Overview and vision for white clover

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Abstract

White clover (*Trifolium repens* L.) is the key to the international competitive advantage of New Zealand's pastoral industries, which are reliant on a cheap, high quality feed source. White clover benefits pastoral agriculture through its ability to fix nitrogen, its high nutritive value, its seasonal complementarity with grasses, and its ability to improve animal feed intake and utilisation rates. The annual financial contribution of white clover through fixed nitrogen, forage yield, seed production and honey production is estimated as $3.095 billion. The impact of white clover has resulted from understanding how it grows, and then developing appropriate management systems, fertiliser strategies, and improved cultivars. While the future of white clover as the legume base of our pasture is secure there are challenges and opportunities ahead. These include the increasing use of mineral nitrogen, competitiveness with high endophyte ryegrasses, filling gaps in our knowledge base, responding to industry signals, the advent of transgenic technologies, the removal of anti-quality characters particularly those associated with the incidence of bloat, and assuring that nitrogen fixation rates, in grazed pastures, increase as the yield potential of white clover is itself increased.

Keywords: economic value, nitrogen fixation, nutritive quality, pastoral agriculture, white clover

The place of white clover in New Zealand agriculture

New Zealand's pastoral industries produce high quality animal products that are internationally competitive. This competitiveness is based on a cheap, high quality feed source provided by the combination of favourable climate, the availability of improved grass and legume species and the advent of fertiliser topdressing. Add to this the uptake of research innovations by our farmers and the result is one of the most competitive agricultural systems in the world. The use of white clover in our pastures provides the cornerstone of this competitiveness. White clover has widespread adaptability and can withstand grazing stress and interspecific competition better than other legumes.

The value of white clover to pastoral agriculture

White clover (*Trifolium repens* L.) is grown in New Zealand pastures because it has four major benefits. As a legume it fixes nitrogen, it improves sward quality, complements seasonal growth patterns of commonly used grass species, and improves forage intake and utilisation rates of animals.

The financial contribution of white clover

White clover contributes to the economy of New Zealand indirectly through fixing nitrogen and forage yield *per se*, and directly through seed and honey production. Average annual nitrogen fixation, attributable to white clover, is estimated at 1.57 million tonnes over the 13.5 million ha of New Zealand grasslands and is worth $1.49 billion (Table 1). New Zealand's gross agricultural production from its pastoral sector is $8.86 billion (*New Zealand Official Yearbook 1994*), of which about two-thirds of this value is for pastoral products from lowland and downland regions. White clover's contribution to total pasture yield is estimated at 20%, with no adjustment for forage quality, giving a value of $1.33 billion. For most hill and high country the white clover content would be lower but selective grazing is expected to enhance the contribution of clover to animal diets, estimated at 10%, to give a value of $0.22 billion. White clover seed production contributes approximately $25 million annually ($18 million in export receipts – New Zealand Department of Statistics Export Report 1995), and clover honey production $30 million annually (New Zealand Beekeepers Association). Thus the estimated total financial contribution of white clover to the New Zealand economy is $3.095 billion.

Table 1: Estimated value annually of nitrogen fixed by clover based pastures in New Zealand.

Land class	Area[a] (million ha)	--- Estimate N-fixation --- kg N/ha/yr[b]	*t*(million) N/yr	Value[c] $ billion
<12° Slope	7.892	185	1.46	1.39
12-28° Slope	5.623	20	0.11	0.10
Total	13.515	116	1.57	1.49

[a] Source – Land Use in New Zealand – A National Goal
[b] Source – Hoglund et al. (1979)
[c] Applied nitrogen cost estimated at $950/*t*

Nitrogen fixation

The potential N-fixation rates from white clover are in the range of 600–700 kg N/ha/year (Crush 1987), however the presence of mineral nitrogen and factors which limit white clover growth (i.e. moisture stress, low soil fertility, grazing, temperature, grass competition, and appropriate *Rhizobium* strains) result in much lower nitrogen fixation rates. As a result, annual nitrogen fixation levels from white clover in grazed pastures are extremely variable, ranging from 17 kg N/ha/year in infertile, unimproved hill pastures (Grant & Lambert 1979) to 380 kg N/ha/year in intensively managed pastures (Rumball 1979). Increases of 3 to 4-fold in N-fixation at the lower end have been achieved with improved cultivars (Cooper & Chapman 1993).

White clover growth and nitrogen fixation rates are dependent on seasonal variation in soil temperature and moisture, and management factors which affect its competitive ability. In the absence of mineral nitrogen there is a direct relationship between nitrogen fixation and white clover growth, but increasing the supply of mineral nitrogen reduces nitrogen fixation (Hoglund & Brock 1987).

Nutritive value

White clover is considered the best quality component of grazed pastures because of its high nutritive and feeding value (Ulyatt 1981; Osbourn 1982; Morrison 1983; Giovanni 1990). Feeding value is an animal production response, quantified by live weight gain (g/d) or milk yield (*l*/d), whereas nutritive value is a response per unit of feed intake. Thus feeding value is a function of both intake and nutritive value (Ulyatt 1973).

Comparisons for nutritional and chemical composition have shown higher concentrations of crude protein (or total N), and readily fermentable carbohydrates, but lower concentration of lipids, water soluble carbohydrates (sugars), lignin, cellulose, and fibre, for white clover than perennial ryegrass (Ulyatt et al. 1977; Ulyatt 1984; Thomson et al. 1985; Minson 1990). White clover has higher concentrations of calcium, phosphorus, magnesium, copper, zinc and cobalt (on non-deficient soils), but lower concentrations of sodium and selenium (on deficient soils) than perennial ryegrass.

Live weight gains (g/d) of animals fed white clover are consistently higher than for those fed perennial ryegrass (Ulyatt 1981), hybrid ryegrass (Ulyatt 1970), lucerne or lotus (Ulyatt et al. 1977), and phalaris (Soeparno & Davies 1987).

Gross milk yield (kg/d or *l*/d), protein yield, lactose yield and to a lesser extent fat yield, are higher from cows fed white clover than perennial ryegrass (Rogers et al. 1982; Thomson et al. 1985). The higher live weight gains and milk yields on white clover are largely explained by higher voluntary intake rates, but also by higher gross efficiency (gain per unit of intake). Osbourne (1982) demonstrated that the amount of absorbed amino acids per MJ of metabolisable energy (ME) consumed was 44% higher for white clover than perennial ryegrass (13 and 9 g.aa/MJ of ME conserved, respectively).

Intake rate

White clover has a lower resistance to chewing than grasses because it has less cell wall and the length/width ratio of fibres is lower (Minson 1990). The lower resistance to breakdown during eating and ruminating results in 10–35% higher intake (kg dry matter/d) of white clover than perennial ryegrass in stall fed studies (Ulyatt et al. 1977; Rogers et al. 1979, 1980; Ulyatt 1981; Castle et al. 1983). In field studies this advantage is, however, only realised when animals are in high nutrient demand, as occurs during rapid growth of young animals and during lactation (Penning et al. 1996).

Seasonal growth patterns

Growth of white clover occurs later in summer and autumn than that for most temperate grasses, although this complementarity can be disrupted by summer moisture stress (Harris 1987).

Development of white clover technologies

Physiology and growth

White clover persistence is dependent on stolon development and replacement. During winter, more than 90% of stolons can be buried, by treading and earthworm activity, with new stolons establishing on the soil surface during spring and summer. However, during spring white clover plant populations are fragile and susceptible to mismanagement and environmental stresses. At this time stolon death exceeds formation of new stolons as larger plants break up into smaller ones (Hay et al. 1988) and photosynthate is redirected from stolon branches into root system and leaf development. In summer, stolon mass increases until the equilibrium between new stolon formation and old stolon death is re-established. This equilibrium remains until late winter.

Increasing the interval between defoliations allows the development of larger plant organs, but has no effect on the structure of plants in terms of number of leaves, stolons, roots and branching complexity (Hay et al. 1988).

Management

The frequency and intensity of grazing can markedly influence the balance between white clover and companion species. Frequent defoliation during spring favours white clover growth, irrespective of stock class (Brougham 1960; Bryant 1991). With dairy cattle, continued frequent grazing into summer shows further advantage, while for sheep, less frequent defoliation in summer is recommended. Overgrazing in summer is detrimental to white clover, possibly due to excessive loss of stolons. These stolons often have fewer and less developed nodal roots when the soil surface is dry.

Rotational grazing by sheep throughout the year leads to higher N-fixation rates in spring, but lower rates in summer and autumn, than set-stocked systems (Brock et al. 1983). Sheep selectively graze white clover, causing a reduction in clover content in mixed swards compared with pastures grazed by cattle (Lambert et al. 1982).

Fertiliser requirements

White clover is well adapted to environments ranging from moderately-low fertility to extremely-high fertility, but is poorly adapted to low fertility soils (Levy 1970). Additionally, in mixed swards, white clover is a poor competitor for phosphorus (Jackman & Mouat 1972a; 1972b), potassium (Mouat & Walker 1959) and sulphur (Walker & Adams 1958). This disadvantage is exacerbated by management practices that increase shading of clover by associated grasses.

To encourage white clover growth and N-fixation large amounts of phosphatic fertiliser and lime, often in association with sulphur, potassium, boron, cobalt and molybdenum, are applied to New Zealand pastures, at an annual cost of $500–600 million. In the mid 1950s and 1960s application of phosphatic fertiliser (by aerial topdressing) and better grazing utilisation (through a better understanding of management practices) increased white clover content. The demand for higher yielding cultivars also increased.

Cultivar development

The identification of white clover strains and ecotypes began in the 1920s and resulted in the commercialisation of New Zealand Certified White Clover. This was successively developed through to the 1950s and culminated in the release of Grasslands Huia (although not named as such until 1964), a general purpose cultivar with widespread adaptation (Williams 1983).

The need for improved winter growth lead to the incorporation of Spanish material and the development of Grasslands Pitau, in the 1970s (Barclay 1969). Acknowledgment that different white clover types were required for different stock classes and management systems resulted in the breeding of Grasslands Tahora for set-stocked wet hill country (Williams 1983), and Grasslands Kopu for rotationally grazed dairy pastures (van den Bosch et al. 1986). Climatic differences between the north and south of New Zealand encouraged the development of Grasslands Demand for sheep grazed pastures in Southland (Widdup et al. 1989), and Grasslands Prestige (Cooper & Chapman 1993) and Grasslands Challenge for sheep and dairy farms respectively, in Northland. White clover persistence is restricted by summer drought and in response Prop was bred as a free seeding type allowing re-establishment from seed (Macfarlane & Sheath 1984).

Persistence and high yield are negatively associated (Caradus & Williams 1989), but deliberate attempts have been made to select cultivars with high stolon growing point densities without sacrificing leaf size or yield, leading to the release of Grasslands Sustain.

Future directions and challenges

The future of white clover as the legume base of our pastures is secure. However, some recent developments will challenge this, while developing technologies should improve reliability and profitability to the farmer from white clover.

White clover versus mineral nitrogen

White clover can use two sources of nitrogen, atmospheric dinitrogen and soil mineral nitrogen. If available, mineral nitrogen is used preferentially but, except in soils with a large content of mineral nitrogen, fixation and assimilation of mineral nitrogen usually proceed concurrently (Hoglund & Brock 1987). The increasing use of fertiliser nitrogen on some high producing dairy farms will inevitably lead to a decrease in white clover content (Ball et al. 1978). The increased competition from grasses as they respond to added nitrogen will need appropriate management to maintain full pasture utilisation allowing white clover to persist.

Endophyte effects

In many regions of New Zealand, persistence of perennial ryegrass is reliant upon its association with endophytic fungi which provide resistance to argentine stem weevil. Recent and future perennial ryegrass cultivars will be bred in conjunction with either wild or novel endophyte strains. These perennial ryegrasses are very competitive and can reduce clover yield and persistence (Sutherford & Hoglund 1989). Clover with improved competitive ability is being developed by selecting for, (a) plants which grow better in shade, (b) plants with more competitive root morphology, and (c) plant spread in grass species commonly found in New Zealand pastures.

Knowledge gaps

Considerable knowledge about the growth of white clover has enabled sensible management decisions to be made, however, there is still much to be understood. For instance, (i) what are the critical stolon characteristics associated with persistence? and (ii) how can the reliability of white clover in our pastures be improved?

Nitrogen-fixation potential

Selection for improved yield has been successful in breeding programmes (Woodfield & Caradus 1994). Annual N-fixation rates are concomitantly higher but N-fixation efficiency (N fixed per unit dry matter) have not kept pace (Chapman & Caradus 1996). Nitrogen deficiency remains the major nutrient limitation which if corrected could increase pastoral production by 30% (Steele 1982). This is currently circumvented through the use of mineral nitrogen. However, further increases in N-fixation by white clover should be expected.

Exploiting genetic variation and transgenic technology

Developments in white clover breeding over the next decades will see the incorporation of drought tolerance, resistance to root invading nematodes and also other invertebrate pests, better tolerance to acid and infertile soils, and improved nutritive properties. Some of these advances will be mediated through interspecific hybridisation with 'wild' relatives and through transgenic technologies. A decade ago methods were developed allowing insertion of foreign genes into white clover (White 1988). This technology is providing the opportunity to introduce resistances to common viruses, and invertebrate pests such as grass grub, porina and nematodes. Genes associated with nutritional quality are also available, and in time genes may be available that provide bloat-safe cultivars of white clover.

Anti-quality factors

The high nutritive and feeding value of white clover is unquestioned, but several anti-quality components merit attention (Caradus et al. 1995). These include (a) the introduction of polyphenols such as tannins to reduce the incidence of bloat, (b) selection for higher non-degradable protein levels to not only reduce nitrogen wastage but also improve protein content of animal products, and (c) selection for reduced levels of oestrogen-like compounds.

Concluding comment

White clover is the key to the competitiveness of our agricultural products on international markets. It has been the nitrogen base of our pastures for more than a century except in our very driest regions providing a cheaper source of nitrogen than fertiliser nitrogen, even with the cost of phosphatic and other fertiliser required to maintain clover productivity. Yet nitrogen deficiency still limits agricultural production. The challenge over the next decades will be to improve the reliability of white clover to increase annual inputs from N-fixation and effectively integrate the strategic use of fertiliser nitrogen without losing the benefits from white clover.

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