Do forage legumes have a role in modern dairy farming systems?

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Intensification in New Zealand dairy farming systems has placed greater pressure on clover performance and fitness and has highlighted the need to develop clover cultivars that are better adapted to intensive grazing systems. Increased stocking rates and increased use of nitrogen fertiliser have put enormous pressure on the contribution of clover to modern dairy systems. Future innovations such as semi-hybrid cultivars offer the potential to improve the competitiveness of legumes with nitrogen-fertilised forage grasses. Similarly, advances in condensed tannin research suggest that significant animal performance gains can be achieved in conjunction with reduced environmental impact. In order to capture these benefits, dairy farmers will need to reassess their grazing management to ensure that legumes can be maintained at economically useful levels. Novel grazing management systems that optimise the benefits provided by the grass and legume components need to be used in future dairy farming systems. Forage legumes, and especially white clover, have an important role to play in modern dairy systems.

Keywords: dairy cows; genetic improvement; grazing management; white clover

Introduction
Forage legumes are used in temperate regions to improve the feeding value of dairy pastures and to provide low-cost N from nitrogen fixation (Ulyatt, 1973). They are also increasingly seen as an important component of environmentally-sustainable grassland ecosystems because of their persistence under grazing, their ability to improve soil structure and also the potential of legumes with condensed tannins to reduce methane emissions (Waghorn et al., 1998; Waghorn, Tavendale and Woodfield, 2002).

Dairy systems in the Southern Hemisphere have historically been dif-
differentiated from those in the Northern Hemisphere by their greater duration and intensity of grazing, their limited use of supplementary feed, irrigation and N fertiliser, and by the significant contribution of forage legumes to overall production (Holmes, 2007). However, increasingly this distinction has become blurred with more supplementary feed, more irrigation and increased N fertiliser use on dairy farms in Australia and New Zealand.

This paper is concerned with the impact of these factors on the role of forage legumes, and in particular white clover (*Trifolium repens* L.), in modern dairy farming systems. Breeding innovations that will improve the adaptation of legumes for future systems are also considered.

**Economic pressure on use of clover in intensive farming systems**

The complete removal of agricultural subsidies in New Zealand during the 1980’s drove dairying down an intensification pathway to remain economically viable. New Zealand’s current 33% share of internationally-traded dairy products (Dairy Australia, 2008) is absolutely dependent on producing milk at lower cost than international competitors. This low cost of production has been achieved through a favourable temperate climate that allows year-round grazing of traditional grass/legume pastures.

Intensification and expansion in the Australasian dairy industry has been spectacular over the past 20 years (Table 1). The average number of cows per herd has more than doubled in both Australia and New Zealand since 1990, and there have been large increases in per cow production in New Zealand (19%) and Australia (38%). However, the biggest change by far in New Zealand has been the 70% increase in the total number of cows since 1990. Low commodity prices for wool and sheep meat have driven conversion of land from sheep and cropping to dairying, with this trend most evident in the South Island. Along with this conversion, the price of dairy farming land has increased by approximately 350% over the past 20 years (Figure 1), which has far exceeded any increases in milk payout to farmers (LIC, 2008). All of these indicators of intensification have slowed since the global economic crisis hit in 2008, but are likely to continue once these financial pressures have eased.

Intensification has placed greater pressure on clover performance and fitness for these farming systems (Clark, Matthew and Crush, 2001; Lambert, Clark and Litherland, 2004), and has highlighted the need to develop clover cultivars that are better adapted to intensive grazing systems. Increased stocking rate and increased use of N fertiliser have put enormous pressure on the contribution of clover to modern dairy systems. Over the past 20 years there has been a 700% increase in use of fertiliser N

<p>| Table 1. Intensification of dairy industry in Australasia since 1990 (LIC, 2008; Dairy Australia, 2008) |</p>
<table>
<thead>
<tr>
<th>Year</th>
<th>New Zealand</th>
<th>Australia</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of farms</td>
<td>14,595</td>
<td>11,436</td>
</tr>
<tr>
<td>Cows (million)</td>
<td>2.31</td>
<td>4.01</td>
</tr>
<tr>
<td>Average herd size</td>
<td>158</td>
<td>351</td>
</tr>
<tr>
<td>Stocking rate (cows/ha)</td>
<td>2.40</td>
<td>2.83</td>
</tr>
<tr>
<td>Production per cow</td>
<td>259 kg MS(^1)</td>
<td>307 kg MS</td>
</tr>
</tbody>
</table>

\(^1\) Milk solids (fat plus protein) per cow was first measured in 1992/93 season.
in New Zealand farming systems, with the largest increases occurring in dairy farming systems (Parfitt, Schipper and Baisden, 2006; Figure 2). Use of N promotes grass growth over clover growth, while shading by grass reduces the intensity and quality of radiation reaching the stolon node which leads to fewer branched nodes and less well developed stolons (Thompson, 1993). This increased competition combined with the arrival in New Zealand of the clover root weevil (Sitona lepidus), has resulted in lower white clover content in New Zealand dairy pastures (Gerard, Hackell and Bell, 2007). The current high cost of N fertiliser relative to the commodity prices for milk does suggest that farmers will need to re-evaluate the long-term role of clover in their system and look at changes to their

Figure 1. The average price (in inflation adjusted NZ dollars) of New Zealand dairy land between 1988 and 2008 (LIC, 2008).

Figure 2. Nitrogen fertiliser (tonnes of N) sales in New Zealand between 1960 and 2006.
management practices to promote higher clover content in pastures.

The increased use of supplementary feeds can also have an effect on clover performance when supplements substitute for otherwise high quality pastures. In these cases pasture quality is reduced as grazing interval is extended and white clover experiences increased competition from the grass for light and water.

The value of clover for milk production

The value of white clover for milk production is unequivocal, with its higher nutritive value, higher intake characteristics and faster rate of passage translating into better milk production than for perennial ryegrass (*Lolium perenne* L.) (Thomson *et al.*, 1985; Johnson and Thomson, 1996).

White clover content of New Zealand dairy pastures generally ranges from 10 to 20% but Harris *et al.* (1997) demonstrated that maximum milk production was achieved when clover content exceeded 50%. Increasing clover content to 50% of the total sward resulted in higher crude protein (+29%), metabolisable energy (+11%), and herbage intake (+23%), which resulted in 33% more milk produced per cow (Table 2). Unfortunately the dynamic nature of clover/grass swards means that clover contents are rarely higher than 30% and more frequently are between 10 and 20% (Chapman, Parsons and Schwinning, 1996). However, improved milk yields do occur even at quite low (5 to 10%) clover contents

The value of other legumes, such as birdsfoot trefoil (*Lotus corniculatus*), has also been demonstrated in grazing trials. Milk yield per cow from a Lotus dominant sward was 10% and 47% higher than a white clover dominant sward and a perennial ryegrass dominant sward, respectively (Harris, Clark and Laboyrie, 1998). Unfortunately, birdsfoot trefoil has lower herbage yield and poorer persistence under intensive grazing management than white clover, which limits its practical value in modern dairy systems.

Milk composition can also be affected by increased clover content and/or alternative legumes. Milk fat concentration tended to to decline with increasing white clover and lotus content, while milk protein and lactose levels were enhanced with Lotus and to a lesser degree white clover (Harris *et al.*, 1997 and 1998). Milk solids (MS; fat plus protein) yield also increases with increasing legume content due predominantly to higher milk yields (Harris *et al.*, 1997 and 1998).

Other perennial legumes that are used to varying degrees in dairy farming systems include red clover (*Trifolium pratense* L.) and lucerne (*Medicago sativa* L.). Red clover performs well in high fertility pastures and under lax grazing but fails to persist beyond 3 years under intensive grazing (Cosgrove and Brougham, 1985). The high herbage yields that can be achieved with lucerne make it an attrac-

<table>
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<tr>
<th>Quality parameter</th>
<th>Grass sward without clover</th>
<th>Grass sward with 50% clover</th>
</tr>
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<tbody>
<tr>
<td>Crude protein (g/kg)</td>
<td>143</td>
<td>184</td>
</tr>
<tr>
<td>Estimated ME (MJ/kg DM)</td>
<td>9.5</td>
<td>10.5</td>
</tr>
<tr>
<td>Herbage DM intake (kg cow⁻¹day⁻¹)</td>
<td>12.1</td>
<td>14.8</td>
</tr>
<tr>
<td>Milk yield (L cow⁻¹day⁻¹)</td>
<td>10.2</td>
<td>13.6</td>
</tr>
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</table>

Table 2. Change in forage quality of swards with either no clover or 50% clover content when grazed *ad libitum* (50 kg cow⁻¹day⁻¹) dry matter (DM) allowance¹

¹ Adapted from Harris *et al.* (1997).
tive option but difficulties with grazing lucerne *in situ* during winter and early spring have limited its use in current dairy systems. The main use of lucerne remains as a conserved forage although ongoing breeding efforts to improve the grazing tolerance of lucernes offer potential for greater use in the future.

**Grazing management and soil fertility**

The non-irrigated perennial ryegrass/white clover pastures that form the base New Zealand’s intensively-managed pastures have a maximum DM yield of about 15 to 16 t ha\(^{-1}\) year\(^{-1}\) (Clark *et al.*, 2001). This system has been effective due to high stocking rates and to managing calving dates so that seasonal pasture supply matches animal demand.

Current grazing management practices are optimised for grass growth with minimal focus on clover. White clover is particularly vulnerable to mismanagement and environmental stresses during spring when the size of individual plants is at its smallest (Brock and Hay, 1996). Brock (1988) showed that under rotational grazing there was a 75 to 90% reduction in stolon mass and that clover content decreased from 15% to 2% during a spring drought. New stolons are produced in early spring and once they become established above the soil surface, older stolons and their associated roots start to die. This causes large plants to break up into many smaller clonal units in the spring and stolon death frequently exceeds stolon growth. This reduction in plant size is occurring as the companion grasses are growing most actively, and the frequency and intensity of defoliation become critical factors in persistence of white clover plants. Frequent grazing by cattle during spring favours the growth and survival of white clover as it reduces competition for light and leads to much higher stolon growing-point density (Brock and Hay, 1996). Heavy treading reduces the yield of white clover in both monocultures or in mixed swards, and this effect is greater at higher stocking rates and in winter when soils are wet.

Management practices such as longer grazing intervals and N fertiliser also contribute to higher grass tiller density which increases competition for white clover. Tiller density plays an important role in influencing the rate of stolon formation and thereby clover content. Brereton, Carton and Conway (1985) showed that clover content decreased once tiller density increased above 5000/m\(^2\). Tiller density frequently exceeds 5000/m\(^2\) under rotational grazing and can be 11000 to 15000/m\(^2\) under continuous grazing. Endophyte-containing ryegrasses, which now dominate the Australasian dairy market, can also reduce clover persistence. The enhanced growth and insect resistance provided by the endophyte can result in higher tiller densities that are more competitive against white clover and can reduce clover yield and persistence (Thom, 2008).

Phosphate and sulphate fertilisers are applied to stimulate white clover growth and N fixation, and subsequently grass growth. However, N levels are deficient in many New Zealand pastures due to sub-optimum clover levels. White clover content can be reduced by N application levels as low as 100 kg/ha. The current trend in New Zealand dairying has been to apply fertiliser N at rates as high as 400 kg/ha, and at these high rates clover content is generally less than 5% (Harris *et al.*, 1996). At intermediate levels of N (100 to 200 kg ha\(^{-1}\) y\(^{-1}\)) a higher stocking rate can prevent this loss in clover content because the additional forage produced is better utilised and the clover receives less shading (Harris *et al.*, 1996).

Novel management options such as growing the clover and grass components as
monoculture rather than in mixtures have given promising results. Nuthall, Ruther and Rook (2000) reported an increase in milk yield of 2 to 3 kg cow\(^{-1}\) day\(^{-1}\) when cows were offered adjacent monocultures of grass and clover rather than a mixed sward in early lactation. Similarly studies in New Zealand involving both spatial and temporal allocation of clover and grass have given increases of 26 to 33% in milk yield (Cosgrove et al., 2006). While this approach clearly offers potential to improve milk yield and to allow targeted use of nutrients such as N and P, it has not been effectively integrated into existing dairy farming systems.

**Clover Improvement**

Genetic improvements of about 1% per year for herbage yield, N fixation, and animal performance have been reported for white clover and red clover. These annual incremental improvements may seem small but each 1% improvement in clover yield is worth more than NZ$20M annually to the New Zealand economy (Woodfield, 1999). These levels of genetic improvement also compare very favourably with those reported for perennial ryegrass (0.5 to 0.7% per year; Woodfield, 1999).

New Zealand-bred white clovers have been extensively used in Ireland and the UK, with the public variety Grasslands Huia marketed widely for 50 years due to its low seed price rather than its agronomic superiority over other varieties. In 1991, a white clover breeding programme involving two New Zealand companies (AgResearch and Midlands Seed) and a European company (Barenbrug) began to develop new varieties that were specifically adapted to European farming systems. This brought together the extensive agronomic testing network of Barenbrug, the breeding expertise and genetic resources of AgResearch and the seed production capability of Midlands Seed. Examples of improvements in key traits that have been achieved are used to illustrate current progress and what is likely to be achievable in the future.

The new varieties (Crusader and Barblanca) have shown particularly strong cool-season growth with improved spring and autumn growth evident in results from Northern Ireland and NIAB list trials from England and Wales (Figure 3 and Table 3). In Northern Ireland, Crusader and Barblanca have shown excellent spring growth. Crusader also has the best autumn yield of the small-leaved varieties, while Barblanca was among the top varieties for autumn growth (Table 3). This extended growing season appears to be a key factor in improving the competitiveness of white clover in grass swards.

The improved spring growth of Crusader white clover in Northern Ireland, when compared with its closest morphological comparator in Avoca (Figure 4), is occurring when white clover is normally under greatest pressure from companion grasses. This improved spring growth is due to inclusion of genetic sources with better cool season growth with Mediterranean germplasm in particular lifting winter activity. Further improvements in both spring and autumn clover growth can be expected to give an even better spread of clover production across the milking season; however, this will have to be balanced against potential damage from frost and freezing.

White clover breeding efforts have also focussed on improving the competitive ability of white clover through:

(i) better stolon growth in association with companion grasses,

(ii) identifying critical morphological characteristics such as different stolon
Table 3. Seasonal dry matter yield and leaf size of white clover varieties relative to the performance of Grasslands Huia in Northern Ireland (adapted from Gilliland, 2008)

<table>
<thead>
<tr>
<th>Variety</th>
<th>Relative leaf size</th>
<th>Seasonal Dry Matter Yield (Huia = 100%)</th>
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<tbody>
<tr>
<td></td>
<td>%</td>
<td>Spring</td>
</tr>
<tr>
<td>Demand</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>Crusader</td>
<td>84</td>
<td>100</td>
</tr>
<tr>
<td>Avoca</td>
<td>92</td>
<td>118</td>
</tr>
<tr>
<td>Aberdai</td>
<td>98</td>
<td>121</td>
</tr>
<tr>
<td>Huia</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Chieftain</td>
<td>104</td>
<td>184</td>
</tr>
<tr>
<td>Alice</td>
<td>126</td>
<td>142</td>
</tr>
<tr>
<td>Barblanca</td>
<td>126</td>
<td>188</td>
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Figure 3. Annual clover yield, in the third year, of 22 white clover varieties in UK Recommended List trials relative to the yield of Menna (=100%). (Adapted from NIAB 2003).

Figure 4. The seasonal yield of clover dry matter (DM) for Crusader and Avoca white clover cultivars in Northern Ireland (adapted from Gilliland, 2008).
and root morphologies which improve persistence (Caradus and Chapman, 1996), and (iii) improved growth under high N conditions.

Selection for increased stolon density has been important in improving the persistence of white clover in New Zealand. Cultivars such as Sustain and Kopu II have significantly higher stolon density than older cultivars with similar leaf size (Woodfield et al., 2001). Maintaining leaf size, while selecting for increased stolon growing-point density, has been shown to be important so that yield potential is not sacrificed when seeking better persistence.

New innovations for future dairy systems

Improvements of around 1% per year are likely to continue to be made by breeding for productivity traits such as yield potential and persistence, however there are a number of innovations that may provide more substantial lifts in animal performance.

The potential to capture heterosis by developing hybrid F1 cultivars has been highlighted over several decades. Hybrid breeding schemes that depend on inbreeding have been tried in the UK, Japan and New Zealand but the severe inbreeding depression has meant that little progress has been made. Recent efforts to develop semi-hybrid cultivars may offer new hope (Brummer, 1999). A recent evaluation of semi-hybrid white clovers under dairy grazing in New Zealand has shown that these semi-hybrids produced 50% more DM than conventional cultivars over 3 years in a replicated small-plot trial (Table 4). Testing in small plots probably over-estimates the size of this yield advantage, however, the substantial yield advantages that were evident in the final year of this evaluation after the Waikato had experienced the worst drought in 100 years suggest that this is an exciting breeding method. Sufficient seed has been produced to begin evaluating the semi-hybrid white clover in large-scale plots at multiple locations under dairy grazing.

Another new frontier that is being actively explored involves better utilisation of the genetic resources that sit within the wild relatives of white clover (Williams, Easton and Jones, 2007). The majority of these related species have poor agronomic value but contain genes for useful traits such as drought tolerance, salinity tolerance, pest and disease resistance, establishment vigour and forage quality. New clover hybrids between white clover and several wild relatives (T. ambiguum, T. uniflorum and T. occidentale) are all being used to introgress new genes into white clover.

Condensed tannins (CT) offer potential to improve protein utilisation by dairy cows, and development of CT-containing forages remains an important breeding

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<tr>
<td></td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Huia</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Kopu II</td>
<td>121</td>
<td>133</td>
</tr>
<tr>
<td>Tribute</td>
<td>135</td>
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</tr>
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<td>Aran</td>
<td>128</td>
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<tr>
<td>Emerald</td>
<td>131</td>
<td>183</td>
</tr>
<tr>
<td>Semi-hybrid</td>
<td>185</td>
<td>283</td>
</tr>
<tr>
<td>LSD 0.05</td>
<td>16</td>
<td>28</td>
</tr>
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target. The high crude protein concentrations in pastures have a significant metabolic cost as well as the environmental impacts of excreted N in urine and dung. CT-containing pasture legumes such as birdsfoot trefoil (*Lotus corniculatus*), *L. pedunculatus*, and sainfoin (*Onobrychis vicifolia* Scop.) have provided increased milk production and altered milk composition (Waghorn *et al.*, 1998) but have agronomic limitations in grazed pastures. White clover and red clover both produce CT in their flowers, but the biosynthetic pathway is not active in the leaves of these species. Transgenic approaches to achieve foliar CT expression in these species look promising. Many of the genes in the CT pathway have now been cloned and expression of anthocyanidin reductase and the PAP1 MYB transcription factor has given foliar expression of CT (Xie *et al.*, 2006). The potential therefore exists to modify the expression of these genes to produce CT in forage legumes and possibly grasses, although large regulatory hurdles will need to be overcome.

The incorporation of novel innovations into dairy systems may require a change from the “more cows = better pasture utilisation = more milk” philosophy that has been so successfully applied to New Zealand dairy farming. In a stocking rate experiment at Ruakura, Macdonald *et al.* (2001) reported that although peak MS yield per hectare occurred at 4.3 cows/ha and maximum profit at 3.2 cows/ha, the lowest stocking rate of 2.2 cows/ha reduced MS yield and profit by only 17 and 3%, respectively, compared with optimal stocking rates. Obviously conclusions about profitability hinge critically on milk price and input cost assumptions, but current prices and costs justify a more critical examination of the use of lower stocking rates in pastoral dairy systems. Lower stocking rates may provide farmers with the option of incorporating higher feeding value plants into their pastures without suffering the penalty of reduced milk yield per hectare. This may not be a simple management change, however, because achieving higher legume contents may require a decrease in N fertiliser use, consideration of alternative grass species, more accurate conservation and topping decisions and greater areas of pasture renewal, in addition to lower grazing pressure. Current research projects in New Zealand have accepted the challenge posed by Clark (2002) to design profitable dairy systems stocked at 2 cows/ha and MS production of 600 kg/cow.

In summary, forage legumes, and particularly white clover, have an important role to play in modern dairy systems. Potential innovations such as semi-hybrid cultivars offer significant benefits to improve the competitiveness of legumes with N-fertilised forage grasses. Similarly, advances in condensed tannin research suggest that significant animal performance gains can be achieved in conjunction with reduced environmental impact. In order to capture these benefits dairy farmers will need to reassess their farm management to ensure that legumes can be maintained at economically useful levels. Novel grazing management systems that optimise the benefits provided by the grass and legume components need to be captured in future dairy farming systems.

References


Brock, J.L. and Hay, M.J.M. 1996. A review of the role of grazing management on the growth and


Williams, W.M., Easton, H.S. and Jones, C.S. 2007. Future options and targets for pasture plant...