White clover performance in sown pastures: A biological/ecological perspective

J.L. BROCK and M.J.M. HAY
AgResearch Grasslands, Private Bag 11008, Palmerston North
john.brock@agresearch.co.nz

Abstract

Recent advances in farming systems, have prompted a re-appraisal of the performance of white clover in New Zealand pastoral agriculture, in response to the question, is white clover delivering? Using recently developed insights into the processes by which our main pasture species, ryegrass and white clover, grow, this paper will briefly examine the establishment of white clover in mixed pastures and the ecological and biological premises of the two main functions of white clover in pastoral ecosystems, which are to 1), support the N economy of pastures via N fixation and 2), provide high quality livestock feed. The impacts of management decisions and environmental conditions are re-interpreted, in order to evaluate realistically (biologically) what our expectations should be. White clover is still able to deliver on function 1, but may not meet expectations in all cases on function 2.

Keywords: ecology, environmental impacts, grazing management, herbage quality, light, mixed pastures, N economy, N fixation, plants, populations, ryegrass, white clover

Expectations

*"White clover (*Trifolium repens *L.) is the key to the international competitive advantage of the New Zealand's pastoral industries, ... through its ability to fix nitrogen, its high nutritive value ... and its ability to improve animal feed intake and utilisation".*

(Caradus et al. 1996)

Introduction

An often-heard comment from farmers is that 'we can't get enough white clover'. There is increasing anecdotal evidence and reports of problems with the initial establishment of white clover (Fraser 2000), while a decline in performance after 2–3 years, even when initial establishment is successful, has long been recognised (Frame & Newbould 1986). This would suggest apparently, that either white clover is not delivering, or what is more likely, that the emphasis and expectations have changed. So is white clover delivering or not?

Using new knowledge of plant development in both perennial ryegrass and white clover, this paper will attempt to provide some understanding of the processes going on in pastures, concentrating on the effects of management and cultural practices during establishment and the functions of white clover within pastoral ecosystems. The focus throughout will be on the requirements of the plants, within the context of mixed pasture growing in a favourable environment (water and temperature) with all edaphic factors (pH, nutrients, etc.) needed for N fixation and plant growth satisfied (Brock *et al.* 1989) and while animal production is not the primary focus, most of the information discussed has been derived from grazing management trials. This is not to suggest these factors are not important, rather the emphasis is on understanding the basis of management practices to get the best out of plant growth.

Control of the light environment is a major key to maximising plant growth. A few quotes from Sir Bruce Levy (Levy 1970) illustrate the point. "The most important factor of all governing change is the relative intensity of light and shade": "Light plays a most important part in the establishment of pasture plants": and more specifically, "compared to other pasture species, both ryegrass and white clover are intolerant of shade", and "the light and shade balance in perennial ryegrass – white clover pastures is more delicate than the average farmer realises." This will be a recurring theme throughout the paper.

The function of white clover

White clover has two main ecosystem functions, 1), nitrogen fixation, and 2), the provision of high quality livestock feed. These are inextricably linked, but the adequate delivery of both functions, which have different biological goals, may not, and possibly cannot, be easily resolved simultaneously. In the more productive lowland pastoral ecosystems in New Zealand, white clover is almost invariably grown in mixtures, which include perennial ryegrass as a major component. The interaction between white clover and ryegrass is so interwoven, that in considering white clover performance, account must also be taken of the responses of the companion grass to the same environmental variables.

Clover establishment

Before white clover can contribute to either of these functions, it must first be successfully established within pastures. Historically, there has always been a need to re-evaluate establishment procedures as new more vigorous cultivars of grasses and clovers reach the market. Traditionally, seedbeds were prepared after taking a crop to cash in on the soil fertility accumulated under grazing, effectively reducing soil fertility (N) levels. Full cultivation was followed with broadcast sowing such as by roller drill and harrows. Re-evaluation hinged around adjusting sowing times, seeding rates and inoculation.

However, the last 20 years have seen a marked change in sowing techniques as more cost effective direct-drilling and precision-seeding methods developed, with an emphasis on reducing the down time of establishment in order to return pastures to full productivity as soon as possible, e.g., grass to grass direct drilling. This emphasised the importance of a new group of variables, such as seed placement (depth and density), soil conditions (compaction and root penetration), pest control (particularly slugs), intensified interspecific competition (particularly from new, more aggressive grass cultivars), and soil fertility, all of which need careful management. Complete failure of the clover within the first year of sowing has been reported (Fraser 2000), indicating the problem is serious, and that there may be further factors to take into account.

Seedbed preparation and sowing methods have important implications. Full cultivation and broadcast sowing allows optimal sowing depth (5 mm), strong root growth, better spatial separation of plants hence a better light environment and faster seedling development. Direct drilling into uncultivated soil often results in restricted root penetration and poor spatial distribution of seedlings, increasing competition for light (and nutrients) to the detriment of white clover. Reduction in grass competition in the first few months is vital. Grass sowing rate should be kept down (maximum 15 kg/ha) and available soil N levels reduced if possible.

The detailed mechanisms of plant development are useful to help understand the complex interactions occurring during pasture establishment.

Life cycles

White clover development from seed has three distinct morphological phases, each with its own characteristics and requirements/limitations (Erith 1924; Westbrooks & Tesar 1955; Thomas 1987a & b; Brock *et al.* 2000). First is a small, slow growing, compact, rosette *seedling phase* (1–3 months, 2–3 branches, 10–20-mm spread), followed by a rapidly expanding and branching large *tap-rooted phase* (1–2 years, 16–20 branches, 300-mm spread), and finally upon the death of the tap-root, fragmentation into small plants (4–6 branches, 50–70-mm spread), i.e., the ‘normal’ *clonal phase* of white clover growth typical of permanent pastures.

By contrast, the seminal root of ryegrass is rapidly replaced by adventitious roots and within 6 months of sowing, plants attain their maximum mean complexity (8–10 tillers), then fragment into smaller clonal plants (4–7 tillers), arranged in closely aggregated dense tufts (Brock unpublished data).

White clover seedling phase

Sown in autumn, white clover can germinate more rapidly than ryegrass, giving the initial advantage to clover. However, subsequent development is slow. Leaf production proceeds slowly, and while axillary buds may develop to produce leaves as well, there is no stem elongation, and consequently, no nodal root formation. The hypocotyl region between the seminal tap-root and primary stolon is contractile (Cresswell *et al.* 1999), pulling the shoot down into close contact with, or even below, the soil surface. The resulting compact rosette habit may last several weeks dependent on temperature, before commencing stolon elongation.

In comparison, ryegrass seedlings have leaf appearance rates up to three times faster than white clover seedlings (Brock unpublished data). Adventitious root formation (usually two roots per node) proceeds, and a new tiller can become independent of the parent tiller by the time it has produced its third leaf. By the time of first grazing (mid-winter), ryegrass seedlings are much larger than white clover seedlings. For example, in an experiment where the soil had been cropped for 4 years to lower available N, autumn-sown ryegrass seedlings at 3 months were 7–8 times heavier with three times more leaves than white clover, but more importantly had 3–4 times more branches and 17 times more stem (Brock unpublished data).

Careful management of this phase is critical, and the light environment in particular, requires controlling to accommodate the large differences in ryegrass and white clover seedling growth rates and so allow white clover to grow.

Timing of the first grazing is crucial and may be compromised by direct drilling. Ideally it appears best to time the first grazing to coincide with the beginning of clover expansion while the seedling is small and compact in order to avoid possible damage to new elongating stolons. With direct drilling where grass and clover seedlings are forced into close proximity, it may be necessary to advance the first grazing to remove competition for light by the grass, particularly if soil N is high. Any delay in grazing will weaken clover establishment.

White clover expansion phase

The primary stem of white clover rarely elongates, but once the secondary branches (stolons) begin to develop, their elongation and expansion is very rapid and quite large plants can form. On average six (up to 15) secondary stolons radiate from the central tap-root/primary stolon, to form a plant with an average diameter of 250–300 mm (up to 1.5 m). By summer, plants attain a complexity of 3–4 (maximum 6) levels of branching with 15–20 growing points. Rooting from nodes close to the tap-root is relatively weak perhaps an expression of tap-root dominance, and it is not until tertiary branching occurs that effective rooting from stolon nodes develops. Large-leafed, slower branching cultivars with larger diameter tap-roots, are especially slow to form nodal roots, but compensate to some degree by producing extra roots at the point of junction with the primary stolon as the secondary stolon develops, forming a very strong central anchorage (Brock & Tilbrook 2000). The smaller leafed, rapidly branching cultivars with smaller tap-roots, such as Grasslands Prestige and Grasslands Demand, root from the branch nodes earlier and more freely. Unless soil N levels are high, pastures are often clover dominant over this phase, particularly during the first year.

Grazing management should still aim to control light competition for maximum clover growth, but should not be too severe until effective roots form on the new stolons, as hard grazing can result in stolon stripping. Large, thickened nodal roots, once developed, have a contractile portion immediately under the stolon that, like the tap-root, can pull the stolon down to the soil surface or below, increasing anchorage and reducing the chances of stolon loss through grazing (Cresswell 1996).

About 1 year after sowing, death of the tap-root occurs in some plants of the population. This starts earlier in small-leafed cultivars, but regardless of morphological type, all cultivars of white clover have lost all their tap-roots within 2.5 years (Brock & Tilbrook 2000; Brock *et al.* 2000). Death of the tap-root is the first step in fragmentation of the seedling plant to form clonal plants. Thus from 1–2.5 years after sowing, there is a transition phase in which the population has both tap-rooted and clonal plants. During this phase there is usually little evidence of any change in the expression of the expected morphological characteristics of the cultivars, as many of the fragments formed are still of considerable size.

During this period, ryegrass plants are growing clonally and have a stable population structure as regards plant morphology. The tuft or clump increases steadily in size to typically contain around 15 plants (50–60 tillers) for Grasslands Nui, or nearly double that for Grasslands Impact, after 2 years (Brock unpublished data).

Clonal phase

This is the normal status of white clover populations in mixed, permanent pastures, and the form assumed for the remainder of this paper. The processes of clonal growth (Harper 1977) in both perennial ryegrass and white clover are remarkably similar (Brock *et al.* 1996) and provide the basis of perenniality in these species. Through the continual process of growth at the stolon tip and decay at the stolon base, a relatively stable population of plants of varying size and complexity is formed, but this has a seasonal pattern showing a greater proportion of smaller plants in spring than at any other time of the year (Brock *et al.* 1988; Hay *et al.* 1989).

Once clonal populations have developed, the characteristics and performance of the white clover may change (Caradus & Williams 1989). Often about the time that clonal populations establish, a 'clover decline' commences. Plants are now much smaller, and while numerous individually, no longer have a strong tap-root, but rely on smaller nodal roots, and hence are more vulnerable to stress. Pests and diseases play an important role in the vigour and persistence of white clover. While there are many pathogenic agents present in pastures that can affect general performance, there are some that can produce major stress, such as white clover leaf mosaic virus, slugs and root-feeding nematodes and insects, particularly grass grub, white fringed weevil (Watson & Barker 1993; Watson *et al.* 1994) and more recently, clover root weevil.

The growth of white clover plants in established mixed pastures

Pastures, through the process of animal grazing and uneven re-distribution of herbage-derived N in high concentration patches in urine, are a mosaic of ever shifting patches of high and low soil N sufficiency and changing balance of grass and clover (Schwinning & Parsons 1996). Within the urine patch, the sedentary ryegrass with its larger root system, dominates the high N environment. Clover, with its mobile, horizontally spreading network of stolons, expands into the low N niches where competitive pressure is reduced, thus avoiding excessive competition for light from the erect grasses, which perform poorly when under N stress. In such a mixed association, white clover operates in a secondary role as an opportunist species, making the best of the conditions available.

Grazing management and plant growth

Defoliation systems for mixed pastures operate by manipulating the light environment by removal of herbage to provide the best conditions to encourage the sub-dominant white clover component. Brougham (1958b, 1959, 1961; Brougham *et al.* 1976) advocated rotational grazing systems based on the principle of grazing once 95% of the light is intercepted or full canopy closure has been attained, there being little further gain in yield as senescence increases to balance new growth. During regrowth, this generally coincides with the time needed for individual grass growing points to produce a maximum of three fully expanded leaves before canopy closure. The situation is similar for white clover, except in the cool season when leaf appearance rates fall to two-thirds that of ryegrass (Chapman *et al.* 1983), reducing the average number of leaves produced to nearer two. Seasonal growth rate determines the regrowth period needed to reach full light interception, which may vary from 12–15 days in spring–summer, to 50–60 days or longer in winter. While longer regrowth may result in larger yields, this is at the expense of pasture quality and density, as shading results in senescence of older leaves, an increase in the proportion of low quality stem, and tiller death.

The removal of herbage (defoliation) has two components, frequency or time between defoliations, and severity, the proportion of herbage removed per defoliation, which determines the degree of physiological stress placed on the plant. To intercept light, white clover with its prostrate stems, must elevate its horizontal leaf blades into the upper levels of the canopy on long petioles. Defoliation per leaf is therefore usually severe, as the laminas of fully expanded, elevated leaves are removed in total relatively early in the grazing process. Consequently, defoliation frequency is the more important aspect of defoliation controlling white clover growth. For ryegrass, with vertically orientated leaves, severity is of equal importance as it determines the proportion of leaf blade removed, hence light interception and regrowth potential, depending on stocking rate and grazing duration.

The morphological consequence for white clover of having to replace all the main leaves immediately following defoliation, is a reduction in the size of the next new leaf produced in the now short and open canopy. Successive leaves increase in size as canopy height rises, until the original pre-grazing leaf size is restored and the system remains in balance for the particular rotation being used (Brougham 1958a). If the frequency of grazing is increased, the reduced time for regrowth results not only in fewer leaves being produced, but also in smaller leaves, as there is not enough time to re-establish leaf area (Carlson 1966). This is accompanied by a simultaneous reduction in growing point diameter, hence stolon thickness. As a result, plants organs reduce in size to compensate. Under continuous grazing where defoliation of individual growing points may occur every 7–10 days, there may be only one small, fully expanded leaf per growing point. Despite these marked changes in size, there is no change in plant morphology (shape or complexity) or population structure, whether grazed by sheep (Brock *et al.* 1988; Hay *et al.* 1988, 1989), beef cattle (Pinxterhuis *et al.* 1993) or dairy cattle (Harris 1994). All white clover cultivars react similarly (Brock & Tilbrook 2000). However, despite white clover having high plasticity, there appears to be a definite limit to the degree of reduction in organ size. This may be set by the grazing level or pasture canopy height, which is largely controlled by the ryegrass component. For instance, under continuous grazing, provided one fully expanded leaf survives below grazing level until the next leaf is being produced, it may be possible for white clover plants to survive. Large-leafed cultivars, because of their larger and taller leaves, may not be able to so, which may explain their observed poor performance in such conditions compared to the relative success of small-leafed cultivars (Brock 1988; Brock & Hay 1996).

Performance and persistence

Ryegrass plants react to defoliation pressure in a similar manner, but with vertically orientated leaves and by remaining closely packed together in dense tufts or clumps, are able to avoid some of the more severe effects of defoliation through mutual protection. It is the density and size of these structures that influence the level of performance and persistence of the pasture. For any given stocking rate, increasing the frequency of defoliation reduces the severity and physiological stress of defoliation, reduces leaf and tiller size, resulting in increased tiller survival, a trade-off between tiller size and density (Chapman & Lemaire 1993). Under continuous grazing where only 50% of leaf blade is removed per defoliation (Curll & Wilkins 1982; Parsons *et al.* 1991) physiological stress is lowest and tiller survival is greatest.

This is particularly important for white clover. For instance, it has been shown that white clover performance in mixed pastures is related to grass density, in that mean grass densities below 5000 tillers/m^2 do not restrict potential clover growth, but as grass density increases, clover content decreases through competition (Brereton *et al.* 1985). Hence low-density (<5000 tillers/m^2) rotationally grazed cattle pastures, usually have a greater clover content than shorter, denser (8–10 000 tillers/m^2), sheep-grazed pastures, which in turn have more clover than high-density (>14 000 tillers/m^2) continuously grazed pastures. Persistence of white clover exhibits the converse trend, in that open, low-density pastures, while providing space for growth, leave white clover plants open to overgrazing in periods of feed shortage and environmental stress. Plants growing between clumps or rows are often much smaller due to severe overgrazing compared to those gaining protection from close association within grass rows or close to the base of grass clumps. This is most apparent in summer, and is intensified by drought (see below). Other factors affecting grass density and the availability of space for white clover growth are physical damage from treading, usually in periods of excess soil moisture with high stocking rate, and pests and diseases.

Grazing management is most critical in the spring when the seasonal pattern of the population characteristics has white clover plants at their smallest (Brock *et al.*1988), and more vulnerable to environmental stress and mismanagement. Reducing physiological stress on the grass by increasing defoliation frequency has beneficial effects for both species. For ryegrass, continuous grazing increases tiller survival and is most effective in the late spring by controlling seedhead development to promote survival of the post-flowering daughter tillers (Matthew *et al.* 1989, 1991), which enhances summer growth. For white clover, provided the cultivar is small-leafed enough to cope, growing point density can also increase when continuously grazed in spring-early summer. Heavy continuous grazing in spring can increase clover content and has been advocated as a method of providing high quality summer feed for finishing lambs (Hay & Baxter 1989). In a similar manner, denser pastures with more white clover were produced with 5-day rotations compared to 20-day rotations with dairy cows with no loss in milk production (Thom & Bryant 1993).

N fertiliser and white clover

Maintaining white clover and using fertiliser N are not incompatible (Clark & Harris 1996). Use of fertiliser N to increase productivity and reduce seasonal variation in the feed supply is becoming a common practice. Raising available mineral N in the soil reduces N fixation rates, but may even enhance white clover growth (Hoglund 1973). The problem is that it also boosts grass growth to a greater extent and unless strictly controlled, can cause severe competition for light, leading to clover suppression. The key lies in the control of the light environment.

Experience has shown that white clover content can be maintained in dairy pastures receiving 200 kg N/ha/yr, provided stocking rates are sufficient to fully utilise the additional pasture grown (chiefly grass), particularly in spring (Harris *et al.* 1996). Clover plant characteristics were not affected until rates of 400 kg N/ha/yr were used and these resulted in smaller plants through reduced branching and stolon growth (Hoglund & Williams 1984). Similarly, a Taranaki dairy farmer (Barr 1996), found that clover persistence with N fertiliser use was a grazing management issue, not an effect of mineral N itself. By controlling regrowth to a maximum of 1200 kg DM/ha between grazings, good clover content was maintained at annual application rates of 200 kg N/ha. Sheep and beef farmers in the South Island have achieved general increases in the base stocking rate of up to 2 s.u./ha from one application of 20–40 kg N/ha in autumn, provided grazing pressure was increased early, in line with the expected response, in order to maintain a low canopy height and keep light available for the clover (Hoglund & Pennell 1989; Hoglund & Schurink 1989). Practices such as applying late winter N to accumulate a feed bank for early lactation or silage making in spring on dairy farms are particularly hard on white clover, occurring at a time when the clover population is at its weakest.

Moisture

Rainfall is probably the most important environmental factor defining the geographical range of white clover. Sir Bruce Levy classified both ryegrass and white clover as being not particularly tolerant of dry conditions, and observed that, “stoloniferous plants in general, unless they are capable of sending down strong roots from the creeping stems, suffer from drought very readily” (Levy 1970). White clover has a low root:shoot ratio (1:4) (Forde *et al.* 1989) and is particularly vulnerable in seasonally dry regions. Summer rainfall and summer management are probably the main delimiting factors affecting the performance and persistence of white clover. In the generally favourable white clover environment of the Manawatu, Brougham (1960) demonstrated the importance of not hard or over-grazing rotationally grazed systems during periods of restricted growth, particularly in summer, for maintenance of white clover performance.

Studies have illustrated the potential severity of drought on white clover persistence and some of the principles involved. For instance, in dryland Canterbury, a summer drought caused a 30% loss of white clover, and a spring drought a 50% loss (Vartha & Hoglund 1983), while in the Manawatu, summer drought in two consecutive years resulted in a reduction in white clover content from 30% to 2–3%, but with rapid recovery to 25% in the third wet summer (Brock, unpublished data). More detailed measurement at the same site, demonstrated some of the principles operating (Brock 1988). In this case, a single late-spring drought (late November to late January) caused a loss in clover content under rotational grazing from 15–20% down to <3%, with a 95% loss of plants and poor recovery. Conversely, there was no loss in the adjacent continuously grazed pastures and clover content increased from 8% to 15%. This difference was attributed to pasture density. In the low-density rotationally grazed pastures, direct solar radiation on the exposed soil surface raised temperatures to around 50°C, killing clover plants once soil moisture had fallen to wilting point and cooling through transpiration had ceased. The dense cover of continuously grazed pastures, even when wilted, shaded the soil surface lowering soil surface temperatures by 8°C, and sheltered the stolons resulting in almost total survival (>85%) of the clover plants. Small-leafed cultivars with higher stolon density fared better than large-leafed low-density cultivars (Brock & Kim 1994). Improving drought resistance by breeding plants with larger tap-roots may assist during the tap-rooted phase (Woodfield *et al.* 1996).

Other survival mechanisms such as developing buried seed banks built up by allowing natural reseeding of white clover in summer are a possibility, but it could be argued that if the climate is that reliably dry, then it may be better to consider using annual clovers adapted to such conditions.

Ecosystem function # 1: N fixation

Nitrogen is the principle macro element required by all plants for growth, usually taken up from the soil by the root in a mineral form via the slow process of mineralisation of organic matter. Legumes, which include white clover, can use atmospheric N fixed by a *Rhizobium* bacterial association in their roots that can, and will supply N to the plant when needed, in return for energy supplies (carbohydrates etc.), i.e., a symbiotic relationship. The primary role of white clover in agriculture is the provision of free fixed atmospheric N that accelerates the process of building soil fertility. Transfer of this N to the soil occurs through tissue death or the grazing animal and is retained within the ecosystem by a build up in soil organic matter (Sears *et al.* 1965; Walker 1968). Once the initial clover dominant phase is over, white clover is suppressed to a sub-dominant status within the pasture, at a level required for maintenance of the N economy of the ecosystem.

How does it work?

First, all other factors necessary for the successful growth of the host plant white clover and its associated rhizobial symbiotic partner must be satisfied. This is the major cost to white clover-based agriculture in New Zealand, hence the importance of alleviating deficiencies in soil pH, phosphorus, sulphur, potassium and molybdenum in particular.

Remember, N fixation is not the only method of white clover obtaining N. Like all plants, white clover prefers to use soil mineral N, as N fixation has a higher energy cost than N uptake. In the absence of mineral N, there is a direct 1:1 relationship between N fixation and growth (Hoglund 1973). The two sources of N interact. As mineral N availability increases, it substitutes for an equivalent proportion of the N fixation, lowering N-fixation rates. Once the mineral N is fully utilised, continued demand for growth can only be satisfied by N fixation, and the relationship is restored to the 1:1 state. This means that for N fixation to proceed, there must be N deficiency within the host plant where demand for growth exceeds the N supply from the soil. Low available soil N arises for two reasons, low mineralisation rates from soil organic matter (as may occur with low winter temperatures), or depletion by the more competitive grasses. Models show positive effects of both grass and clover growth on N fixation, and negative effects of soil or herbage nitrate levels (Hoglund & Brock 1978, 1987). Nevertheless, even in supposedly high-fertility pastures, clover can still gain considerable N from the soil (50% annually), falling to 10–20% in winter, and rising to 60–70% in summer (80% in dry summers) when grass growth is less vigorous relative to clover because of clover's higher temperature optimum for growth (Hoglund & Brock 1987). There is a clear seasonal pattern to N fixation governed by growth and mineral N availability.

For white clover to exist in mixed pastures, there must be a level of N deficiency. A consequence of white clover being able to fix N, is that ultimately, the resulting increase in N availability will limit its own productivity. Once soil fertility has increased, the grasses dominate by competing more successfully for the clover-derived N and other plant nutrients through their larger root systems. As competition for light increases from more erect species (grasses), white clover growth and N fixation is reduced until a new equilibrium balance is attained. In most stable pasture systems, N fixation needs only to replace losses (leaching, volatilisation and transfers). In this scenario, white clover has been estimated as fixing around 180 kg N / ha/year (range 100–300) for high-producing sheep systems (Hoglund *et al.* 1979), and higher for dairy farms (250 kg N/ha, range 200–350) (Field & Ball 1982). With a mean N fixation efficiency of 60 kg N/ tDM (range 40–100), this would be satisfied by clover herbage production of 2–4 t DM/ha/yr, or 10–30% of total production. There is no ecological need or mechanism to allow more clover growth in established, stable mixed grass/clover pastures and only relatively low levels of white clover are needed to maintain pasture productivity.

Ecosystem function #2: Herbage production

Expectations are changing. More emphasis is being placed on white clover as a quality herbage in its own right, particularly where high performance is needed such as milk production in the dairy sector and high liveweight gains with strict controls on carcass quality in the sheep and beef sector. The proportion of white clover in mixed pastures dictated by the ecological constraints of a direct linkage to the N economy of the system as in function 1, is insufficient to meet the requirements desired for a high quality feed source.

This is not surprising. White clover herbage provides very high liveweight gains in sheep (Ulyatt 1981) and diet selection studies show that given the choice, sheep prefer around 70% of their intake to come from white clover and 30% from grass (Parsons *et al.* 1994). Dairy cattle milk better on white clover dominant pastures (Harris *et al.* 1998). Clearly, a greater proportion of white clover in mixed pastures on farms would be beneficial to animal production. Unfortunately, in mixed pastures, grasses will continue to dominate and provide the bulk of animal feed in high-fertility systems because of their greater competitive ability for nutrients. More clover is not possible without massive intervention or the development of more novel approaches to farm management systems.

Manipulation of the grass/clover balance in mixed pasture

Grazing management and fertiliser N technology as discussed above, may be able to maintain clover at a relatively acceptable content (20–30%). Traditional plant breeding and novel genetic engineering techniques will help to some degree. For instance, white clover growth and competitive ability could be enhanced (e.g., larger leaves, a higher leaf:stolon ratio, greater branching density, a larger and more efficient root system to compete with ryegrass for soil N, reduced N fixation efficiency), while developing less competitive but more nutritious grasses (low shoot:root ratio, high mineral and carbohydrate content). While these characteristics can be manipulated, they are unlikely to achieve major sustainable improvements, as the same ecological constraints imposed by N cycling will still apply.

Temporary manipulation to induce white clover dominance for special purposes on part, but not all, of the farm, can be accomplished, usually in late spring–summer, as an alternative way of controlling surplus growth. As outlined earlier, selective, heavy, set-stocking in spring can induce clover dominance for lamb fattening (Hay & Baxter 1989). Herbicides applied in late spring can achieve similar effects, but with variable economic benefits. The increased white clover contents resulted in greater live-weight gains in lambs (Rolston *et al.* 1985; Casey *et al.* 2000), beef, cattle and deer (Leonard *et al.* 1985), but with milk production results have been variable (Leonard *et al.* 1985; Brookes & Holmes 1985).

There remains the possibility of capitalising on the life cycle of white clover as a partial solution. During the tap-rooted expansion phase and transition period, white clover growth is considerably and reliably stronger than in clonal plant populations. Over-sowing every 3 years to capitalise on these attributes could reliably increase clover content, provided good establishment conditions and competition from the grass component is controlled by use of seasonal herbicide applications as required.

White clover as a crop

Under equivalent conditions, white clover alone can produce 10–12 t/ha/year of higher quality feed (Brock 1973), at least comparable to the 15t/ha from mixed pasture with 20–30% clover. Growing the required proportion of the farm or paddock as a white clover monoculture, is possibly the only way to reliably ensure animals have access to the desired diet (Parsons *et al.* 1994).

Environmental consequences

The major detrimental ecological consequences to all scenarios involving increased clover content may be the impact on the environment. Inputs from N fixation would be reduced. Nevertheless, as a consequence of the grazing process, the problems of uneven return of high concentrations of urinary N could have major detrimental ecological consequences. With a low root to shoot ratio (1:4), white clover will be unable to intercept and utilise as much of the high urine N loadings as the grasses can. Nitrate N leaching will increase (Chapman *et al.* 1996), with downstream (literally) consequences for water quality.

One solution is to remove the cause of this variability, the grazing animal, and use a cut and carry system with housed or penned animals as practised in Europe and the USA. The N in the collected effluent is hydrolysed to ammonia and lost to the atmosphere during storage. Returned to the land, the remaining effluent though low in N is high in other nutrients P, K, etc., and organic matter, sufficient to support strong pasture growth with a higher clover content. However, on a global scale, this is still not environmentally acceptable, and certainly not an innovation of much attraction to New Zealand farming.

The prospect of increasing white clover content in a viable and ecologically acceptable manner has sensitive problems for environmental issues and is not readily foreseeable in the immediate future. The answer to the question of white clover delivering purely on its herbage quality basis, is definitely yes, but in light of environmental sensitivity and New Zealand's 'clean, green image', it is probably no.

Conclusions

Is white clover delivering on function 1, N fixation? From the perspective of the N economy of the New Zealand agricultural industry, *yes it is*. But there is the proviso of living within the constraints of the biology of the ecosystem. The system must be N-deficient in part or whole therefore maximum pasture potential growth cannot be achieved. Matching pasture growth and animal requirements is more difficult. Environmental conditions have greater influence.

Is white clover delivering on function 2, herbage quality? That depends entirely on the context. The quality of white clover herbage *per se*, is not in question. If the pre-requisite is for maximising the quality potential of white clover, then in mixed pastures, *no, it is not* and cannot, deliver. If using white clover as a special purpose crop, then *yes it can* deliver, but with the constraint of potential environmental problems.

REFERENCES

Barr, S. 1996. A farmer's experience with high N fertiliser inputs on grass/clover pastures. *White clover: New Zealand's Competitive Edge. Agronomy Society of New Zealand Special Publication 11/New Zealand Grassland Association, Grasslands Research and Practice Series 6*: 103–106.

Brereton, A.J.; Carton, O.T.; Conway, A. 1985. The effect of grass tiller density on the performance of white clover. *Proceedings of the 15th International Grassland Congress*: 756–757.

Brock, J.L. 1973. Growth and nitrogen fixation of pure stands of three pasture legumes with high/low phosphate. *New Zealand Journal of Agricultural Research 16*: 483–491.

Brock, J.L. 1988. Evaluation of New Zealand bred white clover cultivars under rotational grazing and set stocking with sheep. *Proceedings of the New Zealand Grassland Association 49*: 203–206.

Brock, J.L.; Kim, M. 1994. Influence of the stolon/soil surface interface and plant morphology on the survival of white clover during severe drought stress. *Proceedings of the New Zealand Grassland Association 56*: 187–191.

Brock, J.L.; Hay, M.J.M. 1996. A review of the role of grazing management on the growth and performance of white clover cultivars in lowland New Zealand pastures. *White clover: New Zealand's Competitive Edge. Agronomy Society of New Zealand Special Publication No.11/New Zealand Grassland Association, Grasslands Research and Practice Series No. 6*: 65–70.

Brock, J.L.; Tilbrook, J.C. 2000. Effect of cultivar of white clover on plant morphology during the establishment of mixed pastures under grazing. *New Zealand Journal of Agricultural Research 43*: 335–343.

Brock, J.L.; Caradus, J.R.; Hay, M.J.M. 1989. Fifty years of white clover research in New Zealand. *Proceedings of the New Zealand Grassland Association 50*: 25–39.

Brock, J.L.; Hume, D.E.; Fletcher, R.H. 1996. Seasonal variation in the morphology of perennial ryegrass (*Lolium perenne*) and cocksfoot (*Dactylis glomerata*) plants and populations in pastures under intensive sheep grazing. *Journal of Agricultural Science, Cambridge 126*: 37–51.

Brock, J.L.; Hay, M.J.M.; Thomas, V.J.; Sedcole, J.R. 1988. Morphology of white clover (*Trifolium repens* L.) plants in pastures under intensive sheep grazing. *Journal of Agricultural Science, Cambridge 111*: 273–283.

Brock, J.L.; Albrecht, K.A.; Tilbrook, J.C.; Hay. M.J.M. 2000. Morphology of white clover during development from seed to clonal populations in grazed pastures. *Journal of Agricultural Science, Cambridge 135*: 103–111.

Brookes, I.M.; Holmes, C.W. 1985. The effect of a plant growth regulator (mefluidide) on pasture growth and milk production. *Proceedings of the New Zealand Grassland Association 46*: 83–87.

Brougham, R.W. 1958a. Leaf development in swards of white clover (*Trifolium repens* L.). *New Zealand Journal of Agricultural Research 1*: 707–718.

Brougham, R.W. 1958b. Interception of light by the foliage of pure and mixed stands of pasture plants. *Australian Journal of Agricultural Research 9*: 39–52.

Brougham, R.W. 1959. The effects of frequency and intensity of grazing on the productivity of a pasture of short-rotation ryegrass and red and white clover. *New Zealand Journal of Agricultural Research 2*: 1232–1248.

Brougham, R.W. 1960. The effect of frequent hard grazings at different times of the year on the productivity and species yields of a grass-clover pasture. *New Zealand Journal of Agricultural Research 3*: 125–136.

Brougham, R.W. 1961. Factors limiting pasture production. *Proceedings of the New Zealand Society of Animal Production 21*: 33–46.

Brougham, R.W.; Cosgrove, G.P. 1985. Pastures and pasture management for high animal production in New Zealand. *Proceedings of the 15th International Grassland Congress*: 1134–1135.

Brougham, R.W.; Ball, P.R.; Williams, W.M. 1976. The ecology and management of white clover-based pastures. pp. 309–324. *In*: Plant relations in pastures. Ed. Wilson, J.R. CSIRO, Canberra, Australia.

Caradus, J.R.; Williams, W.M. 1989. Breeding for legume persistence in New Zealand. pp. 523–539. *In*: Persistence of Forage Legumes. Eds. Marten, G.C; Matches, A.G.; Barnes, R.F.; Brougham, R.W.; Clements, R.J.; Sheath, G.W. ASA/CSSA/SSSA. Madison, Wisconsin, USA.

Caradus, J.R.; Woodfield, D.R.; Stewart, A.V. 1996. Overview and vision for white clover. *White clover: New Zealand's Competitive Edge. Agronomy Society of New Zealand Special Publication 11/ New Zealand Grassland Association, Grasslands Research and Practice Series 6*: 1–6.

Carlson, G.E. 1966. Growth of white clover leaves after leaf removal. *Proceedings of the X International Grassland Congress*: 134–139.

Casey, M.J.; Brown, C.; Stevens, D.R. 2000. A summary of research into the use of low rates of glyphosate as a pasture management tool. *Proceedings of the New Zealand Grassland Association Conference 62*: 123–128.

Chapman, D.F.; Lemaire, G. 1993. Morphogenetic and structural determinants of plant regrowth after defoliation. *Proceedings of the XVII International Grassland Congress*: 95–104

Chapman, D.F.; Parsons, A.J.; Schwinning, S. 1996. Management of clover in pastures: expectations, limitations and opportunities. *White clover: New Zealand's Competitive Edge, Agronomy Society of New Zealand Special Publication 11/New Zealand Grassland Association, Grasslands Research and Practice Series 6*: 55–64.

Chapman, D.F.; Clark, D.A.; Land, C.A.; Dymock, N. 1983. Leaf and tiller growth of *Lolium perenne* and *Agrostis* spp. and leaf appearance rates of *Trifolium repens* in set-stocked and rotationally grazed hill pastures. *New Zealand Journal of Agricultural Research 26*: 159–168.

Clark, D.A.; Harris, S.L. 1996. White clover or nitrogen fertiliser for dairying? *White clover: New Zealand's Competitive Edge. Agronomy Society of New Zealand Special Publication 11/New Zealand Grassland Association, Grasslands Research and Practice Series 6*: 107–114.

Cresswell, A.; Sackville-Hamilton, N.R.; Thomas, H.; Charnock, A.R.; Cookson, A.R.; Thomas, B.J. 1999. Evidence of root contraction in white clover (*Trifolium repens* L.). *Annals of Botany 84*: 359–369.

Cresswell, A. 1996. White clover roots cause stolon burial. *White clover: New Zealand's Competitive Edge. Agronomy Society of New Zealand Special Publication 11/New Zealand Grassland Association, Grasslands Research and Practice Series 6*: 136.

Curll, M.L.; Wilkins, R.J. 1982. Frequency and severity of defoliation of grass and clover by sheep at different stocking rates. *Grass and Forage Science 37*: 291–298.

Erith, A.G. 1924. *White clover* (Trifolium repens *L.*). *A monograph*. London; Duckworth.

Field, T.R.O.; Ball, P.R. 1982. Nitrogen balance in an intensively utilised dairy farm system. *Proceedings of the New Zealand Grassland Association 43*: 64–69.

Forde, M.B., Hay, M.J.M., Brock, J.L. 1989. Development and growth characteristics of temperate perennial legumes. pp. 91–109. *In*: Persistence of Forage Legumes. Eds. Marten, G.C; Matches, A.G.; Barnes, R.F.; Brougham, R.W.; Clements, R.J.; Sheath, G.W. ASA/CSSA/SSSA. Madison, Wisconsin, USA.

Frame, J.; Newbould, P. 1986. Agronomy of white clover. *Advances in Agronomy 40*: 1–88.

Fraser, T. 2000. Pasture persistence for profits. *Meat New Zealand R & D Report 82*.

Harper, J.L. 1977. Population biology of plants. Academic Press, London.

Harris, S.L.; Auldist, M.J.; Clark, D.A.; Jansen, E.B.L. 1998. Effects of white clover content in the diet on herbage intake, milk production and milk composition of New Zealand dairy cows housed indoors. *Journal of Dairy Research 65*: 389–400.

Harris, S.L. 1994. White clover growth and morphology in dairy pastures in the Waikato region of northern New Zealand. *New Zealand Journal of Agricultural Research 37*: 487–494.

Harris, S.L.; Clark, D.A.; Waugh, C.D.; Clarkson, F.H. 1996. Nitrogen fertiliser effects on white clover in dairy pastures. *White clover: New Zealand's Competitive Edge. Agronomy Society of New Zealand Special Publication 11/New Zealand Grassland Association, Grasslands Research and Practice Series 6*: 119–124

Hay, M.J.M.; Brock, J.L.; Thomas, V.J. 1989. Density of *Trifolium repens* plants in mixed swards under intensive grazing by sheep. *Journal of Agricultural Science 113*: 81–86.

Hay, M.J.M.; Newton, P.C.D.; Thomas, V.J. 1991. Nodal structure and branching of *Trifolium repens* in pastures under intensive grazing by sheep. *Journal of Agricultural Science, Cambridge 116*: 221–228.

Hay, M.J.M.; Brock, J.L.; Thomas, V.J.; Knighton, M.V. 1988. Seasonal and sheep grazing management effects on branching structure and dry weight of white clover plants in mixed swards. *Proceedings of the New Zealand Grassland Association 49*: 197–201.

Hay, R.J.M.: Baxter, G.S. 1989. Manipulating the plastic response of white clover through grazing, in a cool, temperate climate in New Zealand. *Proceedings of the XVI International Grassland Congress*: 1053–1054.

Hoglund, J.H. 1973. Bimodal response by nodulated legumes to combined nitrogen. *Plant and Soil 39*: 533–545.

Hoglund, J.H.; Brock, J.L. 1978. Regulation of nitrogen fixation in a grazed pasture. *New Zealand Journal of Agricultural Research 21*: 73–82.

Hoglund, J.H., Brock, J.L. 1987. Nitrogen fixation in managed grasslands. pp. 187–196. *In*: Managed Grasslands, B. Analytical Studies. Ed. Snaydon, R.W. Elsevier Science Publications B.V., Amsterdam.

Hoglund, J.H.; Pennell, C.G.L. 1989. Autumn nitrogen fertiliser in a dryland sheep system. *Proceedings of the New Zealand Grassland Association 50*: 135–138.

Hoglund, J.H.; Schurink, J. 1989. Autumn nitrogen fertiliser: a reliable management tool. *Proceedings of the Agronomy Society of New Zealand 19*: 89–93.

Hoglund, J.H.; Williams, W.M. 1984. Genotypic variation for white clover growth and branching in response to temperature and nitrogen. *New Zealand Journal of Agricultural Research 27*: 19–24.

Hoglund, J.H.; Crush, J.R.; Brock, J.L.; Ball, P.R.; Carran, R.A. 1979. N fixation in pasture XII. General Discussion. *New Zealand Journal of Experimental Agriculture 7*: 45–51.

Leonard, W.F.; Bruce, S.J.; Russell, A.J.; Cook, M.R. 1985. Chemicals for pasture renovation and improvement of herbage quality. *Proceedings of the New Zealand Grassland Association 46*: 77–82.

Levy, E.B. 1970. Grasslands of New Zealand. A.R. Shearer, Government Printer, New Zealand.

Matthew, C.; Chu, A.C.P.; Hodgson, J.; MacKay, A.D. 1991. Early summer pasture control: what suits the plant? *Proceedings of the New Zealand Grassland Association 53*: 73–77.

Matthew, C.; Quilter, S.J.; Korte, C.J.; Chu, A.C.P.; MacKay, A.D. 1989. Stolon formation and significance for sward tiller dynamics in perennial ryegrass. *Proceedings of the New Zealand Grassland Association 50*: 255–259.

Parsons, A.J.; Harvey, A.; Woledge, J. 1991. Plant-animal interactions in a continuously grazed mixture. I. Differences in the physiology of leaf expansion and the fate of leaves of grass and clover. *Journal of Applied Ecology 28*: 619–634.

Parsons, A.J.; Newman, J.A.; Penning, P.D.; Harvey, A.; Orr, R.J. 1994. Diet preference of sheep: effects of recent diet, physiological state and species abundance. *Journal of Animal Ecology, 63*: 465–478.

Pinxterhuis, I.; Chapman, D.F.; Hay, M.J.M. 1993. Structure of white clover populations and plants in grazed pastures by beef cattle. *Proceedings of the XVII International Grassland Congress*: 138–139.

Rolston, M.P.; Clark, D.A.; Devantier, B.P. 1985. Chemical manipulation of hill country pastures to produce legume dominance. *Proceedings of the New Zealand Grassland Association 46*: 89–95.

Schwinning, S.; Parsons, A.J. 1996. A spatially explicit population model of stoloniferous N fixing legumes in mixed pasture with grass. *Journal of Ecology 84*: 815–826.

Sears, P.D.; Goodall, V.C.; Jackman, R.H.; Robinson, G.S. 1965. Pasture growth and soil fertility VIII. The influence of grasses, white clover, fertilisers, and the return of herbage clippings on pasture production on impoverished soil. *New Zealand Journal of Agricultural Research 8*: 270–283.

Thom, E.R.; Bryant, A.M. 1993. Effects of different systems of grazing management during December to May on the grass tiller density characteristics of ryegrass–white clover dairy pasture. *Proceedings* *of the XVII International Grassland Congress*: 877–878

Thomas, R.G. 1987*a*. The structure of the mature plant. pp. 1–29. *In*: White clover. CAB International, Wallingford.

Thomas, R.G. 1987*b*. Vegetative growth and development. pp. 31–62. *In*: White clover. CAB International, Wallingford.

Ulyatt, M.J. 1981. The feeding value of herbage: Can it be improved? *New Zealand Agricultural Science 15*: 200–205.

Vartha, E.W.; Hoglund, J. H. 1983. What is the makeup of a dryland pasture? *Proceedings of the New Zealand Grassland Association 44*: 204–210.

Walker, T.W. 1968. Changes induced in the soil by pastoral farming. *New Zealand Soil Bureau Bulletin 26 (Part 1)*: 104–109.

Watson, R.N.; Barker, G.M. 1993. Towards improving the role of legumes for grassland sustainability. *Proceedings of the 6th Australasian Conference on Grassland Invertebrate Ecology*: 213–226.

Watson, R.N.; Bell, N.L.; Neville, F.J.; Harris, S.L. 1994 Improving pasture sustainability by reducing the impact of clover nematodes. pp. 83–85. *In*: Soil Biota: Management in Sustainable Farming Systems. Ed. Pankhurst, C. E. CSIRO, Canberra.

Westbrooks, F.E.; Tesar, M.B. 1955. Tap-root survival in white clover. *Agronomy Journal 47*: 403–410.

Woodfield, D.R.; Caradus, J.R.; Cousins, G.R.; Dunn, T. 1996. Response to selection for increased tap-root diameter. *White clover: New Zealand's Competitive Edge. Agronomy Society of New Zealand Special Publication 11/New Zealand Grassland Association, Grasslands Research and Practice Series 6*: 141–143.

■