

Plant population, yield and water use of lucerne sown in autumn at four sowing rates.

D.J. MOOT, K.M. POLLOCK and B. LEWIS

Agriculture and Life Sciences Division, Lincoln University, Lincoln 7647, Canterbury

Derrick.Moot@lincoln.ac.nz

Abstract

Successful establishment of lucerne requires an adequate plant population to maximise yield and maintain stand persistence. The impact of autumn sowing lucerne at four sowing rates was investigated in a split-plot experiment at Lincoln University, Canterbury from 2007–2012. Emerged seedlings represented about 50% of the seeds sown regardless of the 7–16 kg/ha sowing rate. Self-thinning occurred at a faster rate from the higher sowing rates with populations of 80 plants/m² in all treatments by Year 6. These populations ensured annual DM yields were maximised and similar across sowing dates and rates, in all years. However, the 10 t DM/ha yield in Year 1 was below the 13 t/ha average from Years 2–5. This suggests Year 1 crops were still in an establishment phase in their first spring after autumn sowing. This is supported by the initial spring water use efficiency (WUE) in Year 1 crops of 15–20 kg DM/ha/mm of water used. This was lower than the 30–40 kg DM/ha/mm in subsequent years, and is consistent with Year 1 crops partitioning a higher proportion of assimilate below ground during the establishment phase. These calculated WUE values were probably overestimated because they were based on NIWA assumptions of 150 mm of available water for pastures, which appears to be too low for lucerne.

Keywords: alfalfa, *Medicago sativa*

Introduction

For lucerne (*Medicago sativa* L.), commercially recommended sowing rates usually result in seedling populations in excess of those required to maximise yield. Palmer & Wynn-Williams (1976) reported on seven spring-sown field experiments that all showed similar patterns of emergence and consequent self-thinning. Wynn-Williams (1982) summarised these and indicated that sowing rates as low as 2 kg/ha could be used to successfully establish a lucerne stand provided it was free of pests and diseases, and suggested as few as 30 plants/m² were required to maximise yield in the second season after sowing. In all cases the plant population declined to an asymptote regardless of initial sowing rate (Palmer & Wynn-Williams 1976).

Recently, Teixeira *et al.* (2007) concluded that the rate

of thinning was independent of grazing management. Their maximum stem population was consistently ca.780 per m² in mid-rotation and DM yields were unaffected by a decline from 130 plants/m² towards an asymptote of 43 plants/m². In these studies the effects were considered under ideal experimental conditions from spring sowing. However, lucerne stands can also be autumn sown, which may affect the success of establishment and yield in subsequent years (Wigley *et al.* 2012).

In this study we examined the effect of autumn sowing dates and sowing rates on the establishment, plant population and yield of lucerne stands over 5 years. Annual dry matter (DM) yields are also influenced by seasonal differences in rainfall patterns during the growing season, and winter storage of soil moisture (Moot *et al.* 2008). Thus, a secondary objective was to determine whether data from NIWA climate stations could be used to estimate water use efficiency (WUE) of lucerne at different times of the year.

Materials and Methods

Site description and experimental design

This experiment was located in paddock Iversen 14 at Lincoln University, Canterbury, New Zealand (43.6480°S, 172.4631°E; 11 m above sea level), where the soil is a Templeton silt loam or stony silt loam (NZ Soil Bureau 1960). The plant available water content for lucerne is about 210 mm in the top 1 m, but this is variable across the site and decreases to less than 100 mm at depths below 1–2 m as the stone content increases (Watt & Burgham 1992; Pollock *et al.* 2009).

Soil fertility

No fertiliser was applied during land preparation. A soil test in October 2007 (Table 1) indicated no nutrient deficiencies so no fertiliser was applied over the duration of this experiment.

Experimental design

The experiment used a split-plot design with four sowing dates in 2007 21 February (SD1), 2 March (SD2), 16 March (SD3) and 30 March (SD4) as main plots and four bare seed equivalent sowing rates (7, 10, 13 and 16 kg/ha) of coated 'Grasslands Kaituna'

lucerne seed as sub-plots, with three replicates. All variables were analysed using the ANOVA for the split-plot design by GenStat release 14.1 for Windows 7.

The establishment period from February to June, 2007 is defined as Year 0. Each subsequent production year from 1 July to 30 June is then defined sequentially as Years 1–6. For annual DM yields, a four-level soil co-factor ($P < 0.01$) was included to account for a change in soil depth along one edge of all reps. Similarly the cofactor was used to account for yield differences in one regrowth cycle attributed to a broken irrigation pipe caused by the 4 September 2010 earthquake in Canterbury (Moot *et al.* 2010).

Weed control and grazing management

The paddock was conventionally cultivated during January and February 2007 (Year 0) and the final seedbed preparation occurred immediately before SD1. A “Duncan” triple disc drill was used for each sowing, set at 150 mm row spacing and 15 mm depth, followed by tyne harrows and a Cambridge roller. Before the last sowing (30 March), perennial weeds in the subplots ready to be sown were sprayed with 4 L/ha of Roundup (360 g/L glyphosate).

Stinging nettle (*Urtica urens* L.) with some fathen (*Chenopodium album* L.) continued to dominate some areas of the experiment into April, so on 15 May 2007 all plots were sprayed with 8 l/ha of 2,4-DB (2,4-DB, 400 g/l a.i.). All plots were grazed with sheep at the end of June 2007 for 3 days. After grazing, *Poa annua* L. remained, particularly in the last sowing, so all plots were sprayed on the 19/7/07 with 2.5 l/ha of Gallant (100 g/l haloxyfop). Since then weed content has been controlled effectively by the mob stocking with at least a 35-day spelling period in summer and autumn.

Plant population

Initial seedling population was counted from three random 1.0-m lengths of drill row per plot when plants had reached the first trifoliate leaf stage and emergence had ceased. Subsequent plant survival was recorded on 13 September 2007 (spring of Year 1) by digging out individual plants along a 0.3 m length of drill row per plot. For Years 2–6 plants were counted in late winter (August) by digging 2 × 1.0 m long × 0.1 m

deep trenches alongside drill rows and counting intact taproots.

Herbage dry matter (DM) production

Above-ground dry matter (shoot) yield was measured just prior to each grazing. Starting in October 2007, there were 5, 5, 5, 6 and 6 regrowth cycles, in Years 1–5, respectively. Unfortunately no data were collected before grazing for the last growth cycle in Year 1, therefore its annual yield includes a DM estimate for the final regrowth cycle based on the average autumn yields and water use from data for Years 2–5. Herbage DM was based on pasture probe readings regressed against harvests from 8–10 plots of 0.2 m², and when quadrat cuts were taken from all plots. Herbage samples were sorted into weeds and lucerne for samples taken immediately after establishment and at regrowth cycle 1 of Years 1 and 2. Weed growth was a minor component (<10%) in subsequent years, so no further dissections occurred. All samples were dried in a forced air oven at 65°C.

Lucerne water use

Water use (WU) for the experiment was calculated from daily potential soil moisture deficits (SMD), rainfall (R) and runoff or drainage (D) for Lincoln (NIWA 2012).

$$WU = SMD_n - SMD_{n-1} + R_n - D_n$$

where the subscript ‘n’ denotes the current day’s value in the record and ‘n-1’ denotes the previous day’s value.

The SMD used in the NIWA database assumes a soil with a plant available water capacity (AWC) of 150 mm. In their database the soil moisture deficit is incremented on a daily basis by the sum of the potential evapotranspiration (PET) minus the rainfall. If SMD becomes negative the amount is attributed to runoff or drainage (D). If the SMD_n is greater than half the AWC the PET is multiplied by the calculated proportion: $(AWC - SMD_n) / (0.5 * AWC)$

This has the effect of reducing the calculated water use as soil moisture stress develops and plant transpiration decreases.

The crop water use efficiency (WUE; kg DM/ha/mm) was calculated using the accumulated crop production (kg DM/ha) divided by the accumulated water use (mm) (Moot *et al.* 2008).

Table 1. Soil test values for Iversen Field 14 at Lincoln University, Canterbury, October 2007.

Site	Ca	K	Mg	Na	P	S(SO ₄)	pH
	me/100g				ppm in the soil		
Iversen Field 14	7.7	1.15	0.93	0.12	53	4	6.2
*Optimum range	6.0-12	0.5-12	0.8-3.0	0.1-0.5	20-40	10-20	6.0-6.5

* Hill Laboratories

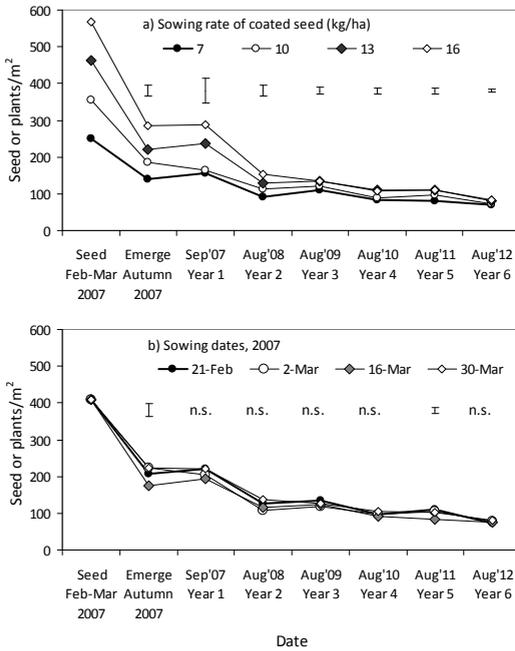


Figure 1. Number of seeds sown and subsequent plant population for lucerne grown at Lincoln, Canterbury when sown at different rates (a) and on different dates in autumn 2007 (b). Error bars represent LSD_(0.05).

Results

There were no significant interactions between sowing date and sowing rate for any of the measured variables (Table 2).

Plant population

As expected, sowing rate affected the number of emerged and established seedlings, and the plant population in each subsequent year (Table 2, Fig. 1a). Field emergence was *ca.* 50% of the seed sown, and these established seedlings survived until spring in Year 1. However, early in Year 2 the plant population declined by a further 20–50% to between 80 and 160

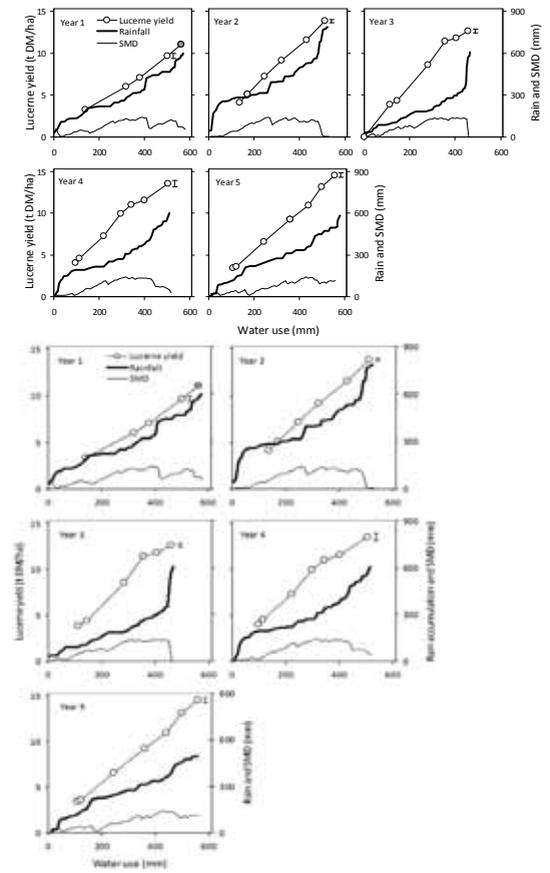


Figure 2. Lucerne crop yield, accumulated rainfall and soil moisture deficits (SMD) in relation to accumulated water use. Lucerne yield is shown as accumulations at each growth cycle relative to the weekly water use, the latter estimated from the climate database for Broadfields, Lincoln (NIWA 2012). Note: the final DM yield for Year 1 (grey circle) is estimated from autumn water use data and not used in the analysis of means. Error bars represent SEM for the final measured DM yield for each year. Soil moisture deficits given in the NIWA climate database were based on plant available water content of 150 mm.

Table 2. Summary of P values from analysis of variance of seedling and plant populations from lucerne crops sown on four dates (Sow Date) at four rates (Sow Rate) at Lincoln University from 2007 (Emergence) to 2012 (Year 5).

Variable	Sow Date	F ratio probabilities	
		Sow Rate	Interaction
Emergence	0.042	<.001	0.709
Year 1	0.890	0.001	0.599
Year 2	0.183	<.001	0.648
Year 3	0.103	0.002	0.590
Year 4	0.925	0.002	0.497
Year 5	0.024	0.008	0.395
Year 6	0.492	0.013	0.116

plants/m². In subsequent years the population was stable for the lowest seeding rate but declined by 6.0–12.0% per annum ($LSD_{0.05} = 5.45$) for the 10–16 kg/ha sowing rates. By the beginning of Year 6 plant populations were 70, 73, 79 and 81 plants/m² for the 7, 10, 13 and 16 kg/ha rates. This represented 28, 21, 17 and 15% of the sown seed, respectively.

Sowing date affected lucerne emergence ($P < 0.042$) but had little effect on plant population in subsequent years (Table 2, Fig. 1b). Specifically, the number of emerged lucerne seedlings was 176/m² for the third sowing date (16 March) compared with over 208/m² from the other sowing dates (Figure 1b). By the beginning of Year 5, plant population had decreased to 84/m² from SD3 ($P < 0.024$) compared with over 103 for the other sowing dates. At the beginning of Year 6 plant population was down to 77/m² with only a small difference between high and low sowing rates (Fig. 1a).

Herbage yield

Annual DM yields showed no effect of sowing rate in any year. For example, in Year 1 the annual yield was 9.6 t DM/ha from 7 kg/ha of seed sown and 9.9 t DM/ha from 16 kg/ha of seed sown ($P = 0.74$). In contrast, annual DM yield adjusted for covariance did show an effect of sowing date ($P < 0.007$), but only in Year 1. Yields were 11.3, 9.0, 8.4 and 10.0 t DM/ha across SD 1–4, respectively ($LSD_{0.05} = 1.24$).

The progressive dominance of weeds in the prepared seed beds during February and March of Year 0 necessitated the herbicide application prior to SD4. At the first harvest of Year 1 weeds were 20, 36, 49, and 81% of the DM ($P < 0.002$; $LSD_{0.05} = 20$) for SD 1–4, respectively. The weeds in SD4 were predominantly winter annuals that had grown despite the additional weed control before sowing. These weeds mostly disappeared by the end of the first regrowth cycle in Year 1 and lucerne dominated for the rest of Year 1. Weed content at the first harvest in Year 2 was 19% and unaffected by sowing date ($P = 0.31$). Subsequently, lucerne content (visual record) was >85% of total yield. Regrowth of annual weeds over winter usually resulted in 10–15% weed content in the first regrowth cycle of

each year but minimal weed content (<5%) in the following regrowth cycles.

Lucerne water use

The DM yield at the end of each growth cycle (immediately before grazing) is plotted against the water used and compared with the soil moisture deficit (SMD) and rainfall accumulated for each year (Fig. 2). For example, in Year 2, lucerne yield averaged 13.2 t DM/ha across treatments. The winter rainfall of over 300 mm, and the regular rain over summer, meant that growth was almost linear with respect to water use (WU) throughout that year. This occurred even though SMD was near the maximum of 150 mm available water capacity (AWC) set by the NIWA (2012) model. In contrast, for Year 3 the annual crop yield was also 13.0 t DM/ha but most of this yield (11.8 t DM/ha) had occurred by early summer. All growth then stopped while the SMD remained high and there was insufficient rain to stimulate and maintain regrowth. Finally, in May and June of Year 3, over 250 mm of rain fell, but the weather was too cold for lucerne growth. Some of this rainfall will have been stored and used in spring regrowth of Year 4.

The slope of lines between data points for yield represents the water use efficiency or rate of DM accumulation against water use. The water use efficiency decreased in mid to late summer of Years 3 and 4 (Table 3) once the soil dried to near its maximum SMD and the lucerne was unable to extract sufficient water for growth.

Discussion

Despite sowing rate affecting seedling and subsequent plant populations across all years, there were no differences in herbage DM yield among stands in any year. Final plant populations in Year 6 were all higher than the 30–45 plants/m² suggested as the minimum required to ensure the productive potential of lucerne crops (Palmer & Wynn-Williams 1976; Teixeira *et al.* 2007).

However, the earliest autumn sowing in February resulted in the highest DM yield in the following

Table 3. Mean water use efficiency (WUE) for lucerne crops sown at Lincoln University, Canterbury estimated from modelled evapotranspiration and soil moisture deficits from NIWA (2012) using a maximum available water capacity of 150 mm.

Period	*WUE (kg DM/ha/mm)				
	Year 1	Year 2	Year 3	Year 4	Year 5
Winter, early spring	23.4	28.8	32.1	39.4	30.5
Spring to mid summer	15.6	26.0	32.0	27.5	23.1
Mid to late summer	20.4	20.9	6.9	9.2	37.6
Spring to autumn	17.5	24.4	28.0	23.1	24.7

* Note: WUE is probably overestimated due to greater soil water extraction by lucerne than is estimated by the NIWA model.

production year. Furthermore, the third sowing date in early March was affected by perennial weeds. This reduced its plant population in Year 1, but there was no adverse effect on yield. Similarly, at SD4 in late March there were carry-over effects of weed ingress on yield and botanical composition. Despite the additional weed control between SD3 and SD4, weeds still represented 60% of the yield at the start of Year 1 for SD4 regardless of sowing rate. These weeds were mostly winter annuals that grew rapidly through late autumn and winter when lucerne is less competitive. They were only dominant in the first spring regrowth rotation and did not re-establish in subsequent years. These results highlight the importance of effective weed control before sowing and the advantage of the earlier autumn sowing dates that enabled the lucerne canopy to out compete weeds. The subsequent low weed content in all crops in Years 2–5 followed the pattern described by Palmer (1982) and supports the conclusion that, with appropriate grazing management, chemical weed control can be minimised in lucerne stands.

The annual DM yields were consistent with previous reports for dryland lucerne in this environment (Mills *et al.* 2008). The lower growth rates and water use efficiency of crops in spring of Year 1 from the autumn sowing indicates a greater allocation of assimilates to roots in seedling crops (Teixeira *et al.* 2011). This implies that these crops were still in an establishment phase, and did not reach full production until 12 months after sowing.

It appears that the standard NIWA method used to predict drought stress in grass-based pastures was less appropriate for lucerne. The crops continued to grow into the periods calculated as having high (>150 mm) SMD. As a consequence, crop WUE (Table 3) was higher than reported previously (Moot *et al.* 2008), which implies crops were extracting more water than calculated from Equation 1. The NIWA model sets the maximum available water content (AWC) at 150 mm, whereas data from Watt & Burgham (1992) and Pollock *et al.* (2009) indicated an AWC of 250 mm is more realistic for the deep rooting lucerne growing in these soils at this site. The NIWA data are widely published as an indicator of soil water deficits for east coast regions of New Zealand. However, these results support the contention that lucerne crops will grow longer into a dry period than grass-based pastures (Moot *et al.* 2008).

There was a depressed lucerne production in mid to late summer (second last growth cycle) in Years 3 and 4 (Fig. 2, Table 3). This was mostly due to high SMD, low canopy cover, and the inability of small (<20 mm) rainfall events to stimulate growth due to high evaporation from the exposed soil surface (Moot *et al.* 2008). In contrast, there was high mid-late summer

WUE in Year 5 where ample rain fell during the late summer. This reduced the SMD and stimulated rapid lucerne regrowth while temperatures were still warm. During dry spells (SMD > half the AWC) the NIWA model possibly underestimates the evapotranspiration, which also overestimates the WUE. In their model, potential evapotranspiration, hence the estimate of WU, is greatly reduced at high SMD, whereas in the paddock small rainfall amounts are evaporated at the potential evapotranspiration rate independent of the high SMD in the lower soil profile. Running the NIWA model with a higher AWC or using other soil moisture models such as that used by Blair (2008) for pasture in Marlborough could provide a more precise estimate of WU and WUE for lucerne.

ACKNOWLEDGEMENTS

We thank Field Service Centre staff for the grazing management and PLSC321 students for collecting data on plant populations. Dr. Annamaria Mills assisted with data analyses.

REFERENCES

- Blair, I.C. 2008. Application of climate data to predict pasture production. *Proceedings of the New Zealand Grassland Association* 70: 153-158.
- Mills, A.; Smith, M.C.; Lucas, R.J.; Moot, D.J. 2008. Dryland pasture yields and botanical composition over five years under sheep grazing in Canterbury. *Proceedings of the New Zealand Grassland Association* 70: 37-44.
- Moot, D.J.; Brown, H.E.; Pollock, K.M.; Mills, A. 2008. Yield and water use of temperate pastures in summer dry environments. *Proceedings of the New Zealand Grassland Association* 70: 51-57.
- Moot, D.J.; Mills, A.; Pollock, K.M. 2010. Natural resources for Canterbury agriculture. *Proceedings of the New Zealand Grassland Association* 72: IX-XVII.
- NIWA. 2012. CliFlo Climate Database. Accessed May 2012. <http://cliflo.niwa.co.nz/>.
- NZ Soil Bureau. 1960. Soils of Lincoln College farms and D.S.I.R. Divisions, Lincoln. Soil Bureau Department of Scientific and Industrial Research. R.E.Owen, Government Printer, Wellington.
- Palmer, T.P. 1982. Weeds in lucerne, why are they there, what harm do they do? pp. 33-35. *In*: Lucerne for the 80's. Special Publication, No. 1. Ed. Wynn-Williams, R.B. Agronomy Society of New Zealand, Christchurch.
- Palmer, T.P.; Wynn-Williams, R.B. 1976. Relationships between density and yield of lucerne. *New Zealand Journal of Experimental Agriculture* 3: 71-77.
- Pollock, K.M.; Mead, D.J.; McKenzie, B.A. 2009. Soil moisture and water use by pastures and silvopastures in a sub-humid temperate climate in New Zealand. *Agroforestry Systems* 75: 223-238.

- Teixeira, E.I.; Moot, D.J.; Brown, H.E.; Fletcher, A.L. 2007. The dynamics of lucerne (*Medicago sativa* L.) yield components in response to defoliation frequency. *European Journal of Agronomy* 26: 394 - 400.
- Teixeira, E.I.; Brown, H.E.; Meenken, E.D.; Moot, D.J. 2011. Growth and phenological development patterns differ between seedling and regrowth lucerne crops (*Medicago sativa* L.). *European Journal of Agronomy* 35: 47-55.
- Watt J.P.C.; Burgham, S.J. 1992. Physical properties of eight soils in the Lincoln area, Canterbury. DSIR Land Resources Technical Record 103, DSIR Land Resources, Lower Hutt. 134 pp.
- Wigley, K.; Moot, D.J.; Khumalo, Q.; Mills, A. 2012. Establishment of lucerne (*Medicago sativa* L.) sown on five dates with four inoculation treatments. *Proceedings of the New Zealand Grassland Association* 74: 91-96.
- Wynn-Williams, R.B. 1982. Lucerne establishment – conventional. pp. 11-20. *In: Lucerne for the 80s. Special Publication, No. 1.* Ed. Wynn-Williams, R.B. Agronomy Society of New Zealand, Christchurch.