Yield and composition of lucerne stands in Central Otago after different winter grazing and weed control treatments

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Abstract
The effect of grazing date and time of spraying with a glyphosate/atrazine herbicide combination on a three-year-old lucerne stand was studied on-farm in Central Otago. Total annual dry matter (DM) yield was highest in the weedy unsprayed control (14.8 t DM/ha) and lowest in the crop sprayed on 18 September (10.1 t DM/ha). However, lucerne DM yield was highest from the 3 July and 22 August spray treatments (11.4 ± 0.39 t DM/ha) and lowest in the unsprayed control at 7.7 t DM/ha. Phytotoxicity symptoms of glyphosate on the lucerne tended to be limited to crops sprayed on 18 September. To maximise yield, a winter clean-up grazing (June) followed by a winter herbicide application (July/August) when lucerne was approximately 3 cm high and with <100 kg DM/ha was required. After this, grazing earlier than October should be avoided as a September grazing resulted in a lucerne yield of about 1.0 t DM/ha less than grazing in October and November. Spring lucerne production was delayed by spraying in September. None of the spray treatments killed the crop, but they all reduced weed content from about 40% to <1%.

Keywords: alfalfa, atrazine, glyphosate, lucerne, *Medicago sativa* L., phytotoxicity, weed control, winter grazing, yield.

Introduction
Lucerne (*Medicago sativa* L.) is a high quality forage with a high energy and crude protein content (Fraser *et al.* 2004) that has been used successfully for lamb finishing in New Zealand (Avery *et al.* 2008), including in Central Otago (Kearney *et al.* 2010; Stevens *et al.* 2012). In a two-year on-farm trial (averaged over three farms) in 2009 and 2010, Stevens *et al.* (2012) reported that lamb liveweight gain was 50 g/head/day greater on lucerne than traditional dryland grass-based pastures. However, rainfall in Central Otago ranges between 300 and 450 mm annually (Cossens 1987). This results in variable late spring/summer lucerne production, when feed demand by lambs is at its highest. Therefore, early spring grazing of lucerne is important to maximise spring lamb liveweight gain, before crops have used all of the plant available soil water.

Weed control is usually required in lucerne because the canopy is periodically completely defoliated which exposes bare ground and enables weed invasion. Competition from weeds during spring and summer can result in greatly reduced lucerne dry matter yields. Commonly winter applications of atrazine and paraquat are used to minimise weed populations to <5% of total dry matter production (Mills *et al.* 2008). Time of herbicide application is also important because developing lucerne buds can be damaged if herbicide is applied too late, and this can delay spring production (Moot *et al.* 2003). Current recommendations are for a clean-up grazing in winter (late June/early July in Canterbury) followed by application of these two herbicides 10–14 days later (Cassells & Upritchard 1968; Forgie 1973; Logan & Arnst 1973; Moot *et al.* 2003). However, glyphosate has also been used (Arregui *et al.* 2001; Dawson 1989, 1992; Wilson 1997), although it is not registered for this use. Davies *et al.* (2003) reported that the translocation pattern of glyphosate in lucerne varied with the stage of regrowth, and found that lucerne could be killed if sprayed in early to mid-spring after 4–5 weeks of regrowth. Therefore, spraying lucerne in winter after a clean-up grazing, when plants are not actively growing, should minimise damage to the plants. Glyphosate is an inexpensive translocatable herbicide that has the potential to control both annual and perennial grass and broadleaf weeds (Young 2010), including rhizomatous and stoloniferous weeds, such as browntop (*Agrostis capillaris* L.) and yarrow (*Achillea millefolium* L.) that are not effectively controlled by the more common contact and residual herbicides such as paraquat. Its efficacy has encouraged the development of lucerne cultivars now available in the USA with genetic resistance to glyphosate bred in (Bouton 2012). However, lucerne cultivars used in New Zealand are not glyphosate-tolerant and therefore care must be taken to minimise damage to lucerne plants because of its non-selective action. Commonly, herbicide application follows a hard winter grazing at a time when lucerne development is slow. Thus, the subsequent regrowth of crops is at a similar stage of phenological development. As a consequence their temporal pattern of growth is similar, which causes peak production at the same time in spring. By manipulating the time of winter herbicide application and final winter/early spring grazing, it may be possible to spread this peak production over a longer window in spring. This could flatten out the feed supply curve and ease the pressure on grazing management, particularly for properties that have a high (>30%) proportion of lucerne on them.

The first objective of the study was to determine the effectiveness of a glyphosate/atrazine combination used for weed control and quantify any damage to the lucerne crop from this combination. The second objective was to determine whether changes in the peak lucerne production period could be induced by the use of herbicide and winter grazing. To assess this second objective, the time to 4 t DM/ha in spring was used as the assessment criterion to represent a stand that could either be grazed or conserved (Moot 2014).

Materials and Methods

Site

This herbicide and grazing management experiment was established on-farm at Hills Creek, northwest of Ranfurly, in Central Otago. The 'Kaituna' lucerne stand was sown on 12 October 2009 and was therefore 3 years old by the start of the experiment in June 2012. Prior to herbicide and grazing treatments, the selected 12.8 ha paddock was soil sampled on 8 June 2012. It was then grazed from 8 to 12 June 2012 using 1600 hoggets and lambs as part of the routine winter clean-up grazing. The experimental site was subsequently located, marked out and fenced off. Soil test results showed an optimum pH of 6.6, but low levels of phosphorus and magnesium. The soil was also slightly potassium deficient (Table 1).

Experimental design and treatments

The experiment had a fully randomised split-plot design (Everitt 2002). Treatments included main plots of three times of additional grazing (6 September, 2 October and an ungrazed hay crop) and sub-plots of four times of herbicide application (unsprayed, 3 July, 22 August and 18 September 2012). The hay crop (control) was left ungrazed from 12 June until 14 November 2012, when the 6 September treatment received its second grazing. The hay crop (14 November grazing) therefore reflected the commercial on-farm winter grazing practice. Ewes, lambs and hoggets were used for grazing as available. Stocking rates were adjusted throughout the experiment to remove the available herbage in 1–3 days.

Herbicides used were a combination of glyphosate (Glyphomax XRT 480) and atrazine (Nu-trazine 900 DF). Glyphosate was applied at 960 g a.i./ha and atrazine at 900 g a.i./ha. Each herbicide date × grazing date combination was replicated four times. There were 48 plots in total, with individual plots measuring 8 × 10 m.

Herbicide was applied using a bike sprayer with a 4 m boom width delivering 200 litres/ha. At the 3 July 2012 spraying there was no live lucerne cover, only 0.1–0.2 m of dead stalk. At the 22 August 2012 spraying, an average of 87 kg DM/ha of short (<30 mm) lucerne was present. At the 18 September 2012 spraying an average of 182 kg DM/ha of lucerne was present (about 100 mm) in the 2 October and 14 November (hay) grazing treatments, but only about 40 kg DM/ha was present after the 6 September grazing treatment.

The weed species that were present at the time of spraying, and remained in the unsprayed plots throughout the duration of the experiment, consisted mainly of green (live) grass weeds (largely brome species), although broad-leaved weeds such as dandelion (*Taraxacum officinale* L.), mallow (*Malva* spp.), nodding thistle (*Carduus nutans* L.) and horehound (*Marrubium vulgare* L.) were also present.

Rainfall and temperature

Rainfall and temperature data from May 2012 to May 2013 were recorded at the Lauder Electronic Weather Station (EWS) meteorological site, located 25 km south of the experimental site (Figure 1). Mean monthly air temperature during the experiment was typical of the long-term average. The average air temperature following spraying was 2.1°C from 4 July to 17 July (following the 3 July spray), 8.5°C from 23 August to 5 September (following the 22 August spray) and 9.5°C from 19 September to 2 October (following the 18 September spray). During the experiment, annual rainfall (445 mm) was consistent with the long-term average (431 mm).

Measurements

Yields and botanical composition of the plots were recorded by harvesting one representative (0.18 or 0.36

Table 1 Soil test results for paddock P 57 at Hills Creek, sampled on 8 June 2012.

	pH	Olsen P (µg/ml)	Calcium (QTU*)	Magnesium (QTU*)	Potassium (QTU*)	Sulphate S (µg/g)	Sodium (QTU*)
Test result	6.6	12	9	13	4	10	3
Optimum	6.2-6.5	20-25	8-15	16-24	5-8	7-12	1-10

*QTU = Quick Test Unit (kg/ha).

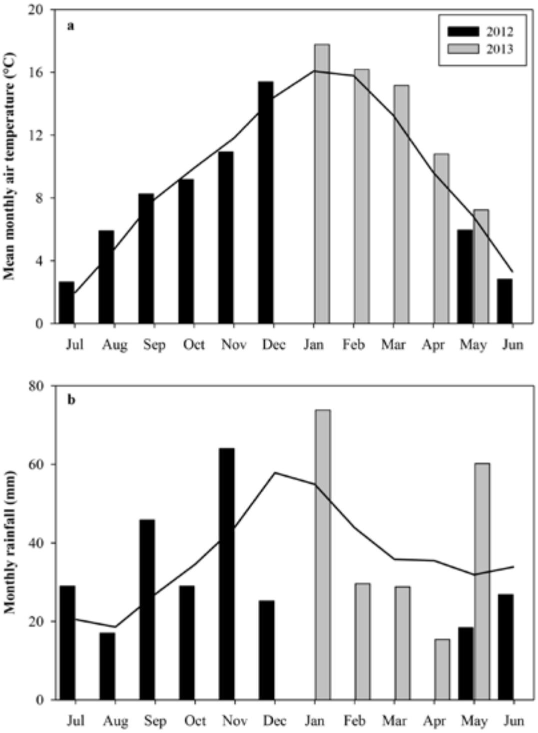

Figure 1 Monthly mean air temperature (a) and rainfall (b) at Hills Creek, Central Otago, from May 2012 to May 2013. The long-term means (—) are for the period from 1990 to 2011.

m^2) quadrat per plot just prior to each grazing. Pasture yield was also recorded prior to each spray treatment. After harvesting, samples were sent to Lincoln University where herbage was sorted into lucerne, weeds and dead matter. Samples were then dried in a forced air oven at 60°C for at least 48 hours and then weighed.

Plots were visually scored for herbicide phytotoxicity in lucerne using the European Weed Research Society (EWRS) scoring system (Kroschel 2001) from 12 October 2012 until no symptoms were present, on 26 January 2013. A score of ≥5 was considered commercially unacceptable (Table 2).

Temperature data from Lauder EWS were used to determine lucerne production in relation to thermal time.

Analysis

Data were analysed using one-way analyses of variance by treating each grazing date treatment as a separate experiment, as plots had been harvested on different dates for different grazing treatments. Two-way analyses of variance were performed on the final harvest (6 May 2013) and annual accumulated dry matter to provide an "end of experiment" comparison. This was to determine whether grazing treatment had an effect on total annual herbage and lucerne accumulation, and whether there were any interactions between grazing and herbicide spray treatments.

Results

Total accumulated dry matter production

Total dry matter production included lucerne and weed yields from June 2012 to May 2013 (Figure 2), and was influenced by both grazing management ($P<0.038$) and herbicide treatment ($P<0.001$). Unsprayed treatments had the highest yields, and these yields were similar regardless of grazing date (14.8 ± 0.84 t DM/ha). When grazed on 6 September and sprayed on any of the three dates, total herbage yield was 10.6 ± 0.87 t DM/ha. All three herbicide application dates combined with a 2 October grazing resulted in a total dry matter yield of 11.8 ± 0.69 t/ha. The 14 November grazing with a 3 July or 22 August herbicide application yielded 11.2 ± 0.52 t DM/ha, but only 9.6 t DM/ha when sprayed on 18 September.

Table 2 Scoring systems used to score lucerne phytotoxicity in response to herbicide treatment.

EWRS* score	Severity of symptoms	% of crop affected
1	Healthy plant	0
2	Very mild symptoms	0.1 – 2.0
3	Mild but clearly recognisable symptoms	2.1 – 5.0
4	More severe symptoms but no effect on yield	5.1 – 10.0
5	Reduction in yield expected - Commercially unacceptable	10.1 – 18.0
6	Reduction in yield expected - Commercially unacceptable	18.1 – 30.0
7	Reduction in yield expected - Commercially unacceptable	30.1 – 45.0
8	Reduction in yield expected - Commercially unacceptable	45.1 – 70.0
9	Heavy damage to total kill - Commercially unacceptable	70.1 – 100

*European Weed Research Society

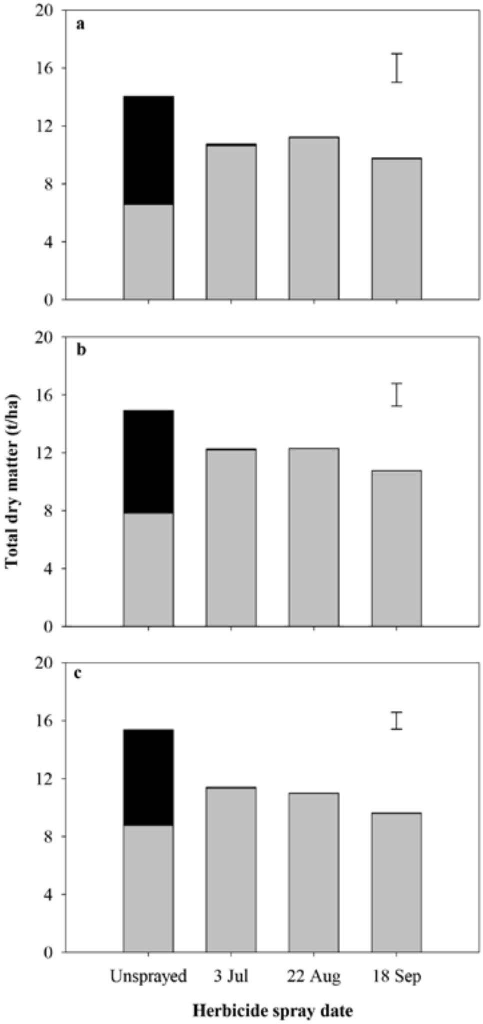

Figure 2 Total dry matter (t/ha) of the 6 September (a), 2 October (b) and 14 November (c) grazing treatments. The yields of lucerne (■) and weeds (■) are illustrated for the four herbicide spray dates, and are accumulated totals from 12 June 2012 to 6 May 2013. Error bars represent the least significant differences (lsd) at α=0.05 for comparisons between herbicide spray treatments.

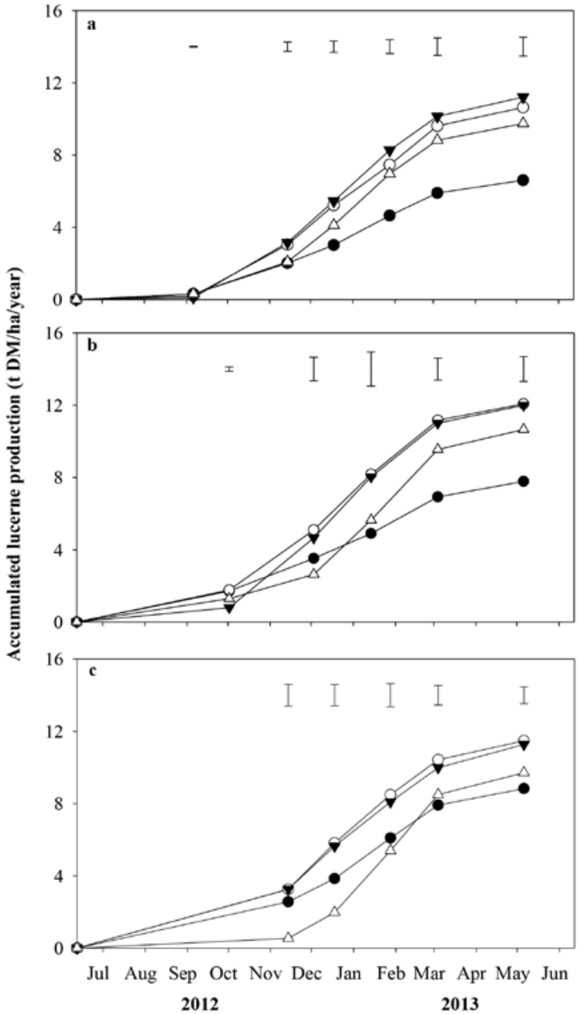

Figure 3 Accumulated lucerne production (t DM/ha) for the 6 September (a), 2 October (b) and 14 November (c) grazing treatments. The four spray dates are unsprayed (●), 3 July (❍), 22 August (▼) and 18 September (Δ). Error bars represent the least significant differences (lsd) at α=0.05 for comparisons among herbicide spray dates at each harvest.

Dead matter content of lucerne crops was affected by herbicide spray date only. For the unsprayed crops and those sprayed on 3 July and 22 August, total accumulated dead matter was approximately 3.0 t DM/ha, but was reduced to 1.8 t DM/ha by the 18 September spray. The dead matter largely consisted of the lucerne stalks that remained after each grazing, but began to rot and therefore decreased. Therefore, dead matter was excluded from the total dry matter calculations.

Lucerne production and weed control

The contribution of weeds to total yield (June 2012 to May 2013) was reduced (P<0.001) from >43% in the unsprayed treatment to <1% in all treatments where herbicide was applied (Figure 2), indicating that all weeds were completely controlled for the duration of the experiment.

Figure 3 shows the pattern of accumulated DM yield of lucerne over the experimental period and compares herbicide treatments for each grazing treatment. Lucerne contribution to total yield was affected by both grazing and herbicide treatments as main effects, but there was no interaction. Lucerne DM yield was 9.5 t/ha in the 6 September grazing treatment, 1.0 t/ha lower (P<0.009) than when grazed on 2 October and 14 November (hay crop). The unsprayed treatment resulted in the lowest (P<0.001) lucerne yield of 7.7 t DM/ha. The lucerne yield from an 18 September spray was 10.0 t DM/ha, and the 3 July and 22 August yielded 11.4 ± 0.39 t DM/ha.

Average lucerne growth rates for the experiment were determined in relation to thermal time (Tt). Thermal time accumulation over the experimental period was calculated using a base temperature of 5°C (Thiébeau *et al.* 2011). The highest lucerne production in relation to thermal time was achieved by the 3 July spray combined with a 2 October or 14 November grazing, and a 22 August spray with a 6 September or 2 October grazing (7.1 ± 0.48 kg DM/ha/°Cd). The unsprayed treatments combined with a 6 September or 2 October grazing resulted in the lowest growth of 4.1 ± 0.48 kg DM/ha/°Cd.

Lucerne phytotoxicity damage

During the initial stages of the experiment, lucerne treated with herbicide showed symptoms of phytotoxicity and these tended to be commercially unacceptable (score ≥5) (Table 2) in the crops sprayed on 18 September, but not when sprayed on 3 July or 22 August (Table 3). The exception was a score of 7.3 in the 14 November grazed crop, sprayed on 22 August. Phytotoxicity scores of the 6 September grazing and September sprayed crop dropped below 5 by 13 November 2012.

Lucerne first grazing

The average number of days required for lucerne to reach a yield of 4 t DM/ha was affected by grazing management (P<0.026) and herbicide (P<0.001) treatment (Table 4). For all three grazing treatments, the 3 July and 22 August sprays resulted in 4 t DM/ha lucerne being achieved the earliest, after 156 to 170 days. Across all grazing and herbicide treatments, the earliest time to 4 t DM/ha of lucerne was on 15 November and the latest on 18 January. The time was longer in the unsprayed and 18 September herbicide treatments (197 ± 5.2 days) compared with the 3 July and 22 August herbicide treatments (163 ± 5.2 days). Across all herbicide treatments, the 6 September grazing treatment (186 days) also took longer to reach 4 t DM/ha than the 2 October grazing treatment (173 days), while the 14 November grazing was similar to both.

Table 3 Lucerne phytotoxicity score, on a scale of 1 (no symptoms) to 9 (heavy damage to total kill), for the 6 September, 2 October and 14 November grazing treatments and four herbicide treatments on three dates in 2012. Values in **bold** were considered commercially unacceptable. Values followed by the same letter in each grazing treatment are not different at α=0.05.

	Observation Date								
	12 Oct		13 Nov			30 Nov	14 Dec		
Grazing date	6 Sep	14 Nov	6 Sep	2 Oct	14 Nov	2 Oct	6 Sep	2 Oct	14 Nov
Unsprayed	1.0 c	1.0 c	1.0 b	1.0 c	1.0	1.0	1.0	1.0	1.0 b
3 July	1.0 c	1.0 c	1.0 b	1.3 c	1.0	1.0	1.0	1.0	1.0 b
22 August	4.8 b	**7.3 b**	1.8 b	2.5 b	1.0	1.0	1.0	1.0	1.0 b
18 September	**7.4 a**	**9.0 a**	4.3 a	**9.0 a**	**9.0**	**9.0**	1.3	**9.0**	**8.9 a**
SED	0.71	0.18	0.58	0.38					0.09

Table 4 Number of days taken to reach a lucerne dry matter yield of 4 t/ha after the 12 June 2012 clean-up grazing, for three grazing treatments and four herbicide treatments. Values followed by the same letter within each grazing treatment are similar at α=0.05.

Herbicide treatment	Grazing treatment		
	6 Sep	2 Oct	14 Nov
Unsprayed	220 a (18 Jan)	187 a (16 Dec)	191 b (20 Dec)
3 July	170 b (29 Nov)	156 c (15 Nov)	161 c (20 Nov)
22 August	168 b (27 Nov)	164 bc (23 Nov)	161 c (20 Nov)
18 September	186 b (15 Dec)	186 ab (15 Dec)	213 a (11 Jan)
SED	8.4	10.0	9.9

Discussion

Herbicide effectiveness and phytotoxicity damage

All applications of atrazine/glyphosate gave effective weed control, and reduced the weed content from >40% in the unsprayed plots to <1%. The weed content in the unsprayed crops also reduced lucerne yield by 2–3 t DM/ha, or 25–30%. Thus, the winter herbicide application was necessary in all treatments to maximise lucerne yield. This result is similar to that reported in Canterbury by Moot *et al.* (2003). They reported a weed content of 31% in October in lucerne that had not received a winter herbicide application or an early spring grazing in August after a winter clean-up grazing in late May at the Ashley Dene research farm, Lincoln University. Their crops that received a winter herbicide of atrazine and paraquat yielded approximately 1.5 t/ha more total dry matter than the unsprayed and ungrazed crops. Mills *et al.* (2008) also applied a winter herbicide application of atrazine and paraquat to their lucerne crops, which resulted in a total weed content of ≤5%. Overall, winter herbicide application was effective for weed control and increased lucerne yield.

The atrazine/glyphosate combination in the current experiment did cause phytotoxicity to the lucerne, but this was almost exclusively limited to the crops sprayed on 18 September. Phytotoxicity was expected because glyphosate is a broad-spectrum herbicide and lucerne cultivars in New Zealand are not glyphosate-tolerant. Despite several phytotoxicity scores of 5–9 (Table 3) recorded in December, only the crops sprayed on 18 September showed a lucerne yield reduction of about 1.5 t DM/ha, compared with those sprayed on 3 July and 22 August. The increased damage was probably caused by the higher herbage cover present at the time of spraying. On 18 September, 180 kg DM/ha (approximately 10 cm) of spaced lucerne plants was present, compared with <100 kg DM/ha for 3 July and 22 August. On 18 September, lucerne plants had an average of 9 nodes/plant, with obvious fully expanded leaves, but no sign of stem extension. Arregui *et al.* (2001) found that glyphosate application to actively growing lucerne of 6 to 10 cm in height resulted in phytotoxicity damage, which caused a yield loss, with no sign of lucerne recovery even at 70 days after treatment. Thus, although glyphosate is not registered for use on lucerne, in this experiment it was used successfully for weed control when minimal lucerne leaf area was present in winter. Lucerne did recover from visible signs of phytotoxicity at levels expected to reduce yields. The timing of leaf development in lucerne is highly dependent on air temperature post-grazing (Bonhomme 2000). Therefore, the window for safe application of glyphosate is likely to have been wider in this cold Central Otago climate than would be expected in other parts of New Zealand where more winter growth occurs.

Temporal pattern of lucerne production

In this experiment, the number of days required for lucerne to reach 4 t DM/ha (Table 4) was used to determine if production could be delayed through grazing or herbicide treatments.

Herbicide spray date affected the time to 4 t DM/ha lucerne being achieved. For the unsprayed crops, the yield of lucerne was compromised by the weed content (Figure 2), so the time to 4 t DM/ha averaged 197 ± 5.2 days (around 26 December).

Spraying in July and August after the initial June clean-up grazing resulted in 4 t DM/ha of lucerne being achieved after 163 ± 5.2 days (around 22 November). The July and August sprays allowed lucerne to achieve a faster growth rate in spring because lucerne cover at spraying was minimal (<100 kg DM/ha), with low phytotoxicity damage (Table 3) and therefore rapid recovery. Spraying before September also allowed lucerne to take advantage of the optimal spring growing conditions.

On 18 September, the herbicide applied to approximately 180 kg DM/ha of slow but growing lucerne resulted in a higher phytotoxicity score and a longer recovery period. This in turn resulted in checking the lucerne so it was unable to maximise spring growth. It therefore required a similar time (197 ± 5.2 days) as the unsprayed crops to reach 4 t DM/ha lucerne.

There is little information available regarding the effect of glyphosate on the time of crop/pasture growth. However, Moot *et al.* (2003) showed that a lucerne crop sprayed with paraquat and atrazine at Lincoln University, Canterbury on 31 July (late spray, following a late May clean-up grazing) resulted in a linear growth rate similar to the growth rate of the unsprayed control, except that growth commenced 14 days later than the control. They concluded that the 31 July spray damaged the developing lucerne buds, resulting in a delay in lucerne growth, similar to the 18 September sprayed crops in the current experiment.

Grazing management also affected the time required for lucerne yield to reach 4 t DM/ha. The 6 September grazing delayed the 4 t DM/ha target by 13 days (until around 15 December) compared with the 2 October grazing. This early September grazing in Central Otago probably removed the nodes that developed during the winter before stem extension accelerated in spring as temperatures increased (Moot *et al.* 2003). The 6 September crops were grazed a second time in mid-November when peak lucerne production is usually achieved. This contributed to the delayed lucerne production because leaf area was removed during the period of peak growth.

Grazing lucerne crops in early October allowed the lucerne a further month's growth (compared with the 6 September grazing) while temperatures were increasing, resulting in increased dry matter accumulation before grazing. The 2 October crops were grazed a second time in early December, which allowed peak production in November when temperatures and soil moisture were optimal. This meant the 2 October crops achieved 4 t DM/ha of lucerne by around 2 December (173 days).

The 14 November grazed hay crops required 180 ± 4.5 days (until around 9 December) to yield 4 t DM/ha of lucerne, similar to both the 6 September and 2 October grazings. Leaving the crops ungrazed until mid-November, allowed the lucerne to accumulate dry matter while temperatures were increasing, similar to the 2 October crops. However, the 14 November grazing interrupted peak lucerne production as it did in the 6 September crops, slowing its overall spring growth rate. Thus, the temporal pattern of lucerne production was altered by herbicide and grazing treatments, and those that interrupted rapid spring growth caused a decrease in annual lucerne yields.

Conclusions

- Winter herbicide was important for effective weed control, and to minimise phytotoxicity damage to the lucerne crop.
- Glyphosate and atrazine were used successfully as a winter herbicide on lucerne when the crop was dormant (July or August) and lucerne cover was below 100 kg DM/ha.
- Early spring grazing (6 September) or a late herbicide application date (18 September) delayed peak lucerne production by 10–30 days. This could be used to change the pattern of spring feed supply on-farm in Central Otago.

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