Annual herbage production increased 40% when subterranean clover was over-drilled into grass-dominant dryland pastures

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Abstract
Annual dry matter (DM) production and botanical composition from dryland cocksfoot and ryegrass pastures grown with and without subterranean clover were measured over 2 years (2006-2008) in Canterbury. Yields ranged from 6.4 to 12.4 t DM/ha/yr. Spring yield was increased by 23-45% by the inclusion of subterranean clover. Total DM production was similar between grass species but ryegrass pastures contained 45% weeds compared with <5% for cocksfoot by the end of winter in 2008. In non water-limited spring conditions, pastures with subterranean clover grew at over 60 kg DM/ha/day which was at least 40% faster than those that were grass-dominant and ryegrass grew faster than cocksfoot. This study confirms the positive impact that over-drilled subterranean clover can have on pasture production in grass-dominant dryland pastures.
Keywords: annual clovers**,** *Dactylis glomerata*, *Lolium perenne,* perennial ryegrass, stocking rate, thermal time, *Trifolium glomeratum*, *T. subterraneum,* soil moisture, water use efficiency

Introduction
About 2.8 M hectares of land or 11% of total land area in New Zealand receives less than 800 mm of annual rainfall (Brown & Green 2003). These areas are consistently prone to dry soil conditions during summer when potential evapotranspiration rates are high. This restricts pasture and animal production and therefore farm profitability. The lack of persistence and production of white clover (*Trifolium repens*) and perennial ryegrass (*Lolium perenne*) under these conditions means alternative pasture species are required (Brown *et al*. 2006; Mills *et al*. 2008). Specifically, spring growth before the summer dry sets in, is crucial to maximise pasture production.

Cocksfoot (*Dactylis glomerata*) is often sown alone or with ryegrass in moderate fertility dryland pastures. However, the persistence of white clover when sown with cocksfoot in these areas is problematic (Lee & Cho 1985). Therefore, alternative grass and legume combinations are needed to provide persistent pastures and high quality feed. It is important that these species grow in late winter and early spring to feed lactating ewes and their lambs, and to ensure that lambs are finished and maximise liveweight gain before the onset of the summer-dry conditions (Grigg *et al.* 2008). In these dry environments a range of annual legumes such as subterranean clover (*T. subterraneum*) may be more productive than white clover (Chapman *et al.* 1986) and persist as a companion for ryegrass and cocksfoot (Smetham 2003; Mills *et al*. 2008). The early growth of the annual clovers may also be aided by the slower spring growth of cocksfoot compared with perennial ryegrass.

Most studies with subterranean clover have examined performance during and after establishment but not when over-drilled into existing pastures. In this study subterranean clover was over-drilled into mature grass-dominant established pastures. The quantity and quality of herbage produced was measured over 2 years. Pasture production was also related to the main environmental variables of temperature and moisture to enable results to be transferred beyond the experimental site.

Materials and Methods
Experimental site
This experiment was in a 2.9 ha paddock at Ashley Dene, the Lincoln University dryland research farm located near Lincoln, Canterbury. The soil type is a Lismore stony silt loam (Cox 1978). The paddock was cultivated and a randomised block experiment was established on 7 October 2002. There were five pasture combinations of 'Aries HD' perennial ryegrass (RG) infected with AR1 endophyte, 'Vision' cocksfoot (CF) and 'Demand' white clover. Perennial ryegrass was sown at 0, 5, 10 or 15 kg/ha with 2 kg/ha of cocksfoot and 2 kg/ha of white clover (Treatments 1-4). A fifth treatment was sown at 10 kg/ha of ryegrass and 2 kg/ha of white clover without cocksfoot. The persistence of white clover in all five pasture treatments was negligible with <0.1% ground cover by early March 2005. Therefore, the plots (16 x 80 m) were over-drilled (on

Figure 1 Mean monthly air temperature at Ashley Dene, Canterbury, in 2006/07 (Sep 06-Sep 07) and 2007/08 (Sep 07-Sep 08). The line is the eight year mean (2001-2008).

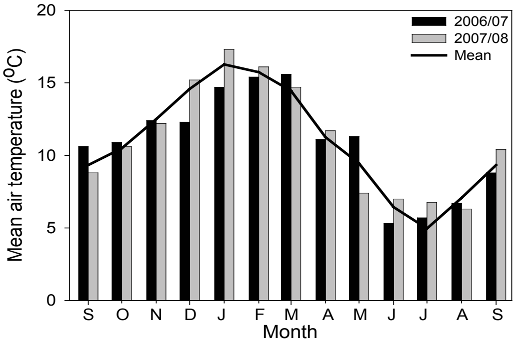


Figure 2 Accumulated weekly rainfall (mm, bars) and soil moisture content (circles, % v/v) in the 0-0.2 m soil layer at Ashley Dene, Canterbury from 15 September 2006 to 10 September 2008. The top and bottom dashed lines represent field capacity and 50% of field capacity, respectively.

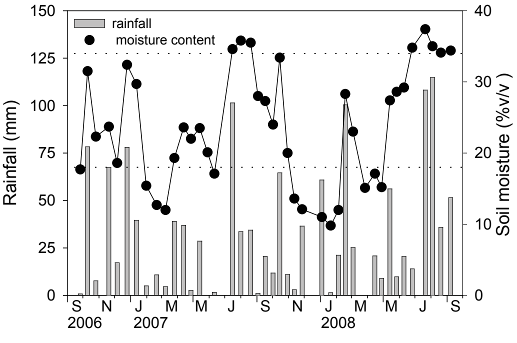


Table 1 Soil test (0-75 mm) results at Ashley Dene trial site from 2006-2008.

Year	pH (H_2O)	Olsen P (µg/ml)	SO_4 S (µg/g)	Ca	K	Mg	Na
				----(meq/100 g)----			
2006	6.4	18	4	10	14	17	6
2007	6.4	30	4	9	24	19	5
2008	6.1	25	2	10	21	20	5

18 March 2005) at right angles to the original sowings with 10 kg/ha of annual (+AC) subterranean clover (5 kg/ha 'Leura' and 5 kg/ha 'Campeda'), but leaving two 10 m wide strips in each block that were not over-drilled. This created a 16 x 60 m (+AC) and a 10 x 16 m (-AC) strip in each of the original plots established in 2002. The subterranean clover was inoculated with Group C peat inoculant before sowing.

Ewes and twin lambs were set-stocked in spring (lactation) and pastures were rotationally grazed in summer/autumn. Mean monthly air temperatures are presented in Fig. 1 and rainfall in Fig. 2. Soil test results are presented in Table 1. Sulphur super 20 (21% S, 18% Ca, 8% P) was applied on 18 August 2006 at 200 kg/ha. All nutrients were present in adequate amounts with the exception of sulphate-sulphur which was below optimum.

The five original pastures were grazed in common (Ates *et al*. 2008). In this study, only two of the original five 2002 pastures were measured. These were i) 10 kg/ha ryegrass + 2 kg/ha white clover and ii) 2 kg/ha cocksfoot + 2 kg/ha white clover. In 2006/07 only three pasture treatments (CF+AC, CF-AC, RG+AC) were measured. In 2007/08 ryegrass without annual clovers (RG-AC) was also included which gave four pasture subplot treatments with six replicates.

Measurements

Treatments were monitored over two growth seasons from 19 September 2006 to 7 September 2008. Harvests were made at ~30 day (range 28-35 day) intervals during active growth and at ~60 day (range 43-97 day) intervals during dry summer and low winter growth periods. Grazing exclosure cages (1.0 m^2) were placed over a pasture area pre-trimmed to 20 mm residual height at the start of each new growth period. Cages were not returned to previously measured sites.

Pasture growth was measured from a 0.2 m^2 quadrat, cut with electric shears, to a residual height of 20 mm within the exclosure cage on each plot. Subsamples of harvested material (Cayley & Bird 1996) were sorted into cocksfoot, ryegrass, annual grass weeds, subterranean clover, white clover, cluster clover (*T. glomeratum*), broadleaf weeds and dead material. Samples were oven-dried at 70 °C to a constant weight.

Soil moisture was measured with Time Domain Reflectometry (TDR) (Trace Systems model 6050X1, Soil Moisture Equipment, Santa Barbara, California, USA). The TDR stainless steel rods were inserted to 0.2 m depth at a central location and data were collected at 13-38 day intervals. Changes in soil moisture content are reported in Fig. 2. Pastures were considered to be water stressed when the volumetric water content in the top 0.2 m was below 18% (50% of field capacity). This occurred from mid January to mid March in 2007 and mid November to mid February in 2008.

Total DM production and mean annual botanical composition were analysed by ANOVA in Genstat 11 (Lawes Agricultural Trust). Temperature adjusted growth rates were derived by linear regression, through the origin, of accumulated DM against accumulated thermal time. Thermal time, also known as heat units or degree days (°Cd), was calculated from air temperatures (base temperature = 3°C; Mills *et al*. 2006) during spring when soil water was non-limiting (e.g. >50% of the field capacity). Slopes were analysed as a split-split plot design with year as a repeated measure. Means were separated by Fishers' protected least significant difference (α=0.05) test.

Results

Dry matter production

Ryegrass pastures with over-drilled annual subterranean clover produced 12.4 t DM/ha/yr in 2006/07 (Fig. 3) which was similar to the 10.7 t DM/ha/yr from cocksfoot. Both yields were greater ($P<0.001$) than from cocksfoot pastures without annual clovers (6.6 t DM/ha/yr). Similarly, in 2007/08 total DM production in the over-drilled pastures was 8.6 to 9.6 t DM/ha/yr and 34-45% higher ($P<0.001$) than from ryegrass or cocksfoot pastures without annual clovers (-AC).

Mean daily growth rates

There were distinctive seasonal shifts in pasture growth rates over the 2 years (Fig. 4). Mean daily growth rate (kg DM/ha/day) was consistently higher ($P<0.05$) for ryegrass compared with cocksfoot pastures either with or without over-drilled annual clovers until December in 2006/07. Subsequently, pasture growth rates did not differ ($P>0.05$) until the end of the growing season. In early spring (September) 2007/08, pastures that included subterranean clover grew 37 kg DM/ha/day faster ($P<0.01$) than pastures without and were 30% faster ($P<0.01$) for ryegrass than cocksfoot-based pastures.

Figure 3 Total accumulated dry matter (DM) production of ryegrass (RG) and cocksfoot (CF) pastures with (+AC) and without (-AC) annual clovers grown in C9(A)S at Ashley Dene, Canterbury from 2006 to 2008. Error bars are SEM for total annual DM yield. Measurements from ryegrass pastures without annual clovers commenced on 3 September 2007.

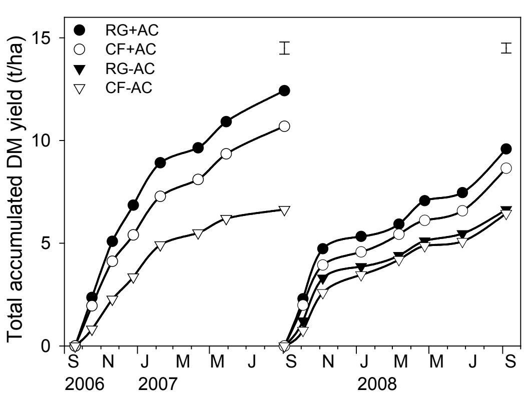
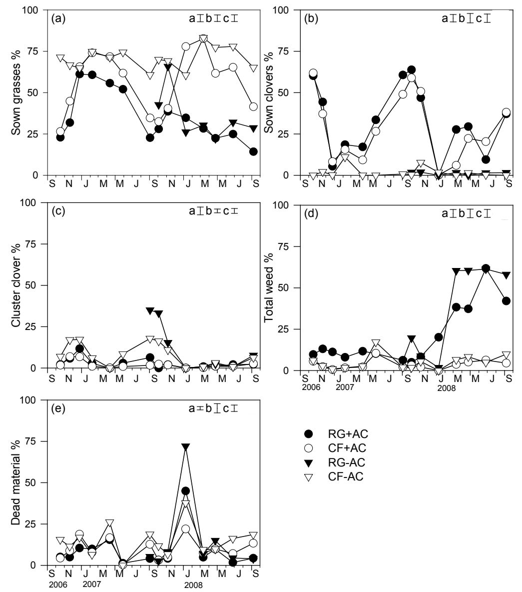


Figure 4 Mean daily growth rates of ryegrass (RG) and cocksfoot (CF) pastures grown with (+AC) or without (-AC) annual clovers at C9(A)S Ashley Dene, Canterbury from 2006 to 2008. Error bars represent maximum SEM for a) pasture type, b) grass species and c) annual clover.



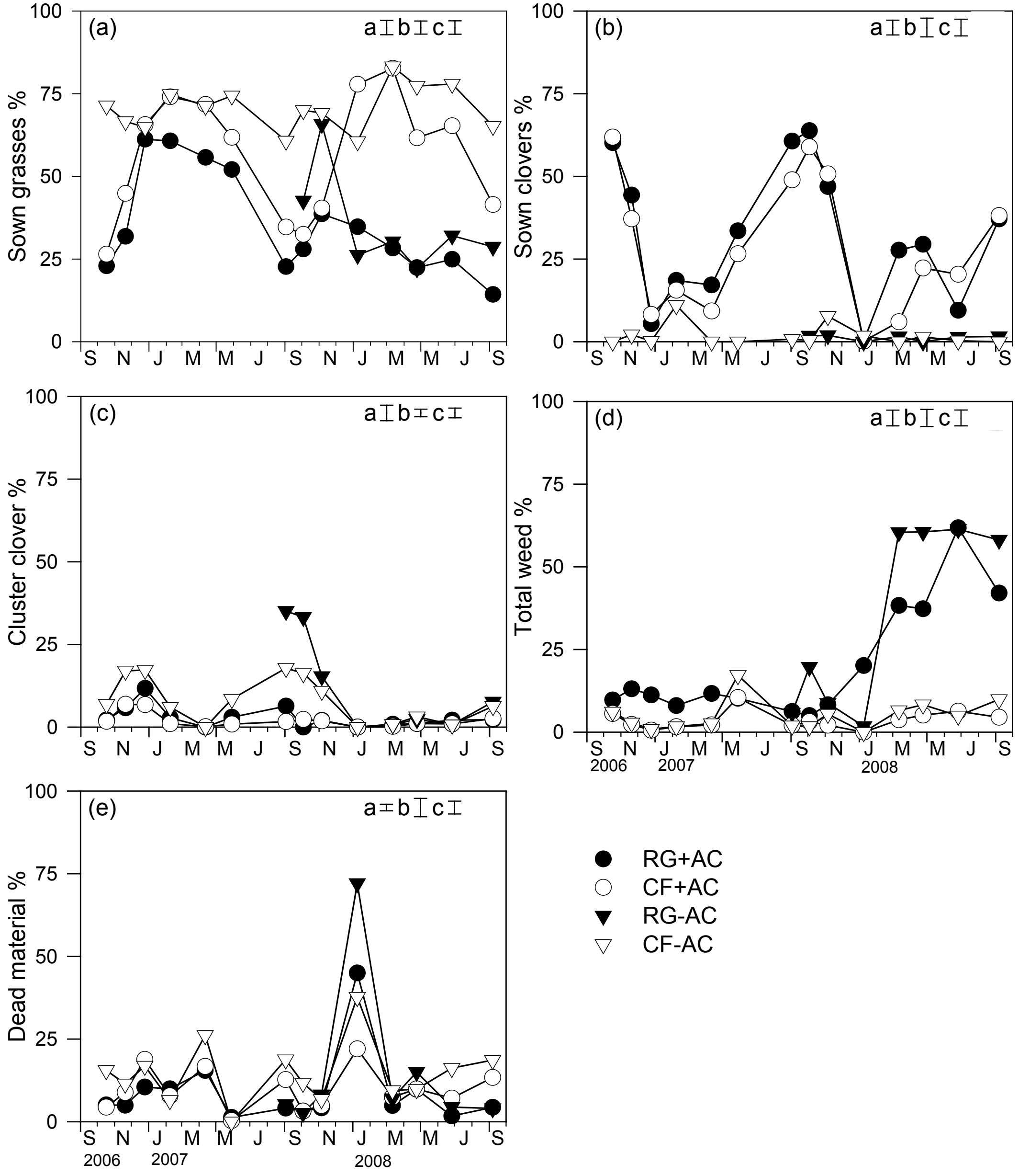
During this time there was also a large increase of ~60 kg DM/ha/day in growth rates for pastures without subterranean clover. This coincided with an increase in the production of the volunteer annual cluster clover (Fig. 5c). Pasture growth rates ranged from 8 to 14 kg DM/ha/day during summer (December to February) and 15-25 kg DM/ha/day from then on through autumn. Cocksfoot pastures had higher ($P<0.05$) growth rates than ryegrass during summer, but ryegrass pastures grew faster ($P<0.05$) during autumn.

Pasture growth rate was related to accumulated thermal time to quantify the seasonal temperature response. Data were analysed for the non moisture limited (>50% of field capacity) spring season each year (Fig. 2). In 2006/07, ryegrass pastures over-drilled with annual clovers grew at 8.4 kg DM/ha/°Cd through September and October compared with 6.8 kg DM/ha/°Cd for cocksfoot (Fig. 6a). Similarly, in spring 2007, ryegrass pastures with subterranean clovers grew 8.7 kg DM/ha/°Cd, compared with 7.2 kg DM/ha/°Cd (Fig. 6b). Ryegrass pastures without subterranean clover grew 6.1 kg DM/ha/°Cd which was faster ($P<0.001$) than the 4.8 kg DM/ha/°Cd for cocksfoot pastures over the same period.

Botanical composition

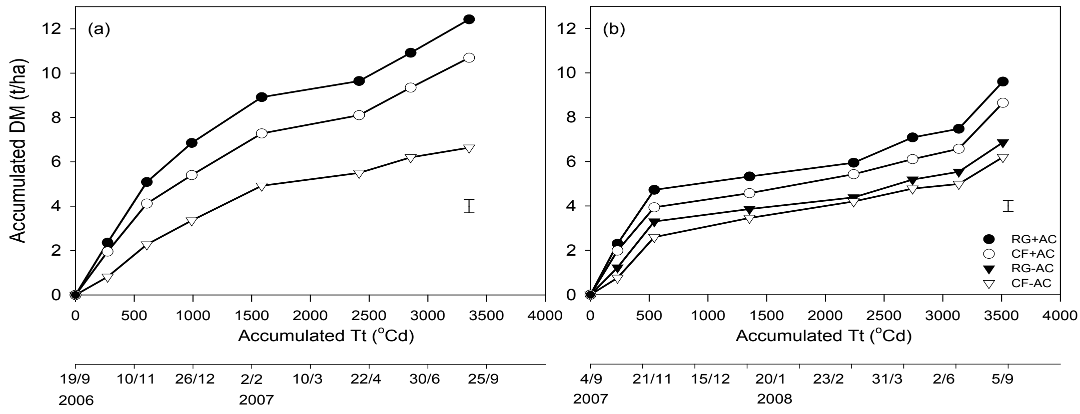
For ryegrass pastures, the average sown grass content decreased from 62% in January 2007 to <30% by the

Figure 5 Botanical composition (%) of pastures showing contributions from (a) total sown grasses, (b) total sown clovers, (c) cluster clover, (d) total weed and (e) dead material in cocksfoot (CF) and ryegrass (RG) pastures grown with (+AC) and without (-AC) annual clovers from 2006 to 2008. Error bars represent maximum SEM for a) pasture type, b) grass species and c) annual clover (sown).



end of the measurement period in September 2008 (Fig. 5a). Conversely, broadleaf weeds, predominantly storksbill (*Erodium cicutarium*), dandelion (*Taraxacum officinale*) and chickweed (*Stellaria media*), and invasive annual grasses such as barley grass (*Hordeum murinum*) and vulpia (*Vulpia* sp.), increased to over 45% of DM after spring 2007 (Fig. 5d). This compared with <5% weeds for cocksfoot-based pastures. Of the sown clovers, 99% was subterranean clover with <1% white clover in both cocksfoot and ryegrass pastures. Subterranean clover content was the highest during spring in both years reaching up to 50% of DM in both grass pastures (Fig. 5b). The volunteer cluster clover content averaged 24% in ryegrass pastures

Figure 6 Accumulated dry matter (DM) yield (t/ha) of ryegrass (RG) or cocksfoot (CF) pastures over-drilled with (+AC) or without (-AC) annual subterranean clover against accumulated thermal time (Tt, °Cd) above a base air temperature of 3°C in (a) 2006/07 and (b) 2007/08. Error bars are SEM for total annual DM yield.



grown without annual clovers from September to November (Fig. 5c) but declined in the second year as the broadleaf weed content increased (Fig. 5d). Dead material generally contributed to 15% (Fig. 5e) of total DM yield. The exception was the dry period in January 2008 when the dead content ranged between 22% (CF+AC) and 72% (RG-AC) of the low (≤0.5 t/DM/ha) total DM yield.

Discussion

The reason for over-drilling these pastures with annual clover was the lack of legume 3 years after their initial establishment in 2002. The failure of white clover to persist in this dryland environment is consistent with previous reports on dryland farms (Knowles *et al*. 2003). In this study, the pastures over-drilled with subterranean clover yielded 34-61% more annually than those without (Fig. 3). The success of these pastures further highlights the potential for commercial dryland farmers to improve the quality and yield of grass-dominant pastures by utilising subterranean clover (Costello & Costello 2003; Grigg *et al*. 2008).

The improved yields from the over-drilled pastures probably resulted from the additional nitrogen input (Tonmukaykul *et al.* 2009). Subterranean clover fixes about 25 kg N/t shoot biomass (Dear *et al.* 1999; Lucas *et al*. 2010) and its annual life cycle means this plus additional nitrogen from roots is released to the soil each summer. Nitrogen has been reported to be more limiting than water in determining the annual production of cocksfoot monocultures (Mills *et al.* 2006). Thus, the current results provide a practical option of over-drilling subterranean clover to overcome this major constraint to pasture production. It is possible that other annual legumes could provide similar results but currently successful management packages for these have not been developed in New Zealand.

Herbage production varied among grass treatments and in different seasons (Fig. 3). Total annual DM production of ryegrass pastures was similar or higher than cocksfoot pastures during spring and autumn, when soil moisture was not limiting pasture growth. Cocksfoot gave greater herbage production during summer in both years. The seasonal pattern of pasture production in both years highlights the importance of a non moisture-limited spring for dryland pastures. The higher mean growth rates in spring from pastures that contained annual clovers (Fig. 4) was the major contributor to their superior annual DM yields. During spring, ryegrass with subterranean clover grew at the fastest rate of 8.7 kg DM/ha/°Cd compared with 6.1 kg DM/ha/°Cd from ryegrass without subterranean clover (Fig. 6).

Of note was the increased weed content of ryegrass pastures even when grown with subterranean clover (Fig. 5d). The AR1 perennial ryegrass used in this study produces peramine which protects plants from Argentine stem weevil (ASW) (*Listronotus bonariensis*) (Popay & Wyatt 1995). However, root aphids (*Aploneura lentisci*) can be an issue in this dry Canterbury environment (Pennell *et al.* 2005) and AR1 offers little or no protection from this insect. The use of AR37 endophyte that produces epoxy-janthitrems may confer greater resistance to this and other insects (Popay & Thom 2009). In contrast, the cocksfoot-based pastures retained over 80% of sown species with less weeds and volunteer adventive annual clover.

Cocksfoot pastures without over-drilled subterranean clover yielded 6.6 t DM/ha in both years. These yields are comparable to other results in this environment (Rickard & Radcliffe 1976; Mills *et al.* 2006). The 40% yield increase from the over-drilled subterranean clover offers an opportunity to increase the yield and quality of cocksfoot-based pastures. This is likely to increase animal liveweight gains through the provision of more high quality feed (Mills *et al*. 2008). The additional nitrogen inputs lead to improved water use efficiency (Moot *et al*. 2008; Tonmukaykul *et al*. 2009), and higher growth rates (7.2 versus 4.8 kg DM/ha/°Cd), particularly during spring.

The importance of available soil moisture can be seen by comparing production between years. Averaged across pasture treatments herbage production was approximately 2.0 t DM/ha/yr higher in 2006/07 than 2007/08. This difference was mainly due to the differences in the amount and timing of rainfall (Fig. 2). Rainfall from December until February was 127 mm in 2006/07 compared with 79 mm in 2007/08. This led to relatively high pasture growth rates during summer in the first year. As a consequence soil moisture dropped below 17% as late as February in the 06/07 season compared with November in 2007. Effectively the spring growth period in 2006/07 lasted for nearly 1500 °Cd (Fig. 6a) compared with only 500 °Cd in the following year (Fig. 6b). As a consequence, less than 1.0 t DM/ha was grown during the summer compared with nearly 4.0 t DM/ha the previous year (Fig. 3). In both years cocksfoot-based pastures tended to yield more than the perennial ryegrass through the summer. However, once moisture stress was relieved in autumn the ryegrass-based pastures showed faster growth rates (Fig. 4). Both pastures had lower growth rates in autumn than spring despite the availability of moisture (Fig. 2) and warm temperatures (Fig. 1).

Conclusions

The benefits of subterranean clover for lamb production have been described by Costello & Costello (2003) and Grigg *et al*. (2008). This paper has shown that over-drilling subterranean clover into clover deficient, grass-dominant pastures is a successful strategy for improving clover content and increasing pasture yields. The increased weed content in the ryegrass pastures highlights its lack of persistence in this environment.

ACKNOWLEDGEMENTS

Colin Pettigrew and Malcolm Smith assisted with stock work and Keith Pollock with environmental data collection. Funding for this project was provided by a New Zealand International Doctoral Research Scholarship to Serkan Ates and Beef + Lamb New Zealand Ltd through the FoRST Pastoral 21 'MaxClover' research project.

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