>
</tr>
<tr>
<td>Lotus+CT</td>
<td>16.8</td>
<td>16.5</td>
<td>1.40</td>
<td>+65</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

* Cows in Trials 1, 2, 3 all received 25 kg DM pasture allowance.

Abbreviations:
DM, dry matter; DM, DM intake; CP, crude protein; NDF, neutral detergent fibre; ME, metabolisable energy; WC, white clover; Lotus, Lotus corniculatus; CT, condensed tannin (CT indicates inactivation by daily administration of polyethylene glycol).

1 Waugh et al., 1998; 2 Clark et al., 1997; 3 Harris et al., 1997; 4 Harris et al., 1998; 5 Woodward et al., 1999.
contain high concentrations of readily degradable protein. Total mixed rations may contain about 30% fermentable carbohydrate and 17% crude protein, (total 47%) of which about two thirds is digested in the rumen. White clover, sulla, red clover, lucerne and Grasslands Tama ryegrass (Lolium multiflorum) contain in excess of 35% readily degradable carbohydrate plus protein, and although less than TMR diets, this does provide a substantial highly fermentable substrate for bacteria. Good use could be made of these forages if protein degradation could be slowed, and this is readily achieved with diets containing condensed tannins (McNabb et al., 1996; Waghorn et al., 1999).

**Principal constraints to production from forages**

This resumé suggests that forages such as sulla, lotus species, white clover and chicory will have few nutritional limitations associated with intransigent fibre characteristic of ryegrass, but the very high moisture content of these forages is likely to limit intake. The growth habit of sulla, and risks of crown damage, suggest a cut and carry system may be an appropriate management, in which case chopping and possibly wilting may be considered, but wilting will result in a rapid utilisation of soluble sugars to respiration and is likely to lower the feeding value.

Current information from *in vitro* incubations and sheep trials suggest these diets will produce a range of VFA similar to those from TMR (A:P 2.5-3.2) and the inclusion of condensed tannin in these diets will reduce rumen protein degradation so the amino acid demands for milk protein synthesis could be met. High protein diets carry a cost associated with ammonia disposal to urea, and lower degradation (with diets containing tannin) will be beneficial.

These options must be tested in order to further progress, and it is particularly important that high quality forages be fed from calving to properly evaluate their potential. The rapid and excessive loss of liveweight and condition experienced by New Zealand cows grazing pasture during the first 6 weeks of lactation must be reduced, and high quality forages may be more important during this phase of lactation than during summer when many supplements have been tested (Table 4). The mixture of forages may best be determined with assistance of nutrition/metabolism based simulation models, such as CNCPS (Cornell Model) although current focus of many models is toward concentrate and silage based TMR.

**Future opportunities**

Use of existing cultivars will not achieve levels of production achieved with TMR because of moisture or fibre constraints, and feeding cows with low fibre rapidly degradable feedstuffs is not an optimal solution. However more information on rumen characteristics associated with digestion of legumes than discussed here, fed in mixtures with pasture, will form a basis for long-term progress in forage-based dairy nutrition. A longer-term vision must focus on forages which have a high DM production, and are persistent. Grasses meet these criteria, with persistence being an important attribute, especially in view of greenhouse gas emissions associated with annual cultivation, use of machinery, high fertiliser inputs etc (Robertson & Waghorn, 2002). The challenge to plant breeders is to modify our most valuable forage by altering its fibre so the plant remains upright, but the fibre breaks up readily to clear the rumen. Add soluble carbohydrates, reduce protein content and degradability and decrease the moisture content. We then must feed appropriate mixtures of the new grasses with our legumes or grains and our cows will be more healthy and produce more milk. There is a lot of work to be done!

**REFERENCES**


