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A Study of Flower Development and Seed Yield Components in Birdsfoot Trefoil (*Lotus corniculatus* L.)[1]

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ABSTRACT

The pattern of seed yield components during the flowering period of *Lotus corniculatus* L. was studied. Changes in yield components during the three month flowering period were monitored using tagged flowers on shoots originating in different months at different positions on the plant. Number of inflorescences was the most important single yield component, a high positive correlation occurring between final seed yield and the number of inflorescences produced. Number of florets per inflorescence declined with time, but was not significantly correlated with final seed yield. Number of seeds per pod and seed weight showed only minor fluctuations during the entire flowering period and made no significant contribution to differences in seed yield. The flower carrying ability of individual shoots (numbers of inflorescences per shoot and number of florets per inflorescence) in each shoot age group was also identified. The quality of seeds produced from early- and late-formed flowers was similar in terms of seed viability and hard seededness. It was concluded that number of inflorescences could be used as a reliable index for predicting harvesting date in *L. corniculatus*. It was also found that throughout the flowering period there was a relatively constant loss of approximately one pod per inflorescence during the period from visible flower buds to the mature pod stage. The causes of this potential yield loss are briefly discussed.

Additional key words: **abortion, herbage seed production, harvest date**

INTRODUCTION

Lotus corniculatus has potential as a pasture legume in agronomic situations where environmental conditions are to harsh for the satisfactory performance of other common legumes such as white clover and lucerne. More widespread use of *L. corniculatus* has been hampered by lack of adequate supplies of high quality seed. This is a direct reflection of problems encountered in obtaining consistent and high seed yields.

Much of the research on the seed production of *L. corniculatus* has included assessments on seed yield components. It is generally agreed that the number of inflorescences (or umbels) is the most important seed yield determinant in various situations (Albrechtsen et al., 1966; Mos, 1983; Stephenson, 1984; McGraw et al., 1986; Li and Hill, 1988) and the number of pods per umbel has a less important role in determining final seed yield (Stephenson, 1984). However, most previous work has not included consideration of the changing pattern of each seed yield component during the extended flowering period. Harvest timing is an extremely important factor affecting seed recovery and ultimate saleable seed yield. This precise timing requirement is a reflection of the plant's indeterminate growth habit and seed shattering characteristics. The objectives of this study were to determine the changing pattern of each yield component; to more precisely define the role of inflorescence numbers as the single most important yield determinant throughout the long flowering period; and to determine its reliability as an index for deciding correct harvest time.

MATERIALS AND METHODS

The experimental work was carried out at Massey University, Palmerston North, New Zealand (400°S, 1750' E). *L. corniculatus* seed was autumn sown directly into a Tokomaru silt loam on 26 March 1986 at a sowing rate of 3.5 kg ha^{-1}. The established plant density averaged 44 plants m^{-2}. A basal application of 350 kg ha^{-1} of 30% potassic superphosphate was applied immediately prior to sowing.

Inflorescences formed on crown shoots originating in different months (July to January) were identified by tagging their peduncles with different colored plastic rings at ten-day intervals from 12 December 1986 to 31 January 1987. This tagged population of approximately 2000 inflorescences was used to determine the time of inflorescence and pod development and subsequently to determine seed yield and seed yield components. Inflorescence numbers were recorded at five-day intervals within eight 1 m^2 permanent quadrats. The five-day counting interval was decided according to the morphological and color changes in flowers and ensured that each inflorescence was not counted twice or missed.

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Number of pods per umbel were recorded every ten-days from 20 randomly sampled umbels on tagged inflorescences. Number of seeds per pod were recorded from 100 pods sampled from tagged inflorescences at ten-day intervals. Seed weight (1000-seed) was recorded at seed moisture contents of 6.8 - 7.5% in seed lots harvested at different times.

Seed quality was assessed by laboratory germination test (4 replicates of 50 seeds) according to the International Seed Testing Association rules (ISTA, 1985).

The number of visible flower buds and number of florets per inflorescence were also recorded to assess possible effects of reproductive abortion at different development stages.

RESULTS

Flower and pod development: Floral development was measured according to morphological and color changes. It was observed that for an average inflorescence with six florets, it took about ten days from the visible floral primordial stage to the first floret bloom stage, and another two to three days for all florets to complete blooming. Florets remained at this 'full bloom' stage for only one or two days. The term 'flowering' used in this paper refers to this 'full bloom' stage. Florets subsequently wilted, a process which involved a change in petal color from bright yellow to purple-yellow. Plate 1 shows the changing reproductive sequence with day 0 as the day of first floret blooming and day 3 as the beginning of floret wilting.

All infloresences used in this study were tagged within these three days. Four or five days after flowering, young pods appeared from the covered petals. Pods then developed rapidly to a maximum size about 20 days after flowering (DAF). Initial pod color was fresh green, then changed to dark brown at 20 DAF and finally to light brown at the full pod maturity stage (32 DAF) (Plate 1).

Flower carrying capacity of different age groups: The flower carrying ability of shoots varied according to the month formed (Table 1). On shoots formed prior to November (which flowered before early January), flower carrying capacity in terms of number of inflorescences per shoot and number of florets per inflorescence, remained relatively constant. The decline in flower carrying ability on later shoots was, however, compensated by increases in the number of shoots through January. December formed shoots, in particular, represented the largest percentage of the total shoot population. Each individual shoot consistently bore approximately three inflorescences in most shoot age groups with each inflorescence bearing a similar number of florets (6.0 - 6.3). For these reasons inflorescence number was considered to be a direct reflection of shoot numbers and was judged to be the most important single yield component determining final seed yield.

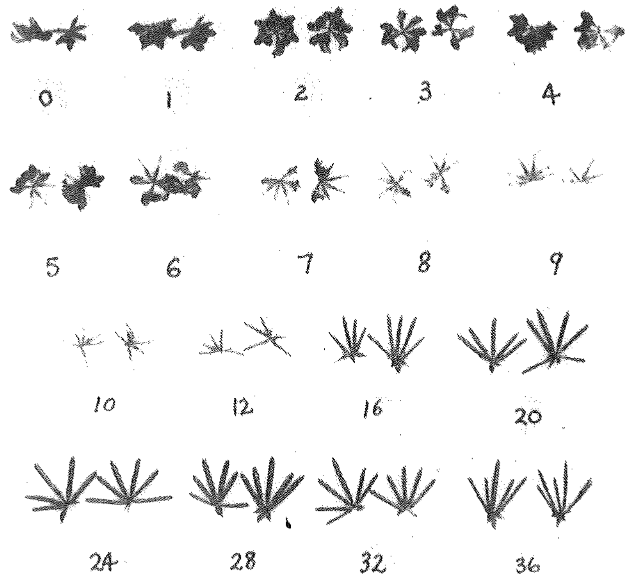

Plate 1. Flower and pod development sequence (days 0 - 36); floret opening (0 - 2); floret wilting (3 - 5); pod appearance (6 - 8); rapid pod development (9 - 20); maturation (24 - 32); ripeness (36).

Changes in seed yield components: Inflorescence number reached a sharp peak at the beginning of January and then dropped rapidly (Figure 1). Number of pods per inflorescence remained reasonably constant during the peak flowering period, but fell by approximately 50% in the late flowering period (early February). This effect was a direct reflection of the similar pattern of change in floret numbers per inflorescence. Number of seeds per pod remained fairly constant with only minor fluctuations during the entire flowering period.

Seed development and seed quality during development: The time required for seed development was recorded for each group of tagged inflorescences. Generally, 30 to 40 days was required from flowering to seed maturity, depending on the time of flower initiation (Table 2). Seed began to acquire viability approximately 22 DAF and reached maximum viability 12 days later. The ability to germinate, as shown by the production of normal seedlings, commenced at 26 DAF and peaked at about 30 DAF. As a result of the increases in hard seed content, germinability dropped after 34 DAF. Early flowers usually required less time to complete their seed development than late flowers (Table 3). Seed quality, in terms of viability and hardseededness, was similar for seed produced at different times (Tables 2 and 3). The percentages of viable seed remained high in all seed lots harvested at different times. The final two lots showed a

Table 1. Flower carrying ability of shoots from different age groups.

Characteristics (Number of)	Shoot groups					
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
Shoots per plant (A)	1.1	2.1	2.7	3.1	16.2	5.8
Inflorescences per shoot (B)	3.1	3.4	3.2	3.2	2.6	2.0
Inflorescences per plant						
Calculated[a]	3.4	7.1	8.6	9.9	42.1	11.6
Observed	2.7	4.6	12.0	10.3	25.9	6.9
Florets inflorescence^{-1}	--[b]	5.7	5.9	5.9	5.2	4.4

[a] Calculation based on A x B, Not all shoots were necessarily flowering at observation so differences existed between the calculated and actual numbers of inflorescences.
[b] Data not available.

Table 2. Seed development (viability) of *L. corniculatus* at various days after flowering (DAF).

DAF	Germination test results (%)					Total viable seed (%)
	Normal seedling	Abnormal seedling	Hard seed	Fresh ungerm.	Dead seed	
18	0	0	0	0	100	0
22	0	0	0	8	92	8
26	5	12	0	13	70	30
30	28	18	16	14	25	75
34	23	7	62	4	4	96
38	2	3	85	0	10	90
41	6	0	92	0	2	98

Table 3. Quality of *L. corniculatus* seed harvested at various dates.

Harvest date	DAF	Germination test results (%)					Total viable seed (%)
		Normal seedling	Abnormal seedling	Hard seed	Fresh ungerm.	Dead seed	
15 Jan.	32	1	0	99	0	0	100
20 Jan.	--	1	0	98	0	1	99
26 Jan.	35	10	1	89	0	0	100
31 Jan.	--	5	0	95	0	0	100
6 Feb.	37	4	0	95	0	1	99
11 Feb.	--	1	0	86	0	1	99
16 Feb.	40	12	0	86	0	2	98
22 Feb.	--	10	0	85	0	5	95
3 Mar.	40	11	1	83	0	5	95

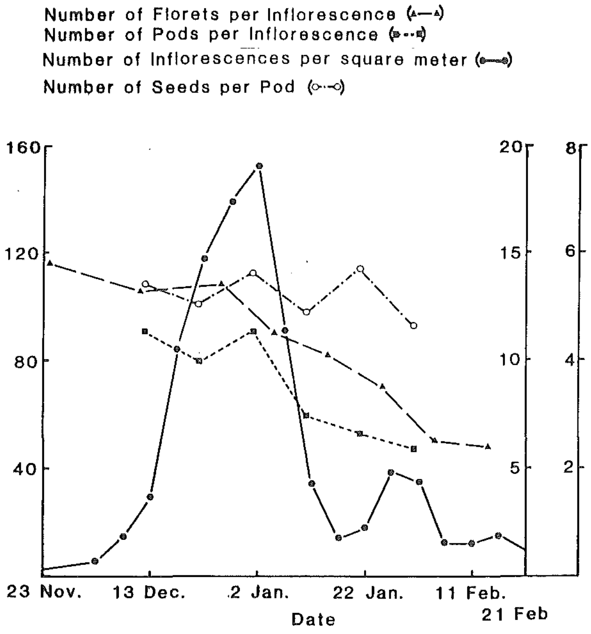

Figure 1. **Changes in seed yield components during the period of flowering in L. corniculatus.**

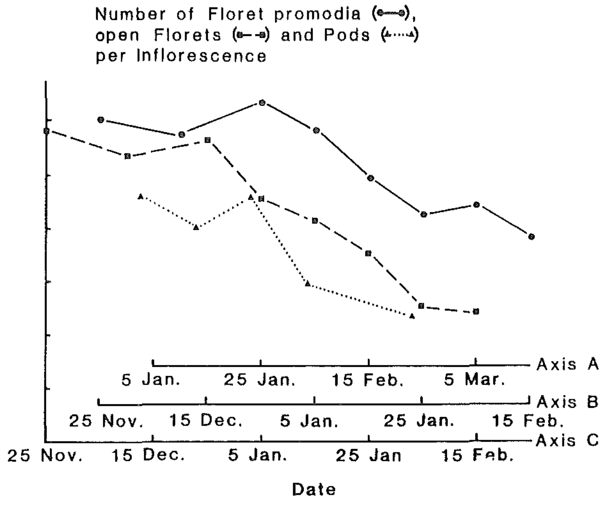

Figure 2. **Number of flower buds, open florets and pods per inflorescence in L. corniculatus at various dates (axes A, B, C are used to show the time sequence of pod, floret bud and open floret formation, respectively).**

small reduction in viability, however, all samples still retained a high level (>95%) of viable seeds. All seed lots contained a high percentage of hardseeds. Since all germination tests were conducted on 26 March, approximately one month after the last two seed collection dates, the slightly lower level of hardseededness in late harvested lots may have been affected by incomplete dehydration of seeds prior to germination testing.

Abortion at different stages of flower development: In order to investigate levels of seed abortion during reproductive development, the number of visible floret buds, number of blooming florets, and number of pods per inflorescence (umbel) were recorded and compared (Figure 2). The base scale (time axis) was adjusted according to time difference in the developmental sequence of the three components (about ten days from visible bud to blooming flower, and 20 days from blooming flower to premature pod). From the time of visible floral bud formation (representing pod bearing ability) to premature pod (representing actual pod carrying ability) there was a relatively constant loss of one pod regardless of time during the flowering season. This was due to the failure of blooming florets to set pods. It was observed that the 'one pod' loss was mainly due to the abortion of floral buds during the early flowering season, whereas in the late season it was due to failure of florets to form pods.

DISCUSSION

Protracted flowering and subsequent pod dehiscence have been identified by many researchers as the major obstacles to obtaining high seed yields in *L. corniculatus* (Buckovic, 1952; Anderson, 1955; MacDonald and Winch, 1957; Metcalfe et al., 1957; Seaney and Hanson, 1970; McGraw and Beuselinck, 1983). In seed production practice, these characteristics make it difficult to determine the precise harvest time for maximum seed yield. Information about the seed yield components which have the greatest effect in determining correct harvest time can assist in making accurate harvest recommendations.

The results of this study indicate that the number of inflorescences has the greatest single influence on seed yield in *L. corniculatus*, since greatest fluctuations occurred in this component throughout the flowering period. Other components showed comparatively smaller changes. Multiple regression analysis showed that the number of inflorescences per unit area was the main factor influencing final seed yield (r=0.97 at P=0.01). These results are in agreement with (Albrechtsen et al., 1966; Mos, 1983; Stephenson, 1984; McGraw et al., 1986). The result of this and other research covering a wide range of climatic situations, as well as a range of genotypes and management strategies, strongly suggests that number of inflorescences can be used as a guideline for deciding the most correct time of harvest. Since approximately 35 days is required for blooming flowers to develop into mature pods ready for harvest, it is recommended that the best seed recovery can be achieved by harvesting the crop about 35 days after maximum inflorescence numbers are observed.

Floret and seed development patterns in the present study are identical to those described by Anderson (1955) and are very similar to the results reported by Seaney and Hanson (1970). The seed viability and hardseed development sequences in the present study are also similar to the patterns described for Maku lotus (*L. uliginosis*) (Hare et al., 1959), although differences occurred in timing of onset and duration of each seed development stage. Since seed reached maximum viability at about 34 DAF by which time pod color had changed from dark brown to light tan, it is also recommended that pod color be used as a secondary guideline for deciding correct time of harvest. A similar recommendation was made by Hare and Lucas (1984) for Maku lotus.

Loss of potential seed yield as a result of abortion during the time between development of flower buds to mature pods is a common phenomenon in *L. corniculatus* mentioned by many workers (Giles, 1949; Bubar, 1958; Joffe, 1958; Seaney and Hanson, 1970; Stephenson, 1984). Self-incompatibility is considered to be one major cause of abortion in this species (Silow, 1931; Seaney, 1964); however, even when flowers are outcrossed, a large proportion of florets may still abort developing pods (Stephenson, 1984). The exact mechanisms affecting the number of abortive buds is unclear. Although Gauch and Dugger (1954) have reported that boron deficiency is a factor causing abortion in flowers and fruits, this has not been substantiated in *L. corniculatus*. Joffe (1958) investigated the effects of various factors including boron treatment, photoperiod, and temperature on abortion in flower buds of *L. corniculatus*. None of these factors were found to satisfactorily explain the cause or causes of bud abortion. Seaney and Hanson (1970) in their review of seed production in *L. corniculatus* showed that only 40% of the 20 to 70 ovules in an ovary develop into mature seeds, comparable figures were obtained in this study (11 to 14 seeds per pod). Stephenson (1984) reported that only one in three flowers produced a mature pod and three of five pods initiated subsequently aborted. He dismissed the possibility of abortion caused by lack of pollination and concluded that a lack of assimilate supply was responsible for limiting the reproductive output in *L. corniculatus*. If external factors such as unfavorable photoperiod, temperature, or pollination were responsible for high levels of abortion, the abortion rate would have varied during the extended flowering period. The constant 'one pod' loss which occurred throughout the flowering period strongly implicates the role of internal regulating mechanisms.

The contribution and values of seed yield components reported in this study are comparable with other reports (MacDonald, 1946; Seaney and Hanson, 1970). The calculated seed yield of 560 kg ha^{-1} (Fig. 1) also compares well with other reports (Seaney and Hanson, 1970; McGraw and Beuselinck, 1983; White et al., 1987), but is higher than average 200 to 350 kg ha^{-1} commercial seed yields in New Zealand J. Ballinger, Pers. comm.), about half of potential seed yield. The characteristic indeterminate growth habit and pod shattering of Lotus result in a lack of recovery of seed formed by early and late flowers. A more realistic estimate of seed yield potential is to consider only those inflorescences produced during the 20-day peak flowering period from 20 December to 10 January (Fig. 1). This estimate indicates a harvestable seed yield of 420 kg ha^{-1}. More attention should be given by seed growers to the timing of the harvesting and handling operations to recover this yield potential.

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REFERENCES

1. Albrechtsen, R.S., R.L. Davis, and W.F. Keim. 1966. Components of seed yield and associated characteristics in *Lotus corniculatus* L. Crop Sci. 6:355-358.
2. Anderson, S.R. 1955. Development of pods and seeds of birdsfoot trefoil, *Lotus corniculatus* L., as related to maturity and to seed yields. Agron. J. 47:483-487.
3. Bubar, J.S. 1958. An association between variability on ovule development within ovaries and self-incompatibility in Lotus (Leguminosae). Can. J. Bot. 36:65-72.
4. Buckovic, R.G. 1952. Some of the morphological and agronomic factors associated with pod dehiscence in *Lotus corniculatus* L. M.S. thesis, Oregon State College, Corvallis.
5. Gauch, G., and W.M. Dugger. 1954. The physiological action of boron: A review and interpretation. Univ. Maryland Agric. Exp. Sta. Bull. A-80 (tech).
6. Giles, W.F. 1949. The morphological aspects of self-sterility in *Lotus corniculatus*. Ph.D. Thesis, University of Missouri.
7. Hare, M.D., and R.J. Lucas. 1984. 'Grasslands Maku' Lotus (*Lotus pedunculatus* (Cav.)) seed production. 1. Development of Maku Lotus seed and the determination of time of harvest for maximum seed yield. J. of Appl. Seed Prod. 2:58-64.
8. Hyde, E.O.C., M.A. McLeavey, and G.S. Harris. 1959. Seed development in ryegrass and in red and white clover. N.Z. J. of Agric. Res. 2:947-952.

9. ISTA. 1985. International rules for seed testing, Annexes. Seed Sci. and Technol. 13(2):444.

10. Joffe, A. 1958. The effect of photoperiod and temperature on the growth and flowering of birdsfoot trefoil (*Lotus corniculatus* L.). S. Afri. J. of Agric. Sci. 1:435-446.

11. Li, Qingfeng, and M.J. Hill. 1988. An examination of different shoot age groups and their contribution to the protracted flowering pattern in birdsfoot trefoil (*Lotus corniculatus* L.). J. of Appl. Seed Prod. 8:54-62.

12. MacDonald, H.A. 1946. Birdsfoot Trefoil (*Lotus corniculatus* L.): Its characteristics and potentialities as a forage legume. Cornell Univ. Agric. Exp. Sta. Memoir 261. 188 pp.

13. MacDonald, H.A., and J.E. Winch. 1957. Birdsfoot trefoil seed production. Cornell Univ. Dept. of Agron. Memor. 57-18. Cornell Univ., Ithaca, NY.

14. McGraw, R.L., and P.R. Beuselinck. 1983. Growth and seed yield characteristics of birdsfoot trefoil. Agron. J. 78:201-205.

15. McGraw, R.L., M.P. Russelle, and J. Grava. 1986. Accumulation and distribution of dry mass and nutrients in birdsfoot trefoil. Agron. J. 78:124-131.

16. McGraw, R.L., P.R. Beuselinck, and K.T. Ingram. 1986. Plant population density effects on seed yield of birdsfoot trefoil. Agron. J. 78:201-205.

17. Metcalfe, D.S., I.J. Johnson, and R.H. Shaw. 1957. The relationship between pod dehiscence, relative humidity and moisture equilibrium in birdsfoot trefoil, *Lotus corniculatus* L. Agron. J. 49:130-134.

18. Mos, M. 1983. Components of seed yield in Polish varieties of birdsfoot trefoil (*Lotus corniculatus* L.). Agraria 22:75-87.

19. Seaney, R.R. 1964. Cross and self seed set in birdsfoot trefoil plants selected for self-fertility. Crop Sci. 4:440-441.

20. Seaney, R.R., and P.R. Hanson. 1970. Birdsfoot Trefoil. Adv. in Agron. 22:119-157.

21. Silow, R.A. 1931. Self-sterility of Lotus species. Welsh Pl. Breed. Sta. Bull. 12:234-240.

22. Stephenson, A.G. 1984. The regulation of maternal investment in an indeterminate flowering plant (*Lotus corniculatus* L.). Ecology 65(1):113-121.

23. White, S.K., R.L. McGraw, and M.P. Russelle. 1987. Effect of growth retardants on seed yield of birdsfoot trefoil. Crop Sci. 27:608-610.