PERENNIAL RYEGRASS - SAINT OR SINNER IN TEMPERATE DAIRY SYSTEMS?

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Summary

Perennial ryegrass is the most important plant for pastoral agriculture in temperate pasture grazing systems. It provides flexibility in grazing management and, in its vegetative state, is a high quality feed for animal production. The ability to maintain high ryegrass yields depends on the provision of an optimized biophysical and nutrient environment. Historically, a complementary association with clover has provided some of the grassed nitrogen requirement and improved overall pasture quality. Clover content of 50+% has consistently been shown to maximize animal intake and production. However, current establishment, agronomic, plant breeding and grazing practices restrict clover production and persistence. Clover maintenance within a pasture requires an understanding of its growth requirements and adoption of appropriate grazing management strategies. The ongoing battle between ryegrass and clovers may be moved in favour of the legume through reduced ryegrass sowing rates, temporal and spatial separation of species at establishment, and grazing strategies aimed at maximizing legume rather than grass production.

Introduction

Temperate grazing systems are heavily reliant on the complementary nature of the relationship between perennial ryegrass *(Lolium perenne* L.) and white clover (*Trifolium repens* L.). Ryegrass is ideally suited to intensive grazing systems and can easily be conserved as hay or silage. In New Zealand it is the basis for pastoral farming. This reliance on ryegrass has led to extensive research into on-farm production systems and consequent grazing management recommendations. Further, there is a continual release of new cultivars to meet farmer demands for improved pasture production, persistence and resistance to pests and diseases. Driving much of the research and development has been the New Zealand dairy industry which has seen the national herd expand from 3.84M in 1994 to 5.26M in 2007 (Moot *et al*. 2010a).

Much of this expansion has come through the conversion of less profitable sheep and beef properties in the South Island. For example, in Canterbury, livestock numbers over the last 20 years (Figure 1) show an extra 800 000 dairy cows that have displaced almost 5.0M sheep (Moot *et al*. 2010b). The low (600 mm) annual rainfall and low water holding capacity of the soils in the province has meant dairy conversions are only possible in irrigated areas. Canterbury now has 364 000 ha under irrigation which represents ~70% of the nation's irrigated land. The province also has the largest average herd size (>700 cows), stocked at 3.3 cows/ha on average pasture yields of 12-15 t DM/ha. In most cases the sole grass sown on dairy farms is perennial ryegrass. The inclusion of white clover is usual. However, some farmers now substitute regular fertilizer nitrogen applications to maintain maximum pasture growth rates throughout the milking season. Inevitably this leads to low pasture clover content and a requirement to maintain nitrogen applications to maximize pasture quantity. Nationally, this has led to the increased use of nitrogen fertilizer (Figure 2) with $50x10^3$ t of nitrogen applied in 1990/91 and $280x10^3$ t in 2008/09 (New Zealand Fertiliser Manufacturers' Research Association 2009). Alternatively, farmers may focus on pasture quality through grazing management and limit nitrogen applications to the shoulders of the season to maintain clover content. The aim of this paper is to review the roles of perennial ryegrass and clover in pastoral systems and identify strategies that have been used to maximize clover content in dairy pastures. The issue of ryegrass endophytes is not covered because it has been substantially reviewed in other publications (e.g. Easton 1999; Fletcher and Easton 2001).

Pasture production

At its simplest, dry matter production is the product of the amount of photosynthetically active radiation intercepted and the efficiency of conversion of this radiation into the chemical constituents of plants. The amount of light intercepted is quantified by the green area index (GAI). This represents the ability of the canopy of leaves to capture available light. In a pasture, maximizing light capture is inevitably compromised by grazing. This reduces the GAI to below a critical level at which 95% of the light is captured. In practice, the targeted grazing residual reflects a balance between the conflicting needs to graze a pasture before green leaves begin to senesce, yet leave sufficient herbage for rapid re-establishment of the photosynthetic canopy. Often forgotten is the impact of these residuals on the light seeking clover growing within the sward. During the period in which the canopy is recovering, light not intercepted by green leaf is lost from the biological system. To maximize leaf expansion, adequate water and nutrients (particularly nitrogen) are required with temperatures in the optimum range for growth and development.

The conversion efficiency of transforming captured light into dry matter reflects the rate of photosynthesis of plants and is also dependent on water, nutrients and temperature. At a fundamental level tropical species (C4) are more efficient at light conversion than temperate (C3) species because of differences in their photosynthetic pathway (Hay and Porter 2006). At a species level the optimum temperatures for ryegrass are lower than for white clover (Mitchell and Lucanus 1962). This is one of the reasons that temperate pasture production in the winter, early spring and late autumn is predominantly from ryegrass with little white clover. The difference in the temporal pattern of ryegrass and white clover was shown in a classic illustration by Brougham (1959). In one of the few studies that have looked at how all three biophysical factors affect pasture production together, Peri *et al*. (2002) showed a multiplicative effect on pasture production. For example, the consequences of water stress on photosynthesis were compounded by nitrogen deficiency or sub-optimal temperatures. Thus, whenever pastures are limited for water nutrients, (predominantly nitrogen) or temperature, both canopy expansion and conversion efficiency are reduced, which limits pasture production. Recent research has quantified this for dryland pastures in New Zealand where the water use efficiency of pure ryegrass was shown to be 13 kg DM/ha/mm of water compared with 20 for perennial ryegrass/white clover and 24 kg DM/ha/mm for lucerne (Moot *et al*. 2008). The advantage for the pure legume was due to it never being deficient in nitrogen, compared with grasses which always require an external source of N, and are therefore frequently N deficient.

In circumstances where water and nutrients are maintained at optimum levels differences in total pasture production can only result from differences in either the amount of light intercepted or the conversion efficiency. Indeed the biophysical environment at any given location is the major driver of the total potential pasture production. This limits the opportunity for plant breeders to greatly increase pasture yields through plant selection and small incremental gains (~0.4%) for perennial ryegrass are the 30 year norm (Woodfield and Easton 2004). These authors commented that seasonal differences in yield exist among cultivars, associated predominantly with heading date, but noted for example, that gains in late winter/late spring production were offset by poorer early spring and autumn growth. Results from an extensive national network of forage variety trials, highlights the uniformity in yield amongst cultivars under optimum management. Averaged over all trials in New Zealand, the 35 year old public cultivar “Nui’, produced ~1 t/ha/yr less than the highest yielding new cultivars (New Zealand Plant Breeding & Research Association Inc. 2010). Overall, these results suggest differences in seasonal growth rates of cultivars have predominantly come from selection for genetic differences in plant development processes rather than growth attributes, although the physiological basis of gains are seldom reported if they are known.

Pasture quality

Pasture quality is used as a relative term to describe the degree to which the nutritional requirements of animals are met (Allen *et al*. 2011). The potential gains in pasture quality from improved ryegrass cultivars also appear limited. The range of maturity dates and ploidy levels available offers some opportunity to control the negative quality changes associated with flowering in ryegrasses (Woodfield and Easton, 2004). However, in a four year dairy systems trial Woodward *et al*. (2003) showed, no major benefit in terms of milk solids production or economic farm surplus to sowing different combinations of old versus modern cultivars. They did show differences in seasonal production patterns. Equally, enthusiasm for 'high sugar' grasses has been tempered by the inconsistency of trait expression, suggesting a genotype x environment interaction, and difficulty in confirming intake or animal performance gains (Edwards *et al*. 2007). Plant breeders are currently developing white clover populations of high water soluble carbohydrates (Widdup *et al*. 2010). These selections are at a "proof of concept" stage and unlikely to be commercially available for several years. Evidence to support significant animal performance gains from the use of any individual cultivar of perennial ryegrass or white clover over any others appears limited.

In contrast, the overriding benefits of maximizing white clover within a pasture are well documented. In an *ad lib*. and restricted diet feeding trial with C4 grasses and white clover, Harris *et al*. (1997) showed that milk yields of Friesian cows were maximized when clover made up over 50% of the diet. Increases were due to the higher nutritive values of the white clover and the higher intake. These results are consistent with several studies for grazing preference that have shown ruminants prefer to eat a 70:30 clover:grass diet (e.g. Cosgrove *et al*. 2003; Parsons *et al*. 2006). Thus, in many cases animal performance gains achieved through improved pasture quality relate to improved clover content. The questions for plant breeders are then how actively are they selecting for more competitive white clover cultivars? And to what extent have current breeding strategies for perennial ryegrass been detrimental to the associated growth and development of white clover within a pasture?

Pasture establishment

Regardless of the cultivar combinations being used there are several viable strategies for establishing higher clover content within the initial 18 month establishment phase of pastures. The effect of ryegrass sowing rate on white clover establishment was documented by Cullen as early as 1958. He recommended that no more than 10 kg/ha of ryegrass was required to establish a pasture that contained at least 20% of other species. Extending this approach to include a range of autumn sowing dates, Dumbleton (1997) followed by Nicholls (1998) concluded white clover was successfully established in pastures with 4-8 kg/ha of perennial ryegrass (Figure 3) provided the soil temperature was above 14 °C. Total DM production was more dependent on the sowing date than the sowing rate of perennial ryegrass in both years (Figure 4). Black *et al*. (2006) found similar results with 3-12 kg/ha of perennial ryegrass in spring and autumn.

At a rate of 10 kg/ha about 500 perennial ryegrass seeds are sown/m^2 and at least 50% are expected to establish. At emergence, light is usually the most limiting factor. Individual plants and species that emerge first and can display their leaf area in an advantageous position will out-compete others. Moot *et al*. (2000) used thermal time (°Cd) to quantify germination and emergence of several temperate herbage species including perennial ryegrass and white clover. They found that white clover germinates rapidly and emerges relatively quickly but it is a poor competitor with perennial ryegrass in terms of seedling growth. It is therefore not surprising that white clover establishment within pastures sown with commercially recommended rates of 20-30 kg/ha of perennial ryegrass are deficient in white clover. Such high rates of perennial ryegrass may have developed as additional broad leaf species such as plantain (*Plantago lanceolata* L.) and chicory (*Chichorium intybus* L.) have been included in pasture mixes. Their presence reduces the chemical control options for broad leaf weeds. A problem is that the highly competitive perennial ryegrass does not recognise that clover is not a weed! In an on-farm survey of 32 paddocks, Brock and Kane (2003) highlighted that poor white clover establishment is compounded by direct drilling techniques, poor seed bed preparation and inappropriate early grazing management. To maximize clover establishment soil nitrogen levels should be reduced (e.g. using a cropping phase), a well consolidated seed bed prepared (that enables control of sowing depth), phosphorous but not nitrogen fertilizer used and frequent light grazing for the first 6-9 months (Brock 2006).

A further problem of a two species mix of ryegrass and white clover is the fluctuating nature of the dominance of each species over time. Stimulation of clover with phosphorous fertilizer can lead to clover dominance which increases the nitrogen input from biological N fixation. In turn this leads to an increase in the grass component that then shades out the clover. This ‘self regulation’ was defined as a “predator/prey” interaction by Parsons *et al*. (2006). Maintaining the clover within the system was identified as difficult at a paddock scale due to the deposition of urine swamping the soil leading to grass dominant patches. This is maintained until the available N is used up and the advantage of the nitrogen fixing species returned. Research in the last 10 years has used spatial separation of grass and clover as an alternative strategy to remove the competitive advantage of the grass, provide ruminants with more legume, (closer to their preferred diet), with mainly positive animal performance results. On-farm perception of difficulties in managing the separation in terms of weed, pest control and potential environmental problems, have been highlighted as impediments to commercial adoption. Until tried, spatial separation remains viable in principal. Potentially the idea can be shrunk to micro levels with the use of alternate drill rows during establishment. Through serendipity it has been utilized at a large paddock scale with the grazing of lucerne in various New Zealand dryland environments where grass is available on surrounding hill slopes (e.g. Avery *et al*. 2008).

Grazing management

To maintain clover within a pasture beyond the establishment phase requires an understanding of the dynamics of competition between the two species. The basic principles to maintain white clover within diary pastures were well developed by the 1960's. Brock (2006) lists these as 1) close grazing over winter, when clover growth is low, 2) frequent close grazing in spring, to control ryegrass seed head development and increase light levels to the base of the sward (to increase clover growing point density) 3) lax grazing in summer to maximize clover growth and spread followed by 4) a hard autumn graze to promote ryegrass for winter. He noted that recent dairy grazing systems that focus on pasture cover and grazing residuals to maximize light interception do not provide clover friendly environments. These grass based solutions raise the question of whether clover has any role in these systems? Those wanting to maintain clover within their system are encouraged to concentrate on spring management without nitrogen fertilizer but grazing to low (1000 kg DM/ha) residuals with development of a longer summer rotation.

Caucasian clover – a case study

The difficulties currently facing the maintenance of white clover within dairy pastures are exemplified by the frequent failure to encourage alternative clovers with more specialist management requirements. Caucasian, or Kura, clover (*Trifolium ambiguum* M. Bieb.) is a case in point. It is a large leaved perennial clover capable of complimenting white clover to increase the total legume content of pastures (Black *et al*. 2000). It has shown higher photosynthetic rates than white clover over a wide range of temperature and moisture regimes (Black *et al*. 2003) and like most legumes fixes nitrogen at approximately 25 kg N/tonne of above ground herbage grown (e.g. Widdup *et al*. 2001). However, it is extremely slow to establish and is therefore outcompeted by other species, including white clover, even when low (3 kg/ha) rates of perennial ryegrass are used (Black *et al*. 2006). This lack of competitiveness at establishment is due to a greater partitioning of carbon to below ground structures (Widdup *et al*. 1998) in the seedling phase and a consequent delay to secondary leaf development (Black *et al*. 2002). For example, above a base temperature of 0 °C, Caucasian clover takes 774 °Cd to reach secondary leaf development compared with 532 °Cd in white clover and 375 °Cd for perennial ryegrass. Effectively, Caucasian clover is out competed for light and requires alternative establishment strategies for successful integration in a dairy system. A lack of understanding of this basic biology led to inappropriate sowing recommendations for the use of Caucasian clover in New Zealand.

In an on-farm experiment, Hurst *et al*. (2000) showed successful establishment was attained by temporal separation of Caucasian clover and other pasture species. The Caucasian clover was sown in spring and the other species components overdrilled in autumn. In other studies a cover crop of rape has been used at a low rate (1.5 kg/ha) with the grasses drilled after the rape was grazed (Moot unpublished). In the United States Kura clover has been established as a living mulch crop to provide nitrogen under maize crops (Affeldt *et al*. 2004).

In summary, there are three legs to the stool for development of specific solutions to improve legume content in pastures. An understanding of the biology of the legume of choice and how it interacts with the biophysical environment of the given location must be integrated with on-farm practices. Ignoring any one of the three factors is likely to lead to repeated failure of the most vulnerable species in the system, usually the legume, a return to the status quo and an ever increasing reliance on inorganic nitrogen fertilizer as farmers lose confidence with the latest "silver bullet" cultivar on the market.

Conclusions

- Dry matter production is the product of light intercepted and the efficiency of its conversion to biochemical products. Both processes are affected by temperature, moisture and nutrient availability.
- Water use efficiency of pastures is highest when plants have adequate nitrogen to maximize photosynthetic rates. Grasses require an external source of nitrogen to maintain high rates and canopy expansion.
- The biophysical environment of a location sets the potential DM yield limit and the impact of new ryegrass cultivars on annual yields at any given location has been small.
- Animal performance and dietary preferences indicate significant advantages with >50% clover content. Current on-farm establishment and grazing management practices often restrict pasture clover content.
- An understanding of the interaction of clover species, biophysical environment and on-farm management is required to maximize clover content in pastures.

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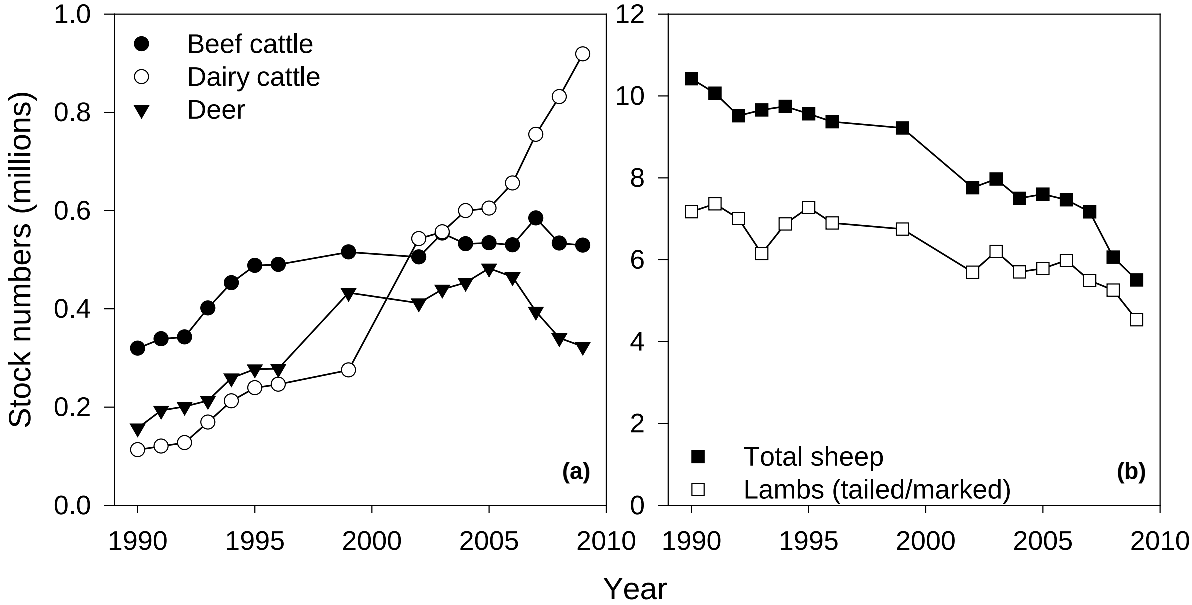

Figure 1. Changes in the number (millions) of (a) beef and dairy cattle and deer and (b) sheep (rams, ewes and wethers) and lambs in Canterbury between 1990 and 2009 (Department of Statistics 2010).

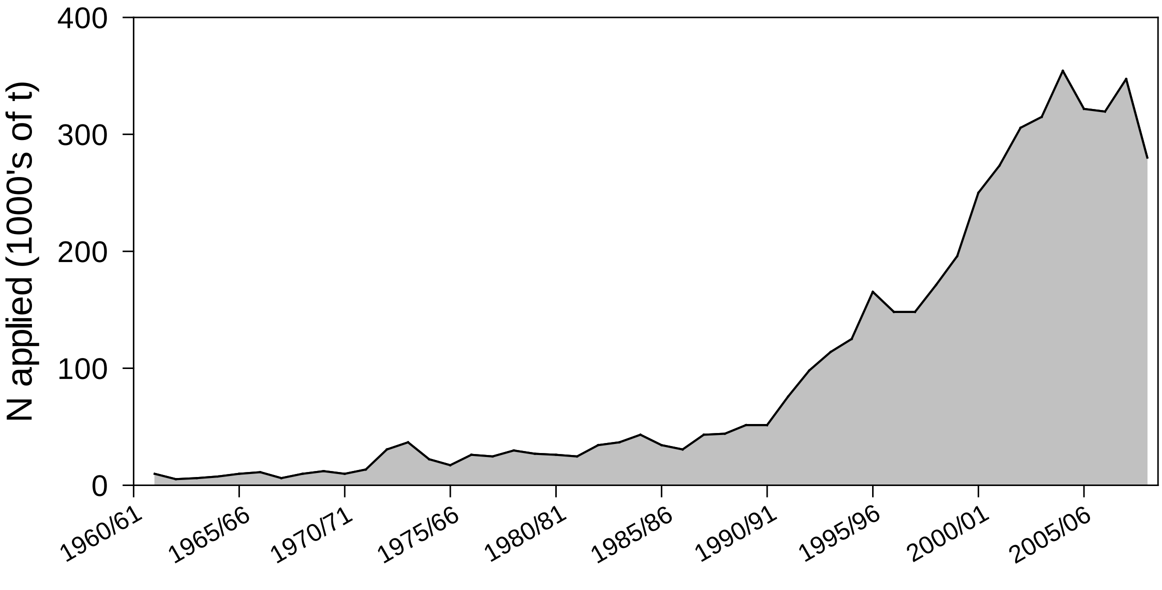

Figure 2. Total nitrogen (N) fertiliser applied in New Zealand between 1961/62 and 2008/09 (New Zealand Fertiliser Manufacturers' Research Association, 2009).

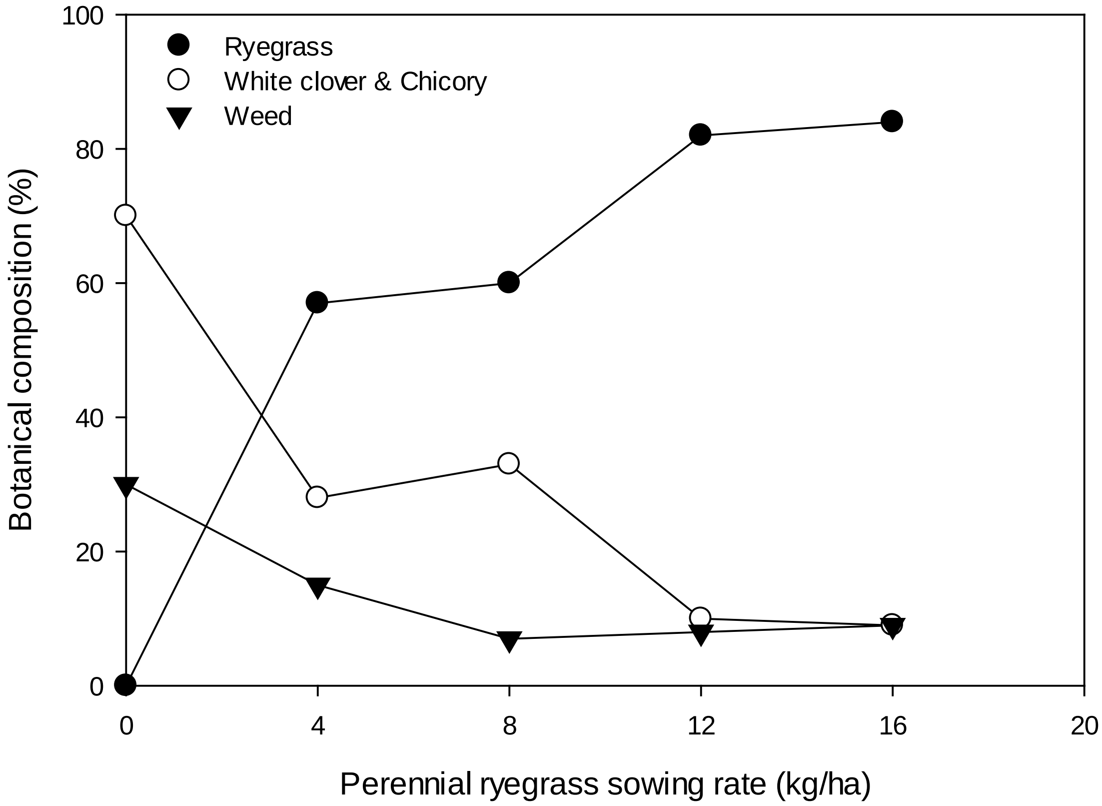

Figure 3. Botanical composition (%) in the establishment year of pastures established with perennial ryegrass at five different sowing rates sown on four different dates in the establishment year at Lincoln University, Canterbury, New Zealand. Pastures had basal white clover (3 kg/ha) and chicory (1.5 kg/ha) (redrawn from Dumbleton, 1997).

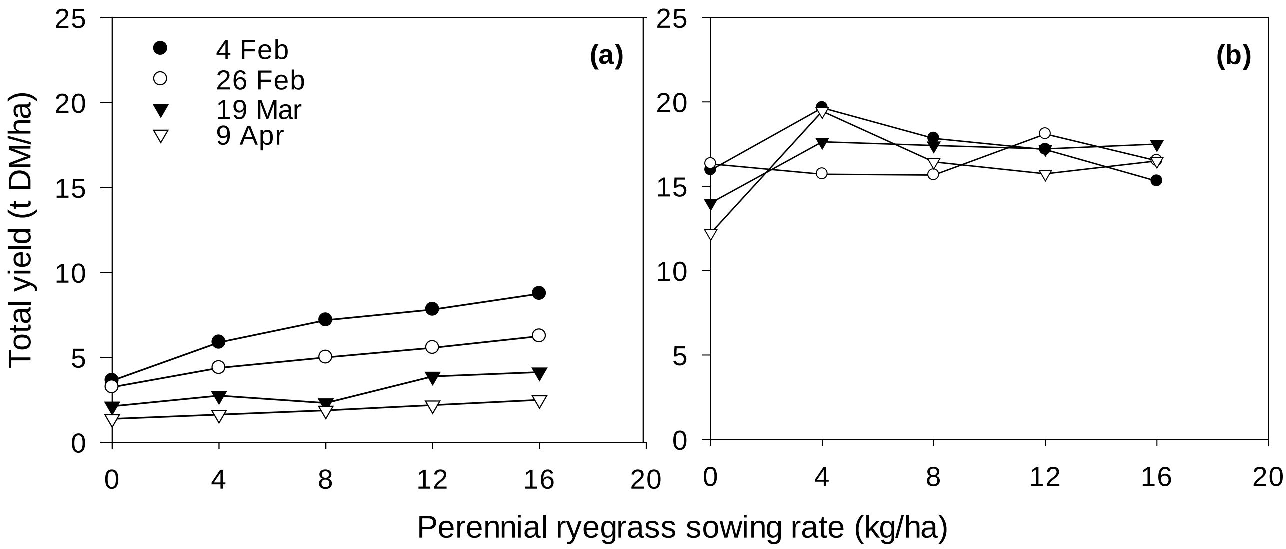

Figure 4. Total annual dry matter (DM) yields (t/ha) in (a) the establishment year and (b) Year 2 of pastures established with perennial ryegrass at five different sowing rates sown on four different dates at Lincoln University, Canterbury, New Zealand. Pastures had basal white clover (3 kg/ha) and chicory (1.5 kg/ha) (redrawn from Dumbleton 1997 and Nicholls 1998).