Establishment, annual yield and nitrogen response of eight perennial grasses in a high country environment

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Abstract

An experiment was established within the Lees Valley (400 m a.s.l.), Canterbury out of low producing, browntop dominant grassland. The aim was to quantify dry matter (DM) production of improved perennial grasses in relation to temperature and nitrogen inputs. Ten grass monocultures were established in 2006. For the first year, annual DM yield ranged from 4.2 t/ha (timothy) to 10.6 t/ha ('Aries' perennial ryegrass). On 15/8/2007 either 0 or 150 kg N/ha was applied to half of each plot. At the end of the spring 2007, yields were 1.3 t/ha ('Aries' no N fertiliser) to 5.5 t/ha ('Revolution' perennial ryegrass with N fertiliser). Yield responses ranged from 8.3 to 20.1 kg DM/kg N applied with an average spring growth rate of 3.2 kg DM/ha/^{o}Cd for grass with no N and 8.8 kg DM/ha/^{o}Cd for the N fertilised grasses, using a base temperature of 3^{o}C. Results highlighted the need to maximise spring growth in summer dry environments, especially when there is a large potential response to the addition of N. Cocksfoot and tall fescue produced more DM in summer dry conditions indicating some opportunity to spread production through the year, in regions with highly variable summer rainfall.

Keywords: *Bromus stamineus*, *Bromus valdivianus*, *Dactylis glomerata*, dryland, *Festuca arundinacea*, *Lolium perenne*, pasture establishment, *Phleum pratense*

Introduction

Farming systems of the undeveloped hill and high country of New Zealand are becoming more intensive as flat land is converted to irrigated dairying and lamb finishing while high altitude land may be retired through tenure review (Swaffield & Hughey 2001). Resident species vary with aspect and altitude (Pedofsky & Douglas 1987) but much of this land is dominated by browntop (*Agrostis capillaris* L.), sorrel (*Rumex acetosella* L.), hawkweed (*Hieracium pilosella* L.) and fescue tussock (*Festuca novae-zelandiae* (Hacke.) Cockayne). Pasture improvement of such land is required to match the increase in feed demand, as a result of increased stocking rates and lambing percentages, in these locations (Pedofsky & Douglas 1987; Matthews *et al*. 1999). However, there is little recent information regarding the ability of this land class to cope with increasing farming intensity under highly variable climatic conditions (Rattray 1978).

Critical aspects of successfully introducing improved pastures include rectifying any soil nutrient deficiencies at establishment, particularly those that may limit legume growth. In addition, control of poor quality low producing resident vegetation is required through the introduction of alternative species. Fast establishing species with high seedling vigour, such as perennial ryegrass (*Lolium perenne* L.), have the ability to reduce weed competition to a greater extent than slower establishing species such as tall fescue (*F. arundinacea* Schreb.), cocksfoot (*Dactylis glomerata* L.) and timothy (*Phleum pratense* L.) (Moot *et al*. 2000). In the Lees Valley, and many similar sites on the east side of the Southern Alps, moisture stress limits pasture production in summer and autumn before low temperatures constrain production in winter (Pollock *et al*. 1994). This leads to highly variable and inconsistent pasture supply (Rickard & Radcliffe 1976). Perennial grasses that can tolerate summer dry and/or low winter temperatures may be beneficial. In this study, improved pasture grasses were established as monocultures, (which is not commercially recommended), with the objective to identify grasses which would be productive and persistent in grass/legume mixtures within this environment.

In summer dry environments, the spring period is critical to maximise pasture production from available soil moisture (Mills *et al*. 2008). Nitrogen (N) deficiency can also be a major constraint to productivity in low input, extensive, hill country properties particularly during spring (Gillingham *et al*. 1998). In this study the productive potential of improved perennial grass species are compared after transition from undeveloped, low performance browntop dominant pasture. The objectives were to quantify the amount and temporal pattern of perennial grass production, interpreted as the growth response to thermal time (Mills *et al*. 2006), and to determine the effect of N fertiliser on yield and pasture composition, of the different grasses.

Materials and Methods

A 10 ha experimental site was established on the flat floor of Lees Valley, North Canterbury. The soil is a Tasman sandy loam (D.S.I.R. 1968). No historical weather records have been collected onsite so only data from the experimental period are available (Table 1).

Prior to the current experiment, the site was dominated

Table 1 Mean monthly air and soil temperatures (100 mm) and monthly rainfall (mm) at Lees Valley, Canterbury.

Year	Month	Air temp. (°C)	Soil temp. (°C)	Rainfall (mm)
2006	Nov	11.5	13.0	89
	Dec	11.1	14.2	106
2007	Jan	14.8	16.0	17
	Feb	14.4	15.8	30
	Mar	15.1	14.9	14
	Apr	9.1	11.2	37
	May	9.7	8.7	34
	Jun	3.3	4.2	49
	Jul	3.4	3.4	26
	Aug	5.2	5.5	26
	Sep	7.9	8.0	28
	Oct	9.7	9.5	109
	Nov	11.8	14.5	23
	Dec	14.9	17.5	28
2008	Jan	17.0	20.3	19
	Feb	15.2	18.4	95
	Mar	13.3	15.6	25
	Apr	9.3	12.6	30

Table 2 Soil test (0-75 mm) results from Lees Valley, Canterbury. Soil samples were analysed using MAF Quicktest procedures.

Year	pH (H_2O)	Olsen P (μ/mL)	SO_4^--S (μ/g)	Ca^{2+}	K^+	Mg^{2+}	Na^+
				(meq/100 g)			
2005	5.5	8	3	2	8	15	3
2007	6.1	16	9	9	9	8	2

Table 3 Actual emergence rate (plants/m²) and dry matter (DM) production (kg DM/ha) in the emergence phase (13/2/2006-26/4/2006) of perennial grass monocultures sown at Lees Valley, Canterbury.

	Emergence (plants/m²)		Yield
Treatment (Sowing rate)	8/3/2006	15/11/2006	(kg DM/ha)
Perennial ryegrass			
'Aries' (8 kg/ha)	446 $_{c}$		948 $_{ab}$
'Aries' (12 kg/ha)	655 $_{b}$		1241 $_{a}$
'Aries' (15 kg/ha)	821 $_{a}$		962 $_{ab}$
'Cannon LE' (8 kg/ha)	454 $_{c}$		929 $_{b}$
'Revolution' (8 kg/ha)		201	
Brome			
'Bareno' (20 kg/ha)		142	
'Gala' (20 kg/ha)	223 $_{d}$		534 $_{c}$
Cocksfoot			
'Kara' (3 kg/ha)	199 $_{d}$		235 $_{cd}$
Tall fescue			
'Advance' (12 kg/ha)	217 $_{d}$		113 $_{d}$
Timothy			
'Viking' (5 kg/ha)	433 $_{c}$		296 $_{cd}$
SEM	25	27	104
Significance	***	NS	***

***=P<0.001 and NS = non significant. Treatment means followed by the same letter subscript are similar.

by fescue and blue tussock grassland, browntop and matagouri (*Discaria toumatou* Raoul) scrub. The site is 400 m a.s.l. in an area that experiences cold winters (Table 1). Growth in spring increases with temperature until low soil moisture in summer and autumn becomes the main environmental limitation to pasture production.

Site preparation included 4 L/ha of Roundup (360 ml/L glyphosate) and 5 t/ha of lime applied in April 2005. The browntop mat was then broken down by being mob stocked with cattle in August. In October, a second herbicide application (360 ml/L glyphosate) was made to kill remaining resident vegetation. In January 2006, the site was disced, harrowed and heavy rolled. Fertilisers (400 kg/ha superphosphate and 300 kg/ha of DAP) were incorporated during cultivation to address fertility issues identified from soil tests taken in 2005 (Table 2). The site was then fallowed until sowing in February 2006. Soil tests were repeated in August 2007.

Ten grass monocultures, which included 'Aries' perennial ryegrass sown at three rates, 'Cannon LE' perennial ryegrass, 'Revolution' perennial ryegrass, 'Kara' cocksfoot, 'Gala' grazing brome (*Bromus stamineus* Desv.), 'Bareno' pasture brome (*Bromus valdivianus* Phil), 'Viking' timothy and 'Advance' tall fescue were sown with a Duncan triple disc drill into 9 x 40 m plots. Sowing rates and plant populations at emergence are given in Table 3. The experimental design was a randomised complete block with four replicates. Eight of the grass monocultures were sown on 13/2/2006, but unavailability of seed meant 'Bareno' brome and 'Revolution' perennial ryegrass were not sown until spring on 1/11/2006 after a 9 month fallow. The Duncan drill was calibrated for sowing but the uneven trial site coupled with a stony soil meant emergence counts were used to identify the sowing rate with a target population of at least 150 plants/m^2 (Table 3).

Measurements

Seedling emergence was counted from 4 x 1.0 m drill rows/plot on 8/3/2006 and 15/11/2006 for the February and November sowings, respectively. Dry matter production was measured prior to grazing at the end of seven regrowth cycles (26/4/2006, 6/9/2006, 26/10/2006, 1/7/2007, 27/11/2007, 17/1/2008 and 8/4/2008) using both cutting and a pasture capacitance probe (Mosaic Systems Ltd, Palmerston North). Twenty probe readings were taken from each plot and averaged. Paired comparisons of destructive harvests with probe readings were used to create the calibration.

The period from sowing until April 2006 was a partial growth season and considered the establishment phase. Year 1 annual DM production was accumulated from 1/7/2006–30/6/2007 and Year 2 was the period 1/7/2007-5/6/2008 and included DM produced by N fertilised pastures in spring. At the end of each rotation, prior to grazing, DM production was determined from destructive harvest of a 0.2 m^2 quadrat cut to ground level in each plot. Subsamples were taken following standard practice (Cayley & Bird 1996) to determine botanical composition.

Spring 2007

Plots were mob stocked for grazing between 29 June and 1 July 2007 to remove the previous season's biomass. Plots were then halved to form a cross plot experiment and one half of each of the main plots received calcium ammonium nitrate (150 kg N/ha) on 15/8/2007 in line with the scheduled on-farm management. The response to nitrogen was measured for the spring regrowth period to 20/11/2007, prior to grazing. The next regrowth period was from 21/11/2007 to 17/1/2008 at which time pastures were mown and dead and reproductive material removed.

To return all pastures to the original randomised complete block experiment after the spring 2007 regrowth period, all plots (both +N and -N) received an autumn N application of 46 kg N/ha (as urea) on 19/2/2008 as was scheduled on-farm. Observations 1 month after the application showed visual symptoms of N deficiency were still evident in subplots which had not received the spring N. Consequently, a further 50 kg N/ha (as urea) was applied to the –N plot halves on 18/3/2008.

Analysis

Data collected up to spring 2007, were analysed by least squares regression in Genstat 9 and means were separated by Fisher's protected LSD. After N fertiliser application in August 2007, the experiment was analysed as a cross plot design in Genstat 10. The relationship between DM yield accumulation and thermal time was determined by linear regression. Full details of the method used were described previously (Mills *et al*. 2006). When interactions were significant but the F ratio for main effects was more than two orders of magnitude greater than the interaction, discussion focuses on the main effects.

Results

Establishment

On 8/3/2006 there were 820 plants/m^2 when 15 kg/ha of 'Aries' was sown compared with ($P<0.001$) 655 and 446 seedlings/m^2 for the 12 and 8 kg/ha sowing rates, respectively (Table 3). The low endophyte 'Cannon LE' and timothy had >430 plants/m^2 and there were <230 plants/m^2 for the other five species ($P<0.001$). By 26/4/2006 all 'Aries' treatments produced 1050±103 kg DM/ha which was more than the 534 kg DM/ha from 'Gala' brome ($P<0.001$). The remaining slower emerging species produced only 100-300 kg DM/ha in the 2 month emergence phase.

Figure 1 Accumulated DM yield for eight perennial grasses in Year 1 (1/7/2006-20/6/2007) and Year 2 (1/7/2007-5/6/2008) at Lees Valley, Canterbury. Values are maximum annual treatment yields achieved during the growth season.

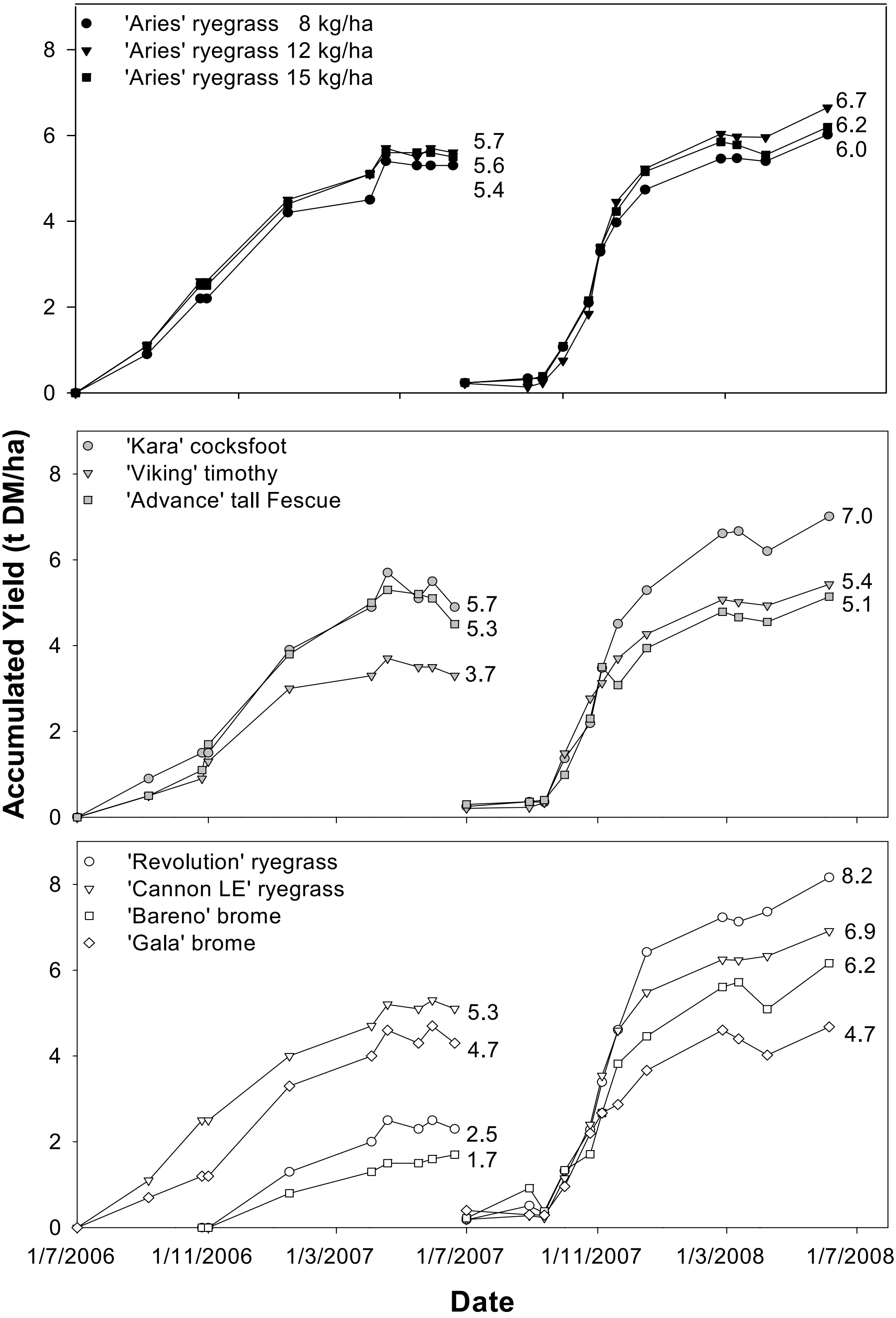
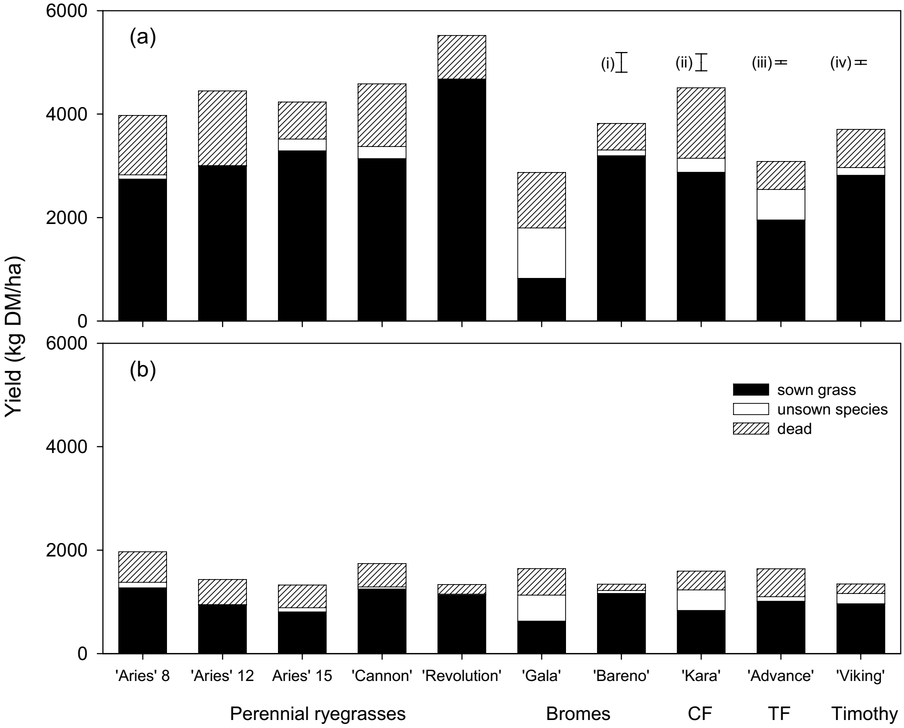


Table 4 Dry matter (DM) responses (kg DM/kg N applied) and growth rate (kg DM/ha/°Cd) of grass monocultures which received 0 or 150 kg N/ha in spring 2007 (1/7/2007-20/11/2007). Thermal time was calculated using a base air temperature of 3°C for grass monocultures at Lees Valley, Canterbury.

Treatment	DM response (kg DM/kg N)	Growth rate (kg DM/ha/°Cd) 0 kg N/ha	150 kg N/ha
Perennial ryegrass			
'Aries' (8 kg/ha)	13.4 $_{bcd}$	4.2	8.3
'Aries' (12 kg/ha)	20.1 $_{ab}$	3.1	9.1
'Aries' (15 kg/ha)	19.4 $_{abc}$	2.7	8.7
'Cannon LE'	19.0 $_{abc}$	3.7	9.4
'Revolution'	27.9 $_{a}$	2.5	10.3
Brome			
'Bareno'	16.5 $_{bcd}$	2.3	6.4
'Gala'	8.2 $_{d}$	3.4	6.1
Cocksfoot			
'Kara'	19.4 $_{abc}$	3.1	9.0
Tall fescue			
'Advance'	9.6 $_{cd}$	3.6	8.0
Timothy			
'Viking'	15.7 $_{bcd}$	2.9	7.6
Mean	16.9	8.3 $_{a}$	3.2 $_{b}$
SEM	3.43	0.17	
Significance	**	***	

**P≤0.01, ***P≤0.001, treatment means followed by the same letter subscript are similar.

Figure 2 Yields of sown grass, unsown species and dead material at the end of the spring on 20/11/2007 at Lees Valley, Canterbury for (a) pastures receiving 150 kg N/ha and (b) pastures that received no spring nitrogen. CF is cocksfoot, TF is tall fescue. Error bars are SEM for (i) the interaction between N and sown grass on total DM yield, (ii) the effect of N on sown grass, (iii) the effect of grass type on unsown species yield and (iv) the effect of N on yield of dead material.



Annual DM production

In the first year after establishment, the lowest (P<0.01) total DM yield was from timothy (3.7 t/ha) while other autumn-sown treatments produced 4.7-5.7 t/ha (Fig. 1). There were temporal differences in the DM production among species. Between July and November 2006 the autumn sown perennial ryegrass pastures produced 2.5 t DM/ha compared with 1.4 t DM/ha for slower establishing autumn-sown species. Over the next 33 days to mid January, cocksfoot produced 2.4 t DM/ha which was similar to tall fescue (2.2 t DM/ha) and higher than that from the perennial ryegrass pastures (1.8 t DM/ha).

In spring of Year 2, total DM yield was affected by the interaction between grass species and N fertiliser rates (Fig. 2). However, the main effect of nitrogen was dominant (P<0.001) and represented 64% of the total sum of squares compared with only 7% for the interaction. The absolute range in spring growth was from 1.3 t DM/ha from the unfertilised 'Aries' at 15 kg/ha to 5.5 t DM/ha for 'Revolution' perennial ryegrass that received spring nitrogen. Averaged over all pastures that received nitrogen, spring DM yield was 4.0±0.09 t/ha compared with 1.5±0.09 t/ha from the unfertilised pastures.

Botanical composition was also affected by the interaction (P<0.01) of grass species and N fertiliser rate but again the N effect (P<0.001) was dominant (Fig. 2). Pastures that received spring N contained 2850±88 kg DM/ha of sown grass which was more than double the 1000±88 kg DM/ha in pastures that received no spring N. The amount of unsown species (mainly regenerating browntop) was highest (P<0.001) in 'Gala' grazing brome which contained 738 kg DM/ha or twice that found in cocksfoot and tall fescue. There was <100 kg DM/ha of unsown species in the perennial ryegrasses, 'Bareno' brome and timothy pastures. The common grazing meant it was not possible to control grazing for each species individually. Furthermore, the timing was deferred to maintain cover for a farmer field day in November leading to 25% dead material being present which was greater than ideal

The maximum DM response to the N fertiliser applied was 27.9 kg DM/kg N for 'Revolution' ryegrass compared with 13.4 kg DM/kg N for 'Aries' sown at 8 kg/ha (P<0.05). For the other grasses the lowest response (8.2 kg DM/kg N) was from 'Gala' grazing brome compared (P<0.05) with 19.4 kg DM/kg N from the cocksfoot (Table 4). The impact of the spring nitrogen application can also be quantified by the spring pasture production in relation to thermal time. Regression analyses showed the fertilised grasses averaged 8.3 kg DM/ha/^{o}Cd compared with (P<0.05) 3.2 kg DM/ha/^{o}Cd for the unfertilised plots (Table 4). There was some variation around the mean with perennial ryegrasses and cocksfoot being more responsive per unit of temperature than the bromes.

Due to low rainfall (Table 1), DM production between 21/11/2007-17/1/2008 was only 324±56.8 kg DM/ha for all pastures. In the final rotation for Year 2 (12/4/2008-5/6/2008), the highest (P<0.01) yield was 1.1 t DM/ha ('Bareno' brome) and the lowest was 0.5 t DM/ha (timothy). Annually, total DM yield for Year 2 (Fig. 1) from the spring fertilised monocultures was lowest (P<0.05) for 'Gala' brome (4.7 t DM/ha) and highest for 'Revolution' perennial ryegrass (8.2 t DM/ha).

Discussion

The results highlighted rate of emergence and spring production as the two most important factors for maximising DM production in this environment. The challenge for grass establishment is to ensure that the species sown are sufficiently competitive to suppress the resident low quality vegetation and allow the sown species to thrive. In this experiment, ensuring successful establishment was aimed at soil and seedbed management in the 10 month period prior to sowing. This addressed soil acidity and nutrient deficiencies (Table 2), double sprayed resident herbage followed by winter grazing and trampling, a summer fallow and heavy discs and rolling to prepare as ideal a seedbed as possible (Pottinger *et al.* 1993). In practice it is often not physically or economically viable to utilise such a long and expensive preparation period for establishment. Despite this intensive preparation, there was variability in the emergence and establishment success of the species sown (Table 3), with low yields in the establishment phase compared with lowland sites (Mills *et al*. 2007), which reflected the dominant effect of the environment. The rapidly establishing perennial ryegrasses (Moot *et al.* 2000) were more successful than the slower emerging cocksfoot, timothy and tall fescue in maintaining pure grass swards through the first 2 years of this experiment (Fig. 2). The unsown species returning to the pasture was predominantly browntop which the preparation methods had targeted for control through the addition of phosphorus, autumn spraying of a translocatable herbicide and winter mob stocking (Pottinger *et al.* 1993). The invasion of this species in the 'Gala' grazing brome highlights the open nature of its canopy despite the number of seedlings emerging being similar to other species.

Of note was the similarity in perennial ryegrass yields with a range of sowing rates (8-15 kg/ha) and differences in sowing time between 'Revolution' and the other cultivars. The ability to succeed at establishment is an important factor to consider when pastures are sown in less than ideal seedbed preparation and environmental conditions. Over time the persistence of perennial ryegrass within a dryland sward may become compromised by the low summer rainfall (Table 1) compared with other grasses (Mills *et al*. 2008). This means ongoing monitoring of the yield and botanical composition over several years is required to assess the total suitability of each species within the environment.

A feature of the experiment was the large and consistent response of all pasture grasses to the application of spring nitrogen. Absolute yield responses of over 25 kg DM/kg N applied (Table 4) have been reported for unimproved grasslands (Gillingham *et al*. 1998). This highlights the lack of available nitrogen from soil mineralisation despite the break down of the resident vegetation at establishment. The strategic use of nitrogen is a management tool available in dryland environments that can help to overcome a feed deficit. The response per unit temperature highlights the importance of nitrogen in the spring period when soil moisture is at its highest levels. The 3.2 kg DM/ha/°Cd was similar to the N response to temperature recorded for an 8-year-old 'Wana' cocksfoot pasture at Lincoln University (Mills *et al*. 2006). The consistency of this result suggests that in spring many dryland pastures are nitrogen deficient and are growing at about half their potential rate. During this period most of the available soil moisture is utilised whether the pasture is growing at 3.2 or 10.3 kg DM/ha/°Cd (Table 4). The analyses used a base temperature of 3°C for accumulation of thermal time (Mills *et al*. 2006) but there was a systematic error in the regressions with a positive x-axis intercept of ~250°Cd. This was probably due to slow canopy closure in cold winter conditions which limited leaf expansion. Thus DM production in relation to thermal time accumulation based on soil rather than air temperature may be more appropriate. The potential to double yield in spring was shown for all pasture grasses sown (Fig. 2). The affordability of 150 kg N/ha for dryland farmers may be limited, particularly since the cost of CAN or urea has more than doubled since 2001 (Fleming 2003), but this result highlights the importance of nitrogen in the spring production period. Visually there were still differences the following autumn.

In practice, most New Zealand pastures are established with one or more legumes to improve the pasture quality, nitrogen status and overall production of the pastures. This study was instigated to identify the most appropriate grasses, which are productive, persistent and responsive to N within this environment as the basis for grass/legume mixtures. The provision of nitrogen to grass pastures through fixation by legumes is being explored in separate experiments at the site. The lack of summer moisture and cold winter conditions limit the potential of white clover in this environment and annual clovers that are more active in spring could be appropriate. The annual death of these plants each summer should produce a flush of nitrogen that is available to the associated grasses in the following autumn or spring (Mills *et al*. 2008).

Conclusions

These results highlight the ease and competitiveness of perennial ryegrass at establishment. They also indicate tall fescue and cocksfoot have potential to offer growth outside of the main ryegrass spring production period. The importance of increasing the herbage N content to maximise spring growth when moisture is available was also highlighted through the use of inorganic N applications but may be achieved through appropriate clovers.

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