

The production and water extraction of lucerne and ryegrass under different irrigation frequencies on a shallow soil.

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Abstract

A field experiment was conducted on a shallow soil (low plant available water holding capacity) at Lincoln (Canterbury, New Zealand) to compare the biomass production of lucerne (*Medicago sativa* L.) and perennial ryegrass (*Lolium perenne*) under four different irrigation frequencies: (T1) replacing water use (WU) twice a week (replicating centre pivot rewetting frequencies); (T2) replacing WU fortnightly (replicating travelling irrigator); (T3) replacing WU every 3 weeks (replicating border dyke); (T4) nil irrigation (rain fed only). Soil water content was measured hourly at 0–30 cm depth and fortnightly at 0–150 cm depth. Plots were sown in March 2011 and defoliated on eight (ryegrass) and five to six (lucerne) occasions each season between September 2011 and May 2014. Annual biomass production during the first year was highest for ryegrass under each treatment because the lucerne crops were still establishing. During the second and third year of experimentation ryegrass yielded higher or similar to lucerne under the irrigated treatments (T1, T2 and T3). This was attributed to a decline in lucerne stands due to weed pressure. It is important to note that the ryegrass crop has received 250–700 kg N/ha per year depending on the irrigation treatment. Under dry conditions (T4) ryegrass yielded more than lucerne in both year 2 and 3. This result contrasts the literature and is attributed to the greater capacity of ryegrass to grow in cooler season and the stony sub-soil meaning lucerne received no summer yield advantage from its deep tap root.

Key words: *Medicago sativa* L., *Lolium perenne*, biomass, water extraction, irrigation frequency

Introduction

A large extent of Canterbury's agricultural land is characterised by shallow and drought-prone soils (Moot *et al.* 2010). The recent expansion towards large-scale, intensive dairy farming in the region over the last decade has driven a rapid development and expansion of irrigation. The Canterbury region is historically subjected to dry summer spells and these are projected to become more frequent and intense in the future (Salinger 2003). Under dry conditions pasture production is limited by water availability, and there is

an increasing pressure on irrigation water resources. Thus, it is important to develop irrigation management practices that increase utilisation efficiency of water (Hayman 1985; Moot *et al.* 2008; Moot *et al.* 2010). The optimisation of irrigation frequency and application amounts, and the choice of more water efficient crops are typical examples of such management interventions. For example, the use of lucerne (*Medicago sativa* L.) in dryland grazing systems has been shown to increase yields in comparison to the more commonly used ryegrass pastures (*Lolium perenne*) in New Zealand deep soils (Douglas 1986; Moot 2012; White 1982). The main adaptive mechanism is the deeper root system of lucerne that enables access to larger volumes of soil water (Sheaffer *et al.* 1988). However, previous studies were mainly performed on deep soils with high plant available water holding capacity (PAWHC). It is unclear how these crops compare when grown in shallow soils and under different irrigation frequencies.

In this study, we compare the annual biomass production, water extraction and water use efficiency of lucerne and ryegrass on a shallow stony soil with low PAWHC and under different irrigation regimes. This comparison will help understand the influence of irrigation management on pasture production in Canterbury.

Materials and methods

Experimental site and crop establishment

This experiment was established at the AgResearch farm, Lincoln, Canterbury (43°37'16"S and 172°28'15"E), on an Eyre silt loam soil with 30 cm top soil overlying gravel containing more than 2% of stones (Minchin *et al.* 2011). The site came out of 'Conquest' wheat in February 2011 and more than 5 years of pasture before that. The site was sprayed twice with Roundup 360® applied at 3 litres/ha, equivalent to 1080 g glyphosate/ha, before direct drilling the lucerne on 10 March 2011 and the ryegrass on 24 March 2011. Cultivars used and sowing rates were, respectively, '54V09' (Pioneer) and 14 kg/ha for the lucerne and, 'Samson' (AGRICOM) and 25 kg/ha for the ryegrass. Two t/ha of pelleted lime were applied (broadcasted) after drilling to the lucerne to raise the pH from initial values of 5.4. Lime was applied five more times at

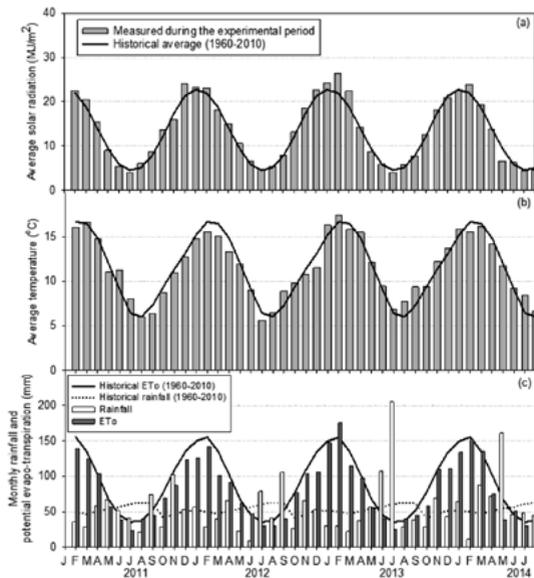


Figure 1 (a) Monthly average solar radiation from January 2011 to July 2014 at Broadfields weather station (black curve represents historical average (1960-2010)). (b) Monthly average temperature from January 2011 to July 2014 at Broadfields weather station (black curve represents historical average (1960-2010)). (c) Monthly average rainfall (white bars) and PET (grey bars) from January 2011 to July 2014 at Broadfields weather station (black curve represents historical average (1960-2010)).

6–8 months interval and 200 kg/ha during the 3 years of experimentation. All crops received base mineral fertilisation (N, P, K, S and micronutrients) based on previous soil analysis in early spring. Ryegrass received applications of N after each harvest. Lucerne received applications of 155, 30 and 95 kg K/ha during year 1, 2 and 3 respectively. Agrichemicals were applied to minimise pests and diseases pressure throughout the experimental period. Of note, was a winter application (June 2012) of 3 litres/ha of Roundup 360®, equivalent 1080 g/ha glyphosate, on lucerne plots to manage white clover and dandelion invasion. The experiment was conducted over 3 years (March 2011–May 2014).

Rainfall, Penman potential evapotranspiration (PET), and temperature data for the period of the experiment (March 2011–April 2014) were recorded at Broadfields meteorological station, accessed from the NIWA website (Figure 1). The weather station was 400 m south of the experimental site.

Experimental design

The experiment was set up as a latinised row by column design with four replicates of eight treatments: two crops, lucerne and ryegrass; and four different irrigation managements: (T1) replacement of water

use twice a week, (T2) replacement of WU every fortnight, (T3) replacement of WU every 3 weeks, (T4) nil irrigation (rain fed only). For the first year of the experiment, T2 was replacement of WU weekly and T3 was replacement of water use fortnightly. After a preliminary analysis of the yield differences between treatments, it was decided to increase the period between irrigation events between T1, T2 and T3 to better understand the impact of irrigation frequency on the growth of those crops.

Application of irrigation treatments

Irrigation was applied to each plot independently using drip lines spaced 0.3 m apart.

During the first year of the experiment, irrigation requirements for each treatment were calculated using Penman's PET data recorded at Broadfields meteorological station, accessed from NIWA website. The amount of irrigation applied for a given treatment was equal to the sum of daily PET values minus rainfall for the period between irrigation events for that treatment.

From the second year of the experiment (November 2012) onwards, irrigation requirement (the proxy for WU) for each treatment was calculated (Equation 1) from volumetric soil moisture content (SMC) measured in the top 0.3 m of soil in each plot. Soil below this depth was not considered because of the very low WHC of the gravels below this depth. Field capacity of the top layer was assumed at 32.5% based on the highest SMC reading from the first year of experimentation. The targeted refill soil moisture content (RSMC) was set to SMC of 27% to minimise risk of water loss through drainage.

$$\text{Irrigation requirement (mm)} = (\text{RSMC} - \text{SMC}) \times 300 \text{ (mm)} \quad (1)$$

Table 1 shows the yearly amount of irrigation and rainfall received by each treatment during the 3 years of experimentation.

Harvest management

Dry matter (DM) production was measured at the end of each regrowth period using a small plot forage harvester (CIBUS Forage Chopper). Crops were defoliated at intervals of 4–8 weeks at 500 mm height. Ryegrass and lucerne were defoliated eight and five times, respectively, during year 1; eight and six times, respectively, during season 2; and eight and five times, respectively, during season 3. After harvest, nitrogen, in the form of urea, was applied to the ryegrass treatments in proportion to the amount of biomass harvested from that treatment as suggested by Gastal & Lemaire (2002). Nitrogen fertiliser applications were, for T1 to T4 respectively: 696, 679, 665 and 464 kg N/ha during

season 1; 649, 591, 512 and 347 kg N/ha during season 2; and 443, 417, 382 and 239 kg N/ha during season 3. The lucerne crop received 150, 30 and 95 kg N/ha during year 1, 2 and 3 respectively.

Measurements

Biomass production

Total above-ground biomass measurements from each harvest were taken from a 5–7 m long and 8 rows wide area (6–8 m² area) using the forage harvester. A subsample of constant weight from each plot was then dried in a forced-fan oven at 90°C for 24 h and weighed to measure the DM content.

Soil water content

Volumetric water soil content (SMC) was measured in the top 0.3 m of soil in each plot using two water content reflectometers (Campbell Scientific®, model CS 616) installed at 0–0.15 m and 0.15–0.3 m depths connected to a data logger (Campbell Scientific®, model CR1000).

For the 0.3–1.5 m depth, SMC was measured fortnightly for each plot from at 0.2 m intervals (0.1 m for the first and the last depths, respectively 0.3–0.4 m and 1.4–1.5 m) using a neutron probe (CPN, model 503DR Hydroprobe).

Calculations

Water use

The water content of the 1.5 m soil profile (PSWC) was calculated at the date of each neutron probe measurement by multiplying the SWC of each layer (%) by the layer’s depth (mm) and summing water content in all layers.

Table 1 Amount of irrigation applied per treatment (mm) and yearly rainfall (mm) during the 3 years of experimentation. For each treatment, both crops received the same amount of irrigation.

Year	Treatment	Irrigation applied (mm)	Rainfall (mm)
1	T1	390.4	593.6
	T2	363.4	
	T3	369.9	
	T4	0	
2	T1	490	829.1
	T2	353	
	T3	318	
	T4	0	
3	T1	293	633.4
	T2	261.6	
	T3	191.2	
	T4	0	

The PSWC change (Δ PSWC) over each measurement period was calculated as the difference of profile content at the beginning of the period less that at the end of the period.

The crop water use (WU) (mm) was then calculated from a water balance (Equation 2)

$$WU \text{ (mm)} = \Delta PSWC + \text{irrigation (mm)} + \text{rainfall (mm)} \quad (2)$$

Water use calculated by equation 2 includes crop transpiration, soil evaporation and drainage.

The water use efficiency (WUE) was calculated using WU and biomass production measurements (Equation 3).

$$WUE \text{ (kg DM/mm)} = \text{Yield (kg DM)} / WU \text{ (mm)} \quad (3)$$

Statistical analyses

Data were analysed by Analysis of Variance (ANOVA) using GenStat (14th Ed, VSN International Ltd). An indication of the variability associated with the calculated means is provided by the least significant difference (LSD) ($\alpha=0.05$) for the interaction between the treatments.

Results

Total above ground dry matter yield

Year 1

Ryegrass under frequent irrigation (T1) had the highest annual biomass production during the first year of experimentation (P=0.09) at around 23.8 t DM/ha (Figure 2a).

Under each irrigation treatment, lucerne had the lowest annual biomass production (P=0.09) at around 10.4 t DM/ha under frequent irrigation (T1), down to 2.8 t DM/ha without irrigation (T4) (Figure 2a).

Annual biomass production was the lowest under T4 for both crops at 13.8 and 2.8 t DM/ha for ryegrass and lucerne respectively.

Year 2

Annual biomass production was highest for both crops (P=0.002) under the most frequent irrigation treatment (T1) at around 18.6 t DM/ha (Figure 2b).

Biomass production of both crops declined with less frequent irrigation (P=0.002) to 13.5 and 14.9 t DM/ha for ryegrass and lucerne, respectively, under T3 (Figure 2b).

Annual biomass production was lowest for both crops (P=0.002) under the treatment with no irrigation (T4). For that treatment, ryegrass biomass production was higher than that of lucerne (P=0.002) at 8.2 and 4.6 t DM/ha, respectively.

Year 3

Annual biomass production of ryegrass declined with

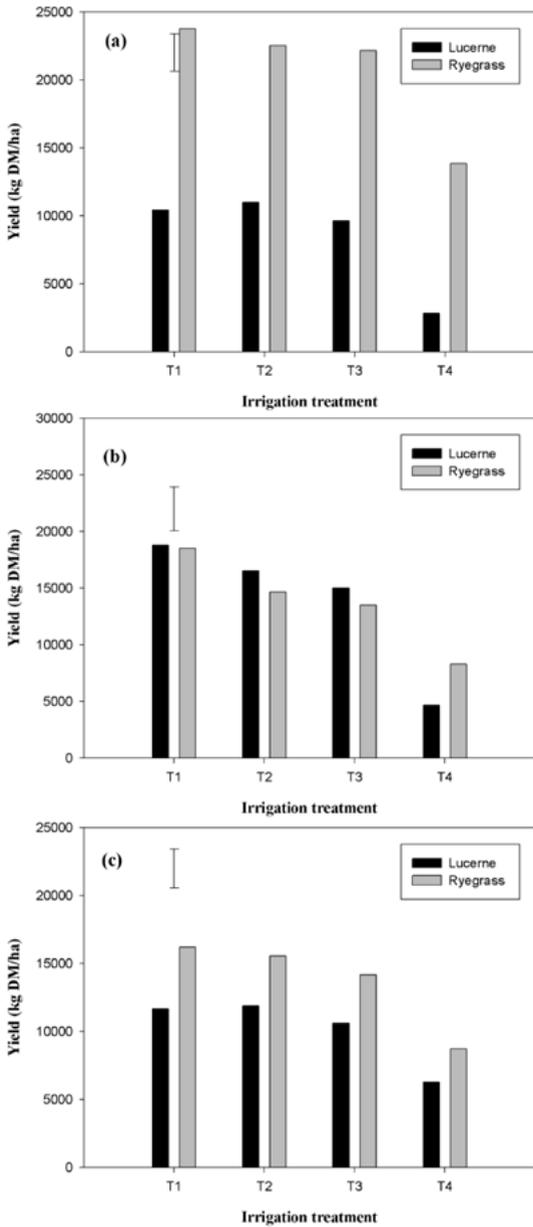


Figure 2 Annual above ground biomass yield (kg DM/ha) of lucerne and ryegrass under four different irrigation regimes: replacement of water use (WU) twice a week (T1), replacement of WU every fortnight (T2), replacement of WU every 3 weeks (T3), and nil irrigation (T4). (a) First year after sowing. (b) Second year after sowing. (c) Third year after sowing. Bar represents LSD (df=21, α=0.05).

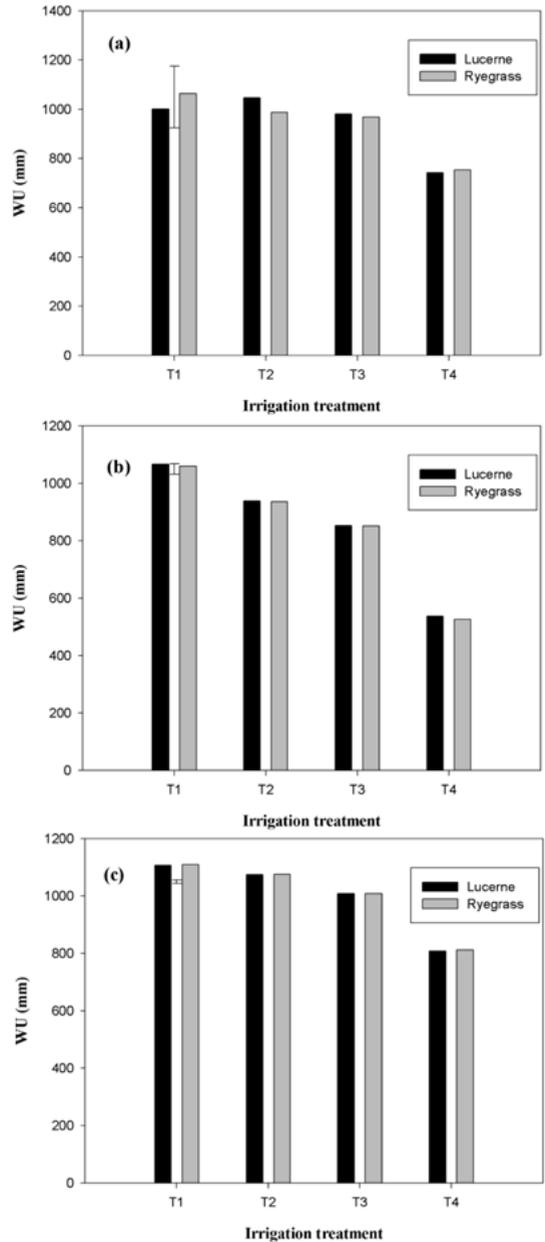


Figure 3 Annual water use (mm) of lucerne and ryegrass under four different irrigation regimes: replacement of water use (WU) twice a week (T1), replacement of WU every fortnight (T2), replacement of WU every 3 weeks (T3), and nil irrigation (T4). (a) First year after sowing. (b) Second year after sowing. (c) Third year after sowing. Bar represents LSD (df=21, α=0.05).

less frequent irrigation ($P < 0.001$) from 16.2 to 14.2 t DM/ha for T1 and T3 respectively (Figure 2c).

Lucerne had an annual biomass production of 11.8 t DM/ha under T1 and T2, and 10.6 t DM/ha under T3 (Figure 2c).

Both crops had their lowest annual biomass production under T4 with 8.7 and 6.3 t DM/ha for ryegrass and lucerne respectively (Figure 2c).

Ryegrass produced more annual biomass than lucerne under every treatment ($P < 0.001$).

Water use and water use efficiency

Year 1

Annual water use of both crops was similar for each treatment ($P=0.994$) and was the highest under T1 at around 1000–1050 mm (Figure 3a). It was the lowest under T4 at around 750 mm.

Ryegrass had an annual water use efficiency higher than that of lucerne ($P<0.001$) under every treatment (Figure 4a). WUE of ryegrass ranged from 22.8 kg DM/mm under T1 to 18.5 kg DM/mm under T4. WUE of lucerne ranged from 10.5 kg DM/mm under T1 to 3.8 kg DM/mm under T4. Both crops had their lowest WUE under T4.

Year 2

Annual WU of both crops was similar under each of the irrigation treatment ($P=0.191$) and was the highest under T1 at around 1064 mm (Figure 3b). WU declined with less frequent irrigation: 938 mm under T2, 853 mm under T3 and 532 mm under T4.

Both crops had similar WUE under T1, T2 and T3 at around 17.5, 16.7 and 16.7 kg DM/mm respectively (Figure 4b), but ryegrass had a higher WUE than lucerne under T4 ($P<0.001$) at 15.7 and 8.6 kg DM/mm respectively.

Year 3

Both crops had similar annual WU ($P=0.228$) under each treatment (Figure 3c). Annual WU declined with less frequent irrigation: from 1108 mm under T1 to 1075, 1008 and 810 mm under T2, T3 and T4 respectively.

WUE under T1, T2 and T3 was similar for each crop (Figure 4c), but ryegrass had a higher WUE than lucerne ($P<0.001$) at 14.3 and 10.7 kg DM/mm respectively. Both crops showed a lower WUE under T4 ($P<0.001$) at 10.7 and 7.8 kg DM/mm for ryegrass and lucerne respectively.

Discussion

The range of lucerne yields observed in this study (3–11 t/ha for year 1, 5–18 t/ha for year 2 and 6–12 t/ha for year 3) is consistent with irrigated (9.4–14.0 t/ha) and dryland (3.6–11.1) lucerne yields reported on shallow soils (Douglas 1986). These yields are well below the reported potentials for high water holding capacity soils in Canterbury. For example, on a Wakanui deep silt loam soil at a nearby site, yields of 20–28 t DM/ha have been reported for irrigated lucerne (Brown & Moot 2004; Teixeira *et al.* 2008; Teixeira *et al.* 2007). Dryland lucerne crops have been reported to yield 13–21 t DM/ha (Brown *et al.* 2005; Mills & Moot 2010; Mills *et al.* 2008).

Ryegrass yields (14–24 t/ha for year 1, 8–18 t/ha for year 2, 9–16 t/ha for year 3) were limited by water supply in this study. This is supported by previous yield

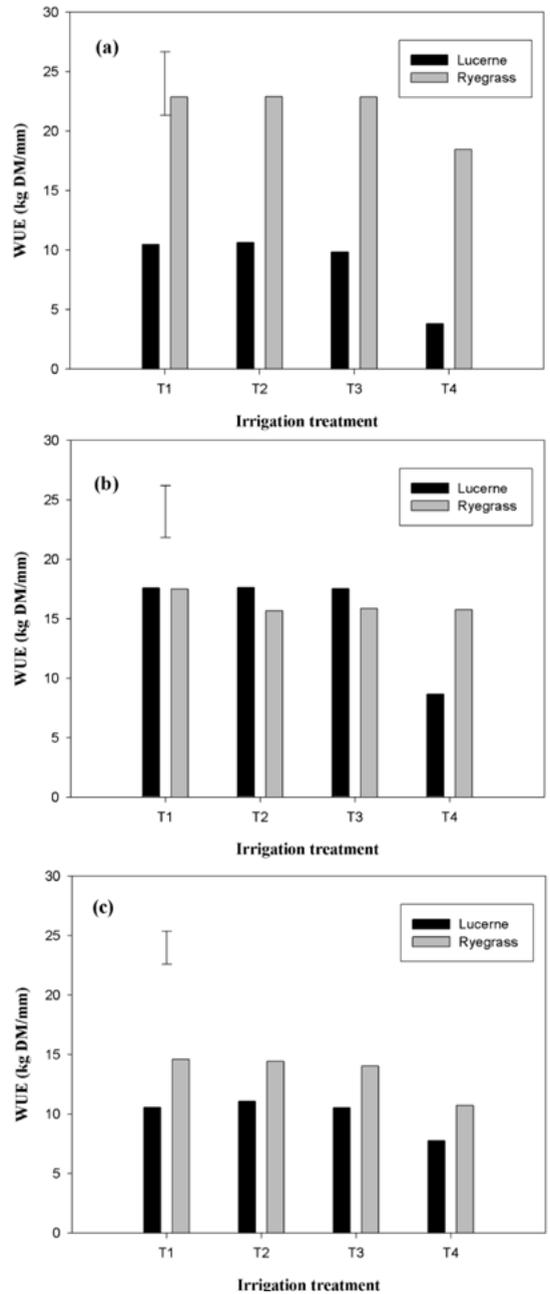


Figure 4 Annual water use efficiency (kg DM/mm) of lucerne and ryegrass under four different irrigation regimes: replacement of water use (WU) twice a week (T1), replacement of WU every fortnight (T2), replacement of WU every 3 weeks (T3), and nil irrigation (T4). (a) First year after sowing. (b) Second year after sowing. (c) Third year after sowing. Bar represents LSD (df=21, $\alpha=0.05$).

reports for Canterbury ranging from 6 to 11 t/ha under dryland conditions (Mills & Moot 2010; Mills *et al.* 2008). While ryegrass and lucerne yields were within

reported ranges, the relative production of lucerne and ryegrass was unexpected. In general ryegrass yielded as much or more than lucerne where other studies show a production advantage for lucerne (Douglas 1986). The low yields for lucerne during the first year of experimentation were expected because it was the establishment season for the crop.

There was a rapid and unexpected decline evident in the production of the irrigated lucerne stands in this trial with substantial weed invasion and unhealthy looking plants evident by the end of year 3 (Field observations). Lucerne represented 59% of the botanical composition of the plots under the fully irrigated treatment versus 89% under the dry treatment (data not shown). Irrigation is expected to hasten the decline of lucerne stands through a reduction in plant population and increase in weed invasion (Brown *et al.* 2005). However Brown *et al.* (2005) showed only significant stand decline by the end of year 6 on a heavier soil (which would be expected to decline faster). While the exact cause could not be determined, the unhealthy appearance and unexpectedly poor production of irrigated lucerne in this trial suggests there was some site specific disease problem and these results should be treated with caution. It is also important to note that ryegrass needed between 700 and 250 kg N/ha, depending on the irrigation treatment, to be applied in each year to produce its yields.

Under dry conditions and no irrigation, the lucerne stand was healthy but ryegrass still yielded more than lucerne. This contrasts with deep soil conditions in which lucerne was shown to consistently yield more than ryegrass in New Zealand (Avery *et al.* 2008; Brown *et al.* 2006; Moot 2012). The dryland yield advantage of lucerne is usually attributed to its deeper tap root system that enables access to additional water supply when compared with the shallow fibrous root system of ryegrass (Moot *et al.* 2008). However, the shallow and stony soil in our study (Minchin *et al.* 2011) provided limited additional water for the crop to take up in the deeper soil layers. Also, the contrasting growth strategies of these two crops, regarding seasonality of growth rates, help explain the lower yield and WUE of dryland lucerne in shallow soils. Ryegrass biomass production is greater during cooler periods (spring and autumn), when the cool temperatures enable higher water use efficiency (Tanner & Sinclair 1983), while lucerne biomass production is greater during the summer months when warmer conditions reduce water use efficiency. Some additional yield would be expected from the lucerne crops sprayed in June with glyphosate, but these showed visual leaf damage and slow early spring regrowth. Nevertheless, these results agree with previous reports showing that lucerne's comparative advantage over ryegrass is not evident in exceptionally dry years in Canterbury (Hayman 1985).

Conclusion

Under irrigation on a shallow soil, and a supply of N through fertilisation (250–700 kg N/ha), ryegrass yielded more than lucerne in the establishment year, which is expected. Yields were similar in the following year and lucerne yields declined below ryegrass in the third year. The unexpectedly rapid decline in lucerne production appeared to be due to disease and weeds limiting the production of irrigated plants. Ryegrass also yielded more than lucerne under dryland conditions on a shallow soil which was attributed to the greater cool season growth of ryegrass and the stony sub-soil meaning lucerne received no summer yield advantage from its deep tap root.

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