The flowering pattern and seed development of *Lotus* species

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Abstract

Flowering pattern and seed development parameters of *Lotus pedunculatus* (tetraploid and diploid), *Lotus corniculatus* and *Lotus tenuis* were studied under identical management and environmental conditions. Flowering occurred a month earlier in *L.. pedunculatus* than *L. corniculatus* and *L. tenuis*; seed development occurred more rapidly in the tetraploid than the diploid species. Although peak flowering and time required for seed development were identified, it did not prove possible (due to poor weather conditions) to relate theory to practice and identify optimum time of harvest in the field.

Additional key words Lotus pedunculatus, Lotus uliginosus, Lotus corniculatus, Lotus tenuis, *flowering pattern, seed development, seed moisture, thousand seed weight (TSW), germination, time of harvest.*

Introduction

Lotus seed yields vary with species and seasonal environmental changes. For instance in Canterbury in 1992, the average seed yield of *Lotus pedunculatus* (syn. L. *uliginosus*) was 227 kg/ha, in 1993 (with a 2°C warmer spring) it was almost double that at 430 kg/ha (Anon, 1993), yet research in Canterbury (Hare and Lucas, 1984) indicates that a yield of 1700 kg/ha is theoretically possible. Li and Hill (1989) reported a theoretical seed yield of 560 kg/ha for *Lotus corniculatus* but suggested that a more realistic estimate of 420 kg/ha of seed was harvestable when considering the umbels present over the defined peak flowering period. This yield is still considerably greater than the average commercial yields (200 - 350 kg/ha) obtained in New Zealand (Li and Hill, 1989). It is unclear if the yields obtained are real or imposed by management practices and/or environmental factors (eg., climate and soil). The indeterminate growth of lotus species, which means that flowering may extend from November to April in New Zealand (Neal, 1983), together with the crop's dehiscent nature, makes it difficult to determine the optimum harvest time. The poor seed production of these species is a major limiting factor in their more widespread use as a pasture legume.

Research to date has involved different lotus species and different seasons in different areas of New Zealand. Thus it is not clear whether seed development, a knowledge of which is fundamental for seed production, differs between species when subjected to the same environmental conditions. An improved understanding of the environmental and developmental factors contributing to seed yield of lotus species is needed so that management practices can be improved to enable seed growers to produce reliable, high yielding crops.

The aims of this study were to:
1. define the flowering pattern and seed development characteristics for lotus species,
2. relate flowering pattern to optimum time of harvesting and
3. compare these parameters for different lotus species and cultivars under the same management in the same season.

Materials and Methods

The trial was sown in October 1991 at AgResearch Lincoln, using precision drilling at 3kg seed/ha in 30 cm rows into a Wakanui silt loam. Seedlings were thinned to 60 plants/m^2.

The species and cultivars sown were:
- 'Grasslands Maku' *Lotus pedunculatus* (Cav.), syn *Lotus uliginosus* (Schkuhr.), a tetraploid
- 'Grasslands Sunrise' G4703 *Lotus pedunculatus* (Cav.), a diploid version of Maku
- G4704 (not released) *Lotus pedunculatus* (Cav.) Portuguese x diploid
- 'Grasslands Goldie' (*Lotus corniculatus*) otherwise known as Birdsfoot trefoil
- *Lotus tenuis*

The trial had a randomised block design with four replicates of each species/cultivar. Plot size was 1.5 m x 8 m. The total area was 240 m^2.

Over the 1993/94 summer the three species of lotus were monitored to identify peak flowering, noting differences between cultivars. Number of umbels with 1-3 open florets found within the confines of 10 x 15 cm^2 quadrats, taken randomly twice a week on each plot, were used in order to obtain flowering pattern details. Seed development was studied by tagging 50 umbels/replicate (each of which had 50% of the florets fully open) on each species or cultivar in mid-December (coinciding with peak flowering of the *Lotus pedunculatus*). Average numbers of florets for each species (i.e., 10-12 florets/umbel for *Lotus pedunculatus* varieties and 3-5 florets/umbel for *Lotus corniculatus* and *Lotus tenuis*) were tagged to ensure differences in assimilate partitioning did not bias the results. Collection of five tagged umbels for each species or cultivar for seed extraction began 10 days post-tagging. Seeds from the tagged umbels were extracted every 3-4 days and seed weight was recorded. This continued for seven weeks, until significant pod shattering had occurred. Climate data were collected throughout the seed development trial period (Table 1). Seed moisture content (%) and seed dry weight (TSW) after oven drying at 20°C to a constant weight, were determined. Drying could not be more extreme as these seeds were required for germination. Germination percentage was obtained by following ISTA rules (1993); that is seeds were prechilled at 5°C and then germinated on top of Whatman paper at 20°C . Germination counts (normal and abnormal seedlings) were made at four and 12 days.

Bulk samples (2 x 0.25 m^2 quadrats) of reproductive and vegetative matter were hand harvested twice a week from late January to mid March, to give an indication of effect of time on seed yield; harvesting was terminated when few intact pods were apparent on any plots. Seed was dressed using a Seed Buro seed cleaner. Two types of shatter traps (funnels and trays) were used to try and obtain data on the degree of shattering occurring in the plots. Both these methods proved unsuccessful; the height of the funnels above the canopy was such that seed escaped entrapment, while birds and stand density (resulting in shattering seed being intercepted by the mass of vegetative material above the shallow tray) made accurate collection of shattered seed impossible.

Results and Discussion

Peak flowering for the *Lotus pedunculatus* cultivars occurred a month earlier (mid-December) than for *Lotus corniculatus* and *Lotus tenuis* species in the 93/94 season (Fig. 1). No difference in flowering pattern among the three *Lotus pedunculatus* cultivars was observed, despite their differences in chromosomal arrangement and the introduction of Mediterranean material to one of the cultivars. This suggests that flowering is in response to daylength (Forde and Thomas, 1966). Peak flowering in this season was a fortnight earlier than that recorded by Tabora and Hill (1991); this is consistent with the difference in latitude between the two sites. *Lotus tenuis*

Table 1. Climate data for the seed development trial.

Month	Date	DAP[1]	Total rain (mm)	Mean T_{max} (°C)	Mean Solar Radiation (mj/m^2)	Mean Rel. Humidity (%)
Dec	17-21	1-5	36.0	17.3	18.7	86
	22-26	6-10	25.0	14.9	17.3	84
	27-31	11-15	5.4	21.5	21.6	90
Jan	1-5	16-20	2.1	23.5	23.8	76
	6-10	21-25	24.5	27.0	22.5	76
	11-15	26-30	8.7	21.6	26.7	70
	16-20	31-35	2.2	23.2	22.0	78
	21-25	36-40	12.5	22.4	13.7	78
	26-30	41-45	0.3	25.1	25.1	80
Jan/Feb	31-4	46-50	1.7	18.8	25.6	84

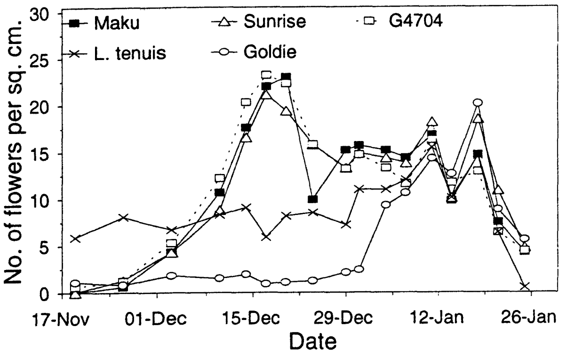


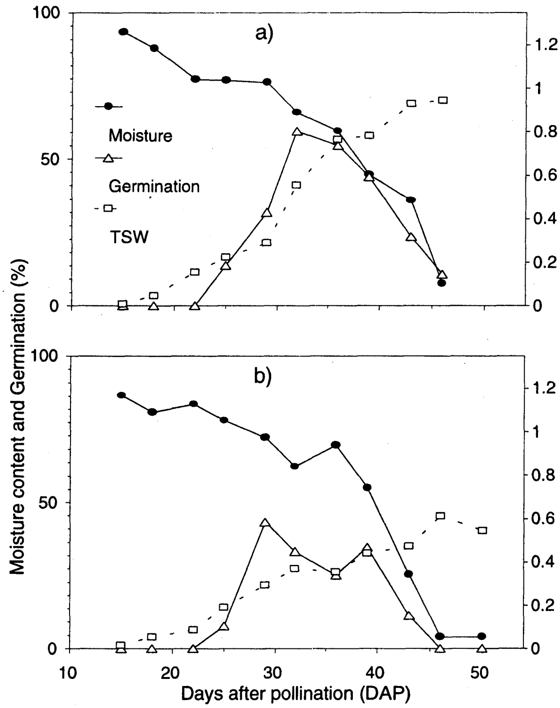
Figure 1. Flowering pattern of five lotus cultivars (three species) in the trial

failed to reach an obvious peak in flower numbers until mid January, though it began flowering earlier than all other species. Numbers of *Lotus corniculatus* flower did not increase until the beginning of January, climbing to a maximum around the same time as the *Lotus tenuis* (mid January).

Seed development of Grasslands Maku (*Lotus pedunculatus*) followed the well documented three stages (Fig. 2a): firstly the growth stage, secondly the seed-filling stage and thirdly, the final ripening stage (Hare and Lucas, 1984). The seed development stages of other lotus species and cultivars used in the experiment are presented in Table 2 and are further illustrated in Figures 2b-2e. The growth phase is in keeping with the 19-23 day period suggested for Grasslands Maku by Hare and Lucas (1984), being 22 days for all the species under investigation. The lack of warm, dry weather conditions over this period may have had a marked effect on the early stages of seed development, as 161.2 mm of rain fell over this time (Table 1). Seeds harvested at this stage were small, had a high moisture content and did not germinate. Hare and Lucas (1984) defined the onset of the ripening phase to be when the seeds had reached a maximum dry weight. Examination of their data revealed that this coincided with a marked drop in seed moisture content. Results from the present trial indicate that the marked decrease in seed moisture did not coincide with a plateau in thousand seed weight (TSW). The continued increase in TSW may have been due to the drying method used (to constant weight at 20°C) but most likely a result of the variation produced by the small sample size. The relatively cool, wet season resulted in considerable vegetative growth and increasing difficulty in finding tagged pods. It is possible that the more deeply buried pods (found late in the season) had an advantage in terms of assimilate partitioning. However an acceleration in the decrease of seed moisture was observed after 36 days for 'Grasslands Goldie' (*Lotus corniculatus*) and the two released *Lotus pedunculatus* cultivars ('Grasslands Sunrise' and 'Grasslands Maku'), and after 39 days for G4704 (*Lotus pedunculatus*) and *Lotus tenuis*. Seed at this point was approaching maximum dry weight, hence the end of the seed-filling stage (ripening phase begins) was identified. During the final stage (36-50 DAP), the seed moisture content continued to decline to a level suitable for harvesting (Hill, 1971). Seed loss through pod shattering became evident at seed moisture percentages below 20. Thousand seed weight remained relatively constant signalling the seed was ripe (Hyde, 1950). The final stage allows for flexibility in harvesting time given that 'seed ripeness' is reached. Beyond 50 DAP no seed was harvestable as all pods had shattered. Pod shattering occurred in 'Grasslands Maku' (*Lotus pedunculatus*) at 46 DAP, and in all other lotus at 50 DAP, despite the differences in other timings. This suggests that the chromosome number of the plant under consideration had more of an effect on seed development than did species. The incidence of pod shattering at this final stage of seed development coincided with 5 days of high irradiation (Table 1).

Seed germination reached 60% in 'Grasslands Maku' and *L. tenuis* 32 DAP, and in 'Grasslands Goldie' 39 DAP. 'Grasslands Sunrise' and G4704 achieved only 40% germination 29 DAP. These results are consistent with those reported by Hare and Lucas (1984) in a cool season. Observation of seedlings indicated only a small proportion of abnormal seedlings (<4% in all cultivars and species). The high percentage of non-germinating seed probably reflects a high incidence of hard seed (Hare and Lucas, 1984), as hand harvesting and hand removal of seed from pods would not provide the scarification necessary to overcome this condition.

Variability in seed yield (g/m^2) with time made interpretation of the data difficult (Figure 3). Defined peaks were present but had no obvious pattern, therefore making it almost impossible to relate to flowering. Yields for all species were low, ranging from 0.96 g/m^2 to 27.70 g/m^2. There was a significant difference ($P<0.01$) between species; G4703 gave the highest average seed yield (18.80 g/m^2) and 'Grasslands Maku' gave the lowest seed yield (4.18 g/m^2). The large differences in seed yields obtained for the three *Lotus pedunculatus* cultivars can, in part, be attributed to the incidence of pod abortion and pod rot, despite treatment with Benlate (50g in 100l water) in mid January and early February.



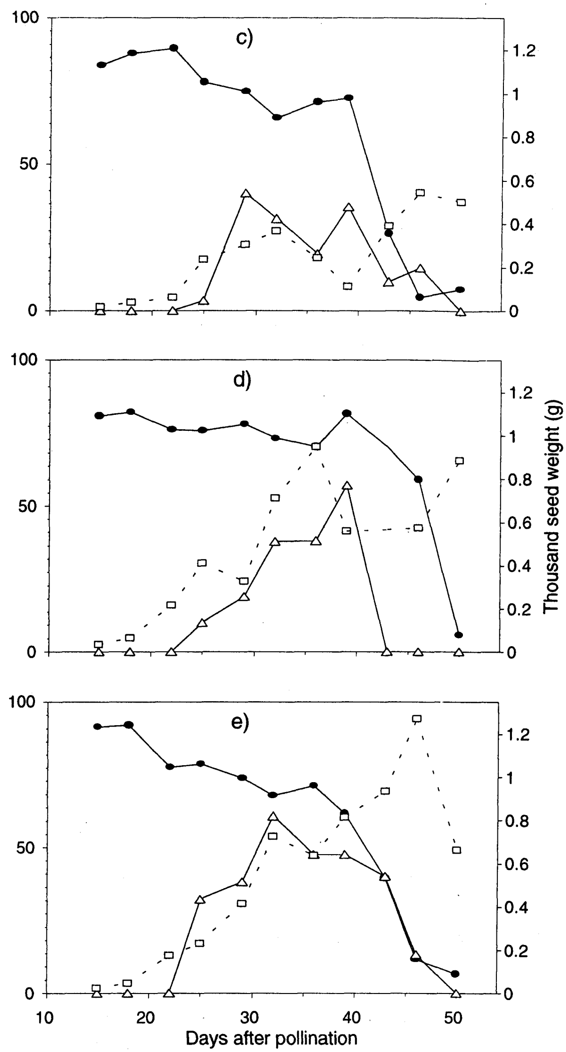


Figure 2. Seed moisture (%), thousand seed weight (g) and normal seed germination (%) changes with time for a) 'Grasslands Maku' (*Lotus pedunculatus*), b) 'Grasslands Sunrise' (*Lotus pedunculatus*), c) G4704 (*Lotus pedunculatus*), d) 'Grasslands Goldie' (*Lotus corniculatus*) and e) *Lotus tenuis*.

The seed development work suggests that, in theory, harvest should take place 43-50 DAP. Peak flowering of *Lotus pedunculatus* was identified as being in mid-December (17th) therefore it follows that *Lotus pedunculatus* seed should be harvested late-January to early-February (30th Jan - 5th Feb). Applying theory to practice proved problematical. Seed yields at this stage were near minimum for all species and defining optimum harvest time from these data was not possible.

Conclusions

There were considerable differences in the time of peak flowering between the three species of lotus

Table 2. Duration of stages of seed development in five *Lotus* cultivars/species.

	Days after pollination		
	STAGE 1 Growth	STAGE 2 Seed-filling	STAGE 3 Ripening
'G. Maku'	0-22	22-36	36-46
G4704	0-22	22-39	39-50
'G. Sunrise'	0-22	22-36	36-50
'G. Goldie'	0-22	22-36	36-50
Lotus tenuis	0-22	22-39	39-50

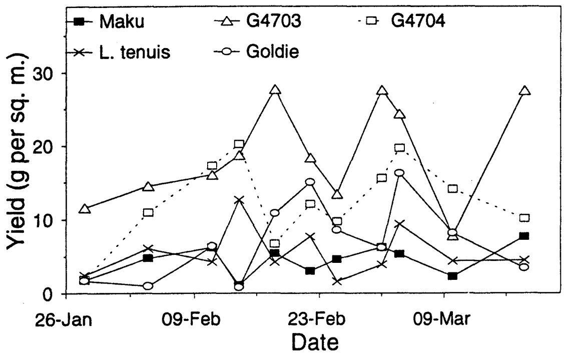


Figure 3. Seed yield (g/m^2) data obtained from bulk harvests for five lotus seedlines. Standard error (Se$_x$) is presented for comparison between species and harvest days.

investigated in this trial, *Lotus pedunculatus* flowering a month earlier than *Lotus corniculatus* and *Lotus tenuis*. Shattering in all species was coincident with a period of intense solar radiation. Differences in seed development among species were small but the variation in the data recorded made it difficult to reach any definite conclusions. This seed development study needs to be repeated.

Although peak flowering and days to reach seed maturity were known, it did not prove possible in this season to extrapolate theory to practice and identify the optimum time of harvest in the field.

Under the same management system and environmental conditions, the lotus species in this trial responded differently. It is possible that to achieve optimum seed yields, the different lotus species require different management; this requires further investigation.

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