The Effect of Closing Date on Seed Production From a Birdsfoot Trefoil (*Lotus corniculatus* L.) Pasture.

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ABSTRACT

The effect of closing date on seed production and quality from a *Lotus corniculatus* L. pasture was examined by removing sheep (closing) on 18 November, 20 December or 10 January. Seed yield did not differ for the November and December closing dates, but was significantly reduced (from 65.1 g m^{-2} to 45.8 g m^{-2}) by the January closing. Seed quality parameters, especially seed viability, germination and 1000 seed weight were superior from the November and December closing dates. Closing date did not affect the number of mature pods or mean pod length at seed harvest. Seed weight and shoot density were the most important factors affecting final seed yield. Defoliation of *L. corniculatus* pasture during November or December is unlikely to decrease seed production, provided that environmental conditions are suitable for rapid plant recovery.

***Additional index words:* *Lotus corniculatus,* seed production, seed quality, closing date.**

INTRODUCTION

Persistence problems with the traditional pasture species used in summer-dry regions of New Zealand have led to investigations of alternative species to improve pasture survival and productivity, while optimizing animal production. Birdsfoot trefoil (*Lotus corniculatus* L.) is one species which has potential as a forage for dryland areas with moderately fertile soils, where acidity or impeded drainage limits the persistence of other legumes (Keoghan and Widdup, 1994). One cultivar (cv. Grasslands Goldie) is currently available in New Zealand (AgResearch Grasslands, 1995). However, poor seed production has prevented its widespread use. The flowering period of *L. corniculatus* in New Zealand may extend from November to April (Sanders and Rowarth, 1995). This, together with the dehiscent behavior of the pods, makes it difficult to select the optimum time for seed harvesting (Li and Hill, 1989).

The persistence of *L. corniculatus* swards can be improved by promoting seedling recruitment through natural reseeding (Alison and Hoveland, 1989; Forde, Hay and Brock, 1989). However, the production of quality *L. corniculatus* seed is critical to ensure re-establishment. Seed quality affects emergence and seedling vigour, and thus may affect seedling competitiveness (Twamley, 1967). Therefore, the persistence strategy and the natural life cycle of this species need to be considered in terms of management practices, such as deferring grazing to allow enhanced flowering and seed production, and seasonal adjustment of grazing pressure, to optimize opportunities to improve seed yield and quality.

Although natural reseeding has been proposed as a management practice to increase the persistence of the species, there is little information about the effect of management variables on seed production of *L. corniculatus* in pastoral systems. In this context, the main objective of the present study was to evaluate the effects of closing date on seed yield and seed quality of *L. corniculatus* established as a pasture.

MATERIALS AND METHODS

The experiment was sited at AgResearch, Lincoln (43° 38' S), New Zealand, on a Wakanui silt loam (Udic Ustochrept). The soil at the start of this trial had a pH of 6.0 and the original Olsen P was 30. The trial was established on a stand of cv. Grasslands Goldie sown in October 1992, in 15 cm row spacings at a sowing rate of 4 kg ha^{-1}. There were three main plots, each of 0.02 ha. The first grazing occurred four months after sowing and rotational grazing with sheep continued at four- to six-weekly (four weeks in spring and early summer, six weeks in late summer) intervals during the growing season (September to May) in 1993 and 1994. The pasture had been fertilized in autumn 1993 and 1994 with 150 kg of superphosphate ha^{-1}.

The trial was spray-irrigated when the topsoil profile dried to 50% available soil water capacity; water (50 mm) was applied four times during the experimental period. Exclusion cages (0.6 x 0.9 m) were used to protect sampling areas from grazing, simulating spelling periods during flowering and seed development. Closing time treatments were applied on the 28 November, 1994, 20 December 1994 or 10 January 1995 after removing all existing herbage by grazing with sheep to a height of 25 mm. The closing treatments were replicated three times in a randomized complete block design. One exclusion cage was placed at random in each plot at each closure date. After each exclosure the pastures outside the cages were rotationally grazed every four weeks. Sheep numbers were balanced according to pasture availability in order to reduce the period of occupation to no more than 12 h. Cages were removed between grazings to avoid

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microclimatic effects; references will be made to exclusion cage sites, indicating that these were fixed sites which were protected from grazing whilst sheep were on the main plots.

Peak flowering was determined by counting open flowers on five plants within each exclusion cage site at weekly intervals. The pasture was open pollinated by undomesticated pollinators and colonies of honeybees (*Apis melifera* L.) located close to the *L. corniculatus* sward. Reproductive and vegetative matter in the cage sites was harvested to a height of 25 mm when approximately 80% of the pods were in the mature yellow-brown and brown stages of development (Anderson, 1955; Li and Hill, 1989; Pieroni and Laverack, 1994). A 150 mm border inside the perimeter of the cage sites was not considered in the measurements because of sheep browsing.

The number of plants in each cage site were recorded at closing and at harvest, while the total number of pods and number of primary branches present in each cage site were recorded at harvest and the number of seeds per pod and pod length were determined on a sub-sample of 100 pods per cage site. Primary branches were considered to be those emerging from the crown. Pod numbers per branch and branch density (branches m^{-1}) were calculated from these data. The number of days required to produce morphologically mature seed was considered as the seed development period (Anderson, 1955).

Pods were separated from vegetative herbage by hand immediately after harvest, and were then placed in paper bags to dry. Thus, seed losses from shattering were limited to that which occurred prior to harvest (less than 10% of the mature pods). The pods were classified into two developmental categories according to their colour. Yellow-brown, brown and dark-brown pods were considered to be morphologically mature while pods in the purple and green developmental stage were considered to be immature (Li and Hill, 1989; Pieroni and Laverack, 1994). The pods collected were dried at ambient temperature for 15 d and then threshed by hand. Samples were cleaned by passing them through 2.0 and 1.4 mm sieves. Seed yield was calculated using the seed obtained from morphologically mature pods. Germination, hardseededness, and thousand seed weight (TSW) were determined for each sample according to internationally agreed methodology (ISTA, 1993). Viability was assessed using tetrazolium in conjunction with germination. Thousand seed weights and seed yield were adjusted to 7.5% moisture content.

Climate data were taken from readings at the Lincoln University Meteorological Station 0.5 km from the experimental site.

All data are presented on a m^2 basis. Means are presented with their standard error (s.e.m). Analyses of variance were computed to test differences between treatments. Data were compared using Tukey's Multiple Comparison test (Zar, 1984). Regression and correlation analyses were also performed when necessary. Results were analyzed using the SAS statistical analysis system (SAS Institute Inc., 1989).

Table 1. Monthly climate data for the experimental period. Deviations from the long term climate average for each period are presented in brackets.

Month	November 94	December 94	January 95	February 95	March 95
Mean maximum temperature (°C)	20.2 (+2.1)	21.4 (+1.4)	21.8 (+0.6)	21.3 (-0.1)	21.3 (+1.2)
Mean temperature (°C)	14.3 (+1.4)	15.7 (+1.6)	16.6 (+0.1)	16.8 (+0.8)	15.6 (+0.4)
Rainfall (mm)	22.7 (-33.1)	24.7 (-33.2)	32.2 (-22.9)	25.3 (-21.7)	32.6 (-23.5)
Evapotranspiration (mm)	159.9	160.9	131.0	84.1	84.4
Average daylength (H:min day^{-1})	14h 54min	15h 24min	14h 56min	13h 52min	12h 35min

Table 2. The effect of closing date on *Lotus corniculatus* seed development period, days from closing to harvest and seed yield (mean ± s.e.m).

Closing date	Seed development period (days)	Days from closing to harvest	Seed Yield (g m^{-2})
November	51 a	82 a	65.1 ± 0.9 a
December	46 a	77 a	60.5 ± 0.9 a
January	33 b	78 a	45.8 ± 1.2 b
Significance	*	n.s.	**

* *significant P<0.05, ** significant P<0.01, ns not significant. Within columns any numbers followed by the same letter do not differ significantly. This applies for all tables*

RESULTS AND DISCUSSION

Mean temperatures during November and December averaged 15°C (1.5°C above the average for the previous 8 years) (Table 1). During January-March, the average temperature increased to 16.3°C (0.4°C above average). The period was drier than normal, but this effect was mitigated with irrigation. Under the 'global warming' scenario, the Canterbury Plains are expected to become warmer and drier (Cherry, 1995); conditions experienced during the trial support the trend.

Closing date treatments did not significantly change the number of days from closing to harvest (Table 2). However, January closing resulted in a significant ($P<0.05$) reduction in the period of seed development (peak flowering to harvest; Table 2).

Seed yield and seed quality

Seed yield decreased with the delay in closing (Table 2), but the reduction was significant ($P<0.01$) only for the January closing for which seed yield was 70% of that of the November closing. The experimental seed yields were higher than average commercial seed yields for New Zealand (300 kg ha^{-1} ; Hampton, Hill and Rolston,1990) but they are low when compared with the potential seed yield of the species (1.2 t ha^{-1}; Lorenzetti, 1993).

Seed weight decreased as closing date was delayed (Table 3). These data compare with the results of Beuselinck and McGraw (1988) and indicate that the shorter maturation time (Table 2) which resulted from closing late in the flowering season shortened the period of pod filling, affecting seed weight. This reduction in maturation time coincided with reductions in daylength and temperature during March (Table 1). Thus, flowers which developed and matured during February and March were likely to experience a less favorable light and temperature environment for the maturation of reproductive tissues and reproductive success.

Seed quality parameters (Table 3) were similar for November and December closing treatments and generally statistically superior to those from the January closing treatment. All closing treatments produced high levels of hard seed; seed viability was considerably lower in the January closing treatment than in the earlier closing treatments. Little is known about the effect of decreasing temperatures on TSW and viability of *L. corniculatus* seed; this requires further investigation.

These trends in seed yield and seed quality components corroborate results presented by Anderson (1955), Albrechtsen, Davis and Keim (1966) and Stephenson (1984), who also reported that early-set pods produced higher seed yields of higher quality than late-set pods.

Li and Hill (1989) showed that in *L. corniculatus* full seed maturity is followed by the rapid onset of hardseededness. Hand-harvesting does not provide the mechanical scarification which machine harvest promotes (Turkington and Franko, 1980). In a pastoral context, hard seeds increase adaptability to the environment by spreading time of germination. Hard seeds also survive passage through the digestive tract of stock, providing a way for plants to colonize new areas (Gardener, McIvor, and Jansen, 1993). Thus, hard seeds are desirable for regeneration and maintenance of pasture populations through spreading by grazing animals and by the development of seed banks (Suckling, 1952).

Branch density and herbage yield

Final plant density in the three closing treatments was not significantly different (mean 39 m^{-2}; range 38.3-40.1 m^{-2}). Herbage dry matter at seed harvest was significantly ($P<0.05$) higher for the November and December closing treatments (4327 and 4296 kg ha^{-1}, respectively) than for the January closing treatment (3560 kg ha^{-1}). Branch density decreased significantly ($P<0.05$) as closing was delayed (783, 672, 500 branches m^{-2} for November, December and January closing treatments, respectively). The relationship between branch density and herbage yield (herbage yield = 2222.9 + 2.8 branch;

Table 3. The effect of closing date on *Lotus corniculatus* seed quality components (mean ± s.e.m).

Closing date	1000 seed weight (mg)	Seed viability (%)	Seed germination (%)	Hardseed (%)
November	1.528 ± 0.007 a	86 ± 7 a	22 ± 4 a	64 ± 4 a
December	1.471 ± 0.007 ab	90 ± 7 a	17 ± 1 ab	73 ± 4 a
January	1.385 ± 0.03 b	68 ± 8 b	12 ± 4 b	56 ± 6 b
Significance	**	**	*	*

Table 4. Reproductive components of *Lotus corniculatus* at seed harvest as afffected by date of closing (mean ± s.e.m.)

Closing date	Remaining flowers m^{-2}	Immature pods m^{-2}	Mature pods m^{-2}	Seeds pod^{-1}	Pod length (cm)
November	153.7 ± 8.5 a	1378.2 ± 56.9 a	3716.1 ± 131.1	12.9 ± 0.1a	4.3 ± 0.2
December	31.5 ± 9.3 b	385.8 ± 18.6 ab	3829.1 ± 254.3	10.9 ± 0.3 b	4.4 ± 0.1
January	46.9 ± 6.9 bc	337.0 ± 16.9 b	3739.5 ± 55.4	9.9 ± 0.6 c	3.8 ± 0.3
Significance	**	**	n.s.	**	n.s.

$R^2 = 0.88$) was significant ($P < 0.01$) and positive, indicating that the reduction in herbage yield with time among treatments resulted from a reduction in branch density.

Herbage yield was less responsive to closing time than branch numbers. Branch numbers decreased about 40% over the range of closing dates studied. Differences in numbers of branches cannot be explained in terms of changes in plant density because no plant deaths were observed during the experimental period. The reduction in branch density in the January treatment was compensated by the relative increase in mean pod numbers per branch (7, 6 and 8 for the November, December and January closing treatments, respectively).

Although the experimental plant population was higher than the optimum of 20 plants m^{-2} suggested by McGraw, Beuselinck and Ingram (1986) as necessary to achieve optimum seed yields, compensation among seed yield components explained the high yields obtained.

Regrowth was generally rapid and was noticeable 5-7 days after grazing in all treatments. Most new branches formed in the first two treatments started flowering 20 days after closing,and peak flowering occurred ten days later. When closing occurred in January, flowering started thirty days later and peak flowering occurred two weeks afterwards. Regeneration from the crown was reduced and fewer branches were formed.

Seed yield components

There was a significant ($P < 0.01$) decrease in the number of immature pods and remaining flowers at harvest (Table 4) between the November and December and January closing date treatments. The flowering habit of *L. corniculatus* is indeterminate, and after each closing it flowered over an extended period (60 to 80 days). Number of flowers at peak flowering did not differ significantly among closing treatments (11,420, 10,970 and 10,350 flowers m^{-2} for November, December and January closing treatments, respectively). Flowering over a long period resulted in a wide range of umbel maturity, and new umbels appeared when pods from old umbels had matured. Flower and immature pod density at harvest were highest for the November closing, suggesting that favorable conditions during December and January promoted a longer period of flowering.

In contrast, differences among closing dates for number of mature pods were not significant. The increase in pod density per branch compensated for the reduction in branch numbers which occurred when closing date was delayed.

Seeds per pod decreased significantly ($P<0.01$) from November to January closing. Seeds per pod tended to be positively associated with mean seed mass and with pod density, suggesting that adjustments in seed number were not a major mechanism regulating seed yield in this species. However, a comparison of the seed yield components of the first two closing dates with those of the last showed that 76 % of the significant decrease in seed production for the January treatment could be accounted for by the significant decrease in the number of seeds per pod, while only 24 % was accounted for by the reduction in mean seed mass. Closing date did not affect mean pod length (Table 4). Therefore, umbels produced early in the season tended to yield similar numbers of pods to umbels produced later, but they had more seeds per pod.

There was a significant ($P<0.01$) and positive relationship between branch density and final seed yields (yield = 19.3 + 0.0584 branch; $R^2 = 0.81$). Since branch numbers and numbers of pods were positively correlated in all the closing time treatments ($R^2 = 0.66$, $P<0.05$), branches appeared to be a major contributor to seed yield, determining not only the final number of pods, but also affecting flowering potential, as noted by Li and Hill (1988). However, there was also a significant relationship between seed yield and stem weight ($R^2 = 0.48^{**}$).

The results from this study support the hypothesis that the indeterminate reproductive habit of *L. corniculatus* enables the regulation of seed yield components to optimize seed production in response to particular environmental conditions or changes in resource availability throughout the growing season (Stephenson, 1984).

The critical photoperiod requirement for full flowering of *L. corniculatus* is 14.0 to 14.5 h (McKee, 1963). This daylength requirement for flower induction was met from late October to mid February (Table 1). Therefore, the decreases in seeds per pod, and seed weight are unlikely to have been in response to photoperiod. The reduction in seed yield which occurred when closing was delayed beyond December might be attributed to a shorter span for reproductive and vegetative phases due to a rise in temperature (Table 1). A shorter maturation time would result in a shortened period of pod fill and may partially explain the lowered seed weight observed for the January closing date. In addition, forced maturity caused by increases in temperature may have resulted in increased embryo abortion and reduced seed numbers. However, Hill and Supanjani (1993) showed that time of flower production did not affect the survival of pods per umbel or seeds per pod. The same authors suggested that seed is the main cause of pod abortion and pods with fewer seeds tend to abort.

CONCLUSIONS

The seed yields reported in this paper indicate that high seed yields of *L. corniculatus* are achievable under pastoral conditions in the South Island of New Zealand. Defoliation of *L. corniculatus* stands during November or December is unlikely to decrease seed yield, provided that conditions are suitable for rapid recovery from grazing. Furthermore, management of early-season growth for seed production is likely to produce a greater quantity of high-quality seed than managing the more variable late-season growth for seed production.

From a pastoral perspective, the quantity of seed produced in this experiment may ensure the development of a seed bank, promoting the persistence of the *L. corniculatus* stand through natural reseeding. Exclosure from grazing is a common management recommendation to promote the production of seed when *L. corniculatus* is used in pastoral systems. Ensuring a good seed set is worthwhile, since the development of a soil seed pool is an insurance against future adverse environmental conditions, or inadequate grazing management. However if dry matter production is required for animal feeding in early summer, January closure may also provide sufficient seed for the soil seed pool, although the processes affecting the development of soil pools of *L. corniculatus* seed require further investigation. The seed yields obtained in this experiment suggest that commercial seed production from grazed pastures may be an alternative to a specialist seed crop, but this would need confirmation from research in other seasons.

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