Lucerne (Medicago sativa L.) Persistence Remains Unchanged under Variable Cutting Regimes

Vivianne F. Burnett 1*, Kym L. Butler 2, Jeff R. Hirth 3, Meredith L. Mitchell 1, Steve G. Clark 4 and Zhongnan Nie 2

1 Agriculture Victoria, Department of Jobs, Precincts and Regions, 124 Chiltern Valley Road, Rutherglen 3685, Victoria, Australia; meredith.mitchell@agriculture.vic.gov.au
2 Agriculture Victoria, Department of Jobs, Precincts and Regions, 915 Mount Napier Road, Hamilton 3300, Victoria, Australia; kym.butler@agriculture.vic.gov.au (K.L.B.); Zhongnan.nie@agriculture.vic.gov.au (Z.N.)
3 Jeff Hirth Editorial and Agronomic Services, 182 Anzac Road, Springhurst 3682, Victoria, Australia; jeffhirth@bigpond.com
4 Formerly Agriculture Victoria, Department of Jobs, Precincts and Regions, 915 Mount Napier Road, Hamilton 3300, Victoria, Australia; bukoba.steve@gmail.com
* Correspondence: viv.burnett@agriculture.vic.gov.au
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Abstract: Lucerne (Medicago sativa L.) persistence is important for farming systems in south east Australia. Defoliation of lucerne that is too frequent (arguably more than once every six weeks) reduces yield and accelerates stand decline. Three experiments were conducted in south east Australia (Burraja, New South Wales; Rutherglen and Hamilton, Victoria) to investigate different cutting regimes on lucerne persistence. At Burraja lucerne was cut 16 (lax) or 33 (severe) times over three years at different plant densities. At Rutherglen and Hamilton lucerne was cut every 21 days (short rotation), every 42 days (long rotation), when new shoots (2.5 cm long) emerged (new shoots) or cutting when new shoots emerged but allowing the lucerne to flower in autumn (new shoots flowering). It was hypothesised that the frequent cutting of lucerne would result in lower plant densities. At Burraja there was little difference between treatments at any density or assessment. At Hamilton, apart from the assessment in June 2016, there was no difference (p > 0.1) between treatments. At Rutherglen, there was no difference (p > 0.1) between treatments at any assessment although plant numbers declined in 2016 from waterlogging. The results provide evidence that lucerne has intrinsic mechanisms that protect it from cutting, often at short intervals, thus promoting its persistence over three to four-year periods.

Keywords: alfalfa/lucerne; defoliation; density; farming system

1. Introduction

It is known that the productive density of lucerne (alfalfa) (Medicago sativa L.) progressively declines with time, even under rotational grazing management [1–3]. The number of plants decline soon after emergence with the rate of decline dependent on the specific environment, grazing or cutting management, the presence of pests and diseases and the ecological process of self-thinning due to plant competition [4–6]. The persistence of the lucerne sward is then affected by its growing environment (e.g., disease, competition from other plants, soil constraints, acidity, waterlogging etc.) and the frequency of defoliation [7,8].

The persistence of lucerne after the second year, a time when the lucerne can be considered to be past the establishment phase, is important for the productivity and profitability of the farming
Frequent defoliation reduces lucerne yield [8,9] and continuous grazing can result in the accelerated decline of the stand [10,11]. Lodge [2] states that the most critical factor for lucerne persistence is the interval between sequential grazing. In Australian temperate dryland farming systems, a minimum rest interval of between 35–49 days is recommended [11,12]. Additionally, the recommendation to rest lucerne in late summer/early autumn to enable root reserves to replenish is derived from northern hemisphere systems where harvesting lucerne prior to winter can result in plant loss [7]. This recommendation has been widely adopted in southern temperate farming systems despite lucerne not being grown in very cold regions [2]. However, recent research has found that this autumn rest period is not required in a mild winter climate and that a simple 6-week rest period is sufficient to retain productivity and persistence [13].

If temperature, moisture and fertility are favourable for growth, lucerne can persist for many years (20–25 years) [2]. In temperate climates however, with wet and dry cycles for soil moisture and the influence of grazing animals, lucerne persistence is challenged and at least half the population of plants can die in 3–4 years [14]. As plant numbers decline, the remaining plants may respond to lower density by increasing crown size and producing more stems so overall productivity can remain constant [15]. In Australia, as lucerne plant density declines, more bare ground is exposed [16] and weed incursion can compete with the remaining plants and accelerate the decline in density [17]. The maintenance of adequate plant numbers under cutting or grazing regimes is therefore important for productivity and persistence.

Three experiments were conducted to investigate the effect of different cutting regimes on the persistence of lucerne. The Burraja experiment was conducted in southern New South Wales with Aquarius lucerne from 1998 until 2003, and experiments were conducted at Rutherglen and Hamilton, Victoria respectively from 2015 to 2017 with SARDI 7 lucerne. The research question was, how do different cutting regimes affect the density of existing lucerne stands? Different cutting regimes were imposed on established lucerne stands and persistence was measured. It was hypothesised that the frequent cutting of lucerne would result in lower plant densities. The results for plant density over successive years are reported.

2. Materials and Methods

2.1. Experiment 1 (Burraja)

2.1.1. Experimental Design

Experiment 1 was located at Hopefield/Burraja, New South Wales, Australia (Lat. ~35.941, Long. 146.445) and comprised a factorial design with two levels of cutting frequency (lax and severe), five levels of lucerne density (3, 6, 12, 24, 36 crowns/m²) with four replicates in randomised blocks. The plots were 3 m × 3 m in size.

2.1.2. Establishment

Lucerne cv Aquarius (winter dormancy 8, winter active) was sown at 6 kg/ha with 20 kg/ha of phosphorus (P) on 3–4 October 1998. The site had been previously prepared with 2.5 t/ha lime in early September 1998.

2.1.3. Treatments

The lucerne was hand thinned to five different crown densities over a period from May 1999. The five density treatments were targeted to have relative densities in the ratio 1, 2, 4, 8 and 12 (e.g., the second treatment had twice the density of the first treatment; the third treatment had four times the density of the first treatment) by the March 2000 sampling. This resulted in treatments comprising 3, 6, 12, 24 and 36 crowns/m².

Two cutting frequencies were imposed comprising ‘lax’ and ‘severe’ from the beginning of November 1999. Lax cutting occurred whenever the lucerne had commenced flowering, and this resulted in an average between-cutting interval of about 11 weeks from November 1999 to May 2003.
(Figure 1). The ‘severe’ cutting occurred whenever the dry matter yields in the 36 crowns/m² plots had reached a nominal 750 kg/ha and resulted in an average between-cutting interval of about 6 weeks from November 1999 to May 2003 (Figure 1). Plots were cut with a lawn mower to a height of 5 cm and the cut material was removed from the plots.

Figure 1. Harvest dates for each defoliation treatment at Burraja (Experiment 1). Lax = +, Severe = ×. Vertical dotted lines represent the start of each calendar year.

2.1.4. Measurements

All measurements occurred in four permanent quadrats (1 m × 1m) that were placed in the inner 2 m × 2 m section of each plot.

Crown density was measured by counting the number of crowns within the quadrat a total of nine times between June 1999 and May 2004, with all plots measured in June 1999, March 2000, November 2000, November 2001, May 2002, October 2002, May 2003, and the ‘severe’ treatment measured again in June 2001 and May 2004.

2.1.5. Weed Control

Weed control was carried out to maintain a healthy monoculture of lucerne. Hogweed (Polygonum aviculare L.) was controlled in the plots by hand weeding during April 2002. The lucerne plots were sprayed to control grass weeds using Sprayseed @ 2.4 L/ha (active ingredient Paraquat dichloride and Diquat dibromide) and Diurex @ 1.5 kg/ha (active ingredient Diuron) in July 2002.

2.1.6. Irrigation

The latter part of this study occurred during drought conditions that would affect the viability of the lucerne. Thus, irrigation with soaker hoses was used in 2002 to maintain conditions that had greater similarity to typical seasonal conditions. An average of 55 mm was applied to each replicate in mid May 2002, 34 mm per replicate in early June 2002, 13 mm per replicate in late June 2002, 25 mm per replicate in mid July 2002 and 46 mm per replicate in mid-August 2002. A further 45 mm per replicate was applied in November 2002 and 16 mm applied in April 2003 to all plots.

2.1.7. Rainfall and Temperature

Rainfall was recorded at Burraja from October 1998 until May 2003. Monthly rainfall averages and the long-term average (LTA 1970–2015) are shown in Figure 2. Maximum and minimum
temperatures were recorded at Corowa, New South Wales, the closest weather station to the Burraja experiment (11 km from Burraja). Monthly maximum and minimum temperatures, compared with the long-term average over 110 years, are shown in Figure 3.

![Figure 2. Monthly rainfall (mm, black squares) and long term average rainfall (LTA, 1970–2015, mm, black line) at Burraja from November 1998 to May 2003 (top); monthly rainfall (mm, black squares) and LTA rainfall (1965–2015, mm, black line) at Rutherglen from January 2015 to January 2018 (middle); monthly rainfall (mm, black squares) and LTA rainfall (1965–2015, mm, black line) at Hamilton from January 2015 to January 2018 (bottom).]
Figure 3. Mean minimum and maximum temperatures (°C, black squares) and long-term average at Burraja over 45 years (black line) (top); long-term average at Rutherglen over 50 years (middle); long term average at Hamilton over 50 years (bottom).

2.1.8. Statistical Analysis

Prior to the analysis of variance, at each sampling time, the number of crowns was square root transformed, to improve the homogeneity of the residual variance as a function of the fitted mean. At each sampling time, the square root of number of crowns was analysed using a 2 cutting frequency by 5 lucerne density factorial randomised block analysis of variance, with 4 replicates. The unit of analysis was a plot (Table 1). The main effect of lucerne density was divided into orthogonal linear and quadratic responses to the logarithm of the relative target density, and deviations from a quadratic response to the logarithm of the relative target density. The dataset is complete, with no outliers deleted, except that no data was available in 2 plots from the November 2000 sampling. The analyses of variance were carried out using the ANOVA procedure in GenStat 17.

Table 1. Structure of analysis of variance for the square root of the number of crowns at each sampling occasion in Experiment 1 (Burraja).

| Source of Variation                                      | Degrees of Freedom |
|----------------------------------------------------------|--------------------|
| Replicates                                               | 3                  |
| Cutting Frequency                                        | 1                  |
| Lucerne density                                          | 4                  |
| Linear response to logarithm of relative target density   | 1                  |
| Quadratic response to logarithm of relative target density| 1                  |
| Deviations from quadratic response                       | 2                  |
| Cutting frequency by Lucerne density interaction          | 4                  |
| Residual                                                 | 27 a               |

*25 degrees of freedom for the November 2000 sampling.

2.2. Experiments 2 (Rutherglen) and 3 (Hamilton)

2.2.1. Experimental Design

Experiment 2 was located at Rutherglen, Victoria Australia (Lat. −36.112, Long. 146.518) and experiment 3 was located at Hamilton, Victoria Australia (Lat. −37.834, Long. 142.086). Both experiments were completely randomised designs with four replicates of four defoliation treatments and had similar methodology. The plot size was 10 m × 5.5 m. Above ground and below ground measurements were taken for the first 18 months of these two experiments, and the above ground measurements, including basal cover, have been previously reported [13]. During this time, the defoliation interval had major effects on both the amount and nutrient concentrations and the yield of both above ground [13] and below ground [18] material, but only minor, if any, effect on basal cover. At each of the two sites, the defoliation treatments were continued for a further 18 months, but only basal cover measurements were continued. This present paper relates to experiments 2 and 3 and extends the basal cover results presented in [13] for 18 months to a total of three years of different defoliation treatments.

Details of the experimental methodology have previously been presented in [13]. The following summarises and extends the methodology for the full three years of each study.

2.2.2. Establishment

Both experiments were established on existing SARDI 7 (winter dormancy 7, winter active) lucerne pastures. Experiment 2 had been sown in October 2013 and experiment 3 in November 2011.
2.2.3. Treatments

Treatments imposed at both sites comprised cutting the lucerne to 5 cm with a lawn mower at 21-day intervals (short recovery, SR); cutting the lucerne to 5 cm at 42-day intervals (long recovery, LR); cutting the lucerne to 5 cm when the new shoots from the crown were at least 2 cm long (new shoots, NS); cutting the lucerne at 5 cm when the new shoots from the crown were at least 2 cm long but allowing the plants to reach flowering from late summer to mid-autumn (new shoots flowering, NSF). This resulted in average cutting intervals of 3 weeks for SR, 6 weeks for LR, about 6½ weeks for NS at Rutherglen, about 5 weeks for NS at Hamilton, about 8 weeks for NSF at Rutherglen and about 6 weeks for NSF at Hamilton (Figure 4).

![Rutherglen](image1)

![Hamilton](image2)

**Figure 4.** Harvest dates for each defoliation treatment at Rutherglen (Experiment 2) and Hamilton (Experiment 3). Short recovery = ×, Long recovery = +, New shoots = ▲, New shoots + flowering = ●. Vertical dotted lines represent start of each calendar year.

2.2.4. Measurements

Basal cover (as a measure of persistence) was measured in two 1 m × 1 m quadrats with 10 cm by 10 cm divisions, to give 100 cells per quadrat at permanent locations in each plot. The number of cells containing the entire or partial plant bases were counted for each square and these totals were
averaged for each plot. At each site, basal cover was measured prior to the application of defoliation treatments in late 2014, and then 5–6 times during the three-year life of each experiment.

2.2.5. Weed Control and Fertiliser Application

Weed control and fertiliser application were carried out to maintain a healthy monoculture of lucerne. Details for the first 18 months of the two experiments are presented in Clark et al. [13]. An application of Jaguar (active ingredient Bromoxynil) at 750 mL/ha was applied at Hamilton to control capeweed (Arctotheca calendula (L.) Levyns) in June 2017. At Rutherglen the experiment was fertilised in April 2017 with 200 kg/ha of fertiliser (P 4.4%; K 25%; S 5.5%; Ca 9.5%). In September 2017 the Rutherglen experiment was sprayed with 75 mL/ha of Nail (active ingredient Carfentrazone-ethyl) to control subterranean clover (Trifolium subterraneum L.).

2.2.6. Rainfall and Temperature

Air temperature and rainfall were recorded daily 1.1 km from Experiment 2 and 2.1 km from Experiment 3. The data for the period of the experiment are compared with the long-term averages in Figures 2 and 3. 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.

2.2.7. Statistical Analysis

The basal cover measurements, at each assessment at each site from winter 2015, were analysed as a four-treatment one-way analysis of variance, with a plot being the unit of analysis. Pre-defoliation treatment basal cover was used as a covariate for the first three assessments at Rutherglen and all assessments at Hamilton, to improve the precision of treatment comparisons. All analyses of variance had 11 residual degrees of freedom, except the analyses for the final two assessments at Rutherglen, which had 12 residual degrees of freedom.

3. Results

3.1. Crown Density at Burraja

There was no evidence \( (p > 0.1) \), at any of the seven assessments, for the main effect response of the square root of crown density to relative target density to deviate from a quadratic response to the logarithm of target density. There was no evidence \( (p > 0.1) \), at any of the seven assessments, for an interaction between the cutting frequency and relative target density treatments. These two outcomes justify summarising the results of the square root of crown density as two parallel response curves, one curve for each of the two cutting frequencies, that are quadratic in the logarithm of relative target density.

One year after lucerne thinning was first applied (March 2000), in both cutting level treatments, crown density was close to proportional to the relative target density (Figure 5), although there was some minor flattening, from proportionality, of the response curves at the highest relative target densities. This indicates that the initial application of the relative target density treatments was successful, at least when assessed at around one year after the start of the experiment. Over the following three years of the experiment (four years after initial thinning), crown density continually decreased in each treatment, so that the number of crowns at four years after initial thinning (May 2003) was around half those present at 1 year after initial thinning (March 2000).

Apart from the March 2000 assessment, there was little difference in crown density between the lax and severe cutting treatments at any assessment (Table 2; Figure 5). In March 2000, the severe cutting treatment had about 10 per cent higher crown density than the lax cutting treatment, at each relative target density.
Figure 5. Crown density, as a response to target defoliation relative to the lowest density treatment, for the lax and severe cutting treatments at Burraja from 6 assessments between June 1999 and March 2003. The response curves represent the square root of crown density being fitted as two parallel response curves, one curve for each of the two cutting frequencies, that are quadratic in the logarithm of relative target density, prior to back-transforming onto the crown density (y-axis) and relative target density (x-axis) scales. Individual points represent plot values that have been adjusted for block on the square root scale of crown density.

Table 2. Estimated difference in the square root of crown density in Experiment 1 (Burraja) between severe and lax defoliation (lax minus severe). In the fitted models, this difference is the same at all target densities. The standard error of difference (SED) and P values use the residual mean square of the saturated cutting level by relative target crown density factorial, as presented in Table 2. This provides 27 residual degrees of freedom, except for the November 2000 sampling that had 25 residual degrees of freedom.

| Date        | Estimated Difference (Lax Minus Severe) | SED  | p Value |
|-------------|----------------------------------------|------|---------|
| March 2000  | −0.19                                   | 0.053| 0.0013  |
| November 2000 | −0.01                                 | 0.071| 0.92    |
| November 2001 | 0.10                                    | 0.060| 0.13    |
3.2. Rutherglen and Hamilton Basal Cover

Basal cover was assessed at Rutherglen on five occasions during the three years of study from January 2015 until December 2017. There was no difference ($p > 0.1$) between defoliation treatments at any assessment (Table 3). Lucerne plant numbers declined markedly between the June and December 2016 assessments, after well above average rainfall (Figure 4) during the spring of 2016.

Basal cover was assessed at Hamilton on six occasions during the three years of study from December 2014 until January 2018. Lucerne plant numbers remained stable over this time. Apart from the assessment in June 2016, there was no difference ($p > 0.1$) between the four defoliation treatments. In June 2016, the short rotation treatment had lower basal cover than the long rotation and new shoots flowering treatments ($p = 0.02$, Table 4).

### Table 3. Basal cover (%) of SARDI 7 lucerne during the three years of study at Rutherglen, from January 2015 until December 2017. Pre-defoliation treatment basal cover, assessed at December 2014, was used as a covariate in the assessments between June 2015 and June 2016, inclusive. The analyses of the first three assessments had 11 residual degrees of freedom, whilst the final two assessments had 12 residual degrees of freedom.

| Date       | Short Rotation | New Shoot | New Shoot + Flowering | Long Rotation | sed | $p$ Value |
|------------|----------------|-----------|-----------------------|---------------|-----|-----------|
| 25 June 2015| 49             | 47        | 46                    | 46            | 2.4 | 0.61      |
| 15 Dec 2015 | 54             | 46        | 49                    | 44            | 4.9 | 0.23      |
| 23 June 2016| 42             | 46        | 49                    | 49            | 3.9 | 0.30      |
| 22 Dec 2016 | 9              | 4         | 7                     | 11            | 4.0 | 0.40      |
| 19 Dec 2017 | 8              | 5         | 9                     | 12            | 4.2 | 0.40      |

### Table 4. Basal cover (%) of SARDI 7 lucerne during the three years of study at Hamilton, from December 2014 until January 2018. Pre-defoliation treatment basal cover, assessed at November 2014, was used as a covariate in all the assessments. All analyses had 11 residual degrees of freedom.

| Date       | Short Rotation | New Shoot | New Shoot + Flowering | Long Rotation | sed | $p$ Value |
|------------|----------------|-----------|-----------------------|---------------|-----|-----------|
| 30 July 2015| 66             | 65        | 68                    | 68            | 2.3 | 0.60      |
| 16 Dec 2015 | 66             | 62        | 67                    | 61            | 3.6 | 0.33      |
| 27 June 2016| 61             | 63        | 72                    | 69            | 3.0 | 0.019     |
| 14 Dec 2016 | 66             | 64        | 67                    | 66            | 2.8 | 0.61      |
| 13 April 2017| 61            | 67        | 69                    | 65            | 5.6 | 0.50      |
| 22 Jan 2018 | 63             | 64        | 69                    | 67            | 2.6 | 0.14      |

4. Discussion

The reported results show that in three separate temperate environments and variable seasons, the cutting regimes imposed had no effect on lucerne plant density for at least three years. This is an interesting result primarily because it is recognised that the continuous grazing or cutting of lucerne without sufficient rest intervals can result in poor persistence [13,19]. Secondly it is known that highly winter active cultivars are more upright in their growth habit than winter dormant cultivars [16,20–22] and have their crown more exposed above the soil surface, making them more susceptible to trampling [23] by sheep and this can affect persistence. The cultivars used in these experiments were winter active (winter dormancies 7 and 8) and had upright growth habits so it might be expected that persistence would be affected. It is also recognised that mechanical cutting and defoliation by grazing animals are different in terms of the effects on plants and nutrient cycling [24,25], with grazing being
less uniform than cutting. However, previous literature indicates that the defoliation interval is a key driver of defoliation effects on lucerne, whether cut or grazed [7,19,22] and thus our results should have relevance to both situations.

There is a decline in the density of a lucerne sward that occurs over time irrespective of the genotype, environment or management imposed [2]. Sudden and significant declines are often associated with waterlogged conditions [26] and this was observed at the Rutherglen site between June and December 2016 (Table 3). The density of lucerne crowns at the Burraja site at the highest density declined by about 38% over three years from an initial density of 36 crowns/m² to 22 crowns/m² (data not shown), which was consistent with patterns of decline reported in the literature [14,27]. At the Hamilton site there was no evidence of lucerne decline during the experimental period. Despite these differences in lucerne decline between the sites, there was no effect of the cutting management on the density of the lucerne sward at any site. In the first 18 months of the Rutherglen and Hamilton experiments, reported in the present study, there was a major effect of cutting regime on lucerne productivity [13]. For instance, the cumulative herbage production, over 18 months, of 42 day cutting intervals (LR) was greater than that of 21 day cutting intervals (SR) by 30% at Hamilton and 40% at Rutherglen. Mitchell et al. [18] provided evidence that this reduction in productivity with shorter cutting intervals was associated with a disruption in the energy cycling between shoots and roots.

Given that persistence is considered an important issue for lucerne pasture [2,3,28], it might be expected that these disruptions in energy cycling would be reflected in a reduction of plant density. However, this did not happen for at least three years of application of the cutting treatments. This lack of effect of cutting regime on persistence, for over three years, also occurred in the Burraja experiment, and occurred for two years in a grazing experiment with a range of stocking treatments at a site adjacent to the Burraja experiment [29]. This indicates that the results from the Rutherglen and Hamilton experiments are not isolated. The result also concurs with that obtained by Hakl et al. [30], where, in one multi-year experiment, cutting lucerne either three or four times in each year had no effect on plant density, despite clear effects on dry matter production and root morphology. It also concurs with results obtained by Teixeira et al. [8], in another multi-year experiment on irrigated pasture in New Zealand, who found that four different grazing regimes had no effect on plant density despite affecting shoot yield and shoot dynamics.

The inference from this is that there are strong physiological processes in the lucerne plant that make it resilient to more frequent defoliation in terms of survival. This resilience in terms of plant survival is much greater than its general resilience in terms of growth and occurs despite the major disruption of energy cycling between roots and shoots [18] and shoot dynamics [8]. This resilience relates to the plant’s intrinsic tolerance to defoliation and includes factors such as increased photosynthetic rate after grazing, high relative growth rates, increased branching or tillering after apical dominance has been disrupted, pre-existing high levels of carbon storage in roots for allocation to above-ground growth and the ability to move carbon stores from the roots to the shoots after defoliation and the availability of residual meristems [31,32]. There are also extrinsic factors that contribute to the lucerne plant’s resilience after defoliation including the availability of nutrients, water and light, and relative competition between plants. Abundance of nutrients can reduce tolerance to defoliation due to reduced root: shoot ratios and increased competition can also negatively affect tolerance to defoliation through increased plant stress [32].

This resilience does not mean that the lucerne plants will not eventually succumb to the stress of disruption to the energy cycling between roots and shoots caused by short defoliation intervals. The results just imply that this is a relatively slow process, and certainly a much slower process than the process of reduced herbage production. The results also do not imply that continuous cutting or grazing, or very short cutting intervals (<3 weeks) will not quickly lead to the loss of lucerne plants.

The practical consequence of these observations is that the influence of decisions on cutting or grazing intervals with lucerne will be reflected in lucerne productivity much earlier than it will be reflected in lucerne persistence. This implies that it is practical for the grazing and cutting regimes for lucerne pasture to be primarily evaluated in terms of pasture production, and not in terms of pasture persistence.
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