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Contains 3 Figures and 2 Tables.
Harvest interval affects lucerne (*Medicago sativa* L.) taproot total yield, starch, nitrogen and water-soluble carbohydrates

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**ABSTRACT**

Lucerne (*Medicago sativa* L.) has a large taproot to store and release starch, carbohydrates and nutrients during the plant’s growth. Recommended management of the lucerne crop aims to keep the taproot stable subject to the demands for feed provision and stand longevity. Field experiments were conducted in Victoria, Australia to examine the effects of recovery period on taproot mass and nutritive status. Both experiments used established SARDI Seven lucerne crops and were either cut every 21-days (short recovery SR) or every 42-days (long recovery LR). At each defoliation taproots were extracted for determination of DM yield and starch, water-soluble carbohydrate (WSC) and nitrogen (N) concentration and DM yield. At both sites, WSC and N DM yields along with total taproot DM yield did not change greatly as the experiment progressed. Starch was responsive to herbage accumulation with both
concentration and DM yield, increasing when herbage accumulation rates were high and decreasing when herbage accumulation rates were low. At both sites, LR taproots had starch levels equal to or higher than those of SR taproots. We conclude that short intervals between defoliations disrupt the energy cycling between shoots and roots. This is likely to reduce lucerne productivity, particularly during periods of rapid growth.

KEYWORDS
Alfalfa, taproots, management, starch, nitrogen, carbohydrate

1. Introduction
Lucerne (or alfalfa) (*Medicago sativa* L.), like any forage species, requires a recovery period following defoliation to allow nutrients stored in taproots to be utilised to promote the growth of new shoots (Bélanger et al., 2006; Pembleton, Cunningham, & Volenec, 2010; Lu et al., 2017). Once shoots have grown sufficiently lucerne plants begin to photosynthesize and nutrients and energy are exported to their storage site - the taproot. The period required to replenish nutrients and energy in taproots after each defoliation depends on the time of the year and seasonal conditions (Teixeira, Moot, & Mickelbart 2007). If the recharge period is too short, especially during the main growing season (spring – early summer in south-eastern Australia) then the productivity of the lucerne crop will be compromised (Clark et al., 2018).

Lucerne is grown throughout the temperate world and there are many published recommendations on how to manage the defoliation frequency to optimise production and persistence. In climates with cold winters (heavy frosts and regular snow) an important recommendation is to allow the lucerne to have a prolonged recovery period from late summer to early autumn to allow taproot reserves to be fully replenished before the cold of winter (Bélanger et al., 2006).

In most areas where lucerne is grown in Australia, the winter periods are not harsh, but the autumn rest period is still commonly recommended (Anon., 2017;
Lucerne plants mobilise carbon (C) and nitrogen (N) reserves from their taproots immediately post defoliation and more generally in spring (Teixeira et al., 2007). They accumulate C and N in their taproots primarily during summer and early autumn if moisture is available. The management system imposed and particularly the timing of defoliation will affect the pattern of accumulation. It is therefore desirable to understand the effect of defoliation interval on the nutrients stored in taproots since it has been reported that the production and nutritive value of the herbage and persistence of the stand are affected by defoliation interval (Avice et al., 1997).

Whilst there has previously been research on dry matter and nutrients of lucerne roots in high rainfall and mild temperature environments in Tasmania (Pembleton et al., 2010), there is no research reported from mainland Australia. The research to date has not focused on more extreme environments, like the extensive grazing areas of Victoria and other lucerne growing regions of southern Australia. These environments have high summer temperatures (often above 40°C), annual rainfall of less than 700 mm and high inter and intra seasonal variability of rainfall. In these environments, the potential evapotranspiration can be more than double rainfall, the evaporation component of the water balance accounts for the greatest proportion (> 90%) of the rainfall (eg. Walker, Gilfedder, & Williams, 1999; Zhang, Dawes, & Walker, 2001) and this may have important consequences for the movement of energy and nutrients, in and out of roots. These areas can support grazing for meat and wool and dryland cropping but, without irrigation, usually not dairying and horticulture. In these environments lucerne, with its deep roots, is one of the few pasture species that can provide green feed in summer and autumn.

Experiments were established at two contrasting dryland sites within the extensive grazing areas of Victoria with the objective of examining the effects of recovery from different defoliation duration and timing regimes on lucerne herbage DM yield, taproot DM production and nutrient concentrations and DM yields in different environments. Rutherglen in north-east Victoria has a relatively equal
contribution of rainfall throughout the year and Hamilton in south-west Victoria has winter dominant rainfall. The experiments were carried out for 18 months during which time the soil wetting/drying cycles and thus the effects of defoliation, manifested themselves. An earlier paper (Clark et al., 2018) presented detailed herbage DM yield and nutritive value and persistence results for four different recovery period treatments. This paper reports on two recovery period treatments (21-day and 42-day) and presents taproot DM yield, starch, water-soluble carbohydrate (WSC) and N concentrations and DM yields, as well as herbage DM yield results presented in a manner similar to the taproot results.

It was hypothesised that a 42-day recovery period after defoliation would result in healthier taproots as defined by taproot DM yield, starch, WSC and N concentrations and DM yields. Further, it was hypothesised that, at each sampling occasion, the percentage increase of these taproot resources in a 42-day recovery, compared to a 21-day recovery, would be of a similar order of magnitude for the different resources in the taproot.

2. Materials and Methods

2.1. Site descriptions and treatments

Two sites were established on agricultural research stations at Rutherglen (S36.112, E146.518; AAR 596 mm) and Hamilton (S37.834, E142.086; AAR 681 mm) in Victoria, Australia. These are regions with extensive sheep and beef cattle industries. Both sites used established SARDI Seven lucerne pastures – 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). 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 Table 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 during the experiment. 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.

Experimental design

The designs at each site were identical except for the randomisation. They consisted of four defoliation/recovery period treatments with plots 10 m × 5.5 m. There were four replicates with the design being completely randomised.

The two treatments reported here were: Short recovery (SR): Herbage on plots was cut to 50 mm at a 21-day interval; Long recovery (LR): Herbage on plots was cut to 50 mm at a 42-day interval.

Short recovery plots were cut at the same time as long recovery plots and then 21 days after the long recovery plots. Treatments were imposed from 6 January 2015 to 16 June 2016 at Rutherglen and from 2 December 2014 to 20 June 2016 at Hamilton.

The Rutherglen site had fertiliser (SuPerfect Pot 1&1) applied in June 2015 (200 kg/ha, P 4.4%, K 25%, S 5.5%, Ca 9.5%). The Hamilton site had fertiliser applied in April and September 2015 (superphosphate 100 kg/ha and muriate of potash 200 kg/ha) (P 8.8%, K 50.0%, S 11.0%, Ca 20.0%). Soil descriptions are presented in Table 2.

2.2. Herbage mass

Herbage DM yield was assessed at each harvest, i.e. every 21 and 42 days for the SR and LR plots respectively. One to three strips per plot (depending on the amount of herbage available) were cut to a height of 50 mm with a ride-on
mower. Each strip was 1.37 m wide × 10 m long. At Rutherglen the herbage in
the mower’s catcher was manually weighed. The Hamilton mower was equipped
with a self-weighing device. After weighing, a sample was taken, weighed fresh,
dried at 100°C to a constant weight and weighed again to determine herbage DM
yield. Harvest dates for the SR and LR treatments were fixed, however in autumn
2016 at Rutherglen, there was insufficient growth for three consecutive SR
harvests and one LR harvest, due to dry seasonal conditions. At Rutherglen, there
were 23 SR harvests and 12 LR harvests and at Hamilton, 28 and 14, respectively.

2.3. Root distribution and taproot mass

Following each herbage mass assessment, i.e. every 21 and 42 days for the SR
and LR plots respectively, taproots and crowns of any plant were extracted from
three 0.01 m² (100 mm × 100 mm) quadrats per plot. The quadrat locations were
chosen on a position basis (the same relative positions in each plot), and not
centred on a particular lucerne plant (or plants). Each sample was obtained from
digging a 300 mm deep hole. Previous research (Nie et al., 2008, Nie et al., 2015)
indicated that over 70% of the lucerne root mass is within 300 mm of the surface
and this provided guidance on sampling depth. Soil was sieved to collect all root
material which was then washed clean of soil. Any above-crown material was
removed and discarded. The remaining crown and taproot was dried at 60°C for
72 hours then weighed. No taproot extraction occurred between 5 January 2016
and 21 June 2016 at Hamilton due to the difficulty of digging holes during this
dry period. At Rutherglen, there were 26 SR crown and taproot extractions and 13
LR crown and taproot extractions and at Hamilton, 21 and 11, respectively.

2.4. Taproot nutrients

All dried taproot samples were ground through a 0.5 mm sieve and were analysed
by Near Infrared Reflectance Spectroscopy (NIRS). NIRS spectra were collected
on all samples using a Bruker MPA FT-NIR instrument (Bruker Optik GmbH,
NIRS calibrations for water soluble carbohydrate (WSC), starch (%) and nitrogen (%) were derived by obtaining spectra from 420 lucerne taproot samples covering multiple seasons and conducting reference analysis on a subset of 178 lucerne taproot samples of which 29 samples were used as wet chemistry test spectra. Standards and test samples were chosen by running principal 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 principal components.

Standard errors of prediction for WSC, starch and N in lucerne taproots were 0.60% WSC, 0.09% N, and 1.3% Starch DM respectively. A comparison between NIRS and wet chemistry results was undertaken for ~15% of samples, with resultant correlations ($R^2$) of 0.94, 0.94 and 0.97 for WSC, starch and N respectively. Reference methods used for NIRS calibrations were as follows:

1. 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.

2. Nitrogen determination by AOAC Crude Protein 990.03 using a LECO Trumac combustion Analyser (LECO Corporation, Saint Joseph, Michigan USA)

3. Starch digestion using heat stable alpha amylase and amyloglucosidase according to AOAC Method 996.11 with a glucose analytical finish using the Alkaline Ferricyanide method and the Lachat 8500 flow injection analyser system (Lachat Instruments, Loveland, Columbia, US)

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

Results from Clark et al. (2018) indicated that LR and SR represented the most and least satisfactory management systems respectively. Statistical analysis was restricted to measurement days, approximately 42 days apart, when taproot samples were obtained from both the SR and the LR plots. For each plot, at each harvest of each site, taproot starch yield, water soluble carbohydrate yield and nitrogen yield were calculated by multiplying DM yield and the corresponding nutrient concentration. The taproot starch yield of one LR plot was excluded from statistical analysis for 22 March 2016 sampling at Rutherglen, because the NIRS reading for starch concentration was negative. This indicated that the true value for the sample was close to zero and the error in the prediction of that particular sample imparted a value slightly below zero.

For each of these same measurement days and plots, an associated 42-day, above ground DM cut was calculated for the previous 42-day period as reported in Clark et al. (2018). This was the DM yield from a single cut for LR plots and the sum of the two previous cuts for the SR plots. As there was some variation in the interval length between harvests, the 42-day DM matter cut values were multiplicatively corrected to a 42-day interval using the formula: Corrected DM yield cut = Measured DM yield cut × (number of days since previous long rotation cut/42). At the Rutherglen site there was insufficient herbage in the LR treatment for the scheduled harvest in March 2016. Thus, the May 2016 readings were taken to be the material grown over an 84-day period since the previous LR harvest, but with the values corrected to a 42-day basis.

For each site, measurement occasion and management system (recovery period), 42-day above ground DM yield, taproot, starch, WSC and N yields were compared using an unpaired t-test, after the plot data had been logarithmically transformed. The plot was the unit of analysis. The concentrations of starch, WSC and N in the taproots were similarly analysed, but the residuals were homogeneous and not skewed and hence did not require transformation. All analyses had six residual degrees of freedom, except for taproot starch yield on
22.03.2016 at Rutherglen which had five residual degrees of freedom. All differences reported were significant at $p < 0.05$.

 Ninety-five per cent confidence intervals for the percentage change in taproot DM yield and taproot starch yield for the LR treatment, between selected pairs of occasions, were calculated by carrying out two-occasion repeated measures analyses of variance (ANOVA) on logarithmically transformed data. Using the repeated measures ANOVA results, 95% confidence intervals for the difference between the LR means for the two occasions were calculated, and then the limits of these confidence intervals were appropriately transformed to create 95% confidence intervals for percentage change.

3. Results

3.1. Herbage mass

The total herbage DM yield from the SR and LR plots cut over 42-day intervals at each harvest and at each site is presented in Figure 1. At both sites the pattern of herbage production was similar with late winter (Rutherglen) and spring (both sites) being the main growth period. On each date, herbage mass in SR was either less than or not different to that of LR. At Rutherglen, the difference between SR and LR was most pronounced during periods of active growth (late winter-spring), while at Hamilton, differences between SR and LR occurred in spring 2015 and early summer 2015/16.

3.2. Taproot mass

Taproot DM yield for Rutherglen and Hamilton is presented in Figures 2 and 3 respectively.

At Rutherglen, the taproot DM yield of LR increased throughout the experiment from 600 kg/ha to 4000 kg/ha by the final measurement (95% CI for percentage increase from 27/1/15 to 16/6/16 in LR = (440%, 830%)), although there were short-term declines in biomass aligned with periods when pasture accumulation...
291 was low (Figure 1a). In contrast, at Hamilton, the taproot DM yield of LR ranged
292 from 3000 kg/ha at the time of lowest pasture accumulation to above 6000 kg/ha
293 at the time of highest pasture accumulation (95% CI for percentage increase from
294 1/9/15 to 3/1/16 in LR = (70%, 130%)).
295 At Rutherglen, differences in the taproot DM yield of SR and LR plots could not
296 be detected until the end of the experiment when SR taproots had 55% less DM
297 yield than LR. At Hamilton, SR taproot DM yield was similar to that of LR
298 taproots until spring 2015 after which they were lighter throughout summer 2015-
299 16, with SR taproot DM yields being approximately 60% less than those of LR in
300 late spring/early summer. At the last measurement at Hamilton, in June 2016, the
301 LR and SR taproot DM yields were again similar.
302
303 3.3. Taproot chemistry
304 Starch, WSC and N concentrations in the taproots are presented in Figure 1 and
305 total, starch, WSC and N taproot DM yields for Rutherglen and Hamilton are
306 presented in Figures 2 and 3 respectively. The root DM, starch, WSC and N DM
307 yield results are presented on a 1000-fold logarithmic scale enabling the pattern of
308 temporal changes in the DM yields within SR and within LR to be directly
309 compared between graphs (i.e. a fixed absolute change on each of the graphs
310 indicates the same fixed percentage change in the DM yields, for all eight graphs
311 in Figures 2 and 3). Similarly, the percentage change of SR compared to LR can
312 be directly compared between graphs.
313
314 3.2.1. Starch
315 At both sites, there were large temporal differences in starch yield and
316 concentration of the taproots (Figure 1c and d, Figure 2b, figure 3b). For
317 instance, from early September 2015 to late November 2015, LR starch yield at
318 Hamilton increased by 1295% (97 – 1256 kg/ha DM) (Figure 3b) while taproot
319 starch concentration increased by 630% (3.6 – 22.8 % DM) (Figure 1d).

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Starch yield changed during the experiment at both sites although the patterns were not the same. At Rutherglen, starch increased from low initial levels (~ 60 kg/ha in LR) to a maximum in early summer 2015/16 (~ 700 kg/ha in LR; 95% confidence interval (CI) for percentage increase from 27/1/15 to 22/12/15 in LR = (780%, 3120%)) and then declined through to autumn 2016 (~ 190 kg/ha in LR; 95% CI for percentage decline from 22/12/15 to 22/3/16 in LR = (72%, 96%)) before rising again towards the end of the experiment (95% CI for percentage increase from 22/3/16 to 16/6/16 in LR = (2%, 150%)) (Figure 2b). At Hamilton, starch yield declined from mid-autumn 2015 (~ 1200 kg/ha for LR) to the end of winter 2015 (~ 100 kg/ha for LR; 95% CI for percentage decline from 27/4/15 to 1/9/15 in LR = (86%, 96%)) followed by an increase from early spring 2015 to early summer 2015/16 (~ 1250 kg/ha in LR; 95% CI for percentage increase from 1/9/15 to 25/11/15 in LR = (580%, 2370%)) (Figure 3b).

In general, at both sites, when SR taproots had high starch yields LR taproots had proportionally higher yields. For instance, at the mid-December 2015 sampling at Rutherglen, the starch yield in LR was about 4.5 times that in SR. At the late November 2015 sampling at Hamilton, starch yield in LR was about 4 times that in SR.

At both sites there was greater change in starch yield than in other measured parameters.

3.2.2. Nitrogen

The temporal change in N yield in the LR treatment largely reflected changes in total taproot DM yield at both sites. At Rutherglen, a reduction in the taproot N yield in SR compared to LR was measured from February 2016 onwards ($p < 0.05$ on 3 of the 4 sampling occasions; $p < 0.1$ on all 4 occasions, Figure 2c). This compares with total taproot DM yield in which a difference was only detected in the last sampling, in June 2016 ($p = 0.2$). At Hamilton, differences between LR and SR in N yield largely reflected differences in taproot total DM (Figure 3).
At Rutherglen there was no difference between SR and LR N concentrations until late summer 2015/16 \((p > 0.1)\) (Figure 1e, f). Thereafter LR N concentrations were always higher than the SR N concentrations \((p < 0.05)\). At Hamilton, there was no difference between SR and LR N concentrations on any occasion \((p > 0.1)\) (Figure 1e, f).

### 3.2.3. Water-soluble carbohydrate

Temporal changes of root WSC yield in LR, and treatment difference between LR and SR, largely reflected changes and differences in root DM yield (Figures 2 and 3).

In the LR treatment, taproot WSC concentration ranged from 7% - 14% at Rutherglen (Figure 1g) and 6% - 8% at Hamilton (Figure 1h). At Rutherglen, the LR taproots had higher WSC concentration than did SR on 6 of 10 occasions from June 2015 onwards \((p < 0.05)\). At Hamilton, WSC concentrations of the LR and SR taproots were similar throughout the experiment except for one occasion (April 2015) when SR taproots had higher WSC concentrations \((p = 0.006)\).

### 4. Discussion

The objective of these experiments was to examine the effect of different lengths of recovery between defoliations on lucerne taproot DM yield, starch, WSC and nitrogen in different environments in Victoria, Australia. A key result of this study was that greater recovery periods generally increases dry matter and reserves in the roots. This is consistent with reports from other environments (Bélanger et al., 2006; Teixeira, Moot, & Mickelbart, 2007; Pembleton, Cunningham, & Volenec, 2010).

Other key results, that were consistent between the two sites but have not previously been reported elsewhere were that,
i. the temporal percentage change in starch levels (both in yield and concentration) of roots is an order of magnitude greater than the temporal changes in dry matter, carbohydrate and nitrogen;

ii. The root starch yield with longer recovery interval is often several times greater (often > 250 % change) compared to the root starch yield with short recovery interval (21-day). In contrast the effects on taproot DM, carbohydrate and nitrogen root yield are much smaller; and

iii. The relative root starch yield of LR compared to SR was greatest during periods of fastest growth. The relative differences at Rutherglen increased from the commencement of experiment to early summer. In particular, while the effect of defoliation interval increased during periods when starch was accumulating in the roots of LR (presumably good conditions for photosynthesis), the effect (both in absolute and relative terms) decreased during periods when starch was reducing in the roots of LR (presumably poorer conditions for photosynthesis). In fact, at both sites there were times later in the experiment when the relative difference in taproot starch yield, between defoliation treatments, was negligible.

The likely reason that these responses have not been reported previously is the environment in which the work was conducted. In particular, the Victorian environment for extensive grazing is one whereby there are strong soil wetting/drying cycles which may affect nutrient and energy cycling between soil and roots and above ground material. Other work has been carried out in more temperate areas (e.g. such as Tasmania, Australia or Canterbury Plains, New Zealand - irrigated) with much greater rainfall or in areas with much colder winter climates (such as Atlantic Canada).

The temporal variations in total taproot DM, starch, WSC and N yields reflect the exchange of nutrients between taproots and above ground material. However, since starch is the major energy store in taproots (Reynolds, 1971, Barber et al., 1994), the particularly large temporal changes and defoliation interval effects with root starch yield indicate that the two-way energy exchange between taproots and shoots is an important biological process of lucerne. Avice et al. (1996) showed

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that most C lost from lucerne after defoliation was due to root respiration and this represented a major expenditure of energy. It follows that the more frequent defoliation of the SR treatment would have disrupted the energy flows between the taproots and the re-growing shoots leading to lower herbage production (Figure 1a, b and Clark et al., 2018) and photosynthesis and ultimately leading to lower taproot mass compared to the LR treatment.

Differences in plant persistence between LR and SR are unlikely to have caused the lower herbage or root production in SR, compared to LR, because there were minimal differences in plant persistence between these two harvest treatments (Clark et al., 2018). Whilst shorter cutting intervals have been shown to reduce lucerne persistence (Judd & Radcliffe, 1970; Brink & Marten, 1989; Gramshaw, Lowe & Lloyd, 1993), in this experiment the time period was most likely too short and the dryland growing environment too harsh to fully demonstrate the differences between the SR and LR treatments with regard to persistence.

The temporality in the relative reduction of root starch yield in SR, compared to LR, indicates that there are feedback mechanisms in the lucerne plant that limit the effect of defoliation on the taproot energy reserves. Presumably, this protects the integrity of the energy exchange process of the plant during dry periods. This may be another reason why persistence of lucerne in the extensive grazing areas of Victoria, at least for a few years, is not sensitive to a range of grazing or defoliation regimes that provide reasonable intervals between defoliation (Burnett et al., 2018; Clark et al., 2018).

The SR treatment was expected to be a test of lucerne’s ability to recover from defoliation compared to the less severe LR treatment. This was found to be the case with SR producing less herbage DM yield than LR on multiple occasions at both sites. This was not so clearly the case with taproot DM yield however. At Rutherglen, the SR and LR taproot DM yields were similar for most of the experiment and at Hamilton LR taproots were only heavier from mid-spring 2015 to mid-summer 2016. This indicates that for most of the year the SR defoliation interval was sufficient for the replenishment of taproot nutrient and energy stores but during the most active growth period – spring-early summer - a longer interval is desirable.
We did not see declines in N concentrations or yield reported by Teixeira, Moot, & Mickelbart (2007) who showed that a grazing interval of 28 days resulted in reductions in taproot N concentrations which reduced leaf growth, leaf size and thus the plants ability to capture light for photosynthesis. This discrepancy is possibly due to the differences between SARDI Seven (dormancy score 7) in our experiments and Kaituna (dormancy score 5) used in the New Zealand experiment of Teixeira et al. (2007), but we do not discount the possibility that the discrepancy is environmental, for example difference in sunlight hours, or because our experiment went for only 18 months. Rutherglen and Hamilton N yields were higher with LR than with SR on three and four occasions respectively. The difference between LR and SR on these occasions was most likely due to the SR treatment using more of the N reserves in the roots to produce vegetative growth than the LR treatment. It is well known that N reserves in the root system are an alternative source of N used by the lucerne plant when N\textsubscript{2} fixation and/or mineral N uptake is reduced (Volenec, Ourry, & Joern, 1996). Hendershot and Volenec (1993) found that N concentrations in taproot bark and wood tissues gradually increased in autumn and declined in spring when growth commenced. The results from Hamilton showed no difference in N concentration between treatments but the N concentration in the taproots did increase at Rutherglen from late summer into autumn thereby supporting the Hendershot and Volenec (1993) finding.

Water soluble carbohydrates were higher in the LR treatment compared with the SR treatment at Rutherglen on two occasions in late summer and winter, and at Hamilton during summer, both towards the latter part of the experiment. This result would suggest that the LR treatment, over time, was better at allowing the lucerne to store WSC between harvests than the SR treatment.

The taproot DM yield data showed differences at Hamilton, and possibly Rutherglen, by mid spring, 2015. At Rutherglen the low SR taproot DM yield thereafter, suggested plants were under stress to some degree compared to LR taproots. By the end of the experiment the Rutherglen treatments had separated out further with LR taproots heavier. The fact that taproots from both treatments at Rutherglen were heavier at the end of the experiment than they were at the beginning is likely due to the fact that this lucerne pasture was still developing.
(initial root DM yield ~ 600 kg/ha), despite being sown in October 2013.

Rutherglen is a hotter and drier environment than Hamilton and this could affect
the time needed for the plants to develop. This also tended to mask any effect due
to the seasons as has been reported elsewhere (Teixeira, Moot, & Mickelbart,
2007) for a 2-year old stand.

At Hamilton the initial high taproot total yield (~ 5000 kg/ha) across both
treatments indicated a lucerne pasture that had been conservatively managed
before the experiment started. This is a common issue with lucerne as farmers
think they are ‘saving’ feed for later. In reality, they are growing feed that
becomes fibrous, loses much of its quality, senesces and is not eaten by livestock
(Beauchemin, 1991; McKinney, 1974; Christian, Jones & Freer, 1970). Promotion
of a simpler, time-based management system should encourage farmers to better
utilise the lucerne they have produced.

5. Conclusions

In extensive grazing environments of Victoria, Australia, with very strong soil
wetting/drying cycles, starch yield in lucerne taproots is strongly temporal. This
indicates that energy cycling between taproots and shoots is also temporally
dynamic. It appears to be more temporally dynamic than either N or WSC
cycling. In agreement with our first hypothesis that short recovery intervals after
defoliation reduces resources in roots, but in contradiction to our second
hypothesis where the percentage decrease is similar for different resources, the
effects of short recovery intervals after defoliation on productivity appear to
primarily disrupt the energy cycling process by reducing the accumulation of
starch during periods of rapid growth. These explanations can be used to advise
producers of the necessity of avoiding short defoliation intervals, especially when
lucerne is actively growing.

Conflicts of interest

The authors declare that they have no conflicts of interest in submitting this paper
for publication.
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Table 1. Monthly rainfall totals compared to long term averages (1965-2015) for Rutherglen and Hamilton

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<th>Month</th>
<th>Rain (mm) Rutherglen</th>
<th>Long-term average (mm) Rutherglen</th>
<th>Rain (mm) Hamilton</th>
<th>Long-term Average (mm) Hamilton</th>
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<td>26.0</td>
<td>38.5</td>
</tr>
<tr>
<td>April</td>
<td>99.0</td>
<td>39.3</td>
<td>32.0</td>
<td>50.9</td>
</tr>
<tr>
<td>May</td>
<td>45.6</td>
<td>51.9</td>
<td>85.8</td>
<td>62.5</td>
</tr>
<tr>
<td>June</td>
<td>73.5</td>
<td>51.1</td>
<td>64.4</td>
<td>67.6</td>
</tr>
<tr>
<td>Month</td>
<td>Rutherglen</td>
<td>Hamilton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>------------</td>
<td>----------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brown Chromosol</td>
<td>Ferric-sodic Chromosol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Description</td>
<td>Total Carbon (g/100g)</td>
<td>Total Carbon (g/100g)</td>
<td>Total Nitrogen (g/100g)</td>
<td>Total Nitrogen (g/100g)</td>
</tr>
<tr>
<td>Rutherglen</td>
<td>1.6</td>
<td>3.8</td>
<td>0.14</td>
<td>0.29</td>
</tr>
<tr>
<td>Hamilton</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Soil test results for Rutherglen (samples collected 16 December 2014) and Hamilton (20 November 2014)
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total organic matter (g/100g)</td>
<td>3.0</td>
<td>7.1</td>
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<tr>
<td>Electrical Conductivity (dS/m)</td>
<td>0.07</td>
<td>0.12</td>
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<tr>
<td>pH(CaCl$_2$)</td>
<td>5.4</td>
<td>5.0</td>
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<tr>
<td>pH(water)</td>
<td>6.2</td>
<td>5.7</td>
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<tr>
<td>Total soluble salts (%)</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>Calcium (meq/100g)</td>
<td>4.1</td>
<td>6.2</td>
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<tr>
<td>Calcium as percent (%)</td>
<td>74</td>
<td>77</td>
</tr>
<tr>
<td>Calcium:Magnesium ratio</td>
<td>5.0</td>
<td>4.9</td>
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<tr>
<td>Magnesium (meq/100g)</td>
<td>0.83</td>
<td>1.30</td>
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<tr>
<td>Magnesium as percent (%)</td>
<td>15</td>
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<tr>
<td>Potassium (meq/100g)</td>
<td>0.57</td>
<td>0.33</td>
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<td>Potassium as percent (%)</td>
<td>10</td>
<td>4</td>
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<tr>
<td>Sodium (meq/100g)</td>
<td>&lt;0.05</td>
<td>0.28</td>
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<tr>
<td>Sodium as percent (%)</td>
<td>&lt;1</td>
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<tr>
<td>Sum of four cations (meq/100g)</td>
<td>5.6</td>
<td>8.1</td>
</tr>
<tr>
<td>Exchangeable Aluminium (KCl)</td>
<td>&lt;10</td>
<td>&lt;10</td>
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<td>(mg/kg)</td>
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<td></td>
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<tr>
<td>Exchangeable Potassium (Skene)</td>
<td>250</td>
<td>150</td>
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<tr>
<td>(mg/kg)</td>
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<td></td>
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<tr>
<td>Available Phosphorous (Olsen)</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>(mg/kg)</td>
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<td></td>
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<tr>
<td>Available Sulphur (CPC) (mg/kg)</td>
<td>&lt;3</td>
<td>19</td>
</tr>
</tbody>
</table>
Figure 1. Accumulated herbage mass at 42-day intervals at Rutherglen (a) and Hamilton (b), effect of defoliation frequency on starch concentration (% DM) (c,d), N concentration (% DM) of taproots (e,f), and WSC concentration (% DM) of taproots (g,h) and from early 2015 to mid 2016, for Long Rotation (□) and Short Rotation (■) (sum of herbage mass at two 21-day harvests) from early 2015 to mid-2016. As intervals were only approximately 42 days, herbage mass values are corrected to a 42-day basis using – Corrected DM yield cut = Measured DM yield cut × (number of days since previous Long Rotation cut/42). For herbage mass, the y-axis is on a logarithmic scale and the full range of the axis represents a 1,000-fold difference. Error bars represent standard error of difference on the logarithmic scale, where * denotes $p < 0.05$, ** denotes $p < 0.01$ and *** denotes $p < 0.001$. Vertical dotted lines represent the official first day of a season (i.e. Dec 1 = summer, Jun 1 = winter).
Figure 2. Effect of defoliation frequency on a) taproot dry matter, b) starch, c) N yield and d) WSC (kg DM/ha) from early 2015 to mid-2016 at Rutherglen for the Long Rotation (□) and Short Rotation (■) treatments. The Y-axis is on a logarithmic scale and the full range of the axis represents a 1000-fold difference. Error bars represent standard error of difference on the logarithmic scale, where * denotes $p < 0.05$, ** denotes $p < 0.01$ and *** denotes $p < 0.001$. Vertical dotted lines represent the official first day of a season (i.e. Dec 1 = summer, Jun 1 = winter).
Figure 3. Effect of defoliation frequency on a) taproot dry matter, b) starch, c) N yield and d) WSC (kg DM/ha from early 2015 to mid-2016 at Hamilton for the Long Rotation (□) and Short Rotation (■) treatments. The Y-axis is on a logarithmic scale and the full range of the axis represents a 1000-fold difference. Error bars represent standard error of difference on the logarithmic scale, where * denotes $p < 0.05$, ** denotes $p < 0.01$ and *** denotes $p < 0.001$. Vertical dotted lines represent the official first day of a season (i.e. Dec 1 = summer, Jun 1 = winter).
Title:
Harvest interval affects lucerne (Medicago sativa L.) taproot total yield, starch, nitrogen and water-soluble carbohydrates

Date:
2020-10

Citation:

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