Spring growth of lucerne (*Medicago sativa* L.) after different dates of winter defoliation

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Abstract

The aim of this work was to determine if autumn/winter defoliation affected the time of lucerne (*Medicago sativa L.*) stem extension in spring. Two experiments were established at the Field Research Centre, Lincoln University. Experiment 1 was established on 1 June 2022 using an existing two year old stand of "Force 4" lucerne. There were four canopy defoliation dates (1 June, 3 July, 17 July and 1 August). Experiment 2 repeated the treatments on the same paddock in the following year on eight defoliation dates (1 May, 15 May, 1 June, 15 June, 3 July, 17 July, 1 August and 15 August). In both experiments, five stems were marked in each plot and stem height was measured weekly. The start of stem extension was unaffected by canopy defoliation date in both 2022 ($P = 0.20$) and 2023 ($P = 0.17$). Initiation of stem extension was triggered by a base photoperiod of 11.1 ± 0.2 h. This meant the thermal time accumulated from final defoliation to the start of stem extension differed among treatments. These results suggest the time of autumn/winter defoliation (the winter clean-up graze) will not affect the time of the first spring grazing, provided the developing basal buds are not removed. All stands reached 150 mm height by mid-September and produced 3.0 t/ha of dry matter by the end of September. This suggests, grazing of the first paddock at Lincoln should commence in the first week of September to create a staggered start to rotational grazing that can maximise lucerne yield and quality for animal production.

Keywords: alfalfa, heightchron, photoperiod, stem extension, thermal time

Introduction

Understanding how crop growth and development are affected by abiotic factors can facilitate informed decision making for the management of lucerne (*Medicago sativa* L.) stands (Moot et al. 2003). Lucerne development can be quantified by thermal time (Tt), with the length of some phases altered by photoperiod requirements (Yang et al. 2021). For example, lucerne is a long day plant so the thermal time to flowering decreases as days lengthen from spring to summer (Moot et al. 2003) while, conversely, the thermal time for leaf appearance increases as days shorten through autumn (Yang et al. 2021).

In New Zealand, during late autumn and winter, growth of the commonly used fall dormancy (FD) 5 rated lucerne cultivars slows, with limited above ground biomass production. This corresponds to a period when carbon and nitrogen are preferentially translocated into the roots (Brown et al. 2006). During winter, lucerne stems remain short but accumulate nodes. These nodes then expand rapidly in spring as stem extension is initiated (Moot et al. 2003), and is supported by remobilization of carbon and nitrogen reserves from roots to shoots. This rapid increase in plant height, and consequently biomass production as internodes extend dictates the time when first grazing in spring should occur (Moot et al. 2003).

The main aim of rotational grazing lucerne in spring is to maximise yield and quality to optimize lamb live weight gain and retain ewe condition through lactation. A critical factor for animal production is therefore the amount of lucerne dry matter consumed, and how efficiently that is utilised (Moot et al. 2016). For a six-paddock grazing rotation, it is recommended to graze paddocks with a rest interval that ensures regrowth height at reentry is ~300 mm to maximise herbage yield and quality (Brown et al. 2006). A major challenge in a six-paddock rotation is to identify when to initiate the first spring grazing. Current recommendations (Moot et al. 2016) are to start with ewes and lambs in spring when the first paddock in a six-paddock rotation is ~150 mm tall, which is equivalent to ~1500 kg DM/ha. This results in utilisation of almost all the herbage in the first 3-4 paddocks. The aim is to ensure the sixth paddock in the rotation is <400 mm tall when it is first grazed, to ensure stand quality is maintained.

To assist the decision of when to start grazing it is important to know whether the time of the previous autumn/winter defoliation affects the start of stem extension in spring. Current literature suggests that grazing stands as late as 21 August, decreases yields by up to 25%, and delays stem extension in spring by up to 4 weeks due to the removal of developing basal buds (Moot et al. (2003). Therefore, the aim of this research was to determine the trigger point for lucerne stem extension in spring. This information should

Table 1 Maximum (T_{max}), minimum (T_{min}) and mean (T_{mean}) air temperature (°C), total rainfall (mm) and total Penman potential evapotranspiration (PET), mean wind speed (m/s) and total solar radiation (MJ/m2) from 1 June 2023 until 31 October 2023, recorded at the Broadfields meteorological station (Agent Number 17603; https://cliflo.niwa.co.nz/). The long-term mean (LTM) is the mean for the period 1993 to 2023.

Months	T_{max} (°C)	T_{min} (°C)	T_{mean} (°C)	Total Rainfall (mm)	Total Penman PET (mm)	Mean Wind Speed (m/s)	Total Solar Radiation (MJ/m^2)
Experiment 1 (2022)							
June	13.5	0.6	7.05	33.0	23.0	3.1	140
July	11.1	0.2	5.65	233	15.4	2.6	129
August	13.5	2.1	7.8	35.6	34.6	2.6	250
September	15.4	3.1	9.25	24.2	56.5	2.9	362
October	16.7	2.6	9.65	30.0	95.6	3.4	558
Experiment 2 (2023)							
May	16.1	7.8	11.9	57.6	34.5	3.2	170
June	12.8	5.4	9.2	52.0	20.6	2.7	126
July	12.1	2.7	7.4	124.0	22.3	2.6	173
August	12.7	2.3	7.5	18.6	42.6	2.7	299
September	16.5	6.2	11.5	51.2	69.8	4.5	362
October	17.4	6.6	12.0	31.6	111.9	4.5	588
2022 Mean	14.0	1.7	1.7	71.3	45.0	2.9	288
2023 Mean	14.6	5.2	9.9	55.8	50.3	3.4	286
LTM	17.0	7.1	12.1	50.5	57.7	4.0	319

assist farmers to make grazing management decisions in autumn/winter to create the most effective rotational grazing system in subsequent spring.

Materials and Methods

Two experiments were located at Iversen Field (-43.649, 172.465 WGS 84 Web Mercator), Lincoln University, Canterbury. The soil type is an imperfectly to moderately well-drained Wakanui silt loam (Aquic Haplustept, USDA Soil Taxonomy), that is prone to waterlogging during periods of high rainfall (Hewitt 1998). Wakanui silt loams typically have 0.3 m of topsoil that sits above the horizons of silt loams to a depth of 3.5 m (Cox 1978). Webb (2003) reported that the plant available water-holding capacity for a Wakanui Silt Loam is 150 mm/m. Rainfall (mm), solar radiation (MJ/m^2/d), wind speed (m/s), air temperature °Cd, and vapor pressure deficit kPa were recorded at the Broadfields meteorological station (Agent Number 17603; https://cliflo.niwa.co.nz/), located 2 km north of Lincoln University. Thermal time (˚Cd) was calculated using the "Moot Model" (Moot et al. 2001). This is a three-stage broken stick function with four cardinal temperatures, a base temperature of 0˚C, a breakpoint at 15˚C, an optimum of 30˚C, and a maximum of 40˚C. Heightchron (°Cd/mm) was calculated as the thermal units required to produce 1 mm of stem.

The experiments used an established stand of "Force 4" lucerne. The experimental area was conventionally drilled with a Flexiseeder 14 coulter plot drill on 21st October 2021 at a sowing rate of 12 kg/ha (coated seed), and at a target depth of 15 mm. Experiments were run over two years as complete randomised block designs with different defoliation dates to mimic the time of an autumn/winter "clean up" graze. In 2022 (Experiment 1) there were four winter defoliation dates (1 June, 3 July, 17 July and 1 August) and three replicates. In 2023 (Experiment 2) there were eight winter defoliation dates (1 May, 15 May, 1 June, 15 June, 3 July, 17 July, 1 August and 15 August) and three replicates. For both experiments, plots were 3.0 x 3.0 m with 1.0 x 24 m buffer strips between replicates. The defoliaton "graze" was simulated using a Lawnmaster lawnmower set at ~40 mm to remove all leaf and stem without damage to the crowns (basal buds remained intact).

Lucerne plant height (mm) and node number (n) of the basal buds were then measured weekly on five marked stems in each plot. Node number was determined as the number of fully expanded nodes, that had a leaflet fully expanded. Shoot yield was measured on the last sampling date by taking a 0.2 m^2 quadrat cut per plot to ~40 mm above ground level with cordless clippers. Samples were then seperated into leaf, and stem and dried for 48 hours at 65 °C before weighing.

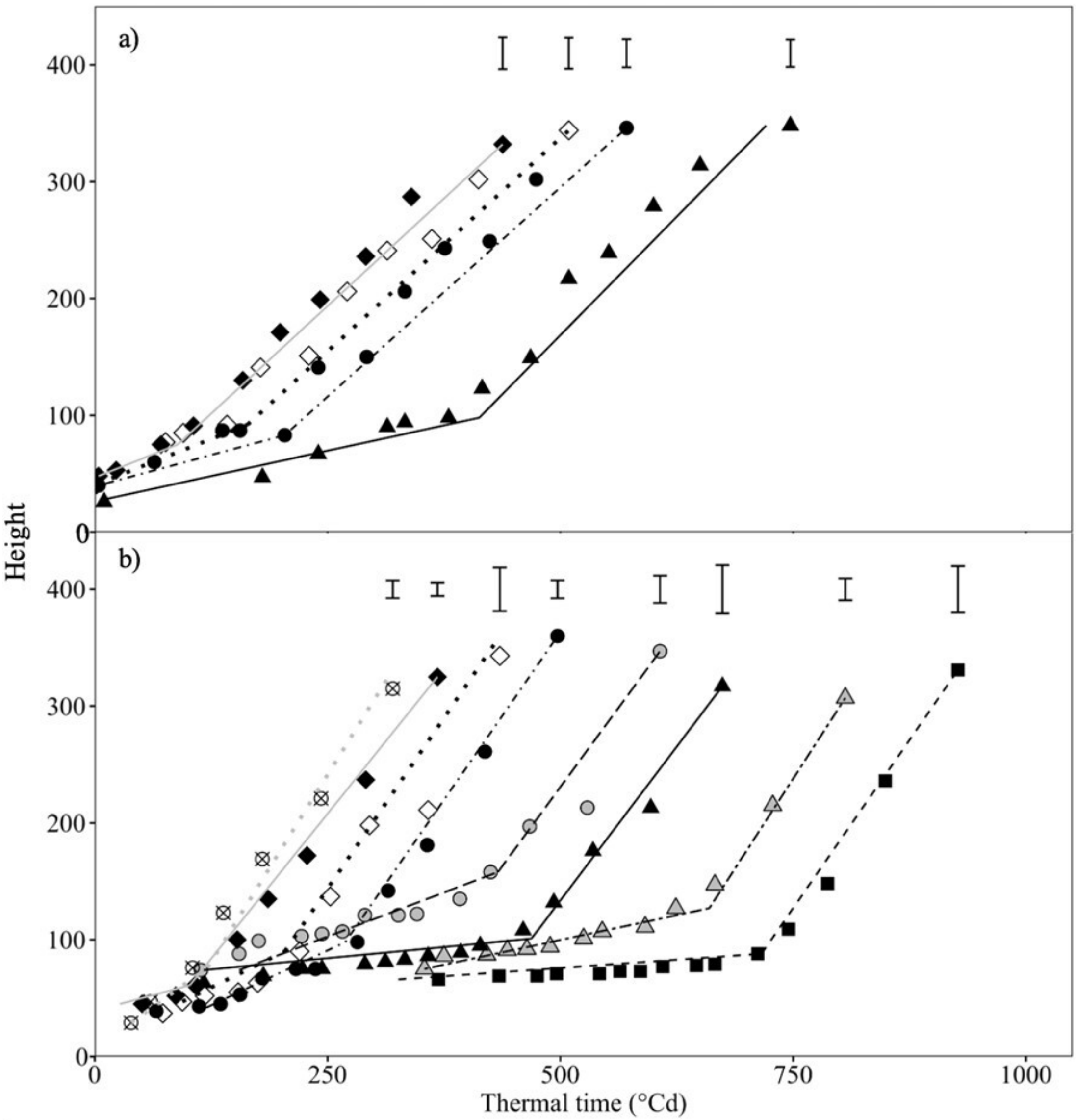

Figure 1 Stem height against thermal time (°Cd/mm) for lucerne defoliated in 2022 on a) four different dates, (1 June (▲), 3 July (●), 17 July (◇), or 1 August (◆) Experiment 1), and b) for lucerne defoliated in 2023 on eight different dates, (1 May (■), 115 May (▲), 1 June (▲), 15 June (●), 3 July (●), 17 July (◇), 1 August (◆), or 15 August (⊗) 2023, Experiment 2). Both experiments were located on the same lucerne stand at Lincoln University, Canterbury, New Zealand. Error bars are the SEM for each defoliation treatment.

Statistical analysis

A one way analysis of variance was performed in R studio (Version 2023.12.0+369) to compare height amongst defolation dates for each sampling date. In addition, two stage broken stick regressions were fitted to analyse the relationships between height, as the dependent variable, and thermal time and photoperiod, as the independent variables. This created paramaters for the slope in Phase 1 (before the break point), the time of the break point, and the slope of the regression in Phase 2, (after the break point). These parameters were estimated for each plot and then analysed by a one way analysis of variance to examine the impact of defoliation date. The break point for stem elongation for both years was compared using a one way analysis of variance. Treatment means are reported with their respective standard error of the mean (SEM). When significant, treatment means were seperated by Fishers protected least significant difference (LSD) at the α=0.05 level. Day length was calculated using sunset

Table 2 Parameters from broken stick regression analyses of stem height (mm) against thermal time (°Cd) for lucerne defoliated on four dates in 2022 and eight dates in 2023 at Lincoln University, Canterbury, New Zealand. SEM is standard error of the mean.

			Slope (°Cd/mm)		
Defoliation date		**Breakpoint (°Cd)**	**Phase 1**	**Phase 2**	**R^2**
Experiment 1 (2022)					
01/06		440	2.99	1.47	0.95
03/07		246	3.12	1.34	0.95
17/07		165	3.57	1.46	0.98
01/08		90	4.40	1.41	0.98
	Mean	235	3.52	1.41	-
	SEM	49.1	0.01	0.01	-
	P value	<0.001	0.12	0.55	-
Experiment 2 (2023)					
01/05		715 a	16.1 a	0.91 a	0.66
15/05		660 b	4.19 b	0.91 b	0.88
01/06		466 b	7.53 b	1.01 b	0.78
15/06		446 b	5.30 b	0.82 b	0.80
03/07		272 b	4.57 b	0.83 b	0.85
17/07		204 b	5.11 b	0.86 b	0.91
01/08		135 b	3.09 b	0.85 b	0.95
15/08		56 b	1.37 b	0.99 b	0.99
	Mean	369	5.91	0.9	-
	SEM	82.6	1.92	0.05	-
	P value	<0.001	<0.001	0.91	-

Note: - indicates data not analysed. Means followed by the same letter are similar at the α=0.05 level.

and sunrise times (https://www.linz.govt.nz/products-services/maritime-safety/astronomical-information).

Results

The thermal time accumulated from defoliation to the start of stem extension differed ($P < 0.001$) among defoliation treatments in Experiment 1 (Figure 1a). It ranged from 440°Cd for the 01/06 defoliation date, to 90°Cd for the 1 August defoliation date. In Experiment 2 the thermal time accumulated from defoliation to stem extension differed ($P < 0.001$) among defoliation dates in Experiment 2 (Figure 1b). In the second year it ranged from a maximum of 715°Cd for the 1 May defoliation date, to a minimum of 56°Cd for stands defoliated on 15 August. Heightchron (°Cd/mm) during Phase 1 was not different ($P = 0.12$) among the defoliation dates in Experiment 1 or Experiment 2 with the exception of the 1 May sampling date ($P = 0.05$) and averaged at 4.7 (± 0.96)°Cd/mm (Table 2). Heightchron on 01/05 in Experiment 2 was 16.1°Cd/mm. Heightchron (°Cd/mm) during Phase 2 was not different among the different defoliation date treatments in either year ($P = 0.91$) and decreased to a minimum of 1.15 (± 0.01)°Cd/mm.

The start of rapid stem extension was not different among the different defoliation dates in 2022 ($P = 0.20$) (Figure 2a), or 2023 ($P = 0.17$) (Figure 2b), and occurred at an average photoperiod of 11.1 (± 0.2) hours.

In 2022 final shoot yield was 2912 (± 61.3) kg DM/ha at the final harvest on 10/10 and did not differ ($P = 0.91$) among defoliation date treatments (Table 4). Similarly, in 2023 at the final harvest on 10/10 shoot yield was 3625 (± 116) kg DM/ha and was also not affected ($P = 0.618$) by defoliation date. Average shoot yield was not different ($P = 0.253$) between Year 1 and Year 2 and averaged 3143 (± 87.7) kg DM/ha.

Nodes accumulated linearly over time in 2022 ($R^2 = 0.95$), and 2023 ($R^2 = 0.94$). Node number was not different between years ($P = 0.39$). The mean number of nodes on the 07/06 sampling date was 3.65 (± 0.17) (Figure 3) which increased to 9.4 (± 016) mainstem nodes on the final sampling date (10 October) in both years.

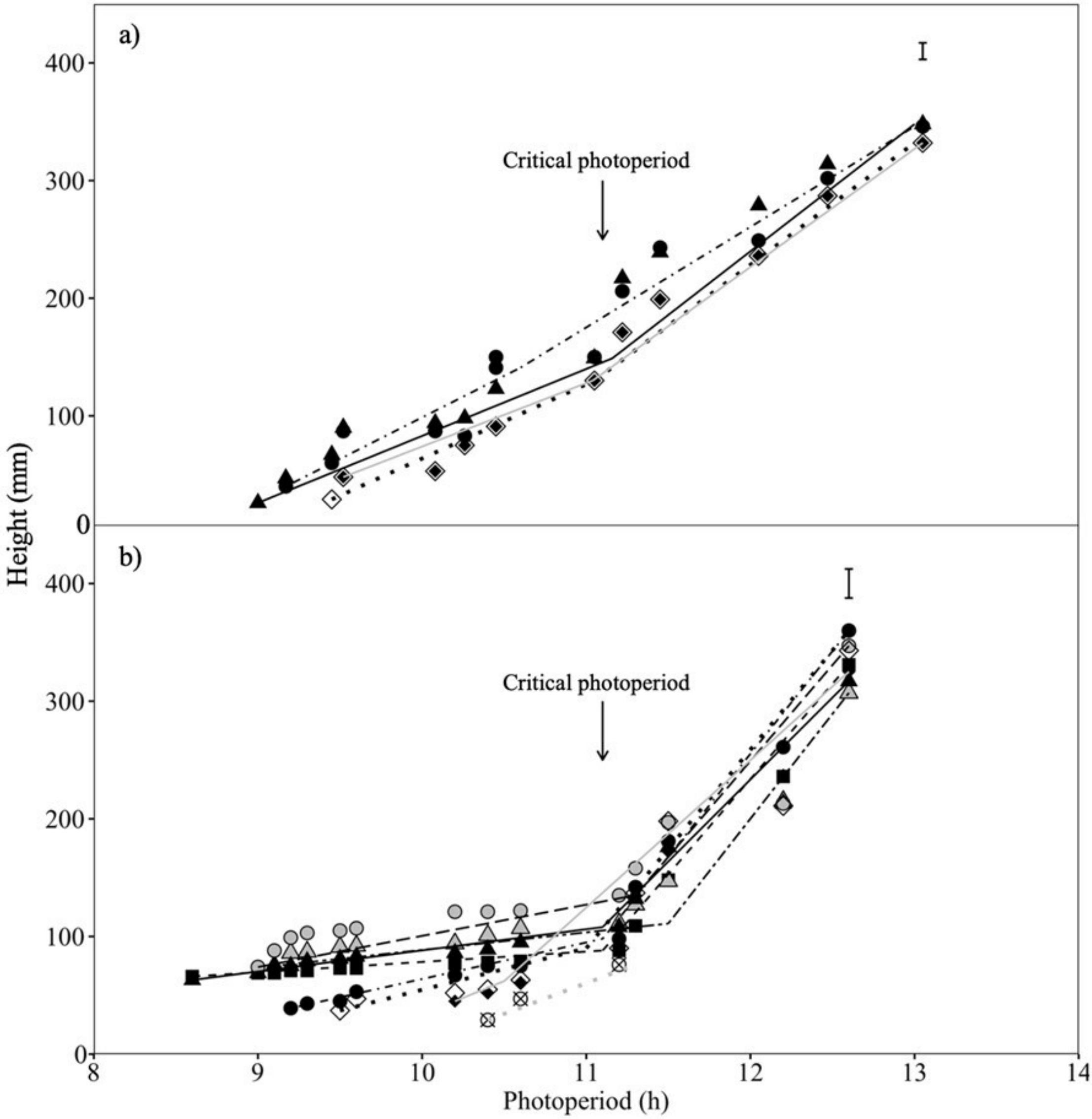

Figure 2 Stem height against photoperiod for lucerne defoliated on a) four different dates in Experiment 1 (2022), 1 June (▲), 3 July (o), 17 July (◇), or 1 August (◆)), and b) for lucerne defoliated in Experiment 2 (2023) on eight different dates, (1 May (■), 15 May (▲), 1 June (▲), 15 June (●), 3 July (●), 17 July (◇), 1 August (◆), or 15 August (⊗) 2023). Both experiments were located at Lincoln University, Canterbury, New Zealand. The vertical bars are the SEM for comparing photoperiod and plant height (mm) at the final observation date.

Discussion

The start of rapid stem elongation in spring was consistent at an 11.1 (± 0.2) hour photoperiod, irrespective of the defoliation date during autumn and winter (Figure 2) and is consistent with the value of 11.1 h reported by Yang et al. (2021). This showed that stem extension of the basal buds was triggered by a critical photoperiod, rather than after the accumulation of a specific amount of thermal time, which ranged from 56 to 715°Cd (Figure 1), since defoliation of the residual stem and leaf.

The robustness of a single critical photoperiod reported here should be validated in different years and at different latitudes. If it is consistent and stable as currently indicated by two years of data, defoliation recommendations should be based on an expectation of the time of rapid stem extension predicted from the critical photoperiod and heightchron. For example,

Table 3 Regression parameters from broken stick analysis of stem height (mm) against photoperiod (h) for lucerne defoliated on eight different dates in 2023 at Lincoln University, Canterbury, New Zealand. SEM is standard error of the mean.

Defoliation date	Breakpoint (h)	Slope (mm/h) Phase 1	Phase 2	R^2
Experiment 1 (2022)				
1 June	11.2$_{a}$	61.0$_{a}$	120$_{a}$	0.93
3 July	10.6$_{a}$	42.4$_{a}$	119$_{a}$	0.7
17 July	10.7$_{a}$	43.7$_{a}$	128$_{a}$	0.7
1 August	11.0$_{a}$	50.2$_{a}$	137$_{a}$	0.76
Mean	10.9	49.3	126	-
SEM	0.11	4.47	4.7	-
P value	0.23	0.46	0.17	-
Experiment 2 (2023)				
1 May	11.1$_{a}$	10.6$_{a}$	160$_{a}$	0.9
15 May	11.5$_{a}$	36.7$_{a}$	125$_{a}$	0.74
1 June	11.1$_{a}$	20.0$_{a}$	123$_{a}$	0.9
15 June	11.3$_{a}$	26.8$_{a}$	143$_{a}$	0.84
3 July	11.1$_{a}$	27.8$_{a}$	167$_{a}$	0.95
17 July	11.0$_{a}$	20.0$_{a}$	162$_{a}$	0.88
1 August	10.5$_{a}$	17.7$_{a}$	127$_{a}$	0.79
15 August	11.3$_{a}$	86.7$_{b}$	146$_{a}$	0.99
Mean	11.1	30.7	144	-
SEM	0.2	5.23	6.77	-
P value	0.17	0.019	0.85	-

Note: - indicates data not analysed. Means followed by the same letter are similar at the α=0.05 level.

Table 4 Shoot yields (kg DM/ha) of lucerne harvested on 10 October 2022 for established Force 4 lucerne monocultures defoliated on four dates (Experiment 1), and 10 October 2023 for lucerne defoliated on eight different dates (Experiment 2) at Lincoln University, Canterbury, New Zealand. SEM is standard error of the mean.

Defoliation Date	Shoot yield (kg DM/ha) Experiment 1 (2022)	Experiment 2 (2023)
1 May	-	3361$_{a}$
15 may	-	3823$_{a}$
1 June	2949$_{a}$	3306$_{a}$
15 June	-	3639$_{a}$
3 July	2854$_{a}$	3686$_{a}$
17 July	2972$_{a}$	2989$_{a}$
1 August	2872$_{a}$	2826$_{a}$
15 August	-	3370$_{a}$
Mean	2912	3375
SEM	61.3	116
P value	0.91	0.61

Note: - indicates treatment not applied in 2022.

rapid stem extension would be expected to occur in Northland on 27 August, compared with 31 August in the Manawatu, 1 September in Marlborough, 3 September in Canterbury, 4 September in Central Otago, and 5 September in Southland (Table 5). The rate of stem extension is then expected to be driven by the accumulation of thermal time in different locations and this should be considered when making grazing management decisions. Using the consistent heightchron, the time to first grazing at ~100 mm will differ based on mean daily temperatures after 03/09. Northland and Manawatu are predicted to reach 100 mm over two months earlier than Central Otago and Southland (Table 5) and reach 300 mm over one month earlier.

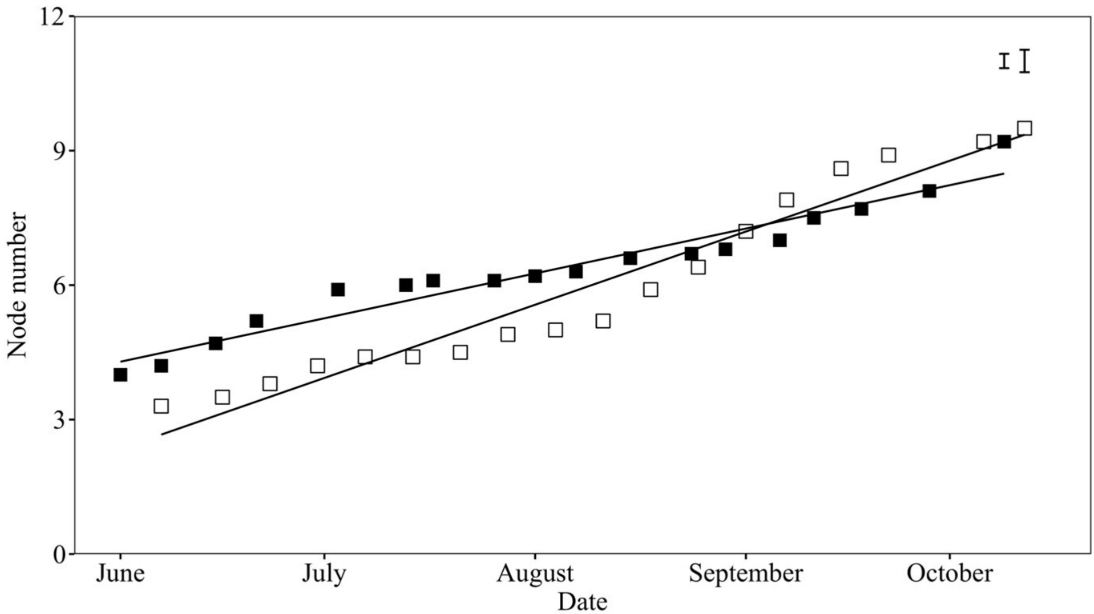

Figure 3 Average lucerne node number over time at Lincoln University in 2022 (□), and 2023 (■), at Lincoln University, Canterbury, New Zealand. Error bar is the SEM for total mainstem node number measured on 10 October in both years.

Table 5 Date of critical photoperiod for lucerne stem elongation, date lucerne stands will reach 100 mm, and date lucerne stands will reach 300 mm, calculated from long term weather data recorded from Agent Numbers 43952. 3243, 12430, 17603, 40986, 24945, 5814 (listed in the same order as in the table); (https://cliflo.niwa.co.nz/), using heightchron values of 4.2oCd/mm (± 0.96) during Phase 1, and 1.35°Cd/mm (± 0.01) during Phase 2.

Location	Date of 11.1h Photoperiod	Date stands reach 100 mm	Date stands reach 300 mm
Northland	27 Aug	7 Aug	22 Sept
Manawatu	31 Aug	27 Aug	4 Oct
Marlborough	1 Sept	2 Sept	6 Oct
Canterbury	3 Sept	5 Sept	11 Oct
Oamaru	4 Sept	7 Sept	15 Oct
Central Otago	4 Sept	23 Sept	13 Nov
Southland	5 Sept	9 Sept	29 Oct

In both experiments each treatment was defoliated to ~40 mm above ground level. This was to simulate a winter clean-up graze but prevent removal of the emerging basal buds. This allowed the basal buds to be initiated and accumulate thermal time and develop nodes ready for expansion after the critical photoperiod of 11.1 h (Figure 3). At the initial sampling dates, in both experiments, there were already 4 (± 0.17) mainstem nodes present in plants ~20 mm tall. However, yields were also not different among defoliation treatments by 10 October in 2022 or 2023. This suggests that each of the cutting dates accumulated nodes and biomass at the same rate (Table 4). These results are supported by previous research. For example, Moot et al. (2003) found plants were <20 mm and had ~4 nodes in August. They examined the effect of grazing and spraying during late winter. Stands sprayed with paraquat and atrazine on the 31st of July had the same linear growth rate as ungrazed/unsprayed crops. This suggested that the basal buds were not killed by that winter spray. For stands grazed after 21 August, yields decreased by up to 25%, and stem elongation was delayed by up to 4 weeks due to the removal of the basal buds. The implication is that if grazing removes the developing basal buds, stem elongation will occur later in the season than observed in Experiments 1 and 2, due to new basal buds having to be initiated.

The reported heightchron (°Cd/mm) of 4.7°Cd/mm (± 0.96) (Table 2) was comparable to previous analyses reporting a value of 3.0°Cd/mm below a photoperiod of 11.1 hours (Yang et al. 2021). This difference may reflect the range of values included, which started at a photoperiod of 8.6 h in this experiment compared with 10 h in the previous analysis. Of note, the Phase

2 slope of 1.15 (± 0.01)°Cd/mm was comparable to the value of 0.92°Cd/mm reported previously (Yang et al. 2021). The increase in height above the critical photoperiod was expected because in Phase 2 lucerne is rapidly remobilising carbon from root stores which supports stem elongation (Moot et al. 2003). The lack of difference in heightchron among defoliation treatments in both years suggests that the time of canopy defoliation did not influence the rate of stem extension during Phase 1, nor the time when the crops switched to Phase 2. The exception was the slope of Phase 1 for the 1 May defoliation date which was highest at 16.1 mm/°Cd (± 0.05). This difference may be explained by the sampling dates including a period of decreasing photoperiod, prior to the 22 June shortest day after which photoperiod increases. Previous recommendations suggested that a winter clean-up graze in June/early July ensures early spring regrowth (Moot et al. 2003). The validity of this statement depends on whether basal buds are removed during that grazing event. There was no difference in the time of rapid spring stem extension, even when crops were defoliated as late as 15 August, as long as the basal buds were not removed. Janson (1974) also investigated grazing lucerne in autumn and winter, just autumn, or just winter. He also reported no difference in the stem height among winter defoliation treatments at the point of stem extension, which suggests his treatments also did not remove the basal buds.

Stem height has a strong relationship with lucerne yield (Mills et al. 2016), with each 100 mm of height equal to ~900 kg DM/ha in spring. This suggests that there would have been no difference in yield among defoliation treatments at the point of rapid stem extension was initiated. The implication is that there is flexibility in the time of winter clean-up grazing, provided basal buds are not removed because this will not affect the timing of rapid stem extension in spring. Thus, mowing with the cutter bar set above the height of basal buds could be used to control the time of spring grazing.

Stem height differed among defoliation treatments for each sampling date until 6 September 2023. At this date the stems across both years were 114 (± 4.85) mm tall regardless of treatment. These results suggest that the first paddock should be grazed prior to the 6th of September in Canterbury. At 114 mm tall, there will likely be ~1000 kg DM/ha available for grazing (Mills et al. 2016). It has been previously demonstrated Moot et al. (2003) that if the first paddock, of a commercially recommended six-paddock rotation, was entered at ~150 mm, it would contain ~1500 t DM/ha (Mills et al. 2016). Yield on entry of subsequent paddocks increased while the first paddocks in the rotation were grazed and the duration of grazing in each paddock would lengthen to consume the extra feed available. However, by the end of the first spring rotation ewes and lambs entered the sixth paddock when it was 480 mm tall and had >4000 kg DM/ha (Moot et al. 2016). This resulted in a reduction in feed utilisation, from 85% in Paddock 1 (150 mm high on entry) to 68% in Paddock 6 (480 mm high at entry), due to increased stem lignification (Brown et al. 2006). These results and those from the current experiment suggest the date of stem extension can be predicted and, therefore, the first paddock can be entered prior to 150 mm height.

Typically, each paddock in a lucerne rotation is grazed for no more than 7 days so as not to remove the emerging basal buds (Moot et al. 2003). However, because the first paddocks in a rotation have less feed, there are only 2-3 only days of available grazing (Moot et al. 2016). Thus, if farmers were to graze their first paddock about 7 days before rapid stem extension, then 2-3 paddocks will have been grazed with higher utilisation. For example, in Canterbury, if Paddock 1 was entered at 80 mm, the stem heights in the sequential five paddocks would be 110, 130, 190, 260, and 340 mm tall. This would maintain a mean utilisation of ~80% for each paddock for the entirety of the first spring rotation (Moot et al. 2016). The maximum height attained in the current experiment was 330 mm on 10 October 2023 and did not differ among defoliation dates (Figure 1). This would be an ideal grazing height for Paddock 6 in the first spring rotation and suggests the first rotation would have provided about five weeks total grazing. If the grazing rotation started later, after the start of the rapid stem elongation, lucerne stem height would exceed 400 mm, and feed utilisation would drop below 70%. A higher feed utilisation maximises livestock growth rates so that stock can be finished prior to the summer dry period (Moot et al. 2016). These results suggest a grazing plan for lucerne can be created based on an estimate of the start of rapid stem extension. The stocking rate should then be set to allow Paddock 1 to recover to ~300 mm before it is grazed a second time, which takes ~30 days in Canterbury.

Conclusion

The break point for stem extension was calculated to be at a critical photoperiod of 11.1 (± 0.2) hours, which occurs on 3 September in Canterbury. This was irrespective of the accumulated thermal time from the autumn/winter canopy defoliation date. Heightchron was not different among defoliation dates during Phase 1, prior to the critical photoperiod, and rapid stem elongation (the break point) occurred at the same photoperiod for all defoliation treatments. This suggested the time of the winter defoliation did not affect the date, nor rate, of stem extension provided the basal buds were not removed. Stem height differed among defoliation treatments prior to the start of rapid stem elongation. This suggested that, even with a staggered winter grazing regime, spring grazing can commence prior to 3 September in Canterbury, to maximise herbage utilisation. Thus, grazing may commence earlier than has been previously recommended in anticipation of rapid stem extension to allow for high feed utilisation by priority stock in early spring. These results remain to be validated in different years and at different locations to determine if 11.1 (± 0.2) h is indeed the critical photoperiod that triggers stem extension.

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REFERENCES

Brown HE, Moot DJ, Teixeira EI. 2006. Radiation use efficiency and biomass partitioning of lucerne (*Medicago sativa L.*) in a temperate climate. *European Journal of Agronomy 25*: 319-327. https://doi.org/10.1016/j.eja.2006.06.008

Cox JE. 1978. Soils and agriculture of part Paparua County, New Zealand. *New Zealand Soil Bureau Bulletin*.

Hewitt AD. 1998. Comparison of sample preparation methods for the analysis of volatile organic compounds in soil samples: solvent extraction vs vapor partitioning. *Environmental science & technology 32*: 143-149. https://doi.org/10.1021/es970431q

Janson C. Lucerne management for the critical spring period under light land grazing *Proceedings of the New Zealand Grassland Association 36*: 66-72. https://doi.org/10.33584/jnzg.1974.36.1411

Mills A, Smith M, Moot D. 2016. Relationships between dry matter yield and height of rotationally grazed dryland lucerne. *Proceedings of the New Zealand Grassland Association 78*: 185-196. https://doi.org/10.33584/jnzg.2016.78.504

Moot D, Robertson M, Pollock K. 2001. Validation of the APSIM-Lucerne model for phenological development in a cool-temperate climate. Presented at: *Science and technology: delivering results for agriculture. 10th Agronomy Conference*. https://doi.org/10.5555/20193228108

Moot D, Brown HE, Teixeira E, Pollock K. 2003. Crop growth and development affect seasonal priorities for lucerne management. *Proceedings of the New Zealand Grassland Association 11*: 201-208. https://doi.org/10.33584/rps.11.2003.3007

Moot D, Bennett S, Mills A, Smith M. 2016. Optimal grazing management to achieve high yields and utilisation of dryland lucerne. *Journal of New Zealand Grasslands*: 27-34. https://doi.org/10.33584/jnzg.2016.78.516

Webb T. 2003. Identification of functional horizons to predict physical properties for soils from alluvium in Canterbury, New Zealand. *Soil Research 41*: 1005-1019. https://doi.org/10.1071/SR01077

Yang X, Brown HE, Teixeira EI, Moot DJ. 2021. Development of a lucerne model in APSIM next generation: 1 phenology and morphology of genotypes with different fall dormancies. *European Journal of Agronomy 130*: 126372. https://doi.org/10.1016/j.eja.2021.126372