Changes in the morphology, production and population of *Lotus corniculatus* L. cv. Grasslands Goldie in response to seasonal defoliation regimes

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Abstract

A field experiment was conducted from April to December 1997 at Massey University, Palmerston North, New Zealand to study responses in morphology, production and population of Birdsfoot trefoil (BFT) (*Lotus corniculatus* L. cv. Grasslands Goldie) to seasonal defoliation strategies. A factorial design (2x3x2) was applied in a complete randomised block arrangement with four replicates on a three-year-old BFT stand with 94 plants/m^2. Treatments included two autumn managements (last cut April or June), and a combination of two defoliation intervals (20, 40 days) and three defoliation intensities (2, 6, 10 cm) during spring (September-December). Herbage mass, sward height, botanical composition, plant density and plant morphology parameters (primary and secondary shoots, root diameter, crown and root mass) were recorded. BFT spring production reached 3000 kg DM/ha with a mean regrowth rate of 34 kg DM/ha/day. Early autumn (April) rest increased BFT spring production 17%, but did not affect plant density or the main morphological parameters. Hard defoliation in spring (2 cm) reduced BFT production (17%) and plant population (21%) compared with the average of other defoliation intensities evaluated, and reduced root mass, crown mass, primary and total shoots/m^2, and root reserves. In general, height of defoliation had the greatest effects. Defoliation frequency did not affect forage production and plant density. Although cv. Grasslands Goldie is a semi-prostrate BFT, intensive spring defoliation greatly reduced productivity and persistence, and late autumn utilisation diminished spring production.

Additional key words: Lotus corniculatus, *seasonal management, forage production, plant morphology, persistence*

Introduction

Birdsfoot trefoil (*Lotus corniculatus* L.) (BFT) has received attention as an alternative legume species for New Zealand pastoral systems, primarily for its adaptability to less fertile dryland environments of hill and high country (Scott and Charlton, 1983; Chapman *et al.*, 1990; Charlton and Belgrave, 1992). It has a high nutritive value for milk (Woodward *et al.*, 1999), wool (Min *et al.*, 1998), and meat production (Douglas *et al.*, 1999) partly resulting from the presence of condensed tannins (John *et al.*, 1980; John and Lancashire, 1981). Grazing management strategies for BFT have received minor attention, and in many cases follow recommendations for lucerne (Scott and Charlton, 1983), despite it being recognised that BFT has a declining production and lack of persistence under intensive grazing (Bologna, 1996). The only BFT cultivar used in New Zealand is cv. Grasslands Goldie, a semi-prostrate type adapted to grazing (AgResearch Grasslands, 1995). Better persistence is reported for semi-prostrate types than for upright-growing types of BFT because of differences in the exposure of meristems to grazing (Van Keuren and Davis, 1968; Beuselinck *et al.*, 1984).

The objectives of this research were to determine the influence of the timing of cessation of defoliation in autumn and the frequency and intensity of spring defoliation on the productivity and persistence of BFT cv. Grasslands Goldie in a preliminary short term study.

Materials and Methods

The experiment was conducted on a three year old *Lotus corniculatus* L. cv. Grasslands Goldie stand, at the Deer Research Unit, Massey University, Palmerston North, New Zealand (latitude 40°23'S), from April 1997 to December 1997. The soil type was a deep Tokomaru silt loam (Hewitt, 1992), with pH 5.7 and moderate fertility (Olsen P 24 mg/g). During summer 1997 and to the end of March, the sward was grazed rotationally at intervals of 30-40 days, at moderate intensities with deer.

The treatments were applied in a 2x3x2 factorial combination, using a randomised complete block design with four replicates in plots of 3 x 6 m. Initially, there were two autumn managements with plots cut on 25 April (early autumn rest) or 25 April and 10 June (late autumn rest) with a residual height of 3 cm. Thereafter, the plots were rested until early spring, when a combination of three defoliation intensities (2, 6 or 10 cm) and two defoliation frequencies (20 or 40 days) were introduced. The 2 and 6 cm defoliation treatments started on 10 September, and 10 cm defoliation started on 30 September, when the BFT achieved the minimum height required. The cutting sequence finished on 19 December for all treatments, to allow spelling for seed production.

Cuts to defined heights were made using a lawn mower, removing herbage from plots. Plots were sprayed on 7 May with Nortron® (ethofumesate, 1.4 l a.i./ha) to control white clover, and on 24 June with Preside® (flumetsulam, 24 g a.i./ha) to control broadleaf weeds.

Measurements

Pre-harvest herbage mass in two 500 x 200 mm quadrats per plot was measured at each harvest date by cutting to ground level with an electric shearing hand-piece. Those quadrat areas were marked to avoid repeat sampling. Botanical composition was measured for each sample, by separating into BFT and other components (white clover, grasses and weeds), and then oven drying at 60 °C for 48 hours. From each sample, 10 stems were randomly collected and dissected into leaves and stems, oven-dried and weighed. Sward height was evaluated in each quadrat, taking four readings at the top of the undisturbed BFT sward. Post-harvest mass was recorded three times during the experimental period using the same procedures, and at other times was estimated from sward height measurements.

Herbage accumulation (Table 2) was calculated as Σ (pre-harvest herbage mass$_{n+1}$ − post-harvest herbage mass$_{n}$). Post-harvest herbage mass (kg DM/ha, y_{post}) when quadrat cuts were not taken was estimated from sward height (cm, x) using an equation constructed with measured post-harvest data.

In July, September and December, a soil block of 250 x 250 x 250 mm was taken in each plot, and manually washed to remove soil and litter. Plants were counted, recording for each plant the number of primary and secondary shoots. Primary shoots were defined as the main shoots emerging from the crown, and secondary shoots as originating in the axils of each primary shoot. The diameter of the main root was measured at a section cut 10 mm below the level of insertion of primary shoots. Crown and roots (> 2 mm diameter) were oven-dried at 60 °C for 48 hours for dry weight. Crown was defined as the portion above the cut for root diameter measurement to ground level.

Statistical analysis

Data were analysed by SAS GLM procedures (SAS Institute, 1990), using a factorial model in a complete randomised block design with subsamples for herbage accumulation, and without subsamples for plant morphology and population parameters. Morphology and population parameters generated from sequential sampling were also analysed using the 'repeated measures' option of the SAS program.

Results

Climate

In general, rainfall was 18% less than the 60-year mean, with a dry winter in which rainfall was 55% of the average (Table 1). In spring, rainfall was 11% less than average. Soil temperatures were similar to the 60-year mean (11.1 °C), particularly during the growing season (AgResearch, Palmerston North).

Herbage production

Herbage production of BFT was on average 3000±783 kg DM/ha during the spring period (10 September - 19 December). Herbage masses pre-grazing (kg DM/ha, y_{pre}) and post-grazing (kg DM/ha, y_{post}) were positively correlated with sward height (cm, x) by the equations $y_{pre} = 325.6 + 120.4x$ ($P<0.01$, $r^2 = 0.72$, n = 246) and $y_{post}=-150.3+139.4x$ ($P<0.01$, $r^2=0.77$, n =144), respectively.

Herbage accumulation was significantly affected by autumn management (P<0.01) and defoliation intensity in spring (P<0.05), but there were no significant effects of frequency of defoliation or interaction between main factors (Table 2). Early autumn rest (April) increased spring production by 17%, and forage production was also greater when managed under 6 cm stubble height than at 2 or 10 cm.

Spring growth rate averaged 34 kg DM/ha/day, and was significantly influenced by autumn management (P<0.01) and defoliation intensity (P<0.01). An extended defoliation period during autumn reduced spring growth by 18%. Hard defoliation (2 cm) decreased growth by 24% compared with the 6 or 10 cm defoliation height (Table 2). Despite the tendency for a high regrowth rate for the 10 cm treatment, total accumulation was lower than for the 6 cm height because of the delay to first harvest and consequent short accumulation period (80 days vs. 100 days).

BFT contributed a mean of 61% of total dry mass in spring (Table 2), but the BFT proportion was reduced by delayed autumn rest (June), short defoliation frequency (20 day intervals), and hard defoliation (2 cm height). There were no significant interactions.

A significant interaction for frequency x intensity of defoliation (P<0.01) was detected for the ratio leaf/(leaf + stem). Under 20 day intervals between defoliation, the proportion of leaves decreased when defoliation intensity decreased from 2 cm to 10 cm residual height, but at 40 day intervals the reduction in the proportion of leaves was higher in 6 cm than the 10 cm height treatment (Table 3). Leaf proportion of plots cut at 2 cm and 20 day intervals was significantly higher than for the other treatments, while the three heights managed at 40 day intervals and the 10 cm height at 20 day intervals were not different, having a ratio leaf:stem near 1:1.

Table 1. Monthly rainfall and soil temperature at 100 mm during the evaluation period and the 60-year average (Source: AgResearch, Palmerston North).

	Rainfall (mm)		Soil Temperature (°C)	
	1997	60-year average	1997	60-year average
April	145	81	12.5	13.2
May	24	89	11.6	10.1
June	60	97	8.1	7.7
July	32	89	6.4	6.7
August	60	89	7.3	7.6
September	79	75	9.1	9.9
October	78	88	12.4	12.5
November	57	78	15.5	15.1
December	103	94	17.0	17.3

Table 2. The effect of defoliation management on birdsfoot trefoil cv. Grasslands Goldie dry matter accumulation, growth rate and contribution to total production (%) during spring.

Cutting treatments	DM accumulation (kg DM/ha)	growth rate (kg DM/ha/d)	BFT contribution (%)
Autumn defoliation			
Early rest	3290	37	65
Late rest	2730	31	56
SEM	134	1.6	1.6
Significance	**	**	**
Spring frequency			
20 days	2830	32	58
40 days	3180	37	64
SEM	134	1.6	1.6
Significance	NS	NS	*
Spring intensity			
2 cm	2690	28	49
6 cm	3400	35	62
10 cm	2920	38	71
SEM	164	1.9	2.0
Significance	*	**	**

* P<0.05; **P<0.01; NS, not significant; SEM, standard error of the mean

Table 3. Leaf/(Leaf+Stem) ratio (dry weight) of birdsfoot trefoil cv. Grasslands Goldie under different defoliation frequencies and intensities in spring.

Frequency	Intensity	Leaf/(Leaf +Stem)	SEM	Observations
20 days	2 cm	0.69	0.017	52
20 days	6 cm	0.61	0.017	51
20 days	10 cm	0.48	0.021	36
40 days	2 cm	0.57	0.024	28
40 days	6 cm	0.46	0.025	28
40 days	10 cm	0.51	0.024	28

Plant density

During winter, stand reduction was 8% but independent of autumn defoliation management ($P<0.85$). Spring plant losses increased significantly ($P=0.01$) with defoliation intensity, with reductions of 2, 16 and 32% for the 10, 6 and 2 cm heights respectively, from September to December (Fig. 1). A significant interaction for time x defoliation intensity ($P<0.05$) was detected. There were no effects from autumn management, spring defoliation frequency or other interactions between treatments on the sampling dates evaluated.

Plant morphology

In general, morphological components of plants per unit area were not modified by autumn management or by spring frequency (Table 4) and no significant interaction effects were observed at the end of the trial. However, root mass/m^2 was decreased ($P<0.05$) by hard (2 cm) defoliation intensity (Table 4), largely due to a reduction in plant density. Crown mass/m^2 was reduced by 45% ($P<0.01$), and total below ground mass/m^2 by 41% in plants defoliated to 2 cm compared with the other defoliation intensities. Hard defoliation (2 cm) reduced primary shoots/m^2 by 49% compared with more lenient defoliation (Table 4). Also, secondary shoots were reduced significantly ($P<0.05$) under short defoliation intervals (20 days).

Autumn management affected root diameter in July (11 and 9 mm for April and June autumn rest, P<0.05,

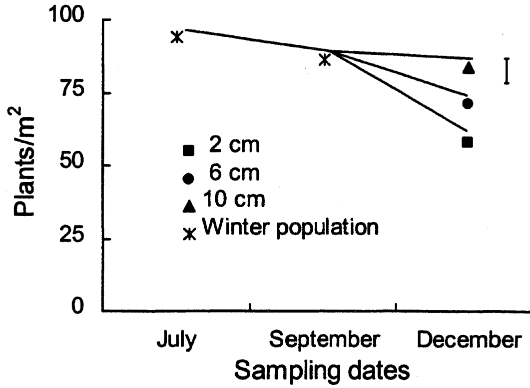

Figure 1. Treatment effects on seasonal changes in birdsfoot trefoil cv. Grasslands Goldie plant density. Vertical bar represents SEM.

Table 4. Effects of defoliation treatments on plant morphology parameters and plant density in December 1997 for birdsfoot trefoil cv. Grasslands Goldie, after different defoliation treatments.

Cutting treatments	Root mass (g/m^2)	Crown mass (g/m^2)	Primary shoots ($no./m^2$)	Secondary shoots ($no./m^2$)	Plant density ($no./m^2$)
Autumn defoliation					
Early rest	40	84	285	661	69
Late rest	38	80	283	689	73
SEM	3.3	6.0	25	49	4.7
Significance	NS	NS	NS	NS	NS
Spring frequency					
20 days	37	74	262	598	69
40 days	41	90	306	752	73
SEM	3.3	6.0	25	49	4.7
Significance	NS	NS	NS	*	NS
Spring intensity					
2 cm	29	53	212	564	58
6 cm	43	97	312	692	71
10 cm	45	96	327	769	84
SEM	4.1	7.3	31	59	5.7
Significance	*	**	*	NS	**

NS, not significant; *, $P<0.05$; **, $P<0.01$; SEM, standard error of the mean

SEM 0.4), but not in early or late spring. Plants defoliated frequently and severely (each 20 days and at 2 cm height) showed a reduced root diameter in December, compared with plants defoliated frequently but at 10 cm height (8 mm vs. 9 mm, P<0.05, SEM 0.4). There were no differences in root diameter between defoliation intensities when defoliated at intervals of 40 days.

Individual crown and below ground masses were affected by spring defoliation frequency (P<0.05), and intensity (P<0.01), with both increasing under 40 day intervals or cutting at 6 cm height. Number of primary shoots declined over time (P<0.01), from 6 shoots/plant in July to 4 shoots/plant in December, but was not affected by management treatments.

In December, a significant cutting frequency x intensity of defoliation interaction was detected for the number of secondary shoots/plant (P<0.05). The number of shoots declined progressively from 10 cm to 2 cm defoliation height in plants defoliated every 20 days, but were higher at 2 and 6 cm than 10 cm in plants defoliated every 40 days (Fig. 2).

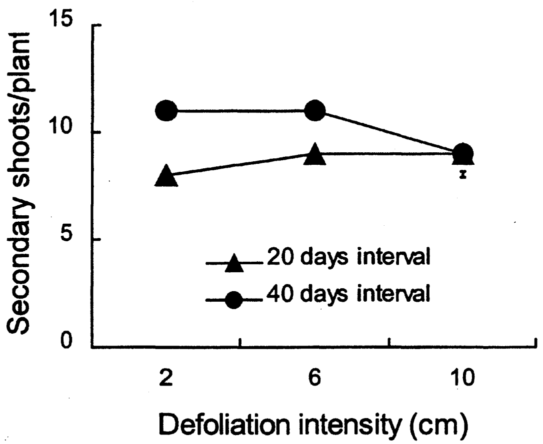

Figure 2. Effects of defoliation management on secondary shoots per plant of birdsfoot trefoil cv. Grasslands Goldie in December, under two intervals and three intensities of defoliation. Vertical bars represent SEM.

Discussion

The most significant result of this trial was the decline observed in BFT plant density, from autumn to the end of spring. The intensity of spring defoliation affected plant survival, which was severely reduced under hard defoliation (Fig. 1). Lesser defoliation intensities resulted in improved plant survival, and for the case of 10 cm defoliation height the initial spring population was effectively maintained. There were no effects of defoliation frequency or autumn management on plant survival. Winter losses were independent of autumn management, suggesting additional factors in that process.

The age of the BFT sward could partially explain plant losses, as a high incidence of crown and root diseases is reported for stands 2-3 years old in other regions (Altier, 1997). In this case, plants taken from the experimental area showed a high incidence of diseases (*Rhizoctonia, Fusarium*), when transferred to a warm and humid glasshouse environment. Diseases can occur early and progress with the age of the plant (Leath, 1989), severe incidence being associated with warm and humid conditions (Greub and Wedin, 1971, Beuselinck, *et al.*, 1984; English, 1999). In Otago, New Zealand, Chapman *et al.* (1990) reported losses of 50% of plants of a 3-year old BFT stand in winter-early spring, a complex of *Fusarium* species being the causal agent.

Intensive defoliation influenced a number of plant characteristics, resulting in poor plant survival. Firstly, root diameter was reduced in plants that were severely defoliated at 20-day intervals. This suggested a decline in carbohydrate reserve levels. Plants with low reserve and under stress are more susceptible to the effect of root diseases (Barta, 1978). Secondly, BFT plants defoliated at both 2 cm and 10 cm height had smaller crowns than plants defoliated at 6 cm. It is possible that in the 10 cm height treatment a wide range of plant sizes could survive. However under intensive defoliation (2 or 6 cm height) only strong plants could survive, but the intensive defoliation (2 cm) depleted the crowns of surviving plants. In addition, the number of secondary shoots was reduced in plants defoliated intensively and frequently (2 cm – 20 days interval).

These findings at the individual plant level associated with the reduction in plant density resulted in declining root mass, crown mass and the number of primary stems per unit area. The consequence of these associated changes was a reduction in spring forage production

(Table 2), when intensive defoliation was applied. Lax defoliation is known to improve the development of shoots and yield (Cordeiro de Araujo and Jacques, 1974), and 7-10 cm of residual stubble height is generally recommended for BFT (Smith and Nelson, 1967). Better stand persistence under intensive grazing (2.5 cm) was observed only when the stand was defoliated three times during the year (Smith and Nelson, 1967). In the current study a reduction of 32% in plant density was accompanied by a 24% reduction in spring forage production, for a stand with 86 plants/m^2. Bologna (1996), managing a 1-2 year old stand of 40 plants/m^2 of BFT Grasslands Goldie, showed spring forage production ranged between 3.1-3.8 t DM/ha in environments of the South Island of New Zealand. There was only a 13% reduction in density if a stand was defoliated at 4 cm height every four weeks and no effects on density when defoliated at 6-8 week intervals. However, a reduction in the defoliation interval to 2 weeks resulted in a decline of 65% in plant density in approximately two years.

In the current trial (Fig. 3), the total number of shoots/m^2 was closely associated with BFT contribution, which was approximately 1100 shoots/m^2 from a stand

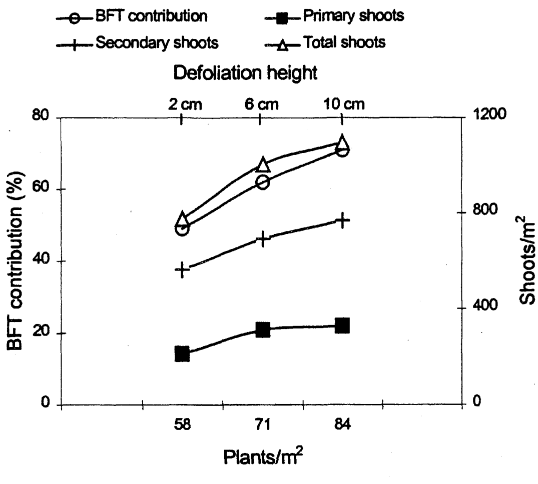

Figure 3. Influence of defoliation height on plant population, shoots density and herbage contribution to total pasture production in birdsfoot trefoil cv. Grasslands Goldie in spring.

density of 84 plants/m^2. Primary shoots contributed significantly to yield when population was increased from 58 to 71 plants/m^2 by a change in defoliation height from 2 to 6 cm. However, plants tended to maintain their primary shoots when defoliation height increased from 6 to 10 cm height, and a further increase in the number of secondary shoots explained the increase in BFT contribution. Similar determinations were made by Volenec *et al.* (1987) for a series of lucerne cultivars, with plant density ranging from 11-172 plants/m^2; shoot density to obtain high dry matter yields ranged from around 900-1000 shoots/m^2.

Thus, the combined effect of intensity and frequency of defoliation can alter stand density drastically, indicating that over short periods of time, defoliation height has a stronger effect than frequency of defoliation. Plant density required for adequate forage production appears to be associated with the age of the stand, because it declines progressively with sward age. The short number of cutting cycles (one season) limited the effects of defoliation interval compared with results for long term trials (Bologna, 1996).

Late autumn defoliation reduced herbage accumulation and growth in spring and possibly root reserves. Assuero *et al.* (1990) found that levels of carbohydrate reserves in late winter explained 48% of the variation in regrowth of BFT during spring. Winter survival was not affected by autumn defoliation as reported for other crown forming species like lucerne (Keoghan, 1970). In the current study, it is likely that winter temperatures were not severe enough to produce the kind of effects reported for more extreme environments. Weakened plants that survive winter could die in spring if proper management is not applied, as is the case for chicory (Li, 1997), or for red clover under high temperatures (Kendall, 1958) or dry conditions (Smith, 1950), where reserves are deficient.

BFT swards under intensive defoliation in autumn also could be less dense and competitive in spring, increasing the proportion of gaps for the establishment of other species, by a depletion in root reserves for winter active BFT types or by reduced competition by low growth of dormant types.

Conclusions

Recommended management to optimise forage production and plant persistence of BFT cv. Grasslands Goldie in spring should contemplate moderate defoliation intensities (6 cm), independently of defoliation intervals if defoliated for short periods. Management strategies based on high residual herbage mass after cutting and extended intervals between defoliation during spring will increase plant survival, but will decrease the number of grazings possible in the growing season and result in lower quality forage. However, inappropriate management can reduce root mass, levels of root reserves and crown size of BFT plants, resulting in less vigorous plants and less dense and productive swards.

No evidence was found at this site to suggest that autumn management had any particular influence on plant losses during winter. However, early rest in autumn will allow an early and high spring regrowth, provided the plants have high carbohydrate root reserves.

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