MR. STEPHEN GARY CLARK (Orcid ID : 0000-0001-5251-5493)

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Department of Economic Development, Jobs, Transport and Resources,

915 Mount Napier Road, Hamilton,

Victoria

3300

Australia.

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Maximising lucerne (*Medicago sativa* L.) production with fixed-length recovery intervals after defoliation in mild winter environments

Authors:

S.G. Clark, Mitchell M.L., Nie, Z.N., Burnett, V.F. Butler, K.L., Zollinger, R.P., Seymour, G.R.

Corresponding author email address:

steve.clark@ecodev.vic.gov.au

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Contains 5 Figures and 5 Tables

Short title:

Harvest interval and lucerne production

Maximising lucerne (*Medicago sativa* L.) production with fixed-length recovery intervals after defoliation in mild winter environments

S.G. Clark¹, Mitchell M.L.², Nie, Z.N.¹, Burnett, V.F.², Butler, K.L.¹, Zollinger, R.P.¹, Seymour, G.R.²

¹Department of Economic Development, Jobs, Transport and Resources, 915 Mount Napier Road, Hamilton, Victoria, 3300, Australia

²Department of Economic Development, Jobs, Transport and Resources, 124 Chiltern Valley Road, Rutherglen, Victoria, 3685, Australia.

Abstract

Lucerne (*Medicago sativa* L.) is an important temperate legume for livestock production systems. Lucerne requires a recovery period after a defoliation event so that taproot energy and nutrient stores can be replenished. A field experiment examined the effects of recovery period management following defoliation, on lucerne herbage production and nutritive value at two contrasting sites in Victoria, Australia. Sites were established at Rutherglen and Hamilton, using established SARDI Seven lucerne stands. Treatments were short recovery (SR; plots cut at 21-day intervals), long recovery (LR; plots cut at 42-day intervals), new shoots (NS; plots cut when new shoots from the crown were at least 2 cm long) and new shoots + flowering (NSF; as for NS but plots were left to grow to reach late flowering from late summer to mid-autumn). At each defoliation, measurements were made of phenology, dry matter production and herbage nutrient concentrations (neutral detergent fibre, crude protein, metabolisable energy and

water-soluble carbohydrate %). Persistence was measured at approximately 6-month intervals.

At both sites, lucerne persisted equally well in all treatments although SR showed some decline at Hamilton at the final measurement. LR led to a more productive pasture (in terms of cumulative dry matter, neutral detergent fibre, crude protein, metabolisable energy and water-soluble carbohydrate %) than the three other treatments. The results indicate that phenological management systems that allow lucerne to replenish reserves through late summer and autumn are unnecessary in mild winter environments.

KEYWORDS

alfalfa, defoliation, management, recovery, persistence.

1 INTRODUCTION

It is well understood and accepted that lucerne (*Medicago sativa* L.) requires a recovery period following defoliation and that recovery time is more important than the level of defoliation (McKinney, 1974; Bélanger *et al.*, 1999; Pembleton *et al.*, 2010; Teixeira *et al.*, 2007; Teixeira *et al.*, 2008). Repeated defoliation with inadequate recovery leads to loss of dry matter production and reduces persistence. While cultivars have been developed that are more tolerant of frequent defoliation (Smith *et al.*, 2000; Humphries *et al.*, 2006; Sewell *et al.*, 2011; Bouton, 2012) this general principle still applies. Although recommendations exist regarding recovery periods following defoliation, evaluation of various recovery regimes in different environments is limited. In south-eastern Australia, lucerne is grazed throughout the year. Growth rates, and therefore available herbage, will vary seasonally however – being typically low in winter when temperatures are limiting and in summer to early autumn when rainfall is often limiting.

Previous Australian studies have recommended recovery periods ranging from 35 days (Clinton, 1968) to 49 days (McKinney, 1974). Popular and scientific literature from Australia and New Zealand often favour grazing when new lucerne shoots reach 2 cm and grazing for 7-8 days, leaving older shoots at least 5 cm long to protect the new shoots during the spring-early summer main growth period

(e.g. Williams, 1996; Moot *et al.*, 2003; Anon, 2017). They also often recommend resting lucerne in late summer-early-autumn until approximately 50% flowering to allow root reserves to be restored prior to winter. These recommendations are likely to lead to long recovery intervals in late summer-autumn because of low growth rates during this period in the absence of irrigation. Longer recovery intervals in autumn have been found to be important for productivity and persistence in Atlantic Canada where winterkill, due to severe frosts in early winter, can greatly reduce plant density (Bélanger *et al.*, 1999).

Both recommendations can be problematic for many producers as there is much subjective skill required to determine what constitutes a new shoot and what 50% flowering looks like. The recommendation to allow lucerne to flower strongly in late autumn occurs at a time when other pastures are dormant or have senesced and green lucerne is most valuable (Clark *et al.*, 2013).

To test the validity of these recommendations under south-eastern Australian conditions, an experiment was conducted at each of two environmentally contrasting locations to examine the effects of recommended periods of recovery from defoliation on lucerne above-ground herbage DM production and nutritive characteristics. The production of nutritive characteristics is presented both in absolute terms as well as a percentage of DM production. This enabled a comparative evaluation, with different defoliation regimes, of the feed resource that can be produced from established lucerne stands, whether the feed resource is utilised by grazing or by cutting and conserving.

It was hypothesised as a starting point that a simple management system of 6-week recovery periods between defoliations would be more productive than a system with 3-week recovery periods. It was further hypothesised that management systems relying on observations of new shoot growth or prolonged flowering periods in autumn would offer no advantages over a 6-week rest system.

2 MATERIALS AND METHODS

2.1 Site description and treatments

An experiment was established at each of two sites, on agricultural research farms at Rutherglen (S36.112, E146.518) and Hamilton (S37.834, E142.086) in Victoria, Australia. These are regions with extensive sheep and beef cattle industries.

Lucerne cultivars are characterised according to a fall dormancy scale developed in the USA (NAAIC, 2004) although in Australian literature this is usually referred to as winter dormancy. Cultivar dormancy scores range from 1 = winter dormant to 11 = highly winter active (Humphries & Hughes, 2006, Reed, 2006). Both sites used established SARDI Seven lucerne stands – sown in October 2013 at Rutherglen and in November 2011 at Hamilton. At both sites the stands had been managed for commercial lamb grazing in spring-autumn. SARDI Seven has a winter dormancy score of 7 (Kobelt, 2002) and has performed well in experiments in Victoria previously (Clark *et al.*, 2013; Ward *et al.*, 2013, Raeside *et al.*, 2014).

The design of each experiment was identical except for the randomisation. Each had four replicates in a completely randomised design. Both site teams adhered to identical experimental protocols.

The treatments were: Short recovery (SR): Plots were cut to 5 cm at 21-day intervals; Long recovery (LR): Plots were cut to 5 cm at 42-day intervals; New shoots (NS): Plots cut to 5 cm when new shoots from the crown were at least 2 cm long; and New shoots + flowering (NSF): As for NS but plots were left to grow to reach late flowering from late summer to mid-autumn (*i.e.* February-May, depending on seasonal conditions).

Treatments were imposed from 6 January 2015 to 16 June 2016 at Rutherglen and from 2 December 2014 to 20 June 2016 at Hamilton. Decisions on the timing of harvests for the NS and NSF treatments were made on a whole treatment basis rather than on an individual plot basis. A defoliation was triggered if an average of 70% of 10 randomly selected plants in all four plots in the treatment met the criteria.

2.2 Fertiliser and pest control

Fertiliser application was based on initial soil test results. At Rutherglen, plots were fertilised with SuPerfect Pot 1&1 (200 kg/ha) on 10 June 2015 (P: 4.4%, K: 25.0%, S: 5.5%, Ca: 9.5%). Broadleaf weeds were controlled with Jaguar (bayercropscience.com.au) (active ingredients – Bromoxynil, 250 g/l and Diflufenican, 25 g/l) at 1 l/ha and Imadan (cropcare.com.au) (active ingredient – Phosmet, 150 g/l) at 135 ml/ha on 7 July 2015 to control insect and mite pests. On 13 August 2015, grass weeds and arthropod pests were controlled with an application of Verdict at 100 ml/ha (www.dowagro.com) (active ingredient – Haloxypol, 520 g/l) and Le-Mat (www.fmccrop.com.au) (active ingredient – Omethoate, 290 g/l) at 100 ml/ha.

At Hamilton, plots were fertilised with superphosphate (100 kg/ha) and muriate of potash (200 kg/ha) on 30 April 2015 and 28 September 2015 (P: 8.8%, K: 50.0%, S: 11.0%, Ca: 20.0%). The second application of fertiliser at Hamilton was considered necessary due to the low initial Exchangeable Potassium level (Table 1). Broadleaf weeds were controlled with Jaguar at 750 ml/ha on 26 June 2015 and 31 May 2016.

2.3 Rainfall and temperature

Air temperature and rainfall were recorded daily 1.1 km from the Rutherglen site and 2.1 km from the Hamilton site. Data for the period of the experiment are compared with the long-term averages in Figure 1. Both sites have warm, temperate climates. Rutherglen has greater seasonality of temperatures and Hamilton has greater seasonality of rainfall. Rainfall is more variable at Rutherglen than it is at Hamilton.

Both sites experienced periods of low and high rainfall. At Rutherglen, the rainfall total for the period July 2015 to April 2016 (395.7 mm) was in the 3rd decile and at Hamilton, the total for the period June 2015 to December 2015 (274.9 mm) was in the 2nd decile.

2.4 Phenology

Prior to each herbage mass harvest, plots were visually assessed for phenological stage using the scoring system of Kalu and Fick (1981) (Table 2). Scores were allocated on the basis of the phenological stage of 70% of plants in a plot.

2.5 Herbage mass

Herbage mass was assessed at each harvest. One to three strips per plot (depending on the amount of herbage available) were cut to 5 cm high with a ride-on mower. Each strip was 1.37 m wide $\times$ 10 m long. The Hamilton mower was equipped with a self-weighing device. At Rutherglen the herbage in the mower's catcher was manually weighed. After weighing, a subsample was taken, weighed fresh, dried at 100 °C for 48 hours and weighed again to determine dry matter (DM) production.

2.6 Herbage nutritive characteristics

Prior to each herbage mass harvest, during late morning, 15 to 20 grab samples were cut to 5 cm high (depending on available DM) and stored in ice-boxes before processing for nutritive characteristics. All samples were dried at 60°C for 48 hr, then ground through a 0.5 mm sieve.

Lucerne herbage was analysed at NSW DPI Wagga Wagga, New South Wales, Australia by Near Infra-red Spectroscopy (NIRS). NIRS spectra were collected on all samples using an Bruker MPA FT-NIR instrument (Bruker Optik GmbH, Ettlingen, Germany) in conjunction with OPUS ver 7.5.18 (Bruker Optik GmbH, Ettlingen, Germany)

NIRS calibrations for neutral detergent fibre (NDF), acid detergent fibre (ADF), Crude Protein (CP), dry matter digestibility (DMD), digestibility of organic matter

in the dry matter (DOMD), metabolisable energy (ME) and Water Soluble Carbohydrate (WSC) were derived by obtaining spectra from 730 samples covering multiple seasons. Standards and test samples were chosen by running principle component analysis on all spectra which had been pre-processed using first derivative and multiplicative scatter correction and using OPUS to select a representative set that covered spectral variation using the first 2 principle components.

A comparison between NIRS and wet chemistry results was undertaken for ~10% of samples, with resultant correlations (R²) of 0.98, 0.98, 0.95, 0.95 and 0.96 for NDF, ADF, CP, DMD, DOMD and ME and WSC respectively. Reference methods used for NIRS calibrations were as follows:

CP using the DUMAS method. Any spectral outliers from the calibrations had analysis conducted by wet chemistry techniques.

Estimated ME (MJ/kg DM) values were calculated from predicted DOMD values using the formula from AFIA Method AFIA Method - 1.14R using data obtained from (MAFF 1990)

$$\text{ME (MJ/kg DM)} = 0.203 \text{ DOMD (\%)} - 3.001.$$

Standard errors of prediction for lucerne herbage were NDF -1.22%, ADF – 1.16%, CP -0.85%, DMD -1.86%, DOMD -1.24% and WSC – 0.41% DM respectively.

Reference methods used for NIRS calibrations were as follows:

1. NDF using the Ankom method including amylase and sodium sulphite (AFIA Method – 1.8A(a)), and Ankom model 200 ANKOM Technology, 2052 O'Neil Road, Macedon NY 14502
2. ADF using Ankom (AFIA Method – 1.9A(a)) and Ankom model 200 ANKOM Technology, 2052 O'Neil Road, Macedon NY 14502

3. Nitrogen determination by DUMAS method (AOAC Crude Protein 2001.11) using a LECO Trumac combustion Analyser (LECO Corporation, Saint Joseph, Michigan USA)
4. DMD and DOMD using a pepsin–cellulase technique (AFIA Method - 1.7R), with analytical values adjusted using a linear regression based on similar samples of known in vivo values.
5. WSC using the Alkaline Ferricyanide method and the Lachat 8500 flow injection analyser system (Lachat Instruments, Loveland, Columbia, US) and according to the Australian Fodder Industry Association Official Method – 1.11A.

Any spectral outliers from the calibrations had analysis by NIRS repeated, as well as further analysis by wet chemistry techniques. Outliers tended to be the result of improper sample preparation for the NIRS system; once analysis was repeated, results were within the acceptable range.

2.7 Persistence

Basal cover was measured prior to the implementation of the defoliation/recovery treatments. Two 1 m × 1 m squares of weldmesh with 10 cm by 10 cm divisions, to give 100 cells per quadrat, were used at permanent locations in each plot. The number of cells containing entire or partial plant bases were counted for each square and these totals were averaged for each plot. This was repeated 3 times at approximately 6-month intervals during the life of the experiment.

2.8 Statistical analyses

Herbage DM, CP, NDF, ME and WSC yields were calculated at each harvest for each plot, at each site. Due to a balance malfunction, the fresh herbage mass was not available for one cut (22 Dec 2014) of one plot (a LR plot) at one site (Hamilton). For this cut at this plot a dry matter herbage mass, equal to the average dry matter herbage mass of this cut of the other 3 LR plots at Hamilton was imputed. This imputation was used as an input to calculate CP, NDF, ME and WSC yield of this cut of this plot. These yields were used to calculate average

values of each of the 4 defoliation treatments of the cumulative (from start of experiment) values of these herbage masses for each cut, at each site. These cumulative values were graphed. Statistical analysis, using a four-treatment one-way analysis of variance (a CRD model), was performed on the cumulative yields at four times at each site, which corresponded to times when (i) all plots were cut within a few days and (ii) could reasonably represent times of seasonal changes or the end of the study.

For the periods between these statistically analysed times and for the entire experimental period, the CP, NDF and WSC percentage of dry matter cut was calculated as 100 times the cumulative CP, NDF and WSC herbage mass (over the appropriate period) divided by the cumulative DM herbage mass (over the appropriate period). Similarly, the ME concentration were calculated as the cumulative ME yield divided by the cumulative DM yield. CP, NDF, WSC and DM percentages, and ME concentrations, for each of these periods at each site, were analysed using a one-way analysis of variance in GenStat release 17 (Payne *et al.* 2014).

The latter three basal cover measurements were analysed as a four-treatment one-way analysis of variance, using the pre-treatment basal cover as a covariate, so as to improve the precision of treatment comparisons. All analyses of variance except basal cover used the plot as the unit of analysis and had 12 residual degrees of freedom. Basal cover analyses had 11 residual degrees of freedom, due to the use of the pre-treatment basal cover as a covariate.

3 RESULTS

3.1 Phenology

All harvest dates and flowering events are shown in Figure 2 with phenological score distributions presented in Figure 3. Over the 19-month study period, the SR treatment rarely developed to flowering, either in absolute or percentage of harvest terms – 1 harvest (4%) at Rutherglen and 2 harvests (7%) at Hamilton. LR was flowering at 4 harvests (33%) at Rutherglen and 7 (50%) at Hamilton; NS 2 (14%) and 3 (14%) and NSF 2 (22%) and 2 (13%).

3.2 Harvest dates

Harvest dates for the SR and LR treatments were fixed and were therefore not experimental outcomes. In autumn 2016 at Rutherglen, there was insufficient growth for three consecutive SR harvests and one LR harvest (Figure 2.). At Rutherglen there were 23 SR harvests and 12 LR harvests and at Hamilton, 28 and 14 respectively.

Harvest dates were experimental outcomes for the NS and NSF treatments. In low growth periods (approximately April-August) at both sites, NS had relatively few harvests with 10 at Rutherglen and 13 at Hamilton and NSF had only six harvests at Rutherglen and seven at Hamilton. (Figure 2). The frequency of harvests of NS and NSF during high growth periods (approximately September-March) differed greatly between the two sites. At Hamilton, during high growth periods, NS and NSF were harvested as often as the SR treatment and at Rutherglen, they were harvested as often as the LR treatment.

3.3 Herbage mass

Cumulative lucerne herbage DM totals (kg DM/ha) are presented in Figure 4. At both sites, cumulative herbage mass did not differ between SR and LR until the high growth rate period in spring 2015 (Figure 4). Thereafter, there was more herbage accumulation in LR than in SR – 30% more at Rutherglen and 40% more at Hamilton approximately.

The cumulative herbage DM production of NS was similar to that of NSF at both sites. At Rutherglen, they had similar herbage DM production to LR and much more than that of SR. At Hamilton, they had similar herbage DM production to SR and much less than that of LR.

3.4 Herbage nutritive characteristics

Nutritive characteristics of lucerne herbage are presented in Tables 3 and 4 and cumulative nutritive characteristics are presented in Figure 5. At Rutherglen, cumulative NDF, ME and WSC yields were similar for LR, NS and NSF (Figure 5). At Hamilton, cumulative NDF, ME and WSC yields were similar for SR, NS and NSF. The higher CP concentrations of NS and NSF compared to LR at Hamilton in Jan-Feb 2015 and Sep-Nov 2015 (Table 4) led to cumulative totals similar to those of LR. In contrast, at Rutherglen the lower CP concentrations of NS and NSF in the final 12 months of the experiment led to the cumulative CP concentrations of NS and NSF being similar to those of SR.

3.5 Persistence

The initial mean basal cover was 44% at Rutherglen (between plot SD = 6.5) and 57% at Hamilton (between plot SD = 10.9). Basal cover % is presented in Table 5. At Hamilton there was no difference between treatments ($P>0.1$) until the last measurement (June 2016) when SR had lower basal cover than LR and NSF. At Rutherglen there were no differences between treatments.

4 DISCUSSION

The production of dryland lucerne was examined in reference to cumulative DM, CP, ME, NDF and WSC production to determine the relative effects of four defoliation/recovery treatments on the productive capacity for animal production. At both sites, the six-week interval between harvests (LR) led to a persistent and substantially more productive pasture in terms of cumulative herbage and nutrient DM than was the case with the three-week interval between harvest treatment (SR).

The concentrations of CP and ME were occasionally higher for SR than for LR. For classes of stock that always need a high nutrient level, such as milking cows and ewes, this might be important. However, with more extensive systems such as meat and wool production and with a pasture that is of high quality throughout the year, productive capacity is likely to be more important. In these cases, the cumulative production of DM, nutrients and energy is likely to be of more

practical relevance especially as the differences between defoliation/recovery treatments are large.

NS and NSF were similar for persistence, cumulative DM and cumulative quality at both sites. This occurred despite fewer harvests and longer harvest intervals with NSF compared to NS. This finding is in line with Teixeira *et al.* (2007) in New Zealand with irrigated lucerne, who found only small differences between cumulative DM production between short (4 week) and long (6 week) grazing intervals over Feb-Jun for lucerne swards that had similar (either short or long) grazing intervals from Oct-Jan. This indicates that there is no clear advantage in long defoliation intervals (i.e. greater than with a fixed 6-week interval) during periods of low growth.

Our findings and those of Teixeira *et al.* (2007) in Canterbury, New Zealand, conflict with the often-stated justification of an NS or NSF management system; namely that long intervals between harvests in low growth periods allow the lucerne plants to replenish resources before winter and promote strong spring growth (Moot *et al.*, 2003; Meuriot *et al.*, 2005). This practice is no-doubt justified in locations with harsh winters (e.g. Atlantic Canada) but appears not to be justified in milder environments. In Mediterranean climates with mild winters, similar results have been found. Lloveras *et al.* (1998) conducted a three-year experiment in coastal north-east Spain and found that harvesting in autumn had no lasting effect on lucerne quality or herbage production. Lodge (1991) identified several Australian studies, where lucerne experienced sufficiently severe winters that grazing in autumn and/or winter damaged plants and led to reduced DM yield and persistence – but concluded that this is not the normal situation in Australia.

For persistence, production and nutritive characteristics at both sites, NS and NSF were never better than the simple LR management system and were often substantially worse. For this reason alone, it appears there is no reason to use either the NS and NSF management systems in environments where mild winters allow some lucerne growth.

Except for cumulative CP, the NS and NSF treatments performed similarly at each site and were close to LR at Hamilton and to SR at Rutherglen. The main

difference between Rutherglen and Hamilton, in the implementation of NS and NSF was the harvest frequency (and hence the recovery period) during the high pasture accumulation periods (Figure 4). At Rutherglen, the recovery periods were similar to those of LR (6 weeks) while at Hamilton they were more similar to those of SR (3 weeks). This indicates that, in terms of productivity, defoliation interval during periods of high growth is very important but, as seen above, defoliation interval during periods of low growth is not very important. This is also in line with Teixeira *et al.* (2007) who found a major reduction in cumulative DM production between short and long grazing intervals from October to January, irrespective of whether short or long grazing intervals were practised from February to June. An interpretation is that short defoliation intervals during periods of high pasture growth will weaken the productive capability of the lucerne plant.

The criterion for defoliation in NS and NSF during high pasture growth periods was the same at both sites, namely the appearance of new crown shoots that were at least 2 cm long. Thus, the substantially longer defoliation intervals during high pasture growth periods at Rutherglen compared to Hamilton indicates that there are differences in the way lucerne responds to contrasting environmental conditions. Possible differences in environmental conditions include soil type, variability of rainfall (greater at Rutherglen than at Hamilton), seasonality of rainfall (greater at Hamilton than at Rutherglen) and temperatures (warmer in summer and more frosts in winter at Rutherglen compared to Hamilton).

Whatever the environmental causes of the site differences in defoliation interval, it is clear the productivity of NS and NSF, compared to the fixed rotation managements, will be highly dependent on the environment.

The one productivity criterion that was inconsistent was cumulative crude protein production. CP concentration of lucerne varies markedly as pasture grows and senesces. At Hamilton, in an earlier experiment over 4 years, SARDI Seven lucerne CP concentrations varied from 19% DM in summer to 39% DM in autumn (Clark *et al.*, 2013). Thus, the cumulative CP production is likely to be strongly dependent on the actual harvest dates and the seasonal conditions at those dates. Hence cumulative CP production may differ from other productivity

criteria at specific sites and times. In the present study, cumulative CP production with the NS and NSF treatments was either similar to (Hamilton) or less than (Rutherglen) that of the LR treatment. Therefore, even at Rutherglen, NS and NSF were substantially inferior to LR in at least this one criterion.

The NS and NSF treatments were designed to encourage the incidence of further phenological development, such as flowering, especially during low growth periods. It appears that simply extending defoliation intervals until further phenological development occurs is ineffective in producing a high incidence of extended phenological development. At both sites, the incidence of extended phenological development (flowering) was greater with the LR treatment than with either NS or NSF.

This experiment ran through two summer-autumn periods and we saw only a hint that persistence might have been impacted by the management system (i.e. SR) at one site (Hamilton) by the end of the experiment. It is possible that treatment differences in persistence would emerge if the treatments were maintained for longer – but this was beyond the scope of our resources.

It is widely recognised that mechanical defoliation and defoliation by grazing animals is different in terms of the effects on plants and nutrient cycling (White 1973; Korte and Harris 1987), with grazing being less uniform than cutting and potentially causing damage to the plants. However, previous literature indicates that defoliation interval is a key driver of defoliation effects on lucerne, whether cut or grazed (Bélanger *et al.* 1999, Ventroni *et al.* 2010, Harvey *et al.* 2014) and thus our results should have relevance to both situations. Further, results obtained under grazing in New Zealand (Teixeira *et al.* 2007) are, in several respects, in accord with the present study. Mechanical defoliation provides a more uniform defoliation than can be achieved with grazing.

For the environments used in this experiment, our results indicate that the most productive management is a simple 6-week recovery period between defoliations. Further, a long period without defoliation in late summer-autumn is unnecessary as we saw no benefits in terms of herbage production or persistence. Finally,

adequate rest periods during the rapid growth phase (spring-early summer) is more important for high lucerne productivity.

Our results offer opportunities for simplifying the management of dryland lucerne in temperate south-eastern Australia and elsewhere with similar climates. In particular, advising farmers to not graze/cut their lucerne from late summer through autumn is problematic because in environments with little and sporadic summer-autumn rain the ability to grow and utilise lucerne has great economic value (Lodge, 1991; Humphries and Hughes, 2006; Sewell *et al.*, 2011; Nichols *et al.*, 2012).

In conclusion, our results indicate that a three-week rest between defoliations can be expected to result in a severe penalty in terms of herbage DM and cumulative nutritive characteristics. The six-week rest treatment optimised lucerne DM and nutritive characteristics accumulation at both sites. More complicated management systems, such as NS and NSF, designed to allow lucerne to replenish reserves through late summer and autumn, offer no benefits over a simple six-week rest system in mild winter environments.

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TABLE 1 Soil descriptions and nutrient status for Rutherglen (samples collected 16 December 2014 and Hamilton (20 November 2014).

	Rutherglen	Hamilton
Description	Brown Chromosol	Ferric-sodic eutrophic brown Chromosol

Total Carbon (g/100g)	1.6	3.8
Total Nitrogen (g/100g)	0.14	0.29
Total organic matter (g/100g)	3.0	7.1
Electrical Conductivity (dS/m)	0.07	0.12
pH(CaCl ₂)	5.4	5.0
pH(water)	6.2	5.7
Total soluble salts (%)	0.02	0.04
Calcium (meq/100g)	4.1	6.2
Calcium as percent (%)	74	77
Calcium:Magnesium ratio	5.0	4.9
Magnesium (meq/100g)	0.83	1.30
Magnesium as percent (%)	15	16
Potassium (meq/100g)	0.57	0.33
Potassium as percent (%)	10	4
Sodium (meq/100g)	<0.05	0.28
Sodium as percent (%)	<1	3
Sum of four cations (meq/100g)	5.6	8.1
Exchangeable Aluminium (KCl) (mg/kg)	<10	<10
Exchangeable Potassium (Skene) (mg/kg)	250	150
Available Phosphorus (Olsen) (mg/kg)	15	20
Available Sulphur (CPC) (mg/kg)	<3	19

TABLE 2 Phenology scoring system

Stage number	Stage	Definition
0	Early vegetative	Stem length < 15 cm; no buds, flowers or seed pods
1	Mid vegetative	Stem length 15-30 cm; no buds, flowers or seed pods

2	Late vegetative	Stem length > 30 cm; no buds, flowers or seed pods
3	Early bud	1-2 nodes with buds, no flowers or seed pods
4	Late bud	≥ 3 nodes with buds, no flowers or seed pods
5	Early flower	One node with one open flower, no seed pods
6	Late flower	≥ 2 nodes with open flowers, no seed pods
7	Early seed pod	1-3 nodes with green seed pods
8	Late seed pod	≥ 4 nodes with green seed pods
9	Ripe seed pod	Nodes with mostly brown mature seed pods

Based on Kalu and Frick (1981)

TABLE 3 Effect of defoliation/recovery period treatment (SR = Short Recovery, LR = Long Recovery, NS = New Shoots, NSF = New Shoots + Flowering) on herbage nutrient characteristics at the Rutherglen site. *P* values less than 0.05 are bolded. The start and end periods are selected so that all treatments are cut within a few days of each other and so that the periods represent times of lower or higher above-ground growth.

Date	SR	LR	NS	NSF	SED ¹	<i>P</i> value ²
<i>Neutral Detergent Fibre (% DM)</i>						
Whole experimental period	37.9	36.3	38.6	38.9	0.58	0.0033
Up until 27.01.15	47.4	44.1 ³	44.6 ³	43.1 ³	1.86	0.18
27.01.15 - 13.07.15 ⁴	40.7	35.9	39.9	38.8	1.01	0.0028
07.07.15 - 22.12.15	32.9	35.7	38.4	39.1	0.77	<0.001
8.12.15 - 16.06.16 ⁵	35.1	32.2	33.0	34.1	0.84	0.024
<i>Crude Protein (% DM)</i>						
Whole experimental period	26.6	24.5	21.4	20.4	0.45	<0.001
Up until 27.01.15	20.5	21.9 ³	22.0 ³	22.5 ³	1.09	0.34
27.01.15 - 13.07.15 ⁴	28.5	27.7	29.0	24.2	0.68	<0.001
07.07.15 - 22.12.15	28.2	22.8	18.1	18.1	0.59	<0.001
8.12.15 - 16.06.16 ⁵	29.1	29.4	26.1	26.0	0.55	<0.001
<i>Metabolisable Energy (MJ/kg DM)</i>						
Whole experimental period	10.8	10.8	10.5	10.5	0.10	0.0052

Up until 27.01.15	8.6	9.4 ³	9.0 ³	9.5 ³	0.36	0.14
27.01.15 - 13.07.15 ⁴	10.6	11.2	10.7	10.6	0.12	<0.001
07.07.15 - 22.12.15	11.6	10.8	10.5	10.5	0.16	<0.001
8.12.15- 16.06.16 ⁵	11.6	11.9	11.6	11.3	0.16	0.010
<i>Water-soluble carbohydrate (% DM)</i>						
Whole experimental period	3.5	3.9	4.3	4.4	0.11	<0.001
Up until 27.01.15	3.3	3.3 ³	3.0 ³	3.1 ³	0.41	0.88
27.01.15 - 13.07.15 ⁴	2.8	3.4	2.6	3.4	0.12	<0.001
07.07.15 - or 22.12.15	3.9	4.5	5.2	5.1	0.15	<0.001
8.12.15- or 16.06.16 ⁵	3.1	3.0	3.7	3.1	0.19	0.010

¹SED = Standard error of difference.

²P values are calculated using an F value with 3, 12 degrees of freedom.

³Long recovery, New shoot and New shoot + flowering are identical treatments at this time.

⁴13.07.15 is for NS and NSF.

⁵16.06.16 is for NS and NSF.

Table 4 Effect of defoliation/recovery period treatment (SR = Short Recovery, LR = Long Recovery, NS = New Shoots, NSF = New Shoots + Flowering) on herbage nutrient characteristics at the Hamilton site. *P* values less than 0.05 are bolded. The start and end periods are selected so that all treatments are cut within a few days of each other and so that the periods represent times of lower or higher above-ground growth.

Date	SR	LR	NS	NSF	SED ¹	<i>P</i> value ²
<i>Neutral Detergent Fibre (% DM)</i>						
Whole experimental period	33.5	36.3	34.0	34.4	0.55	0.0014
Up until 02.02.15	34.0	40.1	36.1 ³	36.2 ³	0.79	<0.001
29.01.15 - 01.09.15 ⁴	34.6	32.5	32.7	31.9	0.73	0.073
01.09.15 - 24.11.15	30.6	34.6	31.3	31.4	0.59	<0.001
24.11.15 - 20.06.16 ⁵	35.2	36.1	34.7	37.5	0.82	0.028
<i>Crude Protein (% DM)</i>						
Whole experimental period	29.2	24.1	27.4	27.8	0.49	<0.001
Up until 02.02.15	27.6	20.2	23.9 ³	25.1 ³	0.44	<0.001
29.01.15 - 01.09.15 ⁴	31.4	28.5	29.7	30.2	0.86	0.035
01.09.15 - 24.11.15	29.8	23.7	30.1	31.5	0.32	<0.001
24.11.15 - 20.06.16 ⁵	30.0	27.1	28.7	26.7	1.09	0.035
<i>Metabolisable Energy (MJ/kg DM)</i>						
Whole experimental period	12.2	11.3	11.9	11.9	0.11	<0.001
Up until 02.02.15	12.2	10.6	11.4 ³	11.5 ³	0.18	<0.001
29.01.15 - 01.09.15 ⁴	12.0	11.9	12.2	12.3	0.13	0.051
01.09.15 - 24.11.15	12.7	11.5	12.6	12.6	0.09	<0.001

24.11.15 - 20.06.16 ⁵	12.1	11.7	11.8	11.3	0.15	<0.001
<i>Water-soluble carbohydrate (% DM)</i>						
Whole experimental period	4.4	5.1	4.8	4.7	0.12	<0.001
Up until 02.02.15	4.4	5.4	4.9 ³	4.4 ³	0.17	<0.001
29.01.15- 01.09.15 ⁴	3.9	4.4	4.4	4.4	0.16	0.014
01.09.15 - 24.11.15	5.1	5.6	5.2	4.9	0.10	<0.001
24.11.15 - 20.06.16 ⁵	3.8	4.4	3.8	4.3	0.30	0.12

¹SED = Standard error of difference

²P values are calculated using an F value with 3, 12 degrees of freedom.

³New shoot and New shoot + flowering are identical treatments at this time.

⁴13.07.15 is for NS and NSF.

⁵16.06.16 is for NS and NSF.

Table 5 Basal cover (%) for each defoliation treatment (SR = Short Recovery, LR = Long Recovery, NS = New Shoots, NSF = New Shoots + Flowering) at approximately 6-month intervals throughout the duration of the experiments. The pre-treatment basal cover was used as a covariate for the analysis to improve the precision of treatment comparisons.

Date	SR	LR	NS	NSF	SED ¹	P ²
Hamilton						
30.07.2015	66	68	65	68	2.3	0.60
16.12.2015	66	61	62	67	3.6	0.33
27.06.2016	61	69	63	72	3.0	0.019
Rutherglen						
25.06.2015	49	46	47	46	2.4	0.61
15.12.2015	54	44	46	50	4.9	0.23
23.06.2016	42	49	46	49	3.9	0.30

¹SED = Standard error of difference

²P values are calculated using an F value with 11 degrees of freedom. (A value in bold is significant at P<0.05).

FIGURE 1 Monthly rainfall totals (a, b) and mean monthly minimum (c, d) and maximum (e, f) temperatures from Jan 2015 to June 2016 (■) compared with the long-term averages from 1965 to 2015 (—) for research stations containing the Rutherglen and Hamilton sites.

FIGURE 2 Harvest dates for each treatment. Short recovery = ■, Long recovery = ●, New shoots = ▲ and New shoots + flowering = ▼. Harvest dates when average phenology score was 4.5 or above, representing at least early flowering, have open symbols.

FIGURE 3 Phenological stage reached by each defoliation/recovery treatment at both sites (% of all harvests) with average phenology score at rating, when average is rounded to a whole number). SR = Short recover (a, e), LR = Long recover (b, f), NS = New shoots (c, g) and NSF = New shoots + flowering (d, h).

FIGURE 4 Effect of defoliation/recovery period on cumulative herbage mass (DM kg/ha) at the Rutherglen and Hamilton sites. Symbols indicate harvest dates while dotted lines are interpolations between consecutive harvest dates. Short recovery = ■, Long recovery = ●, New shoots = ▲ and New shoots + flowering = ▼. The P values and error bars are for comparing cumulative herbage mass between the four cutting treatments on 30.01.2014 or 03.02.2015 (depending on cutting regime), 01.09.2015, 24.11.2015 and 20.06.2016 – date periods on which all treatments were cut. The length of the error bar is one standard error of difference. P values are calculated using an F value with 3, 12 degrees of freedom.

FIGURE 5 Cumulative nutritive characteristics x herbage mass (DM). The effect of defoliation/recovery period on cumulative crude protein (a, b), cumulative neutral detergent fibre (c, d), cumulative metabolisable energy (e, f) and cumulative water-soluble carbohydrate (g, h) at the Rutherglen and Hamilton sites. Symbols (Short recovery = ■, Long recovery = ●, New shoots = ▲ and New shoots + flowering = ▼) indicate harvest dates while dotted lines are interpolations between consecutive harvest dates. The *P* values and error bars are for comparing cumulative nutrients between the four cutting treatments on 30.01.2014 or 03.02.2015 (depending on cutting regime), 01.09.2015, 24.11.2015 and 20.06.2016 – date periods on which all treatments were cut. The length of the error bar is one standard error of difference. *P* values are calculated using an F value with 3, 12 degrees of freedom.

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Author/s:

Clark, SG;Mitchell, ML;Nie, Z;Burnett, VF;Butler, KL;Zollinger, RP;Seymour, GR

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