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SEED DEVELOPMENT AND THE INFLUENCE OF SEVERITY
AND DATE OF DEFOLIATION AND PLANT POPULATION
UPON SEED YIELDS IN
'GRASSLANDS MAKU' LOTUS (*LOTUS PEDUNCULATUS* Cav.)

A thesis
Submitted in partial fulfilment
of the requirements for the degree
of
Master of Agricultural Science
in the
University of Canterbury
New Zealand

by
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Lincoln University College of Agriculture
1983

SEED DEVELOPMENT AND THE INFLUENCE OF SEVERITY AND DATE OF
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'GRASSLANDS MAKU' LOTUS (*LOTUS PEDUNCULATUS* Cav.).

by

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ABSTRACT

Studies of Maku lotus seed production were investigated over two seasons on a fertile silt loam to sandy loam soil complex (pH 6.1, Olsen P 24) at Lincoln College, Canterbury, New Zealand (43° 38'S).

Seed development investigations showed that the optimum time to commence harvesting was two to four days after seed maturity, when the seeds had 35% moisture content, the pods were light brown in colour and three to four per cent pod shatter had occurred. Pollination to seed maturity (maximum 1,000 seed dry weight; 0.70 g 1982, 0.71 g 1983) took 27 days in 1982 and 35 days in 1983. High daily temperatures and vapour pressure deficits caused rapid seed ripening in 1982 and increased pod shatter from 4%, 31 days after pollination, to 82%, 43 days after pollination. Cooler weather in 1983 resulted in slower seed ripening and reduced pod shatter to only 13%, 47 days after pollination.

Cutting to ground level after spring growth commenced significantly reduced Maku lotus seed yields. Maximum seed yields were from uncut treatments, 47 g m⁻² (1982) and 49 g m⁻²

(1983). Cutting to ground level (a) before bud appearance (September 29th, 1982 and October 20th, 1982) reduced seed yields (28 g m^{-2} and 14 g m^{-2}), and (b) after bud appearance (from mid-November to mid-December 1982 and on November 11th 1982) produced negligible yields. In 1982/83 topping before bud appearance produced seed yields (40 and 41 g m^{-2}) which were not significantly different from uncut treatments (49 g m^{-2}). Topping after bud appearance significantly reduced seed yields (26 g m^{-2}) compared with the uncut treatment. The results indicate that Maku lotus should not be cut after spring growth commences, if maximum seed yields are to be achieved.

In the first year of establishment, plant populations of 22 and 33 plants metre^{-2} in 0.45 m and 0.30 m inter-rows, produced significantly higher seed yields (86 and 88 g m^{-2}) than populations of 66 and 133 plants metre^{-2} in 0.15 m inter-rows (61 and 63 g m^{-2}). The evidence suggests that in second and subsequent years, Maku lotus plant populations of 22 plants metre^{-2} or less in 0.45 m inter-rows will produce maximum seed yields.

Keywords

Maku lotus; *Lotus pedunculatus* Cav; seed production; seed development; cutting time; cutting height; plant population.

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CHAPTER 1

INTRODUCTION

Lotus pedunculatus cv. Maku is particularly suitable as a pasture legume on acid soils and in areas of high rainfall. Maku lotus produces more dry matter than white clover under these conditions, where soil phosphate levels are often low, because it can absorb phosphate more efficiently than white clover. In developing hill country pastures, farmers have had to rely on oversowing white clover and applying relatively high rates of superphosphate to produce productive pastures quickly. Rising superphosphate prices have increased the cost of hill country development. To economise on fertilizer use in developing hill and high country, Maku lotus is now looked upon as a cheaper replacement for white clover because no lime or superphosphate needs to be used in order to achieve good dry matter production of Maku lotus (Charlton, pers.com.).

Maku lotus has been successfully oversown on tussock grasslands in the South Island where it has produced up to three times the herbage yield of white clover without fertilizer application. The wet pakihi soils of Westland are being developed by using Maku lotus and no fertilizer. Maku lotus has proved to be most successful in the stabilisation of eroded high country forest areas, and in providing grazing for sheep and cattle under trees in North Island forests. Other valuable features of this legume include its resistance to grass grub and porina, and condensed tannins in the herbage which prevents bloat in grazing cattle (Charlton, 1983).

However, Maku lotus does have limitations as a pasture plant in that it can not be subjected to frequent hard grazings as white clover can. It is very slow to recover from close defoliation and so must be leniently grazed (Sheath, 1980). It will not germinate until temperatures approaching 20°C occur (Charlton, 1977). Maku lotus' high temperature requirement and slow response following grazing limits the length of it's growing season and the amount of grazing it can be subjected to.

Since Maku lotus was released for commercial seed production in New Zealand in 1975, the main problem has been the low and unreliable seed yields obtained by seed growers. In 1982, 46.3 tonnes of certified machine dressed seed were harvested from 520 hectares throughout New Zealand for an average seed yield of 89 kilogrammes per hectare (Ministry of Agriculture and Fisheries, 1983). The low seed yields, together with the strong demand for seed by forestry and some farmers, boosted seed prices of Maku lotus to high levels. These high seed prices have reduced its use by many farmers who regard Maku lotus as too expensive to oversow on to acid high country soils. The situation has now been reached where many seed growers are either unable to sell their seed because of buyer resistance, or the prices offered to them are uneconomic given the low seed yields and high costs of seed production.

Low seed yields and the consequent high cost per kg of seed production have been caused by the following common errors in management and difficulties experienced by seed growers:

1. Unsuitable sites chosen leading to crop failures during establishment, because of poor germination and competition from weeds, clover and grass.
2. Incorrect herbicide applications which have often severely damaged seed stands.
3. Closing seed crops too late in the season for maximum seed set.
4. Insect attacks on developing flowers.
5. Seed losses through pod shatter, before and during harvest.

Weed control problems have been overcome to a certain extent by farmer experience and research by M.P. Rolston of Grasslands Division, Department of Scientific and Industrial Research (D.S.I.R.). Strategies for controlling insects have been developed from research by P.T.P. Clifford and J.A. Wightman of Grasslands Division and Entomology Division, D.S.I.R. respectively. Some of the other difficulties of Maku lotus seed crop management have been investigated in a limited manner only. Further research work was required to indicate ways to increase seed yields and bring the price of seed down, so that graziers could afford to oversow this pasture legume. It was decided that this research project should look at four areas of Maku lotus seed production, optimum time of harvest, closing date, cutting height and plant population.

1. OPTIMUM TIME OF HARVEST

Potentially high seed yields of Maku lotus have been lost through pod shatter caused by farmers misjudging the correct time to harvest and harvesting too late. Pods have either shattered in the stand before harvesting or shattered during windrow drying after mowing. The objectives of this study were:

- a) to describe the growth and development of Maku lotus flowerheads, particularly from pollination to seed maturity and pod shatter, so that farmers would be assisted in judging optimum harvest time.
- b) to test the hypothesis that harvesting operations could start before seed pods were fully ripe, brown and sensitive to shattering.

2. CLOSING DATE

A wide range of closing dates from spring to early summer, have been used by farmers, either following their experience with other herbage legume seed crops or in the belief that reliable seed yields would result from reduced pod shattering during autumn harvests. The objective of this study was to impose a range of closing dates by cutting, in order to test the hypothesis that any cutting treatment from the start of spring growth onwards would be detrimental to seed yields.

3. CUTTING HEIGHT

By allowing an early attack on Maku lotus flowerheads by potato mirids (*Calocoris norvegicus*) and then controlling the mirids with an insecticide, Clifford, Wightman and Whitford (1983) increased stem branching and potential seed yields of Maku lotus. The objective of this study was to test the hypothesis that a high topping, in the absence of a mirid attack, would promote stem branching in the crop leading to increased seed yields.

4. PLANT POPULATION

Seed growers, by sowing between two and four kg ha⁻¹ of Maku lotus seed in order to establish a dense seed crop, have incurred considerable investment costs in buying seed. The objective of this study was to reduce seed crop sowing rates, by testing the hypothesis that plants under low populations would compensate to give higher seed yields per unit area than under high populations.

The overall objective of this research was to develop some important management strategies to produce reliable high seed yields of Maku lotus. These high seed yields would hopefully allow the seed price to fall to levels still giving an economic return to seed growers, but enabling graziers to purchase the seed, thereby establishing a strong and reliable market for Maku lotus seed.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This review will examine the *Lotus* genus, *Lotus* species in New Zealand, the breeding of Maku lotus and briefly, specific aspects of herbage legume seed production pertinent to this research project. These aspects include plant population, closing dates implemented by grazing or cutting, flowering, pollination, seed development and optimum harvesting time, and they will be reviewed in detail in the introductions to Chapters three, four and five.

2.2 *LOTUS*

2.2.1. The *Lotus* genus.

The *Lotus* genus consists of a range of annual and perennial species widely distributed throughout the world. These species show a great diversity in form and they are widely adapted to habitats ranging from sea-level to above 3000 metre altitudes, and from wet soils to xerophytic desert conditions (Grant, 1965).

There are approximately 100 different species in the genus (Polhill and Raven, 1981; Allen and Allen, 1981). The *Lotus* genus is a very difficult genus to classify and there has been considerable disagreement among systematists as to whether to include the genus *Tetragonolobus* in *Lotus* (Callen, 1959; Zandstra and Grant, 1967). This genus is not included now, but debate still continues over the inclusion of some subgenera from North America and Mediterranean areas (Polhill and Raven, 1981).

Lotus originates from two main geographical centres: the Mediterranean areas and western North America. Two species, *Lotus cruentus* and *L. australis* are endemic to Australia (Larsen and Zertova, 1965).

Chromosome numbers in *Lotus* vary from diploids ($2n = 2x=12$ and 14) to tetraploids ($2n = 4x = 24$ and 28) (Polhill and Raven, 1981).

Only a few *Lotus* species are of importance in agriculture. *Lotus corniculatus* is the most widely used, especially in the northern United States and Canada, for hay and silage (MacDonald, 1946; Seaney and Henson, 1970). This perennial species is also used for roadside sowings in Canada (Turkington and Franko, 1980). *Lotus pedunculatus* has been developed in New Zealand as a pasture plant, where drainage is a problem and overall soil infertility is low (Charlton, 1983). With the recent breeding of *Lotus pedunculatus* cv. Maku, the range of habitats has been extended to include high country tussock pastures low in pH and phosphate. *Lotus creticus* is used for controlling sand dunes in Israel (Tsurieil, 1979; 1980).

2.2.2 *Lotus* in New Zealand

Lotus pedunculatus (perennial diploid) is widespread throughout New Zealand, including the Kermadec Islands, Chatham Islands, Stewart Island and Campbell Island (Webb, 1980). It is naturalized in wet swampy areas where soil fertility is low and grazing pressure is light or absent (Charlton, 1983).

L. pedunculatus was first recorded in the Auckland district in 1867 by Kirk (1867), who observed it growing along

ditches. Cheeseman (1883) reported that *L. pedunculatus* was growing abundantly in fields and waste places in the North and South Islands.

Seed of *L. pedunculatus* was imported mainly from Germany (Levy, 1918), with some later imports from Canada (Hill, pers. com.) and from Chile (Charlton, pers. com.). Seed was first produced locally in the Auckland district (Levy, 1918) and later in Southland (Anon, 1924; 1938).

L. pedunculatus was successfully used by pioneering New Zealand farmers to develop pastures on unfertilized bush burn areas and low lying marshes (Levy, 1932; Saxby, 1948). It was listed by Saxby (1956) as one of the four most important pasture legumes in New Zealand along with white, red and subterranean clovers.

Two annual species, *L. angustissimus* (diploid) and *L. suaveolens* (tetraploid) are found in low fertility dry areas particularly in the northern North Island (Charlton, 1983).

L. suaveolens (synonyms, *L. hispidus* & *L. subbiflorus*) was used extensively as a pioneer plant in Northland (Saxby, 1956).

L. corniculatus (perennial tetraploid) has not been widely planted in New Zealand. The rhizobia which effectively nodulate *L. corniculatus* are not present in New Zealand soils (Charlton, Greenwood and Clark, 1981). It may become important as a dryland legume for poorer hill country (Scott and Charlton, 1983). *L. tenuis* (perennial diploid) is only found in a few areas, but it does appear suitable for roadside soil conservation (Charlton, 1983).

2.2.3 Nomenclature of *Lotus pedunculatus*

Systematists disagree as to whether to name the species *Lotus pedunculatus*, or to divide it into two species, *L. pedunculatus* and *L. uliginosus*. Europeans call the species *L. uliginosus* and only use *L. pedunculatus* for the larger leaf types from Spain and Portugal. New Zealand systematists believe that there is not sufficient difference between the types and therefore consider that the older name, *L. pedunculatus*, should be the only name (Forde and Webb, pers. com.). Seed for export must be renamed *L. uliginosus* as the European based International Seed Testing Association uses *L. uliginosus* for what New Zealand calls *L. pedunculatus*.

The common name for *L. pedunculatus* in New Zealand is lotus major, which was an earlier scientific name (Webb, 1980). In Europe, England, Canada and the United States, it is called 'greater marsh' or 'large birdsfoot' trefoil (MacDonald, 1946). This is because it is larger than birdsfoot trefoil (*L. corniculatus*) and is commonly found in marshy areas whereas birdsfoot trefoil is found in drier areas. The name birdsfoot comes from the way the seed pods are borne at right angles at the top of the peduncle resembling a birdsfoot. Trefoil is an erroneous name, as it was originally thought that *Lotus* species had three instead of five leaflets. The pair of basal leaflets were mistaken as stipules. The true stipules are now found to be small erect projections close to the petioles of the basal leaflets on either side of the stem. The two basal leaflets are therefore included in the five leaflets making up the entire leaf (MacDonald, 1946).

2.2.4 Breeding of *Lotus pedunculatus* cv. Maku

Maku lotus is a tetraploid cultivar of *L. pedunculatus* bred at Grasslands Division, D.S.I.R., Palmerston North by Dr P.C. Barclay (Barclay and Lambert, 1970; Armstrong, 1974).

A spaced plant block with collections of diploid *L. pedunculatus* from throughout New Zealand was planted at Palmerston North in 1951. After several seasons of assessment for dry matter production, nine elite plants were selected and inter-pollinated to produce G.4701 which had greater dry matter yield and a dense leafy habit compared with naturalized New Zealand lines of *L. pedunculatus*.

Treatment of G. 4701 with colchicine, followed by three generations of recurrent selection resulted in the development of an induced tetraploid, G. 4702. This cultivar was based on 13 elite parent plants, had larger seeds, greater seedling vigour and was more productive than G. 4701.

New Zealand lines tend to be summer active and winter dormant. Mediterranean lines are winter active in New Zealand. Two diploid selections, G. 4703 and G. 4704, were produced from crossing New Zealand and Portuguese lines in 1957. G.4703 was the better of the two with good summer and winter growth and a dense prostrate habit; it was the most persistent of all the diploids under grazing.

In 1958, G. 4702 was crossed with colchicine-induced tetraploid Portuguese collections. With selection emphasis on good winter growth and less prostrate growth habits, the F₁ plants were backcrossed with G. 4702. Recurrent selection within this material led to the production of G. 4705.

G. 4705 had increased seed size and seedling vigour over the diploid lotus selections. It was more productive than other legumes on the Westland pakahi soils and when over-sown in tussock hill country where grazing pressure was low. It also was the most productive in the stabilization of eroded hill country forest areas in the South Island. Because of its overall performance in many areas (R. Brougham pers. com.), G. 4705 was released commercially in 1975 as the cultivar Grasslands Maku.

Most of the features found in Maku lotus are probably inherent in other *Lotus pedunculatus* selections as well. Maku lotus grows well on acid soils without fertilizer and under low phosphate conditions (Brock, 1973; Kiang, 1981) and it is resistant to grass grub and porina (Farrell and Sweney, 1972; Farrell, Sweney and Jones, 1974). Bloat in grazing cattle is prevented by condensed tannins in Maku lotus and other *Lotus pedunculatus* selections (John and Lancashire, 1981). However, Maku lotus will not compete with the more vigorous growth of white clover on higher fertility soils (pH > 5.2) (Lowther, 1980); it has low winter dry matter production especially in the South Island, poor low-temperature germination (Charlton, 1977) and does not tolerate frequent close grazing (Sheath, 1980).

2.3 SEED PRODUCTION OF HERBAGE LEGUMES

Herbage legumes have been selected for superior growth, nutritive value, establishment characteristics and persistence. Rarely has there been additional selection for seed productivity.

Considerable reliance is therefore placed upon the improvement of agronomic techniques to maximise seed yields.

2.3.1 Plant population

From the literature it appears that annual herbage legumes will give maximum seed yields at considerably higher populations than perennial herbage legumes. The perennial legumes appear to be more plastic than annual legumes and will branch and produce more seed under low rather than high populations. The perennial plants are therefore much larger than annual plants at optimum populations.

For maximum seed yields the optimum population for annual herbage legumes has been found to be approximately 250 plants metre⁻² (Donald, 1954; Shelton and Humphreys, 1971), but for perennial herbage legumes the optimum population has been found to be considerably lower at approximately 20 plants metre⁻² (Clifford, 1974; Kowithayakorn and Hill, 1982a). Above these populations the plants in both annual and perennial species became so weak through plant competition that higher plant population failed to compensate for the low yield of individual plants. Stem barrenness (non-flowering stems) was a major characteristic associated with dense populations.

The spatial arrangement of herbage legumes for maximum seed yields has not been investigated in depth. Trials using different row spacings usually have low plant populations at wide row spacings and high plant populations at narrow row spacings. It is not clear whether the wide rows or low populations produce the highest seed yields. However, in the few reported experiments where plant populations have remained the

same, narrower row spacings (0.15 - 0.30 m) usually produced more seed than wider row spacings (0.45 - 0.90 m), especially in the first year (Clifford, 1977; Pankiw, Bonin and Lieverse, 1977). Row sowing of perennial herbage legume seed crops is now favoured over broadcast sowing, mainly because of the ease of management that row-spaced seed crops give to the farmer (Clifford, pers. com.).

2.3.2 Closing date

Farmers implement closing dates by spraying herbicides, grazing or cutting at the time of closing. In this review only grazing or cutting at closing will be examined.

Defoliation of seed crops at closing, whether by grazing or cutting, is usually characterized by its frequency and severity and by its timing in relation to the developmental stage or environmental conditions. The common response to apex removal before they become sexual, is to promote the vegetative expansion of axillary buds which results in increased branching and bud density.

This occurred in both *Trifolium subterraneum* and *Stylosanthes humilis*, both annual legumes. Frequent and fairly severe grazing and cutting of pure swards of *T. subterraneum* prior to flowering increased seed production by approximately 30% (Rossiter, 1961; Collins, 1973). Similar increases occurred in *S. humilis* (Fisher, 1973). The seed yield increases were due primarily to a larger number of inflorescences in defoliated treatments.

In most cases, however, defoliation after floral initiation reduces seed production. *Trifolium subterraneum* (Rossiter, 1961; Collins, 1978) and *S. humilis* (Loch and Humphreys, 1970; Fisher, 1973) suffered large decreases in seed yield following

defoliation at floral initiation. Similar seed yield decreases following defoliation at bud or flower appearance have been reported for *Medicago sativa* (Melton, 1972; Abu-Shakra, Bhatti and Ahmed, 1977; Kowithayakorn and Hill, 1982a), *Lotus corniculatus* (Anderson and Metcalfe, 1957; Bader and Anderson, 1982), *Stylosanthes guianensis* (Loch, Hopkinson and English, 1976) and *Trifolium pratense* (Dade, 1966).

Late defoliations may shift the flowering time further into the season. Floret abortion in *S. humilis* occurred when late defoliations caused late flowering to occur under cool autumn night conditions (Loch and Humphreys, 1970). This also occurred with *S. hamata* (Wilaipon and Humphreys, 1976).

With long-day plants late defoliations can cause peak flowering to shift to times of decreasing photoperiods. Mid-December defoliation of *Trifolium repens* cv. Huia shifted flowering to January and the decreasing day lengths caused a 50% reduction in most components of seed yield compared to mid-November defoliation (Clifford, 1979a). However, later flowering *Trifolium pratense* cultivars all increased seed yields with December defoliation compared to November defoliation (Clifford, 1979b).

Therefore, time of closing by defoliation varies between the species and cultivars, but in all instances defoliation after floral initiation decreased seed yields.

2.3.3 Flowering

Photoperiod is the dominant factor controlling the time of flowering and this is influenced by latitude. Temperature and moisture will also influence the flowering response of herbage legumes. In general, tropical herbage legumes respond

to short days and temperate herbage legumes respond to long days

Lotus sp. appear to need more than 14 hour photoperiods to flower. *Lotus corniculatus* flowers in 14 to 16 hour photoperiods in a series of flushes (Joffe, 1958; McKee, 1963). Its extended flowering period makes timing of harvest difficult (MacDonald, 1946). No photoperiod responses have been reported for Maku lotus, but a north German variety of *Lotus pedunculatus* needed 14 to 16 hour photoperiods to flower (Forde and Thomas, 1966).

2.3.4 Pollination

Reproductive systems of herbage legumes vary from close, often cleistogamous, self-fertilization of many of the tropical legumes to the self sterile cross-pollinated perennial temperate legumes (Humphreys, 1981). Many of these legumes will not fit precisely into a group, but will occupy an intermediate position; this position is also varied by climate. For example, in the absence of suitable pollinators because of unfavourable climatic conditions, some cross-fertilized legumes will self-fertilize (Poehlman, 1977).

The pollination of cross-fertilized legume flowers depends upon the accidental result of food gathering by bees and other insects. Irrespective of the number and type of pollinating bees in an area where seeds of herbage legumes are produced, the number of flowers pollinated and the ultimate yield of seed will depend upon weather conditions during the critical flowering period and upon the quality of the flowers as a source of food for bees. These conditions have been

discussed by Doull (1967) for *Medicago sativa*, Clifford (1980) for *Trifolium repens*, Clifford (1973), Win Pe (1978) and Clifford and Anderson (1980) for *T. pratense* and Seaney and Henson (1970) for *Lotus corniculatus*.

Different types of pollinating mechanisms are present in different legumes. Lucerne flowers must be 'tripped' to disperse pollen. The long corolla tube of *T. pratense* cv. Pawera means that only long-tongued bumble bees are effective pollinators of this legume (Clifford and Anderson, 1980). In *Lotus corniculatus*, pollen is dispersed by means of a 'piston apparatus' (MacDonald, 1946; Seaney and Henson, 1970).

2.3.5 Seed development

The term 'development' has been described as a progress of a series of internal qualitative changes (with or without external changes) governed by factors of the environment, which lead ultimately to the production of fruit, and in annual plants to death (Satter and Goode, 1967). These changes have been studied in several herbage legumes and are detailed in Chapter three.

2.3.6 Optimum time to harvest

It is extremely important to harvest a crop at the correct time in order to obtain maximum yields of high quality seed and to minimize seed losses through pod shattering, inefficient harvesting and cleaning. Schwass (1973) said that the optimum time to harvest a crop is largely a matter of experience, but by studying closely the growth and development of herbage legumes, more precise advice can be given.

Many reports indicate that colour changes in seed heads, pods or seeds are the best indicators of when to harvest the seed crop. According to Martin and Leonard (1967) the best time to cut *Trifolium pratense* for seed is when the seed heads turn brown and the flower stalks turn a deep yellow; at this stage the seeds show a distinct yellow colour. Jolly (1958) and Davies (1960) state that *T. repens* is ready to harvest when the majority of the seed heads are light brown and the seeds are yellow and hard. The optimum time to harvest *T. repens* according to Scott (1973) is when 80-90% of the seed heads are brown and mature and the seeds can be rubbed out in the hand.

When 70-80% of Maku lotus seed pods have turned brown the crop is ready to harvest (Lancashire, Gomez and McKellar, 1980). Neal (1983), however, states that for a Maku lotus seed pod to be ripe it must be changing on the under side from a green to a yellowish brown colour and must snap cleanly when broken between the fingers. The seed must be turning from green to yellow and must not be able to be squashed.

However, seed shedding and pod shattering of mature seed, particularly if there is uneven seed development in crops, further complicates judgement of optimum harvesting time. Pod shattering has long been a problem in *Lotus corniculatus* and Boitel in 1893 said: 'unfortunately its pod opens at maturity and spreads its seed upon the ground. It is therefore impossible to save it in any quantity. Thus one prefers to birdsfoot trefoil other legumes which are not worth less as forage, and whose seed can be obtained more cheaply.'

Anderson (1955) showed that it is not necessary to delay harvest of *Lotus corniculatus* seed until the pods are fully

dry and dark brown in order to obtain high quality seed. Seeds from light green and light brown pods produced mature seed and these seed pods did not shatter easily under drying conditions. Wiggins et al (1956) stated that seeds of *Lotus corniculatus* became mature approximately seven to ten days before the seed pods shattered. This gives the grower time to apply desiccating chemicals and harvest the seed before shattering occurs. Wiggins et al (1956) found that as chemically desiccated crops were quicker to harvest than crops mowed and dried in windrows, seed losses through pod shattering were minimized, and seed yields increased.

With many tropical legumes such as *Stylosanthes scabra* cv. Seca growers must judge when the rate of increase of ripe seed from new inflorescences just balances the loss of high quality seed from earlier inflorescences (Thomson and Borges de Medeiros, 1981). Klein and Harmond (1971) state that in temperate legumes, optimum mowing time is the result of a balance between seed crop weight gain, germination gain, shatter loss and combining loss. By drawing moisture curves from three years' accumulated data they recommended mowing *Trifolium incarnatum* and *T. subterraneum* at seed moisture contents of 35% and 22% respectively, to obtain maximum pure live seed yields. Moisture meters used by farmers help determine these optimum moisture percentages for mowing.

Despite the closest attention to harvesting detail, farmers rarely reap the full seed yield potential from seed crops (Lay, 1980). In white clover, seed losses during harvesting average about 30% (Clifford, 1980) and can be as high as 75% (Scott, 1973). From the literature, there appears to

be a lack of research by agricultural engineers on improving equipment for harvesting herbage legume seed crops after the agronomists have identified optimum harvesting times.

CHAPTER 3

DEVELOPMENT OF MAKU LOTUS SEED
AND THE DETERMINATION OF TIME OF HARVEST
FOR MAXIMUM SEED YIELDS.

3.1 INTRODUCTION

The low seed yield of Maku lotus and the high costs in establishing a good seed crop have resulted in very high seed prices, which have been a primary obstacle to the more rapid adoption of this herbage legume. Higher seed yields are necessary before seed growers can accept lower prices.

Farmers' experiences have shown that one of the primary factors causing low seed yields of Maku lotus has been pod shatter. With newly formed flowers, immature pods and ripening pods all present on individual plants, farmers have found it difficult to judge the proper time for seed harvest, and many pods have shattered before harvest, or during sward drying (Lancashire et al, 1980).

It is only by studying the growth and development of herbage legumes that optimum harvesting times can be determined, especially by noting the changes in seed development. 'Seed maturity' is the point at which maximum dry weight is first reached (Hyde, 1950; Anderson, 1955). 'Seed ripeness' is defined as the point when the seed has dried to a moisture content in equilibrium with the surrounding atmosphere (Hyde, 1950), or the point when the seed has dried to a moisture content suitable for harvesting (Hill, 1971).

'Seed viability' is the capacity of the seed to resume growth after having been dried (Hyde, 1950). Only normal seedlings can be counted in the percentage germination under the International Seed Testing Association (I.S.T.A.) rules (Wellington, 1970). These normal seedlings are described by Wellington (1970) as having a well developed root system, hypocotyl, shoot apex (not always visible at the end of the test period), and two undamaged cotyledons. A seedling must not be classified as normal if any of the above structures are damaged. If the seed coat still covers the cotyledons at the end of the test period it must be peeled back to determine their state (Wellington, 1970).

Hyde (1950) first described three stages of seed development in herbage legumes: the growth stage, the food reserve accumulation stage and the ripening stage. This course of seed development in some herbage legumes has since been studied (Hyde et al, 1959; Win Pe, 1978; Kowithayakorn and Hill, 1982b). Maximum viability was reached four to seven days before seed maturity in these studies. Seed maturity was reached in 25 days after pollination in *Trifolium repens* (Hyde, McLeavey and Harris, 1959), 20 days in *T. pratense* cv. Hamua (Hyde et al; 1959), 26 days in *T. pratense* cv. Pawera (Win Pe, 1978), 40 days in *Medicago sativa* (Kowithayakorn and Hill 1982b) and 26 days in *Lotus corniculatus* (Anderson, 1955). By mowing or desiccating the crop at seed maturity and allowing the seed to ripen in the sward, Wiggins et al, (1956) reduced pod shatter and increased seed yields of *Lotus corniculatus*.

Thus, to test the hypothesis that seed maturity will be reached before seeds are fully ripe, enabling an earlier harvest date to take place for maximum seed yields, changes were studied in moisture content, dry weight and germination capacity of Maku lotus seed as related to pod colour changes and pod shattering.

3.2 MATERIALS AND METHODS

The trial was conducted at Lincoln College, Canterbury (43° 38'S.) over the 1981/82 and 1982/83 summer seasons. Plants sown in November 1980 on a Wakanui soil complex (Table 3.1) were thinned to a population of one plant per square metre for the trial. The soil profile overall was of variable texture with sand lenses at varying depths. The soils were susceptible to water-logging during the winter and dried out rapidly and cracked during the summer.

Table 3.1 Wakanui soil complex in Maku lotus field

1. Description

- A horizon; 0.25-0.30 m in depth, mainly silt loam
- B horizon; 0.30-0.70 m in depth, mainly sandy loam, with many mottles, overlying either sand or glazed sandy loam.

2. M.A.F. soil quick test (Cornforth and Sinclair, 1982)

Date	pH	Ca	K	Olsen P
October 1980	6.1	14	8	27
January 1982	6.1	13	8	24

Umbel development from bud appearance through to pollination was observed on one marked umbel on each of 10 plants. On December 14th, 1981 and December 17th, 1982, 20 pollinated umbels on each of 30 plants (total of 600 umbels) were marked at peak flowering.

Peak flowering was determined to have been reached when 50% of the umbels on the plants had yellow flowers, 20% had green pods and 30% had orange buds. Umbels were determined to have been pollinated when 30 to 90% of the florets were open and the petals were slightly wilting. It was not possible to obtain 20 umbels per plant all with the same number of open florets per umbel.

Umbels in both years at marking were towards the top of the plant canopy. In December 1982, new vegetative growth appeared which put the second season's marked umbels towards the middle of the plant canopy. Umbels in the first season at the top of the canopy experienced hotter, drier weather than umbels in the second season, especially from 27 to 43 days after pollination (Figures 3.1, 3.2, 3.3). (Detailed weather data is presented in Appendix 1.).

Every four days from 19 days (1981/82) and 15 days (1982/83) after pollination two umbels per plant were collected. In 1982/83 the plants were divided into four groups in order to determine standard errors of mean between groups. The following observations were made:

- i. Pod colour changes
- ii. Pod number per umbel
- iii. Shattered pod number per umbel
- iv. Seed fresh weight, dry weight and moisture percentage.

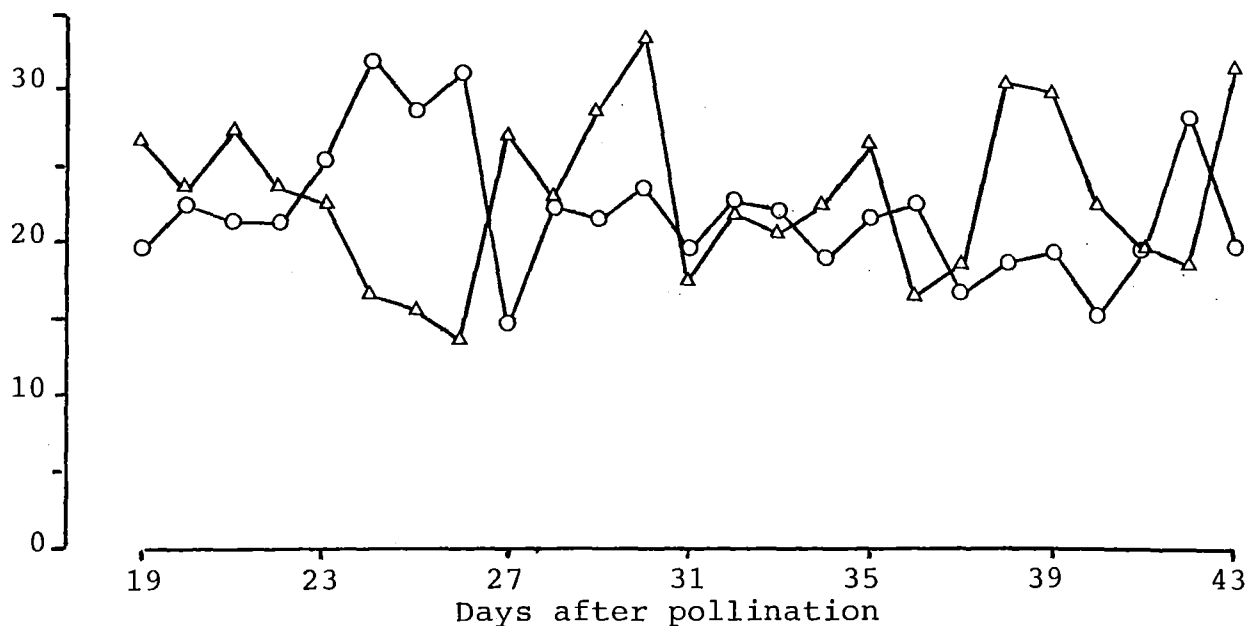


Figure 3.1 Maximum temperatures from 19 to 43 days after pollination (Triangles 1982; Circles 1983)

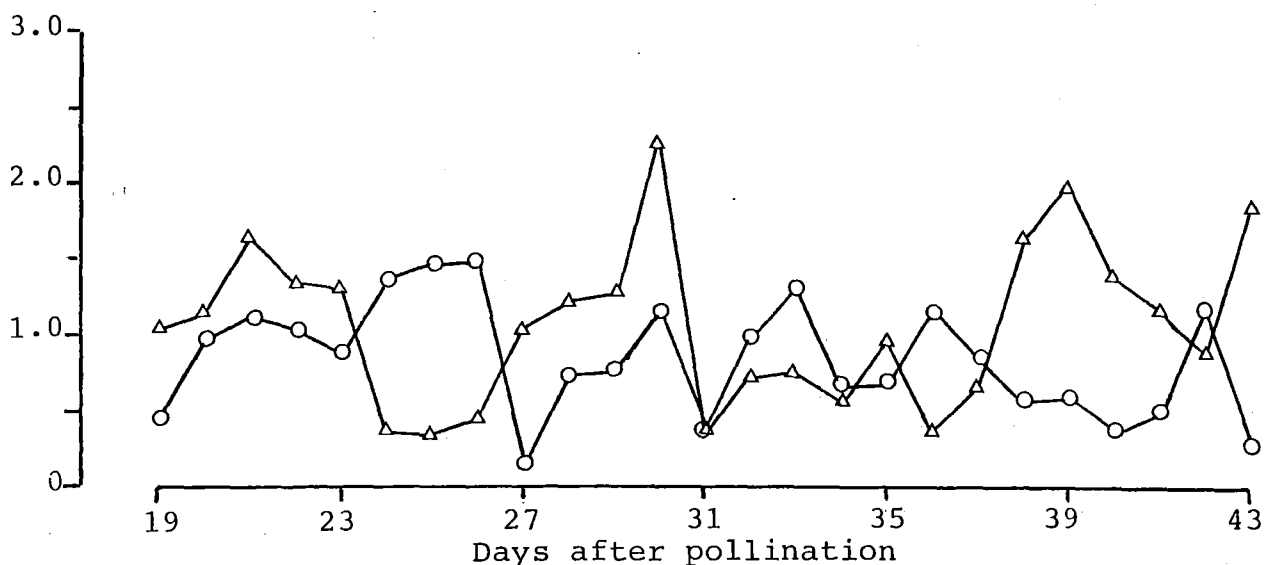


Figure 3.2 Average daily vapour pressure deficits from 19 to 43 days after pollination. (Triangles 1982; Circles 1983)

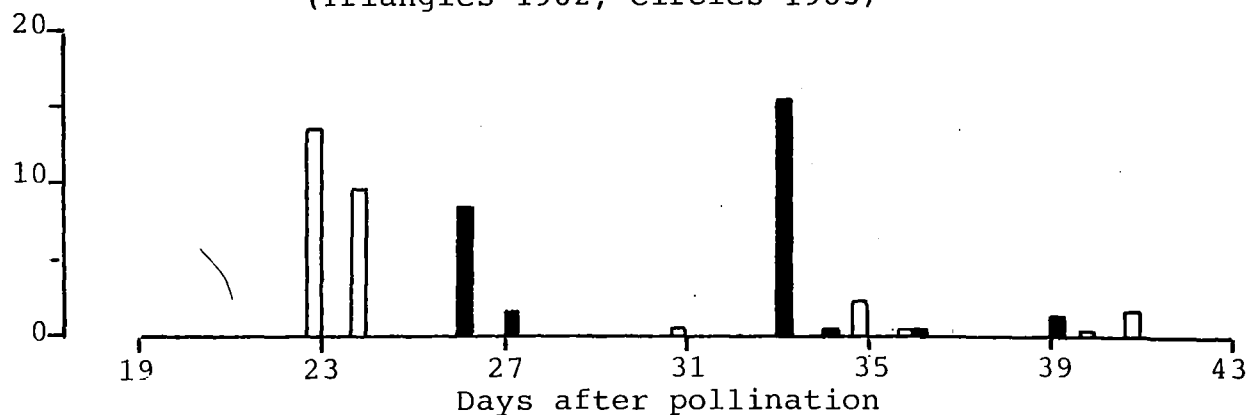


Figure 3.3 Daily rainfall from 19 to 43 days after pollination. (Filled 1982; Unfilled 1983)

- (a) 1981/82. For 1,000 seed weight, 1,000 seeds were weighed fresh and then dried at 80°C for two days to determine dry weight and moisture percentage. Seeds were weighed in grams to two decimal places only.
- (b) 1982/83. I.S.T.A. rules (1966) were followed. For 1,000 seed fresh weight, four replicates of 50 seeds were weighed to four decimal places. These seeds were then put into two 100 seed replicates and then dried by air oven method (130°C for one hour and then put in a desiccator containing silica gel for 30 to 45 minutes), to determine moisture percentage and dry weight.
- (v) Germination percentage.
- (a) 1981/82. Five replicates of 100 seeds per petri dish were germinated on top of blotting paper in a growth cabinet, 20°C with 16 hour light and eight hours darkness. (The cabinet had to be shared and so the light/dark period could not be changed). Germination counts were made at nine and 19 days, with no distinction between normal and abnormal seedlings. The seeds were not pre-chilled.

(b) 1981/82. I.S.T.A. rules (1966) were followed. Four replicates of 50 seeds per petri dish were chilled at 5°C for four days and then germinated on top of blotting paper in a growth cabinet at 20°C in darkness. Germination counts were made at 4, 12 and 20 days. Normal and abnormal seedlings, hard and ungerminated imbibed seeds were recorded. Normal seedlings were those with a good radicle, long hypocotyl and two cotyledons (Wellington, 1970). In many cases the testa still covered the cotyledons at the end of the test period, but these were considered normal (Wellington, 1970; Hill, pers. com.).

3.3 RESULTS

3.3.1 Umbel development

Umbel buds first appeared between November 10th and 15th in both years. The stages of umbel development from green bud through to pod maturity are illustrated in Plate 3.1 and detailed in Table 3.2 and 3.3.

Umbel development from the green bud stage to pollination took approximately 30 to 35 days.

Flowers in Maku lotus are typically papilionate, consisting of one yellow standard petal with red veins, two yellow wing petals and two yellow keel petals which are fused. Parts of the flower, one to two days after pollination, are shown in Plate 3.2. The fused keel petals form a cone-like

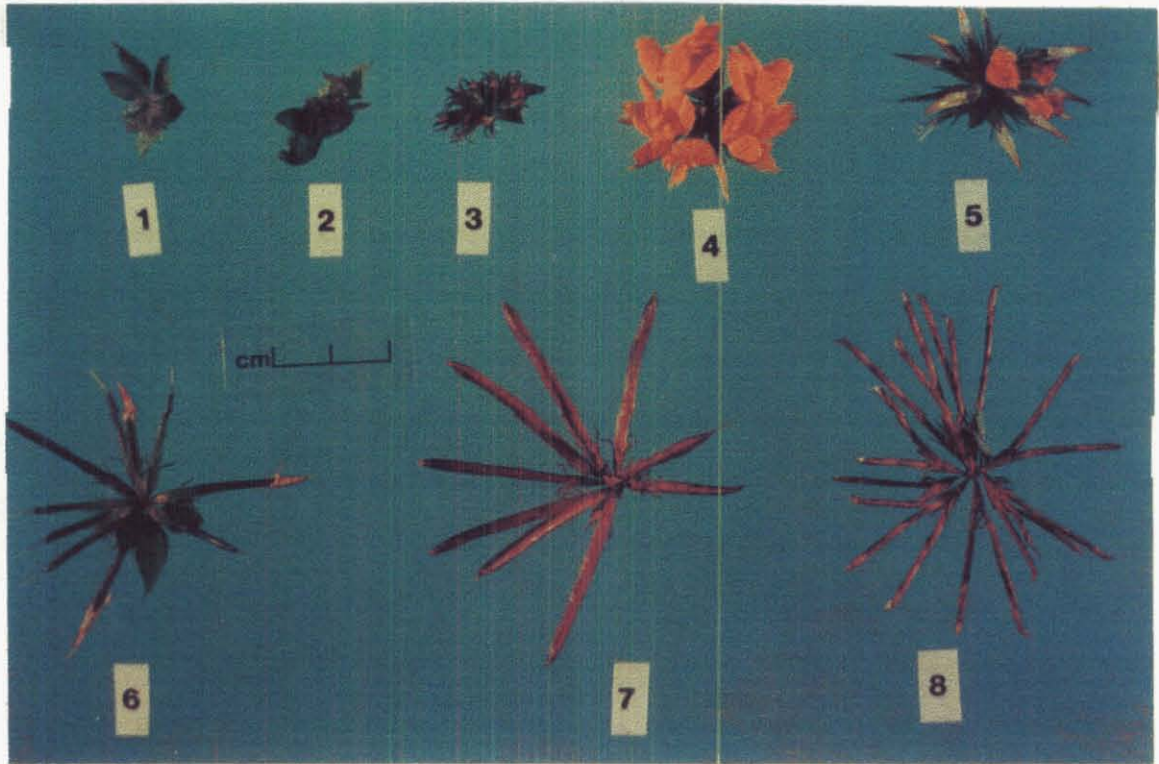


Plate 3.1

Umbel and seed pod development in Maku lotus showing the following stages:

1. Green bud.
2. Brown bud.
3. Orange bud.
4. Yellow flower.
5. Pollinated umbel with developing pods.
6. Purple pod.
7. Brown pod.
8. Shattered pod.

Table 3.2 Umbel development from green bud stage to pollination.

Stage of development	Botanical description of development	Days between stages
1. Green bud stage	Sepals green with white hairy tips; sepals turned outwards giving umbel bud a starlike appearance. Peduncle, one to two mm in length.	0
2. Brown bud stage	Sepals brown.	10
3. Orange bud stage	Peduncle elongates from leaf axil. Yellow standard petals with orange tips protrude from calyx.	10
4. Yellow flower stage	Six to 16 florets (mean 10) attached by short pedicels to a long solitary peduncle, 60-100 mm in length.	10
5. Pollination	Yellow flowers fully open, petals slightly wilting, keel petals pushed slightly out by expanding pods in lower flowers of umbels.	2

cavity towards the apex, open only at the extreme tip. There are nine fused stamens consisting of five stamens, 12 to 13 mm in length, alternating with four stamens, eight to 10 mm in length. The tenth stamen is free, eight to 10 mm in length.

A fully open flower has a green cylindrical tube ovary, six to eight mm in length, with a style slightly shorter than the ovary. The stigma appears as a small capitate structure at the end of the style. Plate 3.3 shows ovary development in a flower, four to five days after pollination. Pollination to the dark brown pod stage took 31 days in 1981/82, but in 1982/83 it took over 47 days because of cooler weather (Figure 3.1, 3.2). Pods were totally shattered by 47 days in 1981/82, but only 13% in 1982/83 because of cooler weather. Over both seasons it took two and a half to three months for umbels to develop from green buds to brown pods (Plate 3.1; Table 3.2 and 3.3).

3.3.2 Pollination

At pollination the yellow flowers were fully open, petals slightly wilting, and lower keel petals in the umbel pushed out slightly by expanding pods. The pollination mechanism in Maku lotus was identical to that described by MacDonald (1946) for *L. corniculatus*. Plate 3.4 shows a honey bee pollinating a floret. Bees stand on the two wing petals and push the standard petal back with their heads. The keel petals are forced downwards and the pollen is pushed out by the 'piston apparatus' on to the bees' undersides. Further depression of the keel petals forces the stigma up to adhere to foreign pollen from the bees' undersides.

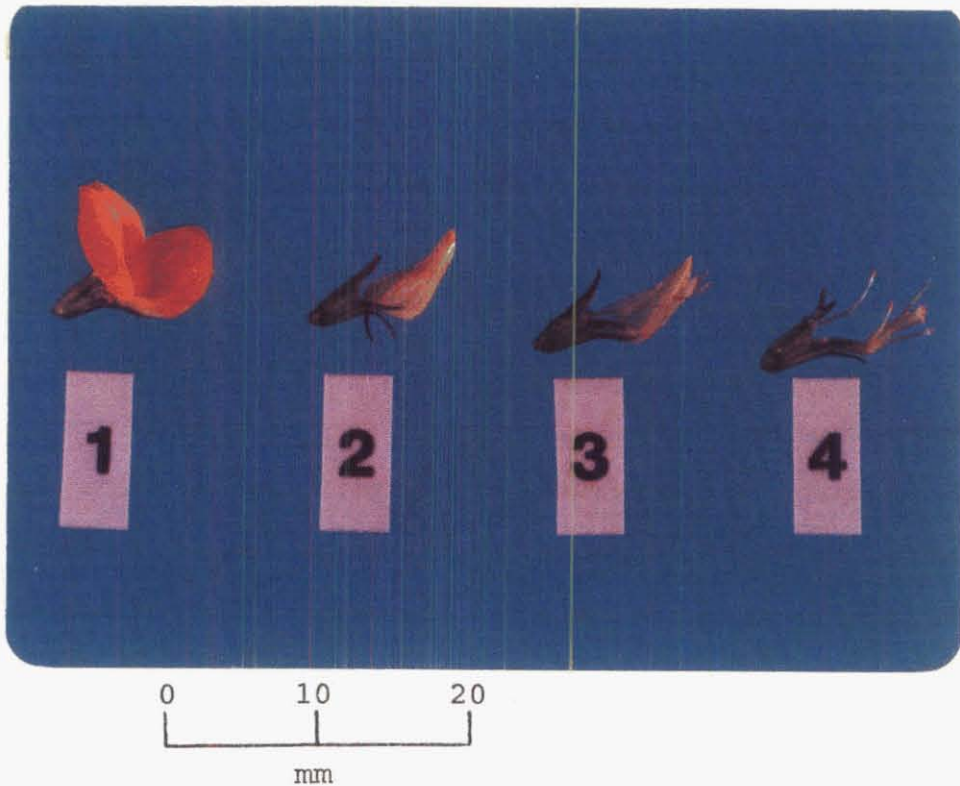


Plate 3.2 Flower structure of Maku lotus one to two days after pollination showing the following:

1. Standard petal and two wing petals.
2. Standard and wing petals removed, leaving two fused keel petals.
3. One keel petal removed showing stamens.
4. One free stamen, nine fused stamens and long style above stamens.

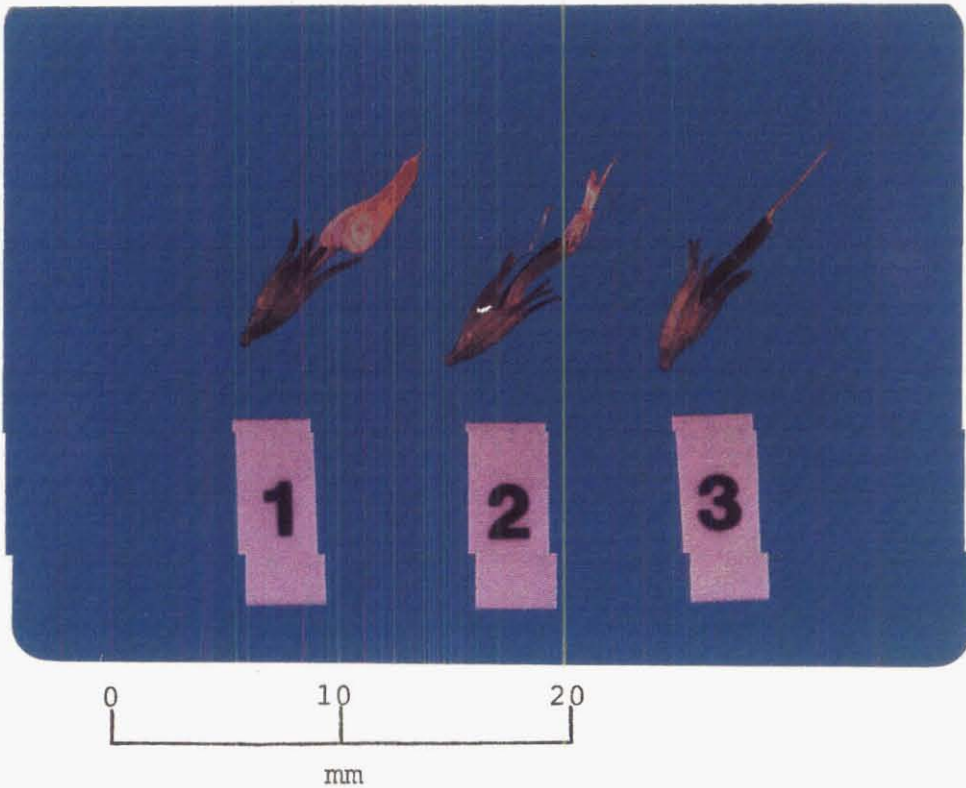


Plate 3.3

Ovary development in a Maku lotus flower four to five days after pollination showing the following:

1. Keel petals fused around green ovary with style protruding.
2. Keel petals removed showing one free stamen, and nine fused stamens around ovary.
3. Stamens removed showing green ovary developing into a pod and a long style with the stigma at the end.



Plate 3.4 Honey bee collecting nectar and pollinating
a Maku lotus flower.

3.3.3 Seed development

In 1981/82 all samples were bulked so no standard errors of means could be determined. In 1982/83 standard errors of means were measured between the four groups. (Detailed analysis for these groups are presented in Appendices 2-5).

3.3.3.1 Fresh weight. In both seasons maximum fresh weight of Maku lotus seeds was reached 27 days after pollination (Figure 3.4). Maximum 1,000 seed fresh weight was 1.9 gram (63% moisture) in 1982 and 1.85 grams (70% moisture) in 1983. In 1982 fresh weight declined rapidly from 27 to 31 days after pollination, with drying caused by the very high vapour pressure deficits and high temperatures for that period (Figure 3.1 and 3.2; Appendix 1).

3.3.3.2 Dry weight. Maximum dry weight of Maku lotus seeds was reached 27 days after pollination in 1982 and 35 days after pollination in 1983 (Figure 3.5). (In 1982 dry weight of seeds on day 31 was incorrect as inaccurate scales were used. As there was no significant differences between seed dry weights on days 27, 35, 39 and 43, it is presumed that on day 31 dry weight was almost the same).

Maximum 1,000 seed dry weight was 0.70 grams in 1982 and 0.71 grams in 1983. In 1982 maximum dry weight was reached at 63% moisture, and in 1983 the moisture content was 61% at maximum dry weight. Once maximum dry weight was reached in both seasons the weight remained almost constant.

3.3.3.3 Moisture percentage. In 1982 the moisture percentage of seeds declined rapidly at 6.7% per day from 27 to 35 days after pollination. (Figure 3.6).

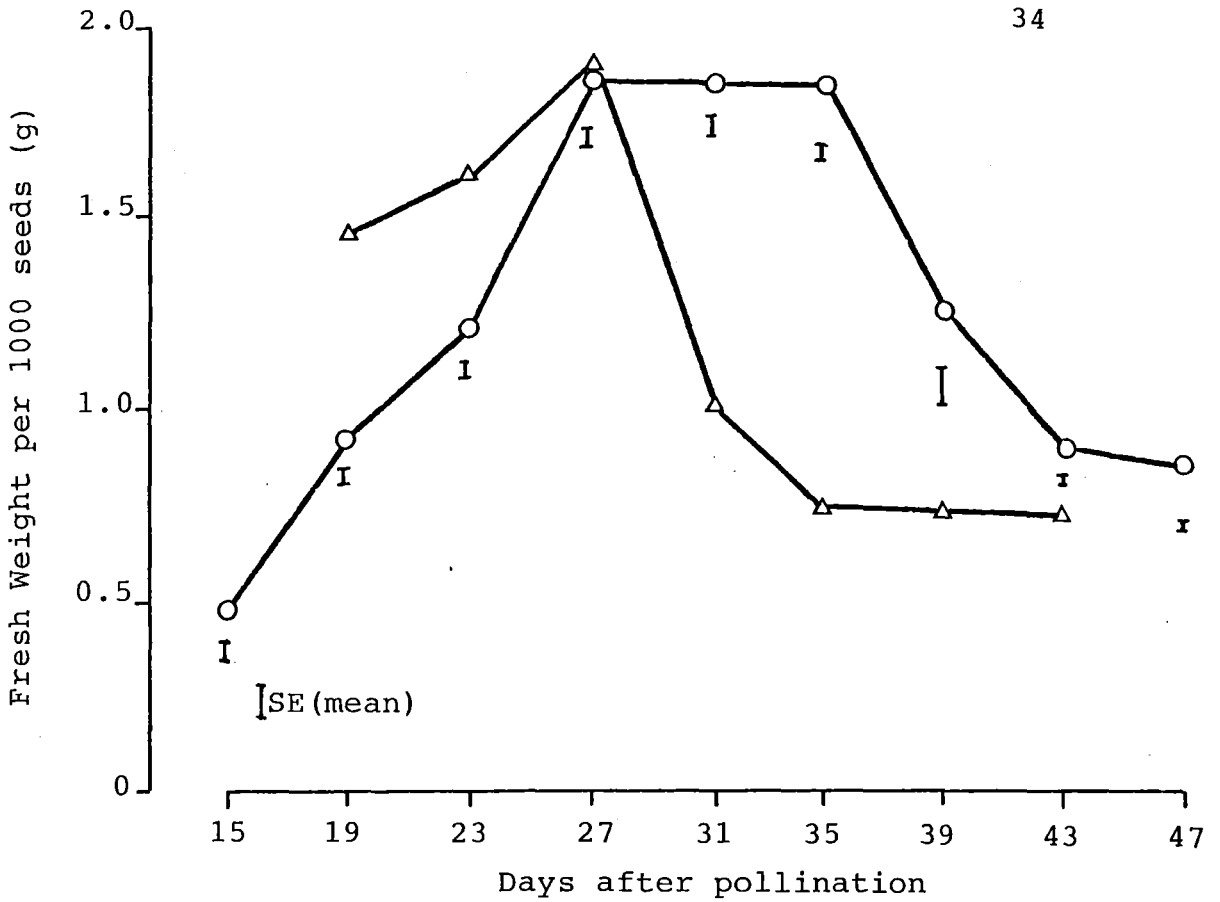


Figure 3.4 Changes in Maku lotus 1000 seed fresh weight from pollination. (Triangles 1982; Circles 1983)

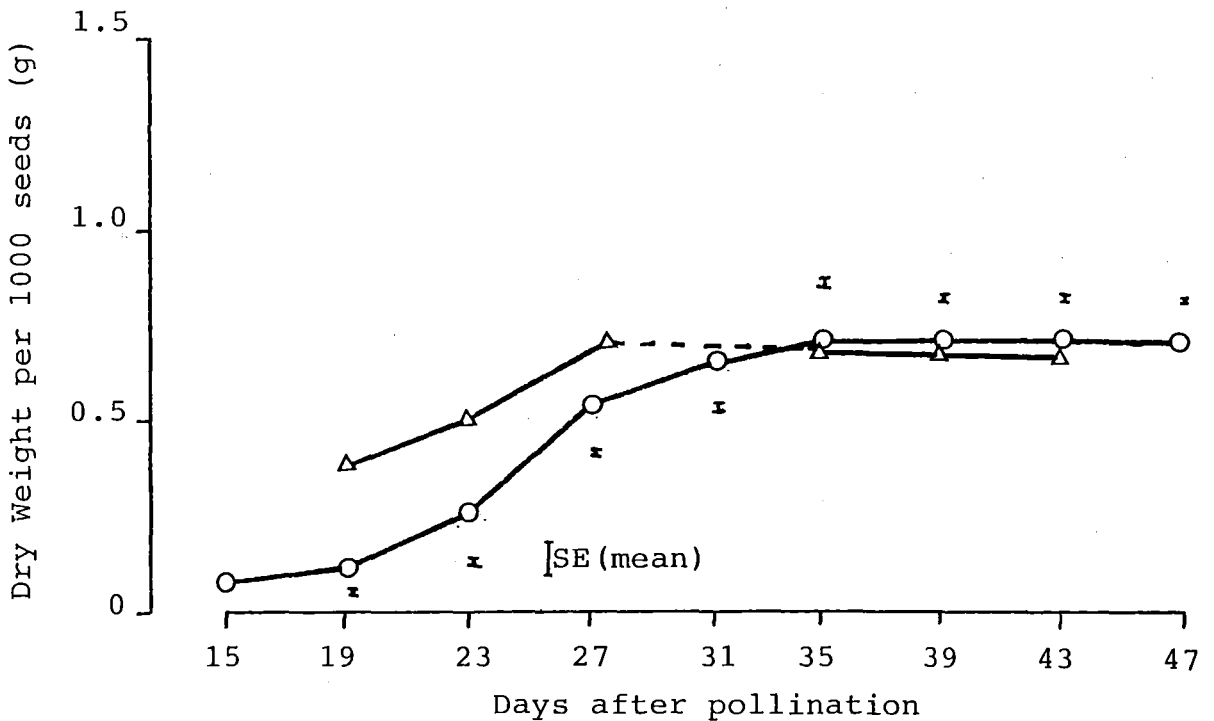


Figure 3.5 Changes in Maku lotus 1000 seed dry weight from pollination. (Triangles 1982; Circles 1983)

By contrast, in 1983 the moisture percentage only declined by 1.1% per day over the same period (Figure 3.6). The rapid decline in 1982 was because of the hot dry weather especially on day 30 when the maximum temperature was 33.5°C and the vapour pressure deficit was 2.26 kpa (Appendix 1).

However, once maximum dry weight was reached (day 27, 1982; day 35, 1983), at between 63 and 61% moisture, the decline in moisture was approximately the same in both seasons (Figure 3.6). In both seasons, rapid seed drying did not occur until maximum dry weight was reached.

3.3.3.4 Shattering percentage. In 1982 pod shattering increased rapidly from 7% at day 35 to 44% at day 39, to 88% at day 43 (Figure 3.7). From day 35 to day 43 pods shattered at a rate of 10% per day. This was caused by the hot dry weather (Figure 3.1 and 3.2).

By contrast, shattering in 1983 only reached 13% by day 47. This was due to the cooler weather conditions. Large pod shattering losses occurred when the seed moisture percentage was below 10% in 1982. In 1983 the seed moisture percentage did not drop below 15.5%, resulting in only slight pod shatter.

3.3.3.5 Pod colour changes. Pod colour progressed from green to purple on top (19 days), to a light brown colour below 20% moisture and to a dark brown colour when pods shattered (Table 3.3). Maximum dry weight was reached in both years when pods were still purple on top. Slow drying caused pods to remain green longer in 1983 than in 1982. Pod colour changes were more rapid in 1982. Pod shattering largely

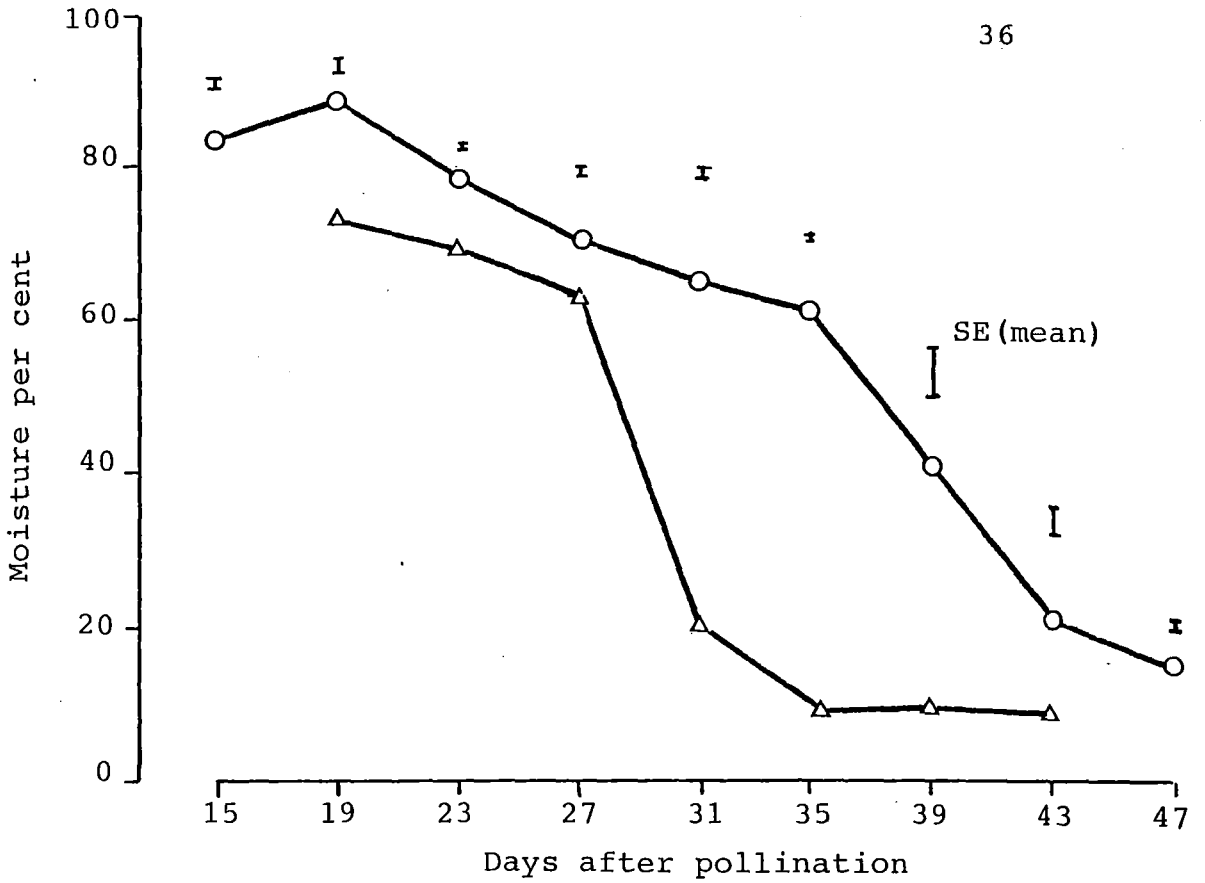


Figure 3.6 Changes in moisture percent of Maku lotus seed from pollination. (Triangles 1982; Circles 1983)

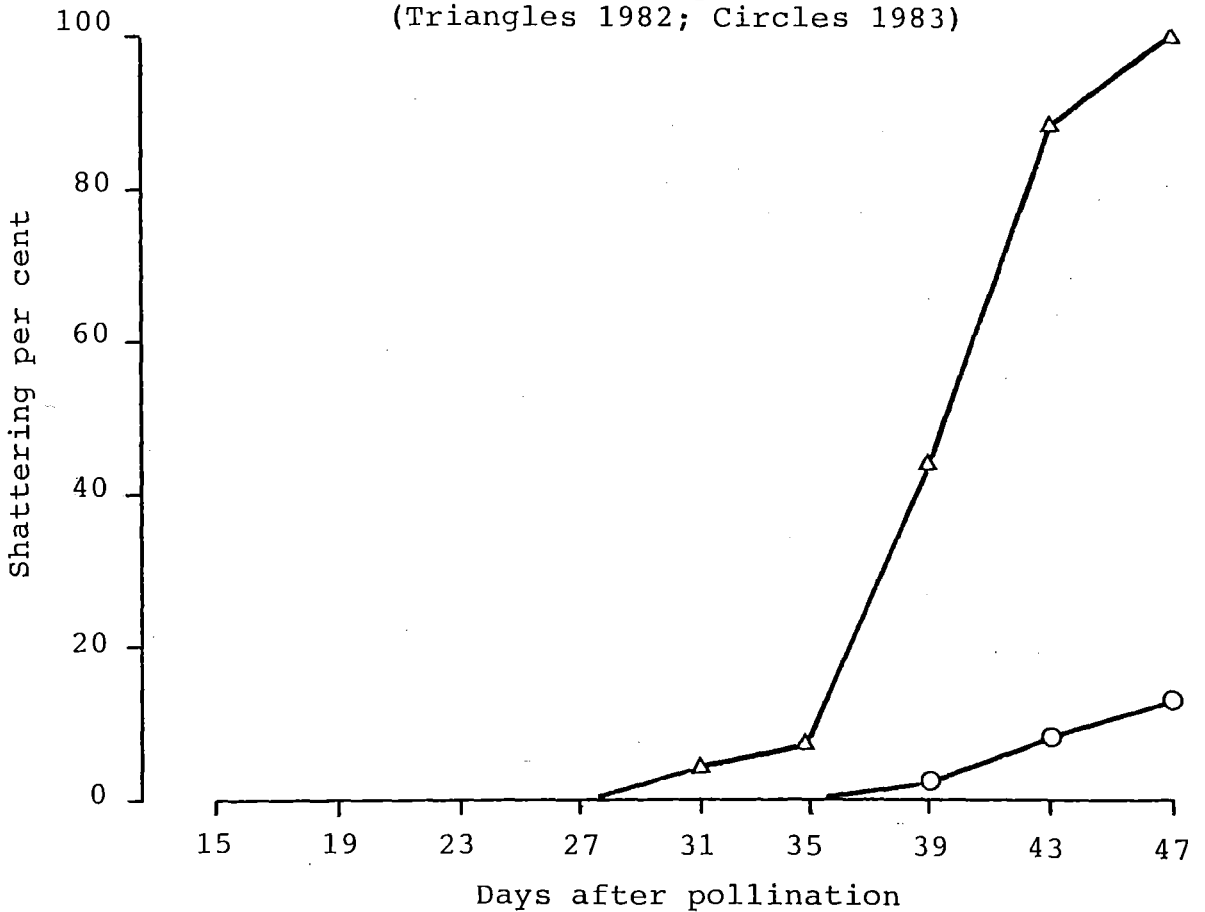


Figure 3.7 Changes in pod shattering per-cent of Maku lotus from pollination (Triangles 1982; Circles 1983)

Table 3.3

Pod colour changes and stage of seed development from 19 to 43 days after pollination.

Days after pollination	Colour of pods		Stage of seed development	
	1982	1983	1982	1983
19	Purple on top, green underneath.	Purple on top, green underneath.		
27	Purple to light brown on top, yellowish green underneath.	Dark purple on top, green underneath.	Maximum fresh & dry weight 63% moisture.	Maximum fresh weight 70% moisture
31	Light brown all over pod.	Dark purple on top, green underneath.	20% moisture	
35	Light brown all over pod.	Purple to light brown top, yellowish green underneath.		Maximum dry weight 61% moisture
39	Dark brown all over pod. Pods crisp & snap easily	Light brown on top, yellowish green underneath.	44% pod shatter	
43	As above	Light brown all over pod.	88% pod shatter	20% moisture 8% pod shatter
47	As above	Dark brown all over pod.	100% pod shatter	13% pod shatter

occurred when seeds dropped below 10% in moisture. At this stage pods were dark brown all over, very crisp, and snapped easily when held between the fingers.

3.3.3.6 Germination percentage. In both years maximum germination percentage of fresh seeds occurred four days before maximum seed dry weight when the seed moisture content was between 69 and 65% (Figure 3.8). At this stage the seed was 71% of its final dry weight in 1982 and 90% in 1983.

In 1982 normal and abnormal seedlings were not separated, as abnormal seedlings were not looked for. Following I.S.T.A. rules (1966), these were measured in 1983, and a large proportion of abnormal seedlings appeared (Figure 3.9). These seedlings had no radicle, as shown in Plate 3.5. Most seedlings in the 1982 tests had green open cotyledons at the end of the test period, whereas in 1983 most normal seedling cotyledons were still covered by the testa (Plate 3.5). Light was included in the 1982 tests but not in 1983.

Hard-seededness appeared as the moisture content decreased below 40%. Over 90% of seeds were observed to be hard in 1982 at moisture percentages less than 10%. In 1983 at 20% moisture content, 50% of seeds were counted as hard and at 15% moisture content 75% of the seeds were counted as hard (Figure 3.9).

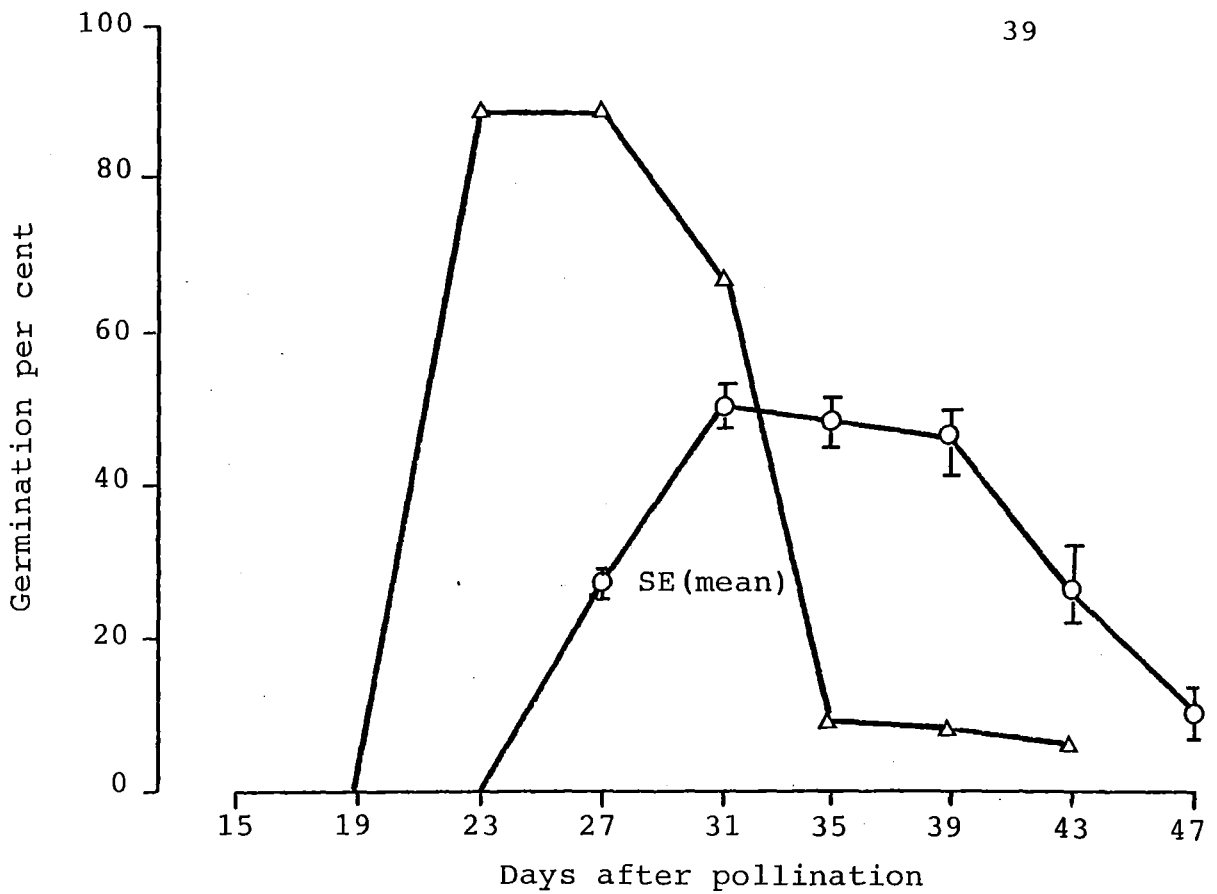


Figure 3.8 Germination per cent of Maku lotus fresh seed from pollination. (Triangles 1982; Circles 1983)

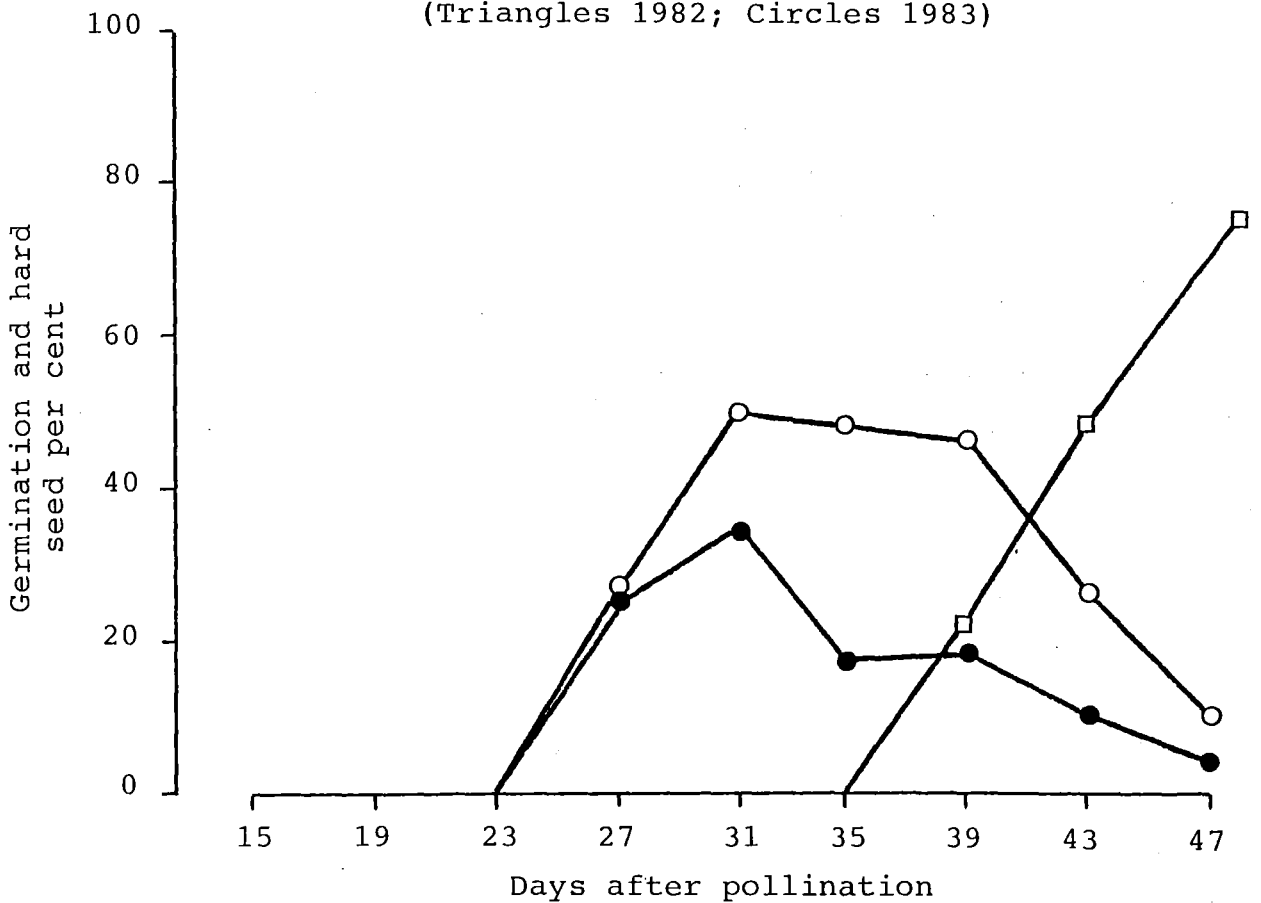


Figure 3.9 Seed quality components of Maku lotus fresh seed in 1983. (Circles: unfilled, normal seedlings; filled; abnormal seedlings; squares, hard seeds)

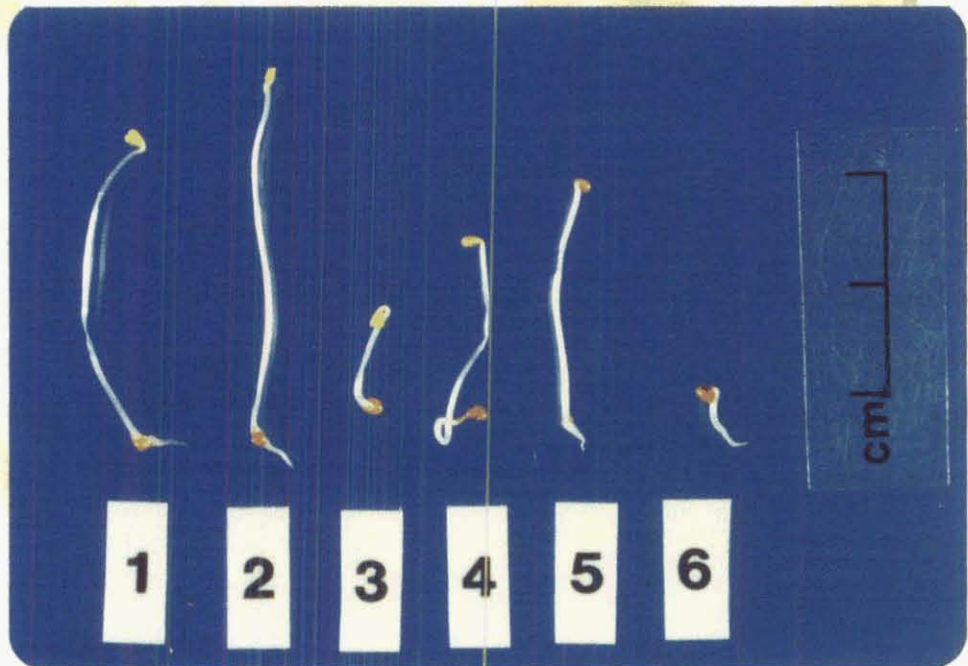


Plate 3.5 Normal and abnormal Maku lotus seedlings from the 1983 germination tests.

- 1 & 2 Normal seedlings with two cotyledons, long hypocotyls, and small radicles.
- 3 & 4 Abnormal seedlings, no radicles are present.
- 5 & 6 Normal seedlings, even though cotyledons are still covered by testa. Radicles are small.

3.4. DISCUSSION

3.4.1 Umbel and seed development

Umbel and seed development in Maku lotus were measured over two contrasting seasons. The 1981/82 season was hot and dry especially during seed ripening. The 1982/83 season was moist in December and cooler during seed development in January. Up to seed maturity, rate of umbel and seed development in both years was approximately the same. Seed ripening was much more rapid in 1982 than in 1983.

Umbel development in Maku lotus from buds to fully mature pods follows stages similar to those described by MacDonald (1948) for *Lotus corniculatus*. The green bud, orange bud, yellow flower, purple pod, light brown and dark brown pod stages are easily recognised in the field and can be used by farmers as important visual indicators in deciding when flowering, pollination and seed development is occurring. By recognizing these stages, and counting the days from each stage, the time of optimum harvest can be more easily judged. Over both seasons it took 30-35 days from green bud appearance to the formation of yellow flowers and pollination, and another 30-40 days from pollination to the light brown pod stage just after seed maturity.

The stage of pollination can be easily recognized by farmers in the field. Flower petals on a pollinated umbel are yellow and fully open. Some petals will look slightly wilted and lower flowers on the umbel which have been pollinated one to two days earlier, have extended keel petals caused by expanding pods. Lower flowers on an umbel may be two to three days more advanced in development than flowers towards the top of the umbel.

Maku lotus and other *L. pedunculatus* selections appear to be cross-pollinated, but no research has been done on self-pollination in *L. pedunculatus*. Seaney and Henson (1970) report that most *L. corniculatus* plants are self-incompatible, setting little or no seed after self-pollination by insects or by hand. The pollinating mechanism and flower organs in Maku lotus have been found to be identical to those in *L. corniculatus*, therefore it is suggested that Maku lotus is also largely cross-pollinated, especially under field conditions.

Seed development in Maku lotus followed three distinct stages, the growth stage, the food reserve accumulation stage, and the ripening stage. These stages are similar to those described in *Trifolium repens* (Hyde et al, 1959), *T. pratense* cv. Hamya (Hyde et al, 1959), *T. pratense* cv. Pawera (Win Pe, 1978), and *Medicago sativa* (Kowithayakorn and Hill 1982b) (Table 3.4).

In Maku lotus the growth stage was up to 19 days after pollination in 1982 and 23 days in 1983. The seed moisture content was very high (70-90%) and no viable seed was formed. The length of the growth stage was similar to the 22 days in *Medicago sativa* (Kowithayakorn and Hill, 1982b), but twice as long as the ten day growth stage found in white and red clovers (Hyde et al, 1959; Win Pe, 1978). Species characteristics seem to cause differences in the length of time occupied by this stage.

The food reserve accumulation stage in Maku which followed the growth stage was eight days in 1982 and 12 days in 1983 (day 19 to 27 in 1982; day 23 to 35 in 1983). Seed dry weight increased at approximately the same rate (0.037 grams per 1,000 seeds per day). Seeds reached a maximum dry

Table 3.4 Length of seed development stages in five herbage legumes.

Herbage legume	Growth stage (days)	Food reserve accumulation stage (days)	Ripening stage (days)
Maku lotus 1982	19	8	8
Maku lotus 1983	23	12	12
White clover (Hyde <u>et al</u> , 1959)	10	10 - 14	3 - 7
Hamua red clover (Hyde <u>et al</u> , 1959)	10	10 - 14	3 - 7
Pawera red clover (Win Pe, 1978)	10	16	10 - 14
Lucerne (Kowithayakorn and Hill, 1982b)	22	17	34

weight at the end of the food reserve accumulation stage and were then considered to be mature, as suggested by Hyde (1950) and Anderson (1955). Seeds became viable early in the stage, but germination capacity declined during the later parts of the stage, with the increase of hard seeds as moisture decreased. The percentage of moisture declined at approximately 1.3% per day in both years.

The above changes during the food reserve accumulation stage are identical to those reported by other workers but with variation in the rate of development. Hyde et al (1959) found that the food reserve accumulation stage took 10-14 days in white and red clovers (similar to the 8-12 days for Maku lotus), but Win Pe (1978) with Pawera red clover, and Kowithayakorn and Hill (1982b) with lucerne, found that this stage took approximately 17 days (Table 3.4). As the effects of weather and species differences on rate of seed development in herbage legumes are unknown, comparisons between species at different sites under different weather conditions are difficult to make. None of the above workers clearly stated the weather conditions at the time of their studies and so it is difficult to interpret whether the differences are due to weather or to species.

In Maku lotus the ripening stage took eight days in 1982 but 12 days in 1983 because of the differences in weather. The seed was considered ripe when it had dried to a moisture content suitable for harvesting (Hill, 1971) and when dry weight was constant (Hyde, 1950). In 1983 the seeds contained six percent more moisture than in 1982 but were still suitable for harvest at 15% moisture, as dry weight was constant.

Weather is the dominant factor influencing the length of ripening (Kowithayakorn and Hill, 1982b). Hot dry weather clearly accelerated ripening in Maku lotus in 1982 and cooler weather delayed ripening in 1983. Hyde et al (1959) reported a three to seven day ripening period for white and red clover which compares with the eight day ripening period in Maku lotus in 1982. Win Pe (1978) found that a 10 to 14 day ripening period was required for Pawera red clover, which was similar to the 12 days Maku lotus ripened in 1983 (Table 3.4). However, both Hyde et al (1959) and Win Pe (1978) did not state the weather conditions of their studies clearly enough for good comparisons to be made with these Maku lotus studies.

Maximum seed viability was reached during the food reserve accumulation stage, four days before seed maturity was reached, and this was also found by Hyde et al (1959) and Win Pe (1978) in their clover studies. However, studies on *L. corniculatus* revealed that maximum seed viability was at or just after seed maturity (Anderson, 1955; McKersie, 1982).

The differences are probably due to technique in that these germination studies on Maku lotus and those by Hyde et al (1959) and Win Pe (1978) on clovers were on freshly harvested seed, but the *L. corniculatus* germination studies were on dry seed stored for several weeks.

The contrasting conditions under which Maku lotus seeds were germinated in 1982 and 1983 may explain why more abnormal seedlings were reported in 1983. In the first year the seeds were germinated with 16 hours of light. Seedlings were not placed in normal and abnormal categories, but most of the germinated seedlings had green open cotyledons with radicles.

Abnormal seedlings were not noticed. In 1983, I.S.T.A. rules (1966) were followed, which state that *L. pedunculatus* seeds must be germinated in darkness. All Maku lotus seedlings in 1983 were very weakly developed and a large percentage were abnormal as no radicle developed (Plate 3.5). Radicles in normal seedlings were small and the seed testa still covered nearly all of the cotyledons. The Ministry of Agriculture Seed Testing Station at Palmerston North germinates Maku lotus seeds in cabinets with glass doors through which daylight filters. Abnormal seedlings in germination counts are usually a very small percentage (Johnson, pers.com.). It is therefore recommended that I.S.T.A. rules not be followed in future Maku lotus germination studies and that a 16 hour light/eight hour dark period be used.

Hard-seededness first occurred in Maku lotus after seed maturity was reached and when seed moisture percentage began to decline. Win Pe (1978) and Kowithayakorn and Hill (1982b) also found hard-seededness developed after seed maturity, when moisture percentage was declining.

In *Lotus corniculatus*, pod colour changes were found to be reliable indicators of seed maturity (Anderson, 1955). Pod colour changes in Maku lotus were found to be consistent with seed maturity and seed ripeness over two seasons under different weather conditions (Table 3.2). Seed maturity occurred when the pods were purple to light brown on top and yellowish green and purple underneath, before changing to a light brown colour all over at seed ripeness. When the pods became dark brown pod shattering occurred.

Pod shattering was much more severe in the 1982 Maku lotus crop than in the 1983 crop. Between day 27 and day 43 in 1982 the vapour pressure deficit exceeded 0.90 kpa ten times (1983, five times) and the maximum temperature exceeded 25°C seven times (1983, one time). Metcalfe, Johnson and Shaw (1957) found that below a relative humidity of 40%, at a temperature above 25°C, seed pod shattering rapidly occurred in *L. corniculatus*, especially in full sunlight. Vapour pressure deficit, however, is a better indicator of atmospheric drying as it records maximum air temperature more closely (Gallagher, pers.com.).

3.4.2 Optimum time to harvest

Two methods of harvesting Maku lotus seed crops have been used in New Zealand (Lancashire et al, 1980). The first method is to mow and windrow the crop, turning the pods into the windrow, so that they are protected from the wind and sun by a cover of slow-drying, thick lotus stems. After two to five days drying, depending on weather conditions, the crop can be harvested by combine harvesters. However, usually some pod shattering occurs during windrow drying. The second method is to spray a desiccant, such as diquat, on to the standing crop and direct head two to three days later. This method has often not been successful, because of the difficulty of getting a good desiccant kill of vegetation in bulky crops.

By measuring the changes in seed dry weight, moisture content and pod shatter and observing pod colour changes, optimum harvesting times for harvesting in 1982 and 1983 have been suggested (Figures 3.10 and 3.11).

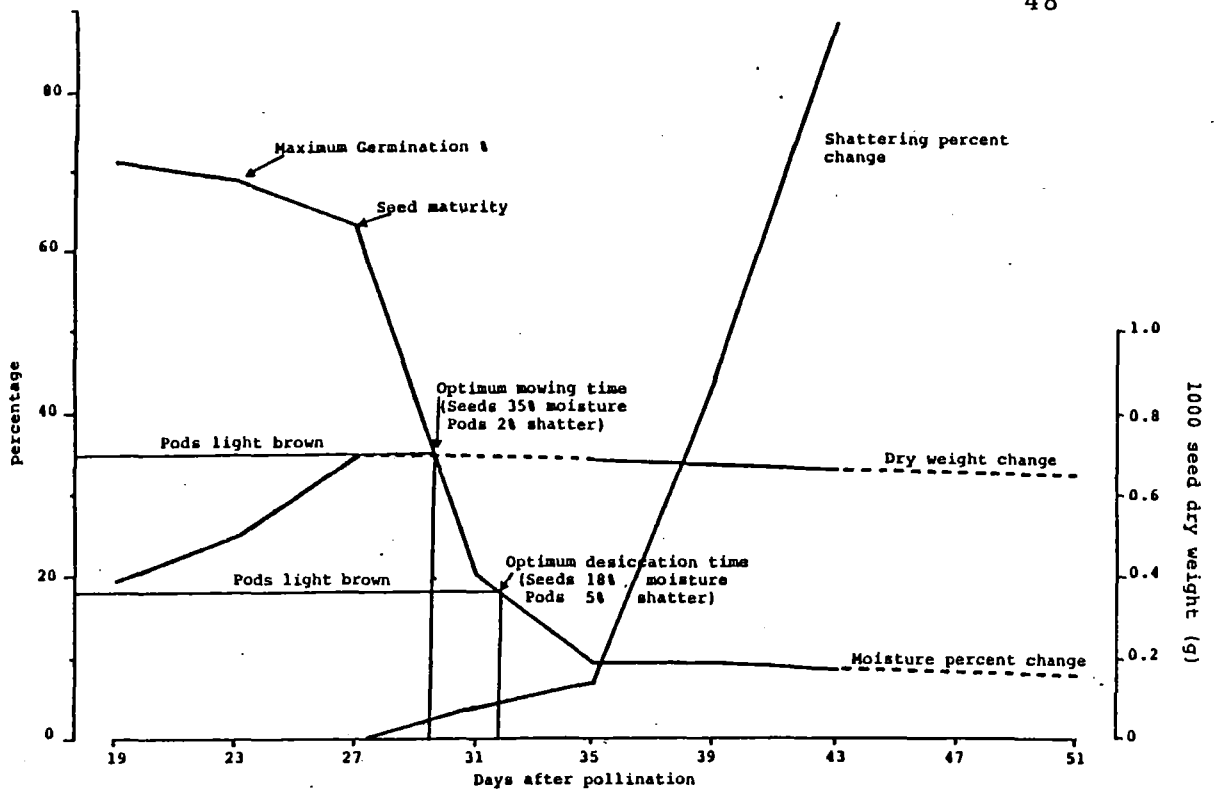


Figure 3.10 Optimum harvesting times in 1982 according to changes in seed moisture percent, pod shattering percent and 1000 seed dry weight. (Dotted lines are predicted changes).

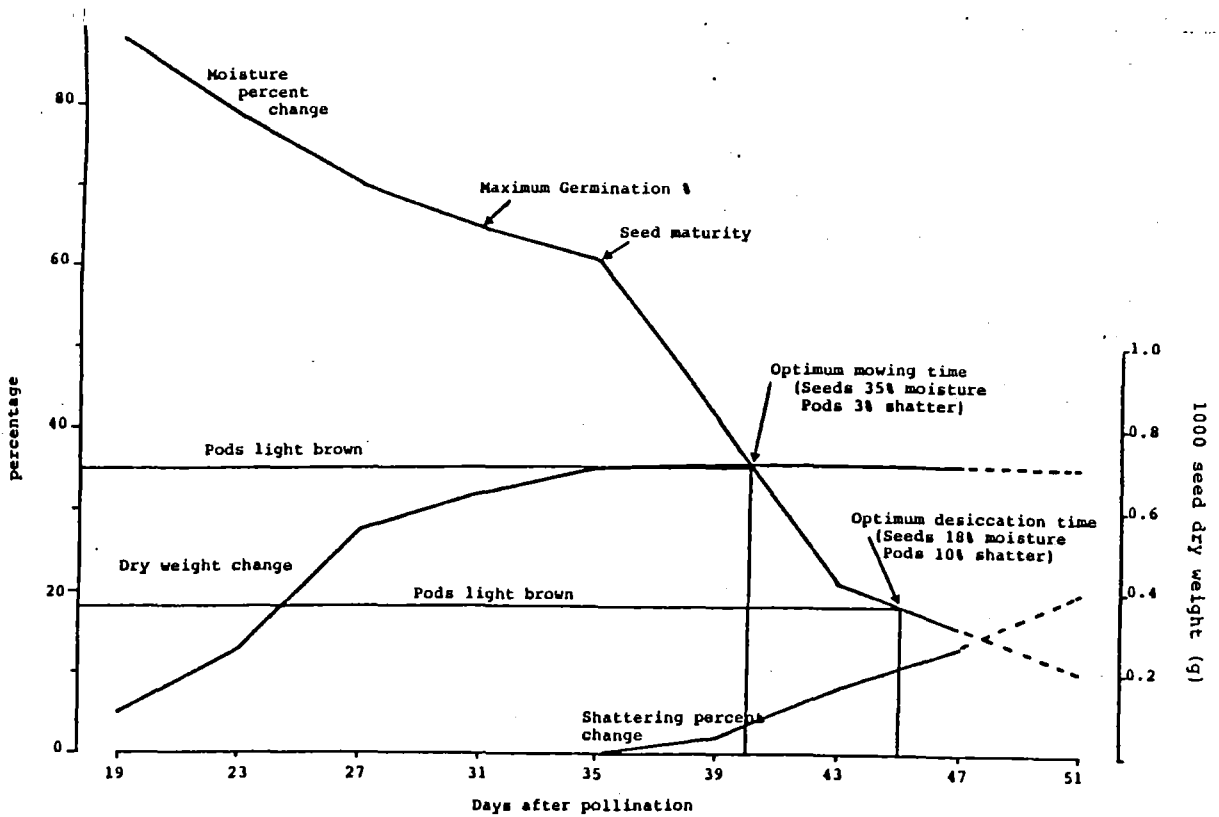


Figure 3.11 Optimum harvest times in 1983 according to changes in seed moisture percent, pod shattering percent and 1000 seed dry weight. (Dotted lines are predicted changes).

Pods colour changes gave the best indication of seed maturity and seed moisture content in both years. Seed maturity occurred when the pods were a mixture of purple to light brown on top and yellowish green underneath. The seed moisture was approximately 65% at seed maturity. The optimum time to mow was after seed maturity, when the pods had just started to turn light brown in colour and about two to three percent pod shatter had occurred.

In 1982 seed ripening was very rapid after seed maturity on day 27. Optimum mowing time was on day 29 when the pods were light brown in colour, seed dry weight was constant, seed moisture was 35%, and pod shatter was two percent (Figure 3.10). After four days of drying the crop could be harvested when the seeds were firm and hard and less than 15% in moisture. The crop would also be dry enough to go through the combine harvester. If the crop had been cut when the pods were dark brown in colour on day 39, then large seed losses would have resulted through the 44% pod shatter (Figure 3.10). Metcalfe et al (1957) found that *L. corniculatus* pods shattered readily below 10.5% moisture. Pod moisture was not studied in this experiment, but when rapid pod shatter occurred (day 39), the seed moisture content was below nine percent, suggesting a close relationship between pod and seed moisture content.

In 1982 the optimum time for chemical desiccation was on day 32 when the pods were still light brown in colour, the seeds were below 20% in moisture, and five percent pod shatter had occurred. After two days drying direct heading could take place on day 34 when the seeds were less than 15% in moisture, but before rapid pod shatter had begun.

In 1983, seed ripening was very slow after seed maturity on day 35. Optimum mowing time was on day 40 when the pods were light brown in colour, seed dry weight was constant, seed moisture was 35% and pod shatter was three percent (Figure 3.11). The cool weather meant that at least eight days' windrow drying were required before the crop could be harvested when the seeds were at about 15% moisture. The optimum time to desiccate chemically would be on day 45 when the seeds were below 20% in moisture, pods were light brown in colour and ten percent pod shatter had occurred. After four days drying, direct heading could take place on day 49, when the seeds would be less than 15% in moisture.

Klein and Harmond (1971), from three years of study, found that moisture content of grass and small legume seeds was the only property that correlated well with obtaining maximum yields of pure live seed. Two years' study of Maku lotus showed that not only seed moisture, but pod colour changes and some pod shatter also correlated well with the production of seed of high weight and quality.

The graphs in Figures 3.10 and 3.11 have been drawn in retrospect. Farmers must, however, be able to predict seed developments and so mow or chemically desiccate at the appropriate time. By closely watching the weather every day from 27 days after pollination, farmers can predict when pod colour changes and pod shattering will occur. If strong drying winds are blowing and the temperatures are above 25°C and even if the vapour pressure deficits are not known, then rapid seed ripening and pod drying will occur. As soon as the pods turn light brown in colour and some pod shattering begins, mowing

must take place. Chemical desiccation will probably depend on the density of the crop and farmer preference. The time taken to dry the sward in the windrow following mowing or in the stand following chemical desiccation will again depend on weather. However, early mowing and desiccation reduces risk of pod shatter and allows for a longer drying time.

3.5 SUMMARY

All data in this study substantiates the hypothesis that it is not necessary to delay harvesting operations until Maku lotus seeds are fully ripe in order to obtain high quality seed. Maku lotus seeds are viable and mature several days before seed ripeness, so that seed quality will not be affected by early mowing or chemical desiccation and then drying in the field before harvest. Early mowing and desiccation reduces the risk of seed losses from pod shatter and enables the crop to dry in the field for a longer period before combine harvesting.

Judging optimum harvest time can be done by counting the days from pollination and observing seed pod colour changes. After 27 days from pollination daily crop inspections must be made and the weather monitored. Under hot dry conditions, the harvesting interval is very brief but timely operations by well prepared farmers will maximise seed yields.

CHAPTER 4

THE EFFECT OF TIME OF CLOSING AND SEVERITY OF DEFOLIATION ON
MAKU LOTUS SEED YIELDS

4.1 INTRODUCTION

Many farmers have implemented closing dates for Maku lotus, from spring to early summer, according to their experiences with clover and lucerne seed crops. It is normal practice for farmers to cut established lucerne stands for hay and then harvest for seed later in the same season (Kowithayakorn and Hill, 1982a). White clover seed crops grazed until mid-November and red clover seed crops closed in early December following grazing will give high seed yields (Clifford, 1980; Clifford and Anderson, 1980).

Research by Clifford in 1975 (reported by Lancashire *et al*, 1980) found that marked reductions in Maku lotus seed yields occurred when crops were closed later than October 1st. Neal (1983) also reports that by closing in mid-October, after close grazing or cutting, seed yields are decreased, compared with earlier closing dates. However, Neal (1983) preferred October closing, as there was less vegetative bulk at harvesting and pod shattering was reduced by harvesting under cooler conditions in March.

It has been found that Maku lotus will not grow rapidly in the spring until temperatures reach approximately 20°C (Charlton, 1977) and that it is extremely slow to recover following close defoliation (Sheath, 1980). Seed production of most perennial herbage legumes will be decreased following defoliation after flower initiation (Humphreys, 1979).

However, by allowing an initial attack on Maku lotus flowerheads by potato mirids (*Calocoris norvegicus*) and then spraying with an insecticide, Clifford et al (1983) increased stem branching and potential seed yields of Maku lotus. They concluded that the increased stem branching was because the early apical dominance of the primary stems was impaired, either by way of physical mirid damage or some hormonal effect induced by the injection of mirid saliva. They also found that flowerheads when protected with an insecticide application following a mirid attack, gave the most concentrated flowering, thereby ensuring minimum seed losses at harvest. It was suggested, that in the absence of a mirid attack, some form of high topping management with a mower to remove only primary apical meristems, might promote stem branching in Maku lotus.

The objective of this study was to impose a range of closing dates by severe or lenient cutting in order to test the following hypotheses that:

- (i) any severe cutting treatment from the start of spring growth onwards would be detrimental to seed yield.
- (ii) a high topping may simulate mirid damage and concentrate flowering time allowing for easier harvest management.

4.2 MATERIALS AND METHODS

The study was conducted over two seasons (1981-83) on a 0.75 hectare Maku lotus field at Lincoln College, Canterbury. Maku lotus was sown on November 5th 1980 in 0.45 m rows, at a sowing rate of three kg ha⁻¹. Each plot in the two trials

averaged six plants m^{-2} . The soil type was a Wakanui soil complex (Table 3.1). No fertilizer was applied throughout the study as nutrient levels were considered adequate, given the good performance of Maku lotus under low fertility conditions. The site was also very weedy and it was thought that any fertilizer application would promote further weed competition.

4.2.1 1981-82 trial

The trial was a randomised block design with five treatments and six replications. Each plot was 15 m x 2.5 m in size. The treatments were as follows:

1. After paraquat spraying in July, the control treatment was left uncut until seed harvest in January.
2. A sickle-bar mower, 1.2 m wide, was used to cut to ground level, treatments on November 12th, November 24th, December 4th and December 15th, 1981.

a) Preharvest treatment

The field was sprayed with paraquat at 0.5 litres a.i.ha⁻¹ in July 1981, to control barley grass (*Hordeum murinum*) and *Poa annua*.

b) Dry matter yields measurements

At closing, material from a 1.2 m x 15 m strip from each plot was weighed fresh in the field, and a 500 gram subsample was taken and dried for four days at 80°C for dry weight analysis. To determine Maku lotus dry weight at seed harvest, 10 stems from each plot were dried and the average stem dry

weight multiplied by the average stem number metre⁻². To measure regrowth after seed harvest, two 0.5 metre⁻² areas were cut on May 4th 1982, weighed fresh and dried.

c) Seed yield measurements

By observing marked stems, optimum harvest time was determined. This was when approximately five per cent of the pods had shattered, 80% of the pods were light brown, ten per cent of the pods were green or purple and five percent of the umbels were still in the yellow flower stage.

One to two days before seed harvest 20 stems were cut from each plot for use in measurement of components of seed yield. At seed harvest two 2x1m areas per plot were cut and put into paper sacks (Plate 4.1), oven dried for four days at 35°C, threshed and cleaned. The harvested areas were vacuumed to calculate shattered seed yield (Plate 4.2). Uncut treatments were harvested again one week after the main harvest from two more 2x1m areas, to calculate the effect of seed shattering upon seed yield. All seed yields were corrected to 12 percent moisture content.

d) Soil moisture measurements

When each treatment was harvested for seed, soil samples at one site per plot were taken at 100 mm intervals to one metre in depth. The soil samples were weighed fresh and dried at 105°C for two days to determine soil moisture percentage by weight. All plots had soil samples taken at seed harvest only. Soil moisture measurements were not taken in the 1982/83 trial.



Plate 4.1 Seed harvesting of Maku lotus. The material was cut from a 2mx1m area and placed in bags to dry before threshing and seed cleaning.



Plate 4.2 Vacuuming shattered seed.

4.2.2 1982-83 trial

The trial was a factorial design [(3x2) + 1] with three closing dates by two cutting heights, plus one uncut treatment, all replicated four times. The factors and their levels were:

1. Closing dates on September 29th, October 20th and November 11th, 1982.
2. Cutting heights at the above dates of
 - (i) cutting to ground level with a sickle bar mower and trimming with rotary mower.
 - (ii) cutting 50-100mm off the top of Maku lotus with a sickle-bar mower.

The uncut treatment plots were not cut until seed harvest in February 1983.

a) Pre-harvest treatments

The field was mown on May 4th, 1982 and the cut material removed. Ioxynil was sprayed twice at 1.6 a.i. ha⁻¹ in August to control groundsel (*Senecio vulgaris*) chickweed (*Stellaria media*), and hawksbeard (*Crepis capillaris*). Carbetamide, at 1.5 kg a.i. ha⁻¹, was applied twice in September to control *Poa annua* and barley grass (*Hordeum murinum*). Glyphosate was applied with a 'hockey stick' wick applicator to small patches of yarrow (*Achillea millefolium*), twitch (*Agropyron repens*) and docks (*Rumex* sp.) in September.

On October 15th, a gross application of 13mm of water was applied by spray irrigation. Two hives of honey-bees were placed in the field in November 1982. No hives were in the field for the previous trial, nor was any irrigation applied in the 1981/82 trial.

Bromophos, at 0.4 litres a.i. ha⁻¹, was applied on December 16th to control potato mirids (*Calocoris norvegicus*) when mirid populations in the field reached 15-20 per 20 net sweeps with a 400 mm sweep net.

b) Dry matter yield measurements

At closing two 2x1m areas were cut from the ground level cut plots weighed fresh and a 500 gram sub-sample taken and dried at 80°C for four days. Dry matter cuts were not taken from topped plots. At seed harvest two 0.5 m⁻² areas were cut from each plot and all the material was dried and weighed. Dry matter measurements were not taken in May.

c) Seed yield measurements

Two 2x1m areas were hand harvested from each plot at the optimum seed harvest time and loosely put into either wool packs or cloth sacks. The wool packs and cloth sacks were put outside each day and opened, so that the harvested stems, leaves and pods dried slowly over a period of four to six weeks. The harvested material was turned regularly and did not heat inside the wool packs and cloth sacks. After drying, the material was threshed and the seed cleaned. Ten stems were cut from each plot for measurement of components of seed yield. As shattering was minimal no vacuuming of the sample areas was done. All seed yields were corrected to 12% moisture content.

4.2.3 Climate

1981-82 was a hot dry season with higher average maximum temperatures, higher average vapour pressure deficits and less total rainfall than the 1982-83 season (Table 4.1).

Heavy hail fell on January 19th, 1983, before any plots were harvested for seed. Estimates of hail damage were made by taking 10 stems from each plot and counting total pods, broken pods and broken stems.

Table 4.1 Mean monthly temperatures, mean monthly vapour pressure deficits and total monthly rainfall for the 1981-82 and 1982-83 seasons.

Month	Mean Temperatures (°C)		Mean vapour Pressure deficits (k pa)		Total Rainfall (mm)	
	1981-82	1982-83	1981-82	1982-83	1981-82	1982-83
August	5.6	8.2	0.20	0.41	122.5	23.4
September	8.7	8.6	0.43	0.25	15.0	20.8
October	11.5	9.9	0.52	0.48	94.4	87.6
November	13.5	15.0	0.48	0.87	34.6	52.2
December	17.1	13.7	0.72	0.59	15.1	94.2
January	17.2	15.7	1.02	0.82	28.2	30.8
February	17.4	14.8	0.93	0.55	15.5	18.5
March	16.0	15.2	0.67	0.81	12.2	24.0
April	10.1	11.6	0.30	0.42	46.6	101.4

4.3 RESULTS

4.3.1 Flowering at defoliation

Stages of flowering at defoliation at each closing date varied from no bud formation to full flowering bloom (Table 4.2).

4.3.2 Soil moisture at harvest

At seed harvest in 1982 soil moisture levels varied between six and ten per cent, on an oven dry weight basis, in the top one metre of soil.

4.3.3 Harvest date

The hot dry weather in 1982 caused rapid pod ripening. Harvest dates were easily determined as over 80% of the pods were light brown and about 5-10% had shattered at optimum harvest date. Defoliation at closing caused harvest dates to be delayed up to two months later than the uncut treatment harvest time (Table 4.3). When uncut plots in 1982 were harvested other plots were still flowering (Plate 4.3).

In 1983 the cool weather caused pods to ripen very slowly, making optimum harvest time very difficult to determine. From stem analysis at harvesting, there was a large proportion of small green pods and a very small proportion of shattered pods (light brown pods 55%, purple pods 9%, green pods 34%, shattered pods 2%). The heavy December rainfall caused a mass of new vegetative growth to appear with new flowers forming in January. It was not possible to delay harvesting until the green pods were ripe, as the brown pods, which were in larger proportion, would have shattered.

Table 4.2 Stage of flowering at each closing date.

Closing date	Stage of flowering at defoliation
November 12th 1981	Green buds forming
November 24th 1981	Orange buds forming
December 4th 1981	Yellow flowers forming
December 15th 1981	Maximum yellow flower bloom
September 29th 1982	No buds visible
October 20th 1982	No buds visible
November 11th 1982	Green buds forming

Table 4.3 Harvest dates and days from cutting to seed harvest.

Time of closing and method of cutting at closing	Seed harvest date	Days from cutting to seed harvest
Uncut 1981	January 21st 1982	
Nov. 12th 1981 Cut to ground level	February 9th 1982	89
Nov. 24th 1981 Cut to ground level	February 18th 1982	86
Dec. 4th 1981 Cut to ground level	March 16th 1982	102
Dec. 15th 1981 Cut to ground level	March 22nd 1982	97
Uncut 1982	February 8th 1983	
Sept. 29th 1982 Cut to ground level Topped	Feb. 1st-16th 1983	125 - 140
	Feb. 1st-16th 1983	125 - 140
Oct. 20th 1982 Cut to ground level Topped	Feb. 16th-24th 1983	119 - 127
	Feb. 1st-24th 1983	104 - 127
Nov. 11th 1982 Cut to ground level Topped	March 2nd 1983	111
	Feb. 16th-24th 1983	97 - 105

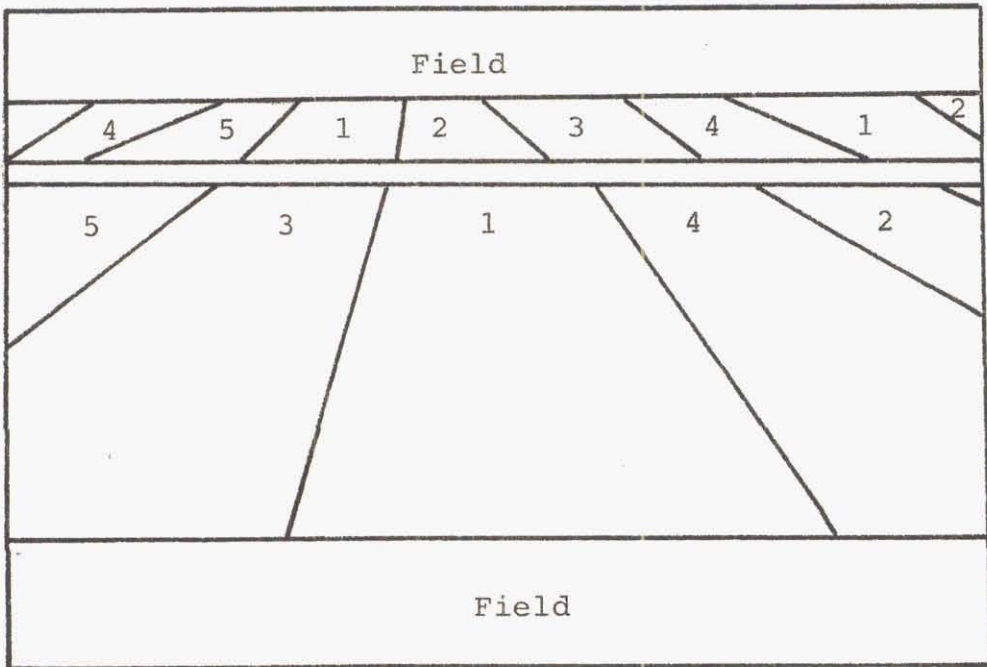


Plate 4.3 Stages of development in closing date treatments following harvest of uncut treatments on January 21st 1982.

1. Control treatment - harvested.
2. Closed Nov. 12th 1981 - Purple and green pods developing.
3. Closed Nov. 23rd 1981 - Main flowering.
4. Closed Dec. 4th 1981 - Green and orange buds forming.
5. Closed Dec. 15th 1981 - No buds formed.

In 1982, each plot of a given treatment was harvested on the same date. In 1983, plots of the same treatment varied in harvest date according to the proportion of light brown pods ready for harvest. Cutting to seed harvest took over 20 days longer in 1983 than 1982 (Table 4.3). Plots cut to ground level on November 12th, 1981 took 89 days to seed harvest, but plots cut to ground level on November 11th, 1982 took 111 days to reach seed harvest.

4.3.4 Dry matter yields

The maximum dry matter yield at seed harvest in 1982, was 1135 g m^{-2} from the uncut treatment. This was three to four times greater than the defoliated treatments which averaged 330 g m^{-2} of dry matter at harvest (Table 4.4). The uncut treatment produced 1258 g m^{-2} of dry matter for the season from two cuts, which was considerably more than the 830 g m^{-2} of dry matter produced by the defoliated treatments from three cuts.

Cutting to ground level on November 12th, 1982 significantly reduced dry matter at seed harvest in 1983 to 806 g m^{-2} compared to topping, 1112 g m^{-2} (Table 4.5). There were no significant differences in dry matter at seed harvest in 1983 between methods of cutting at earlier closing dates.

All cut treatments in 1983 grew at a faster rate per day and yielded approximately two times more dry matter at seed harvest than cut treatments in 1982. The November 12th 1982 ground level cut treatment grew 4.7 g m^{-2} of dry matter per day to seed harvest, considerably less than the 7.3 g m^{-2} of dry matter per day produced by the November 11th 1982 ground level cut treatment.

Table 4.4 Effect of closing date upon Maku lotus dry matter yields at closing, harvest and post-harvest in 1982.

Treatments	Dry Matter g m ⁻²			
	Closing date 1981	Closing	Harvest	Post harvest (May 4th 1982)
Control	-	1135	123	1258
Nov. 12th	263	416	92	771
Nov. 24th	406	330	113	849
Dec. 4th	480	365	80	925
Dec. 15th	408	208	61	777
SE (mean)	55	164	11	193

Table 4.5 Effect of closing date and method of cutting at closing upon dry matter yields at harvest in 1983.

Treatment		Dry matter g m ⁻²	
Closing date	Method of cutting	Closing	Harvest
not cut	not cut	-	1044
Sept. 29th 1982	Ground	204	905
	Topped	-	943
Oct. 20th 1982	Ground	288	1034
	Topped	-	999
Nov. 12th 1982	Ground	350	806*
	Topped	-	1112
SE (mean)		-	51

* significance 5% level

4.3.5 Bulk density at seed harvest

Bulk density of the sward at harvest was measured as grams of dry matter per square metre per 100 mm of sward height.

In 1982 cutting at closing reduced stem length (sward height) at seed harvest from 850 mm for the uncut treatment down to 370 mm (Table 4.6). Bulk densities at seed harvest in 1982 were considerably reduced by cutting at closing from 132 g m^{-2} of dry matter per 100 mm sward height down to 88 g m^{-2} (average of all cut treatments).

In 1983 cutting at closing only affected stem length of the November 11th ground level cut treatment which was 620 mm, compared with 730 mm for all other treatments (Table 4.7). There were no major differences in bulk densities at seed harvest in 1983 which averaged 137 g m^{-2} of dry matter per 100 mm of sward height.

4.3.6 Seed yield

Maximum seed yields in both years were from the uncut treatments; 47 g m^{-2} in 1982 (Table 4.8) and 48.8 g m^{-2} in 1983 (Table 4.9).

Seed yields in 1982 were considerably reduced by cutting. Plots cut on November 24th and December 4th 1981, did not produce any seed at all, as the very dry conditions caused the pods to shrivel and produce no harvestable seed. Plots cut on November 12th and December 15th 1981 produced 1.2 and 1.5 g m^{-2} of seed respectively (Table 4.8).

Table 4.6 Effect of closing date upon stem length and bulk density at harvest in 1982.

Closing Date 1981	Method of cutting	Stem length (mm)	Bulk density (g m^{-2} per 100 mm sward height)
Uncut		860	132
Nov. 12th	Ground level	460	90
Nov. 24th	" "	420	78
Dec. 4th	" "	330	110
Dec. 15th	" "	280	74
SE (mean)		103	10.8

Table 4.7 Effect of closing date and method of cutting at closing upon stem length and bulk density at harvest in 1983.

Closing Date 1982	Method of cutting	Stem length (mm)	Bulk density (g m^{-2} per 100 mm sward height)
Uncut	-	710	147
Sept. 29th	Ground level	760	119
	Topped	730	129
Oct. 20th	Ground level	730	141
	Topped	730	136
Nov. 11th	Ground level	620	130
	Topped	710	156
SE (mean)		16.7	4.7

Table 4.8 Effect of time of closing on Maku lotus seed yields in 1982.

Treatment (Closing date)	Seed yield g m^{-2} (12% moisture)
Control	47
SE (mean)	(4.8)
Nov. 12th 1981	1.2
SE (mean)	(0.25)
Nov. 24th 1981	0
Dec. 4th 1981	0
Dec. 15th 1981	1.5
SE (mean)	(0.47)

Table 4.9 Effect of time of closing and method of cutting at closing on Maku lotus seed yields in 1983.

		Seed yield g m ⁻² (12% moisture)	
Time of closing		Cut to ground level	Topped
September 29th 1982		28.2	39.9
October 20th 1982		13.6	41.1
November 11th 1982		6.7	25.9
	SE(mean)	4.24	7.39
	Significance	L**	N.S
Contrast Uncut Versus Mean of 6 cut treatments		48.8	
	SE(mean)	5.8	
	Significance	**	
Main effects.			
1. Method of cutting			
	Ground level	16.0	
	Topped	35.5	
	SE(mean)	3.36	
	Significance	**	
2. Time of closing			
	September 29th 1982	34.1	
	October 20th 1982	27.4	
	November 11th 1982	16.3	
	SE(mean)	4.11	
	Significance	L**	
Interaction		N.S.	

Increasing delays in closing with ground level cutting decreased seed yields linearly from 28 g m^{-2} (September closing) to 6.7 g m^{-2} (November closing) in 1983 (Table 4.9). There was no significant difference in seed yield between topped treatments. The November 11th 1982 topped treatment yielded 26 g m^{-2} of seed, significantly less seed than the 48.8 g m^{-2} produced from the uncut treatment.

Delays in closing significantly reduced seed yields from 34 g m^{-2} (September closing) to 16 g m^{-2} (November closing). Topping at closing produced significantly higher yields, 35.5 g m^{-2} , than cutting at closing, 16 g m^{-2} (Table 4.8).

Pod shatter was rapid in 1982 when harvesting was delayed. Uncut plots harvested on January 21st 1982, had 11% of total seed on the ground and eight days later 47% of total seed was on the ground. Dry hot conditions caused the rapid pod shatter. In 1983 pod shattering was minimal, with only three per cent pod shatter in the control plots at harvest. Before any seed was harvested a heavy hail storm on January 19th, 1983, caused approximately 10% seed loss in all plots.

4.3.7 Components of seed yield

In 1982 cutting reduced the number of umbels per stem and pods per umbel (Table 4.10). Seeds per pod were not measured. In 1983 seeds per stem, umbels per stem and seeds per pod showed highly significant linear decreases from September to November closing dates and were significantly reduced by ground level cutting compared to topping (Table 4.11). Pods per umbel and 1,000 seed weight were not affected by successively later closings and severity of defoliation.

Table 4.10

Effect of time of closing on Maku lotus components of seed yield in 1982.

Treatment	Stems m^{-2}	Umbels $stem^{-1}$	Pods ₋₁ umbel	1000 seed wt (12% moisture)
Uncut	325 (36)	8.5 (0.55)	8.0 (0.33)	0.930 (0.006)
Cut to Ground Level.				
Nov. 12th	427 (20.2)	4.2 (0.37)	5.2 (0.20)	0.918 (0.018)
Nov. 24th	345 (17.4)	-	-	-
Dec. 4th	373 (16.5)	-	-	-
Dec. 15th	343 (13.2)	1.9 (0.42)	2.6 (0.18)	0.938 (0.014)
(SE mean)				

Table 4.11 Effect of time of closing and method of cutting at closing on Maku lotus components of seed yield in 1983.

Components of seed yield

Treatment	Stems _{m⁻²}	Seeds _{stem⁻¹}	Umbels _{stem⁻¹}	Pods _{umbel⁻¹}	Seeds _{pod⁻¹}	1000 seed weight (gm) 12% moisture
<u>Cut to ground level</u>						
Sept. 29th	452	0.18	9.4	5.5	5.6	0.970
Oct. 20th	476	0.09	7.6	6.0	2.7	0.977
Nov. 11th	502	0.02	4.7	6.7	1.2	0.912
Significance	N.S.	L**	L**	N.S.	L**	N.S.
SE (mean)	21	0.2	0.6	0.3	0.5	0.019
<u>Topped</u>						
Sept. 29th	449	0.24	10.1	5.7	6.9	0.944
Oct. 20th	447	0.19	9.4	5.7	5.6	0.929
Nov. 11th	374	0.08	8.5	5.5	2.6	0.994
Significance	L**	L**	N.S.	N.S.	L**	N.S.
SE (mean)	21	0.2	0.6	0.3	0.5	0.019
<u>Contrast</u>						
Control	481	0.18	10.4	5.1	7.5	0.926
v mean of 6 treatments	450	0.13	8.3	5.8	4.1	0.954
Significance	N.S.	*	*	N.S.	**	N.S.
SE (mean)	30	0.3	0.9	0.4	0.7	0.027
<u>Main effect</u>						
1. Method of cutting						
Ground level	477	0.10	7.2	6.1	3.7	0.953
Topping	423	0.17	9.3	5.6	5.1	0.956
Significance	*	*	**	N.S.	**	N.S.
SE (mean)	17	0.02	0.5	0.2	0.4	0.015
2. Time of closing						
Sept. 29th 1982	451	0.21	9.8	5.6	6.3	0.957
Oct. 20th 1982	562	0.14	8.5	5.9	4.2	0.953
Nov. 11th 1982	438	0.05	6.6	6.1	1.9	0.953
Significance	N.S.	L**	L**	N.S.	L**	N.S.
SE (mean)	21	0.2	0.6	0.3	0.5	0.019
Interaction	*	N.S.	N.S.	N.S.	N.S.	N.S.

The uncut treatment in 1982 had 8.5 umbels per stem and 8.0 pods per umbel. The uncut treatment in 1983 had more umbels per stem, 10.1, but fewer pods per umbel, 6.9, than in 1982. There were no differences in 1,000 seed weight between years and between treatments in both years.

4.4 DISCUSSION

Increasing delays in closing and severity of defoliation at closing depressed seed yields of Maku lotus. This pattern of reductions in seed yield following either high or low defoliations, particularly after bud formation, has also been reported in other herbage legumes: *Lotus corniculatus* (Anderson and Metcalfe, 1957; Bader and Anderson, 1962), *Medicago sativa* (Kowithayakorn and Hill, 1982a), *Stylosanthes guianensis* (Loch et al, 1976), *S. humilis* (Loch and Humphreys, 1970; Fisher, 1973), *Trifolium subterraneum* (Rossiter, 1961; Collins, 1978) and *Trifolium pratense* (Dade, 1966).

Results in this experiment also support the findings of Clifford (Lancashire et al, 1980), that closing Maku lotus seed crops from November onwards significantly reduced seed yields. However, closing even earlier, in late September and October, with a close ground cutting, also decreased seed yields. These decreases, from September and October closing dates, are caused by the following:

1. Slow recovery from low defoliation, supporting Sheath's (1980) research in Maku lotus.

2. Slow growth until warm temperatures approaching 20°C are reached. Charlton (1977) also found that Maku lotus was slow to grow under cool conditions.

Both lucerne and white clover recover rapidly from defoliation and grow in the early spring when the average daily temperatures are still about 10° to 15°C. Grazing can therefore be practised before closing white clover and lucerne for seed. Maku lotus has comparatively little winter or early spring growth. Spring grazing can not be carried out if maximum seed yields are to be produced, because of the slow regrowth and warm temperature requirement of Maku lotus.

Topping did not simulate mirid damage, as the stems did not branch and produce more umbels per stem and concentrate flowering (Table 4.11). Instead there was a decrease in umbels per stem following topping. Clifford et al (1983) found that mirids only damaged the umbels. Topping in this study removed the umbels and 50-100 mm of stem, and this may have been too severe to allow Maku lotus to recover, branch and produce more umbels per stem. It must be noted that some mirid damage did occur before insecticide was applied; thus, mirids may have increased seed yields in all plots, counteracting whatever topping effects there may have been. However, it is impractical for farmers to remove any less stem by topping in November or December, because of the uneven growth of Maku lotus stands and the tall height, 0.4 to 0.7m, of Maku lotus then. It would be difficult to adjust mowers to that height. There is a need, however, for more detailed study on removing only umbels and the effect on seed yield.

Similar reductions in the same components of seed yield, following defoliation in Maku lotus, were found in lucerne by Kowithayakorn and Hill (1982a). Umbels per stem and seeds per pod in Maku lotus and clusters per plant and seeds per pod in lucerne were the sensitive components. In both cases, pods per umbel (Maku) and pods per cluster (lucerne) were not significantly affected by defoliation.

Components of seed yield were calculated on 10 stems taken from 10x4 m plots. Seed yield metre^{-2} was three to four times greater from the analysis of components than from the harvested areas; thus seed yield from 10 stems did not give a true estimate of seed yield metre^{-2} . But the magnitude of differences between treatments from either actual seed yield metre^{-2} or stem yield x stem number metre^{-2} were the same; cutting to ground level after spring growth and topping after bud appearance significantly reduced seed yield.

The main problem with Maku lotus at harvest is to dry the mass of vegetation before pods shatter. Neal (1983) closed fields late in order to have less vegetation to dry at harvest and reduced pod shatter, although this meant a loss in potential seed yield. However, Neal (1983) maintained that it was better to be sure of a low seed yield in the bag rather than risk a high seed yield on the ground.

Bulk density of the sward at harvest was measured in order to try to estimate the degree of lodging as an index or indication of mowing difficulty and drying rate. In this study it was dry matter at harvest and stem lengths that gave better indications of lodging, mowing difficulty and drying rate.

In 1982 no lodging occurred but in 1983 some lodging occurred in all plots. This did not present difficulties for mowing, but drying was observed to be substantially slower in 1983 than in 1982. However, it was found that vegetation at harvest could only be significantly reduced by cutting to ground level from November onwards, when little seed was produced. In order to get high seed yields, large amounts of fresh matter at harvest are unavoidable and must be coped with. Harvesting at the optimum time, as detailed in Chapter 3, will allow sufficient time for the fresh matter to dry, either after mowing or chemical desiccation, before combine harvesting.

Flowering and seed ripening were not concentrated by successively later closing dates as reported by Neal (1983). The uncut treatments in both years were observed to give more concentrated flowering than cut treatments. There were no observed differences in length of flowering and seed ripening between treatments cut to ground level or topped.

4.5 SUMMARY

Maximum seed yields of 47 g m^{-2} in 1982 and 49 g m^{-2} in 1983 were obtained from treatments left uncut from spring growth onwards.

Seed yields of Maku lotus were significantly reduced by cutting to ground level after spring growth started. Topping only reduced seed yields when it was carried out after bud appearance in November. A light topping can therefore take

place in the spring without detrimental effects on seed yields, but it is of no practical value. Cutting at closing, significantly reduced umbels per stem and seeds per pod.

CHAPTER 5

THE EFFECT OF DIFFERENT ROW SPACINGS AND PLANT POPULATIONS
ON MAKU LOTUS SEED YIELDS.

5.1 INTRODUCTION

Maku lotus is an expensive seed crop to grow, with some growers having to wait up to 30 months before getting a return on their investment (Neal, 1983). In establishing the crop, high costs are involved in weed control. Many farmers believe that in order to control the weeds a dense cover of Maku lotus must be established, therefore seeding rates of between two and four kg ha^{-1} are commonly used (Neal, 1983; Lancashire *et al*, 1980).

Lancashire *et al* (1980) recommend, from their experience, that three to four kg ha^{-1} of inoculated seed sown in 0.30-0.60m rows will provide the best Maku lotus seed crop. However, with basic seed costing up to $\$30 \text{ kg}^{-1}$ (Neal, 1983), a considerable cost of between $\$90$ and $\$120 \text{ ha}^{-1}$ must be invested in seed.

From research on plant populations and row spacings on perennial herbage legumes it appears that wide rows and low populations give the highest seed yields. Lucerne sown in 0.30m row spacings at a population of between 11 and 25 plants metre^{-2} gave significantly higher yields than narrower spacings of 0.10-0.15m with plant population of 44-100 plants metre^{-2} (Kowithayakorn and Hill, 1982a). Clifford (1974) found that Pawera red clover gave significantly higher yields at 17 plants

metre⁻² in 0.60m rows than at 33 and 67 plants metre⁻² in 0.15m rows. As there are approximately 450,000 seeds in a kilogram of lucerne and 320,000 seeds in a kilogram of red clover, seeding rates of below one kilogram per hectare will produce enough plants for maximum seed yields.

Since seed yield per unit area is a function of seed yield per plant and plant numbers, it is possible that different plant populations may be one of the most important components governing Maku lotus seed production. Thus the objective of this experiment was to investigate the possibility of reducing Maku lotus seed crop sowing rates, by testing the hypothesis that plants at low populations would compensate to give higher seed yields per unit area than at high populations.

5.2 MATERIALS AND METHODS

Innoculated Maku lotus seed was planted into 150mm long by 25mm wide paper tubes on December 16th, 1981 and established in a glass-house for two months. In February 1982 the tubplings were taken outside to 'harden up' before planting in the field in March.

The experimental area was in the same field as the closing date and seed development trial (Plate 5.1) and on the same Wakanui soil complex (Table 3.1). In February 1982 the area was ploughed, grubbed and harrowed, and trifluralin at 1.0 kg a.i. ha⁻¹ incorporated into the soil to control annual grasses and broadleaf weeds. No fertilizer was applied.

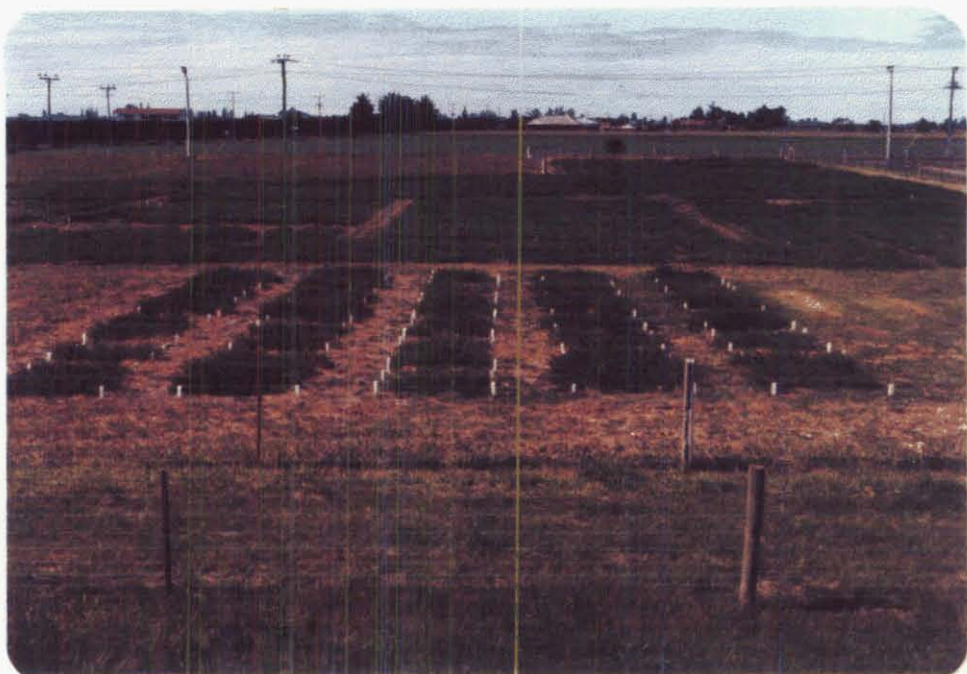


Plate 5.1

Maku lotus population trial November 15th 1982
with the closing date trial in the background.



Plate 5.2

Maku lotus population trial at peak flowering
December 15th 1982.

The Maku lotus tublings were planted in the second week of March 1982 in a randomised block design with five replications and six treatments (Plates 5.1 and 5.2). The treatments consisted of three inter-row spacings of 0.15, 0.30 and 0.45m and two intra-row spacings of 0.05 and 0.10m. Each plot consisted of five rows with variable plot size (Table 5.1).

Table 5.1 Row spacings, plant populations and plot sizes for Maku lotus plant population trial.

Treatment	Inter-row spacing (m)	Intra-row spacing (m)	Plant population (No.) m^{-2}	Plot size (m)
1	0.15	0.05	133	1.5 x 0.9
2	0.15	0.10	66	1.5 x 0.9
3	0.30	0.05	66	1.5 x 1.8
4	0.30	0.10	33	1.5 x 1.8
5	0.45	0.05	44	1.5 x 2.7
6	0.45	0.10	22	1.5 x 2.7

A gross depth of approximately 10mm of water was applied to the plots by spray irrigation on March 15th, 1982 to assist tubling establishment.

Weeds were a problem. Nettles (*Urtica urens*), wart-cress (*Coronopus squamatus*), and mallow (*Maliva* sp.) were hand-weeded in May and July 1982. Ioxynil and carbetamide were applied in August and September at the same rates as in the closing date trial (page 57).

Two hives of honey bees were placed alongside the trial in November 1982. Bromphos at $0.4 \text{ kg a.i. ha}^{-1}$ was applied on December 16th to control potato mirids.

5.2.1 Flowering pattern

At weekly intervals from December 3rd 1982, when first flowers appeared, a small frame, $0.30 \times 0.45 \text{ m}$ in size, was placed on a marked position in the centre row of each plot. Newly opened yellow flowers were counted in order to establish the flowering pattern in Maku lotus.

5.2.2 Seed yields

The same $0.30 \times 0.45 \text{ m}$ sample area was harvested for seed yield. The sample was cut (Plates 5.3 and 5.4) and the harvested material dried outside in cloth bags before threshing and cleaning. Cut stems within the harvested area were counted.

Ten stems were taken from immediately outside the edge of the frame plot and the components of seed yield measured. After harvest, all plots were cut to 50 mm in height and allowed to grow again for 1984 experimental work.

5.3 RESULTS

5.3.1 Flowering pattern

Yellow flowers first appeared at the beginning of December and peak flowering occurred ten days later (Figure 5.1). Flowering then decreased until the end of January, when no more flowers were formed before seed harvest. Harvesting took place during the last week of January and the first week of February. Pods in low population plots ripened first and so were harvested one week before the high population plots.

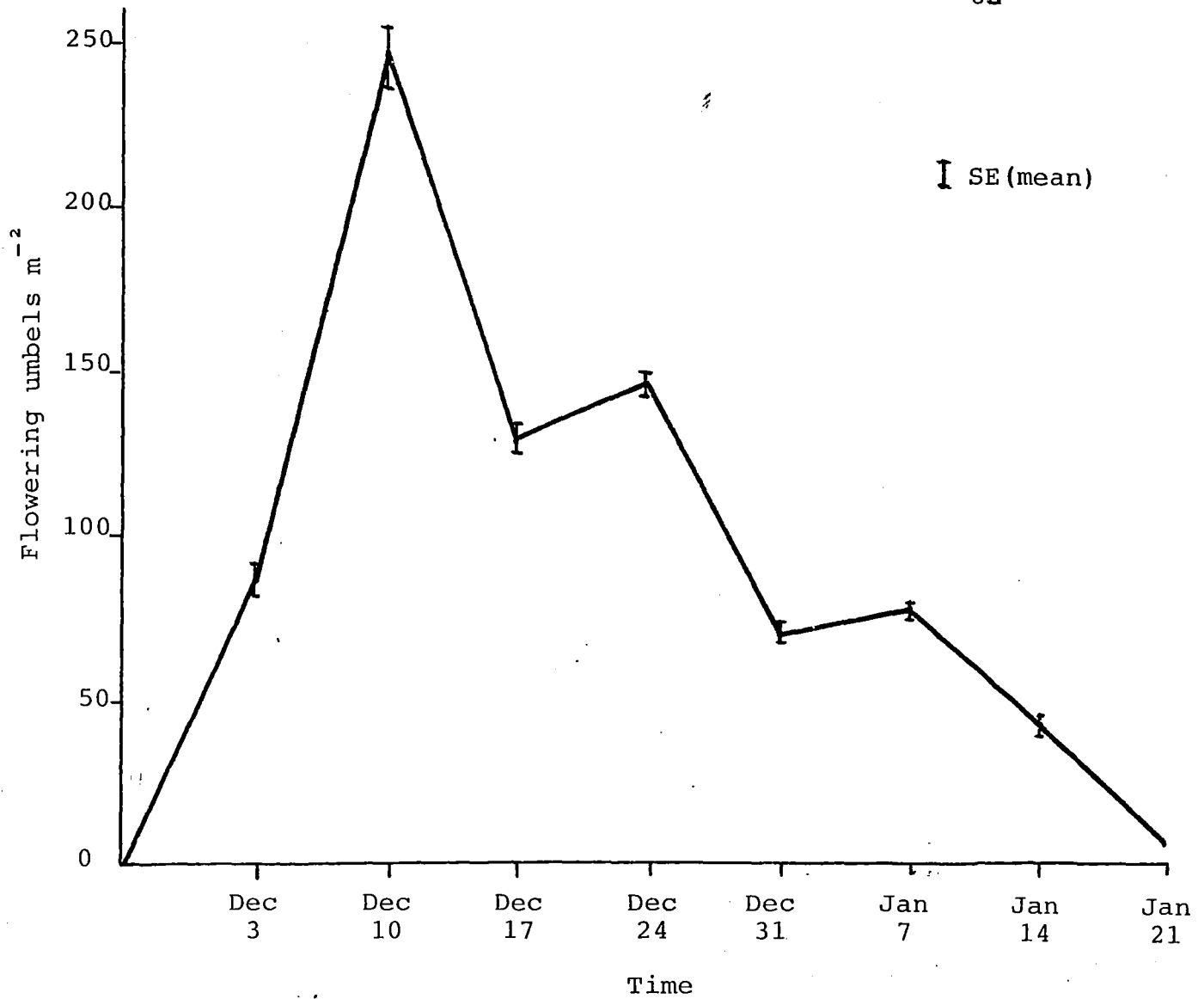


Figure 5.1 Flowering pattern in Maku lotus in 1982/83.

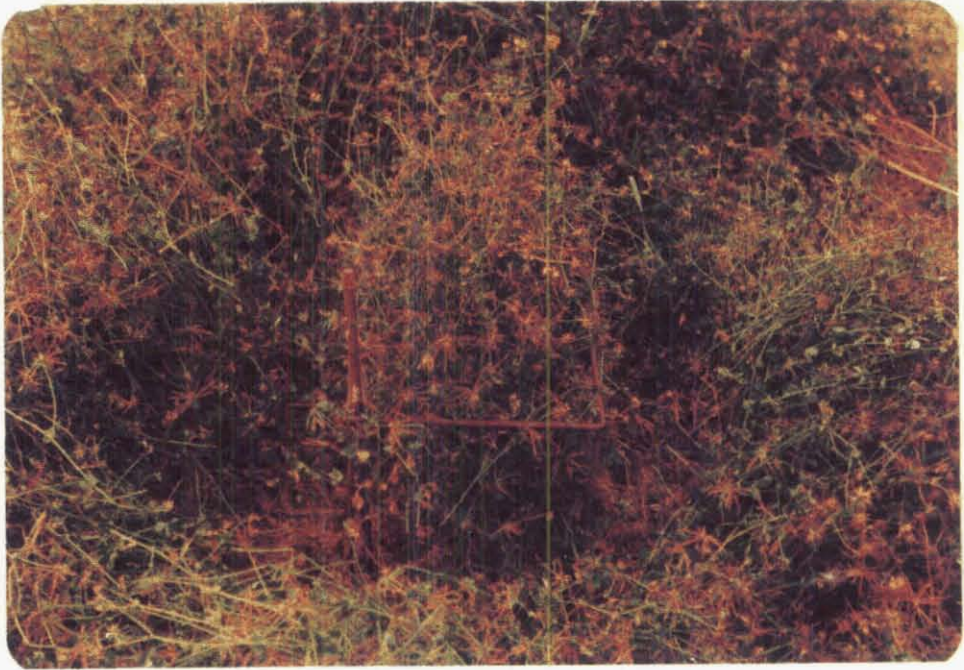


Plate 5.3 Sample area, 0.30x0.45m, before harvest for seed yield in plant population trial.

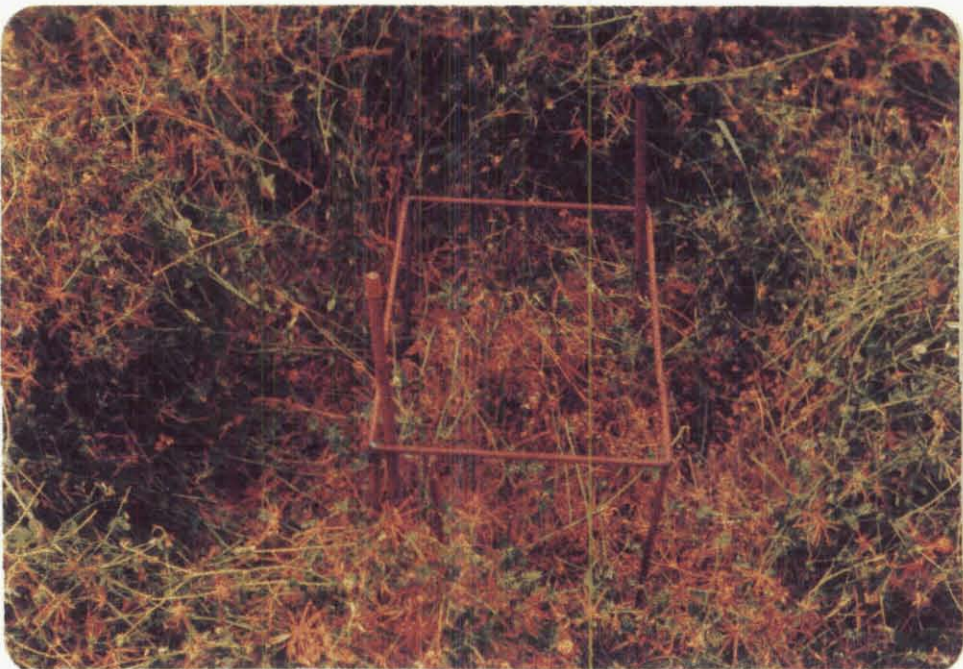


Plate 5.4 Sample area before stem count.

After peak flowering two small flowering flushes occurred. These produced new pods which were still green and very immature at harvest. As these pods were approximately two to three weeks younger than the brown pods, it was not possible to delay harvest until they were mature, otherwise the brown and purple pods would have shattered. The seed harvest therefore took place when 36% of the pods were brown, 19% were purple and 45% were green.

The plots regrew again after harvest and flowers formed in April. Some flowers did form small pods, but frosts in May prevented these pods from developing.

5.3.2 Seed yield

There was a significant linear decrease in seed yield from the low populations (22, 33 and 44 plants metre⁻²) to the high populations (66 and 133 plants metre⁻²) (Figure 5.2). The highest yield of 88 g m⁻² was from 33 plants metre⁻², but this was not significantly different to 86 g m⁻² from 22 plants metre⁻². There was also a linear decrease in seed yield from the wide row spacings, 0.30 and 0.45 m to the narrow row spacing, 0.15 m. There was no significant difference in seed yield between the two intra-row spacings except at the 0.30 m inter-row spacings where the 0.10 m intra-row spacing (88 g m⁻²) was significantly higher than the 0.05 m intra-row spacing (75 g m⁻²).

Plants at populations of 22 plants metre⁻² had significantly higher seed yields of 3.9 g plant⁻¹ (Table 5.2). Narrow inter-row spacings, 0.15 m, and narrow intra-row spacings, 0.05 m, significantly reduced seed yields per plant.

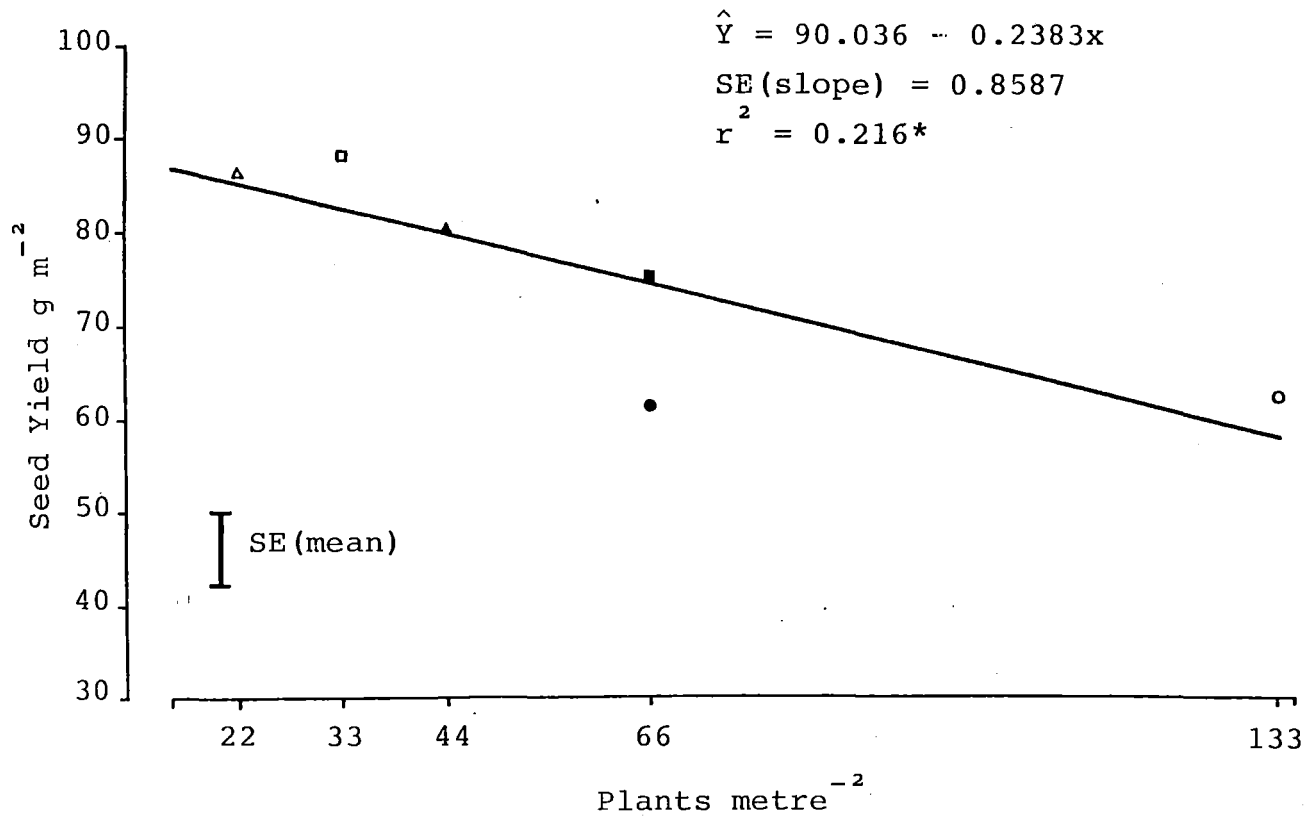


Figure 5.2 Relationship between Maku lotus seed yield and plant population.

Inter-row L**; Intra-row N.S.;
 Inter-row x Intra-row N.S.

Symbols.

Inter-row	Triangles	0.45 m
	Squares	0.30 m
	Circles	0.15 m
Intra-row	Open	0.10 m
	Closed	0.05 m

Table 5.2 Effect of plant population and row spacing upon seed yield per plant.

Plant population no. m ⁻²	Row spacing inter / intra (m)	Seed yield per plant (g)
22	0.45/0.10	3.9
33	0.30/0.10	2.8
44	0.45/0.05	1.8
66	0.30/0.05	1.1
66	0.15/0.10	0.9
133	0.15/0.05	0.5
	Significance	Q**
	SE (mean)	1.83
<u>Inter-row</u>	0.45	2.8
	0.30	1.9
	0.15	0.7
	Significance	L**
	SE (mean)	0.16
<u>Intra-row</u>	0.10	2.5
	0.05	1.1
	Significance	**
	SE (mean)	0.13
Interaction Inter-rowxIntra-row		L**

5.3.3 Components of seed yield

Wide row spacings and low populations had significantly more seeds per stem by producing more umbels per stem (Table 5.3). Pods per umbel, seeds per pod, and 1,000 seed weight were not affected by row spacing and plant population.

Stems metre⁻² were more affected by row spacing than by plant population. The inter-row spacings had significantly fewer stems metre⁻² than the 0.30 and 0.15 m inter-row spacings. Intra-row spacings per 0.10 m had significantly fewer stems metre⁻² than 0.05 m intra-row spacings, at 30 and 15 cm inter-row spacings but not at the 45 cm inter-row spacings (Table 5.3).

5.4 DISCUSSION

Maku lotus plants compensated at low plant populations, by producing more umbels per stem, which increased seeds per stem and seeds per plant. It was observed that up to 50% of the stems at 133 plants metre⁻² were barren, while most stems under lower populations were reproductive. Kowithayakorn and Hill (1982a) and Clifford (1974) also found in lucerne and red clover the proportion of reproductive stems was significantly reduced under high populations.

The populations which gave significant increases in seed yields in lucerne and red clover were below 25 plants metre⁻², whereas in this study Maku lotus showed no significant yield difference between 22 and 33 plants metre⁻². This is probably due to the slow establishment of Maku lotus with the populations at 22 plants metre⁻² not fully branching in the first year. The significant linear increase in seed yield

Table 5.3

Effect of plant population and row spacing on Maku lotus components of seed yield.

Plant population metre ⁻²	Row spacing inter/intra (m)	Stems metre ⁻²	Seeds stem ⁻¹	Umbels stem ⁻¹	Yield pods umbel ⁻¹	Yield seeds pod ⁻¹	1000 seed weight (g) (12% moisture)
22	0.45/0.10	293	0.37	11.9	5.9	10.6	0.881
33	0.30/0.10	369	0.45	12.9	5.8	11.2	0.867
44	0.45/0.05	262	0.31	11.9	5.7	11.2	0.852
66	0.30/0.05	431	0.27	11.6	5.5	10.5	0.829
66	0.15/0.10	311	0.27	11.6	5.9	9.4	0.844
133	0.15/0.05	459	0.20	8.3	5.2	9.4	0.872
Signifi- cance		L**	L**	L**	N.S	N.S	N.S
SE(mean)		33.1	0.041	0.93	0.33	1.11	0.0209
<u>Inter-row (m)</u>							
	0.45	278	0.34	11.9	5.8	10.9	0.867
	0.30	400	0.36	12.0	5.7	10.8	0.848
	0.15	385	0.24	10.0	5.6	9.4	0.858
	Signifi- cance	Q*	L*	N.S	N.S	N.S	N.S
	SE(mean)	23.4	0.029	0.66	0.23	0.78	0.0148
<u>Intra-row (m)</u>							
	0.10	324	0.36	12.1	5.9	10.4	0.864
	0.05	384	0.26	10.5	5.5	10.4	0.851
	Signifi- cance	*	**	*	N.S	N.S	N.S
	SE(mean)	19.1	0.024	0.54	0.19	0.64	0.0121
<u>Inter-action</u>							
	Inter-row x Intra-row	L*	N.S	N.S	N.S	N.S	N.S

metre⁻², with lower plant populations, suggests that in second and subsequent years after establishment the highest seed yields will be from plant populations of 22 plants metre⁻² or less. Wide row spacings, besides giving the highest yields in Maku lotus, have also been found to make management of herbage seed crops easier (Clifford pers.com.). Inter-row cultivation, spraying and fertilizer can be carried out effectively without crop damage. It is recommended that Maku lotus be planted in 0.30-0.60m inter-rows for ease of seed crop management.

There are approximately 1,200,000 seeds in one kilogram of Maku lotus seed. Establishment of Maku lotus is very variable with approximately 30-40% of seed sown producing seedling plants. If only 30% of seeds sown produced seedling plants, then farmers can, therefore, reduce costs by lowering their seed sowing rates from two to four kg of seed per hectare down to between 0.5 and 0.75 kg of seed per hectare in 0.45 m rows for maximum Maku lotus seed yields. It also raises the possibility that with time, Maku lotus seed stands through stem and rhizome production may become too dense for maximum seed yields. Farmers may then have to inter-row cultivate or disc the seed stands in the winter, in order to reduce stem and rhizome populations, and produce a larger population of reproductive stems.

It must be noted that yields from the plant population trial were considerably higher, 86-88 g m⁻², than yields from the uncut treatment in the 1983 closing date trial, 48 g m⁻². This may have been caused by the small plots in the plant population trial exaggerating the seed yields. But the

high yields in the plant population trial were from 331 stems metre⁻² (mean of 22 and 33 plants metre⁻² populations), which was far lower than 481 stems metre⁻² from the uncut treatment in the 1983 closing date trial. The plant population trial had been established for one year at the time of harvest, whereas, the closing date trial stand was two years and three months old at harvest time in 1983. It is therefore suggested that stem populations in the closing date trial field, after over two years of establishment are too dense to produce maximum seed yields of over 50 g m⁻². Inter-row cultivation may now be necessary to reduce stem populations and increase potential seed yields, by increasing the proportion of reproductive stems.

The flowering time of Maku lotus was not affected by plant population and spacing treatments. Flowering peaked in mid-December and then gradually decreased until by the end of January no more flowers were produced. It appears that maximum flower production is before the longest day, making it similar to Huia white clover (Clifford, 1979a) and in 16 hour photoperiods making Maku lotus similar to *Lotus corniculatus* (Joffe, 1958; McKee, 1963) and a north German variety of *Lotus pedunculatus* (Forde and Thomas, 1966).

In December 1981, under very dry soil conditions, flowering was observed to decrease rapidly after peak flowering was reached in the closing date trial. The more gradual decline of flowering in December 1982 was caused by higher soil moisture levels following 94.2 mm of rain compared with 15.1 mm of rain in December 1982 (Table 4.1).

5.5 SUMMARY

Maku lotus has a flowering pattern which peaks in mid-December, producing ripe seed pods in late January. Maximum seed yields of 86 to 88 g m⁻² in the first year of establishment, were produced by plant populations of between 22 and 33 plants metre⁻² in either 0.30 or 0.45 m inter-row spacings. These plants produced more umbels per stem. The evidence suggests that in second and subsequent years, populations of approximately 22 plants metre⁻² or less will give the highest seed yields. Farmers need to sow only 0.50 - 0.75 kg of seed per hectare in 0.30 - 0.60 m inter-rows to achieve these plant populations.

CHAPTER 6

GENERAL DISCUSSION

6.1 INTRODUCTION

Results from this study indicate that by establishing Maku lotus seed stands at low populations, closing seed stands before spring growth commences and closely observing umbel and seed pod development to determine optimum harvesting time, seed yields of well over 400 kg ha^{-1} can be harvested. These seed yields are considerably higher than the national average of 89 kg ha^{-1} in 1982 (M.A.F., 1983).

Farmers have regarded Maku lotus seed production as an extremely risky venture, especially when compared to white clover seed production where consistently high yields can be achieved (White clover seed 1982 national average was 215 kg ha^{-1} , M.A.F., 1983). However, if Maku lotus seed yields of over 400 kg ha^{-1} could be achieved regularly, then the risk of seed production would be reduced and Maku lotus seed production would become an attractive proposition for cropping farmers.

Neal (1983) considered that because of establishment, weed and pod shattering problems, high risk was associated with growing and harvesting Maku lotus seed and so a gross margin of around $\$1500 \text{ ha}^{-1}$ was necessary to interest farmers. If annual seed yields of 400 kg ha^{-1} were harvested, then farmers could accept $\$8 \text{ kg}^{-1}$ for their seed and still get a net return of over $\$1500 \text{ ha}^{-1}$. At this price graziers may

find Maku lotus seed oversowing on hill and high country more economic, especially as they may be able to reduce their fertilizer inputs at the same time.

In order to reduce further the risks associated with Maku lotus seed production, farmers must develop a specialist attitude towards the crop. In many cases farmers have not regarded Maku lotus as a major crop, but rather as a catch crop and have neglected crop husbandry. By giving priority to white clover seed production, especially at harvesting, delays in cleaning white clover seed out of combine harvesters when Maku lotus is ready to harvest has resulted in rapid pod shatter of Maku lotus; thus giving Maku lotus seed production an unjustified reputation for being even more risky. It is suggested that Maku lotus and white clover seed crops on the average farm are incompatible, due to their common harvest time and similar seed size (seed cleaning problems can arise), and that only one of these crops should be grown on the same farm.

Farmers must look upon Maku lotus as a high value seed crop that requires specialist management from sowing to harvesting. Maku lotus must be established on good weed free sites and farmers must apply the correct herbicides correctly, to control weeds that do emerge.

6.2 PLANT POPULATION

The evidence in the present study and that found in other herbage legumes (Kowithayakorn and Hill, 1982a; Clifford, 1974) indicates that low plant populations, 20-30 plants

metre⁻², and wide rows, 0.30-0.60 m are best for maximum seed yields. Maku lotus establishment costs can therefore be reduced by lowering seed sowing rates from two to four kg ha⁻¹ down to between 0.50 - 0.75 kg ha⁻¹ in order to produce a high yielding seed crop.

Maku lotus, with maturity, will produce a large number of rhizomes. A seed crop in time, therefore can become very dense. High plant populations of Maku lotus in these studies produced a high proportion of vegetative stems which decreased seed yields through competition with reproductive stems and it was observed that stems closer to the plant crown produced the most seed. It may be necessary, once a seed crop has been established, to inter-row cultivate or lightly disc in the winter to reduce the number of stems per unit area.

6.3 CLOSING DATE AND DEFOLIATION

Once the crop is established, farmers must not cut Maku lotus seed stands after spring growth commences if high seed yields of over 400 kg ha⁻¹ are to be harvested. Farmers have tried to close Maku lotus seed crops later, in the belief that a shorter period of flowering takes place, pod shatter is reduced and bulk vegetation at harvest decreases enabling a quicker drying (Neal, 1983). However, in these studies it was observed that the length of flowering in early and late closing was the same; pod shatter was reduced, but at the expense of very high seed yields. It also appears that vegetation bulk at harvest can not be reduced without detrimental effects on seed yield. Because of the slow spring growth and

slow regrowth after defoliation, Maku lotus should not be closely cut or grazed in the spring. Farmers have to accept that a high bulk of vegetation at harvest and high seed yields are directly related and that only by harvesting at the optimum time will forage be dry before pod shatter.

The advantages of an initial attack by mirids and then applying an insecticide as found by Clifford et al (1983) were not simulated by topping after bud appearance, a shorter flowering period was not produced and seed yields were reduced. Mirids directly affect the primary stem umbels whereas topping removed the umbels and part of the stems. Maku lotus plants are uneven in height, with vertical and horizontal stems, and so it is impractical for farmers to remove only umbels by topping in order to simulate mirid damage. Nor would a light grazing by lambs be recommended as the lambs would trample and flatten the seed crop and damage the vulnerable main stems of Maku lotus. Because there are no positive advantages from topping after spring growth compared to not topping, topping of Maku lotus seed crops is not recommended if maximum seed yields are to be produced.

6.4 FLOWERING

Most farmers have found that Maku lotus flowers over a very long period, resulting in an extended seed-set and thus making the judgement of optimum harvest time difficult. The hot dry weather after peak flowering in the first season produced very even pod ripening and made judgement of harvesting easy. In the second season it is suggested that, if Maku lotus

had been planted on lighter soils rather than on the Wakanui soil complex, even pod ripening at the end of January would have resulted, despite the late December and early January rainfall. This raises the possibility that Maku lotus planted on light soils, with irrigation to control soil moisture levels up to flowering, may produce a shorter flowering period with even pod-ripening, which would make judging of optimum harvesting time more reliable. Research is needed to investigate the responses of Maku lotus on light soils to irrigation.

In 1982-83 the flowering pattern in Maku lotus, which was not cut or grazed in the winter and spring, was monitored weekly, and it was found to peak in mid-December. In the 1981-82 season, under very dry conditions, flowering was observed to peak at the same time. Peak flowering occurred in both years in December at 16 hour photoperiods, before the longest day, and this was found to be similar to other *Lotus* sp. (Joffe, 1958; McKee, 1963; Forde and Thomas, 1966) and Huia white clover (Clifford, 1979a).

Farmers can judge peak flowering time by counting yellow open flowers in small areas at weekly intervals, from the end of November to early January. It is critical that seeds from the peak flowering pods be harvested in order that maximum yields be obtained. Later maturing pods are too uneven in their development for a good seed-set to be harvested. In most studies it is the seeds from the main flowering periods that produce the highest yields (Humphreys, 1979). Studies on *Lotus corniculatus* have also shown that delay in harvesting, in order to harvest later formed pods, does not compensate for the pod shattering losses from earlier formed pods (Anderson, 1955).

6.5 SEED DEVELOPMENT AND OPTIMUM HARVEST TIME

From peak flowering (which can be called pollination) it took approximately 27-35 days for Maku lotus seed to reach maturity. The rate of seed ripening was dependent on daily temperatures and vapour pressure deficits which influence the rate of moisture loss.

Seed maturity can be judged by pod colour, which was purple to light brown in Maku lotus. Pod colour also indicated seed maturity in *Lotus corniculatus* (Anderson, 1955; Wiggans et al, 1956). The optimum time to begin harvest operations of Maku lotus was after seed maturity, when 3-5% of the pods had shattered and approximately 50-60% of the pods were light brown. Anderson (1955) obtained maximum seed yields of *Lotus corniculatus* when 23% of pods were green, 57% were light brown, 14% were dark brown and 6% had shattered. One week after optimum harvest Anderson (1955) found that no green pods in *L. corniculatus* were harvested, but pod shattering increased from 6% to 38%, with a 40% decrease in seed yield. Maku lotus pod shattering in 1982, one week after optimum harvest, increased from 11% to 47% with a 52% decrease in seed yield. Farmers, therefore, must not wait for more green pods to turn brown once pods from peak flowering have reached the optimum harvesting time, otherwise pod shatter will reduce seed yields.

Once the optimum harvesting time has been reached, farmers must make the decision whether to mow or direct-head the seed crop. Under hot dry conditions, chemical desiccation and direct-heading may be preferred. However, no research has been done on comparing the two methods in Maku lotus. Direct-

heading was preferred to mowing in an experiment with *Lotus corniculatus* (Wiggans et al, 1956). With most Maku lotus seed crops cut at about 70% forage moisture content, it would be important to study how long it takes to dry this forage under different harvesting methods and the effect of drying on pod moisture content and shatter. Maku lotus seed development was closely studied but unfortunately the development of Maku lotus seed pods, their rate of drying, and moisture content at seed maturity and at shattering was overlooked in these studies.

However, with pod shattering occurring rapidly under dry weather conditions, the possibility of vacuum harvesting must be investigated. In Australia vacuum harvesters are used to harvest subterranean clover and tropical legume seed crops successfully. Some of the risk of Maku lotus seed production may be eliminated if vacuum harvesters can successfully harvest seed from the ground after pod shatter. Vacuum harvesters may make white clover and Maku lotus seed crops more compatible, because if Maku lotus seed did fall to ground, through delays in harvesting white clover, this seed could be vacuumed up at a later date. The use of possible chemical sprays to inhibit pod shatter also needs investigation.

6.6 SUMMARY AND FUTURE WORK

The overall objective of this research project was to develop some important management strategies to enable farmers to reduce risks and harvest high seed yields, of Maku lotus, 400 kg ha⁻¹ and above, in most seasons.

These high seed yields may allow Maku lotus seed prices to fall to levels still giving an economic return to seed growers, but enabling graziers to purchase the seed, thereby establishing a strong and reliable market for Maku lotus seed. Important management strategies that have been developed are:

1. Farmers need to sow only $0.50-0.75 \text{ kg ha}^{-1}$ of seed in order to get a plant population of $20-30 \text{ plants metre}^{-2}$ which will produce maximum seed yields. The seed should be planted in rows, $0.30-0.60 \text{ m}$ apart. Seed stands after three years production may have to be thinned by inter-row cultivation to reduce stem populations in order that high seed yields be maintained.

2. Farmers must close their seed crops as soon as spring growth occurs. Any defoliation after this time will reduce seed yields.

3. Optimum time to start mowing or chemically desiccating the crop is when the majority of seed pods are light brown in colour. This will allow plenty of time for the sward to dry before harvesting, reducing the risk of pod shatter.

In order that the above management strategies for high reliable seed yields of Maku lotus be strengthened, further research work should be undertaken on the following:

1. Irrigation of Maku lotus seed crops on light soils be studied in order to synchronize flowering and pod ripening for maximum seed yields.

2. Harvesting techniques comparing direct heading, mowing and sward drying, and vacuum harvesting be undertaken, so that potential seed yields can be harvested and not lost through pod shatter.

3. Chemical sprays to inhibit pod shatter be investigated.

4. Climatic conditions that influence the rate of pod ripening leading to pod shatter be studied, in order that areas suitable for reliable seed yields of Maku lotus be selected.

5. Growth regulator application be studied, in order to reduce bulk vegetation at harvest.

ACKNOWLEDGEMENTS

I would like to express my gratitude to and acknowledge the assistance of the following people:

Nitayaporn, my wife, without whose encouragement I would not have contemplated returning to university to study for a degree, for love and support particularly during my diploma year, for help in harvesting, cleaning and counting seeds and for tirelessly typing and reading draft manuscripts of this thesis.

My parents for invaluable support enabling me to undertake full time study and realize my capabilities in herbage seed production.

Mr R.J. Lucas, my supervisor, for guidance during the field work and for constructive and helpful comments on the preparation of this thesis.

Mr P.T.P. Clifford, D.S.I.R. Lincoln, for technical contributions and assistance throughout the course of field work, without which Maku lotus would have remained a most difficult plant to study.

Professor J.G.H. White, Head, Plant Science Department, for the initial encouragement to investigate aspects of Maku lotus seed production and continual interest in the research.

The Leonard Condell Farming Scholarship trust at Massey University for awarding a scholarship to me in 1982 and 1983, and the Lincoln College Research Committee for providing funds for the field research.

Miss Diane Heslop for the outstanding close-up photography of Maku lotus flowers and honey bees.

Miss Caroline Mason and Mr Bruce Sheed for assistance in harvesting and measurements in the field.

Mr B.G. Love for help with statistical analysis.

Mr D. Heffer and Mr D. Fowler for providing technical field help and other people at the Field Service Centre who helped harvest and clean seed.

Mrs Lillian Falloon and Mrs Diana Atkinson for reading the draft manuscripts, correcting the style and useful comments on presentation and Mr William Atkinson for proof reading the final thesis copy.

Mrs Jenny Morris for skilfully typing and arranging the final presentation of this thesis.

To all these people and others, thank you.

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September, 1983.

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Appendix 1

Climatic data at Lincoln College from when Maku lotus umbels were marked at pollination to 43 days after pollination.

Days after pollination	Maximum Temperature °C		Relative humidity %		Vapour pressure deficit kpa		Rainfall mm	
	1981/82	1982/83	1981/82	1982/83	1981/82	1982/83	1981/82	1982/83
1 to 18 days (total)	-	-	-	-	-	-	9.2	41.3
(average)	21	20.4	80	70	0.58	0.65	-	-
19	26.9	19.5	0.77	92	1.03	0.45	0.0	0.0
20	23.2	22.4	0.58	45	1.11	0.99	0.0	0.0
21	27.2	21.3	0.26	55	1.61	1.11	0.0	0.0
22	23.8	21.1	0.31	41	1.38	1.02	0.0	0.0
23	22.4	25.3	0.35	66	1.30	0.89	13.6	0.0
24	16.4	32.0	0.92	70	0.39	1.36	9.9	0.0
25	15.3	28.5	0.91	58	0.34	1.48	0.0	0.0
26	13.3	31.0	58	54	0.48	1.49	0.0	8.4
27	27.0	14.2	74	95	1.01	0.16	0.0	1.7
28	23.0	22.1	45	66	1.20	0.72	0.0	0.0
29	28.8	21.3	49	49	1.27	0.73	0.0	0.0
30	33.5	23.6	32	44	2.26	1.16	0.0	0.0
31	17.2	19.4	88	73	0.32	0.33	0.5	0.0
32	22.0	22.6	83	47	0.70	0.98	0.0	0.0
33	21.7	22.0	71	37	0.76	1.30	0.0	15.4
34	22.2	18.6	71	64	0.58	0.61	0.0	0.4
35	26.2	21.3	88	82	0.94	0.66	2.2	0.0
36	16.4	22.1	90	36	0.39	1.15	0.2	0.2
37	18.2	16.4	72	52	0.62	0.72	0.0	0.0
38	30.4	18.7	59	72	1.60	0.52	0.0	0.0
39	29.8	19.1	40	67	1.96	0.59	0.0	1.2
40	22.3	15.0	24	84	1.39	0.34	0.1	0.0
41	19.9	19.4	27	73	1.15	0.49	1.7	0.0
42	18.4	28.3	53	85	0.89	1.17	0.0	0.0
43	31.8	19.3	65	83	1.80	0.25	0.0	0.0
44	25.1	25.8	41	63	1.46	1.14	0.0	0.0
45	17.8	16.8	46	66	0.59	0.75	0.0	0.0
46	20.9	20.0	63	95	0.64	0.84	0.0	0.0
47	22.9	23.7	83	65	0.65	0.76	0.0	0.0

Appendix 2 Fresh weight of 1000 seeds in grams for 4 groups of Maku lotus plants, 15 to 47 days after pollination in 1982/83.

Group	Days after pollination								
	15	19	23	27	31	35	39	43	47
1	0.415	0.986	1.240	1.799	1.787	1.782	1.071	0.860	0.868
2	0.390	0.796	1.108	1.819	1.732	1.776	1.551	0.924	0.819
3	0.515	0.957	1.322	1.959	2.015	1.838	1.119	0.946	0.827
4	0.600	0.970	1.162	1.805	1.789	1.889	1.211	0.898	0.837
\bar{X}	0.480	0.927	1.208	1.846	1.831	1.821	1.238	0.907	0.838
SE (mean)	0.048	0.044	0.047	0.038	0.063	0.027	0.108	0.018	0.011

Appendix 3 Dry weight of 1000 seeds in grams for 4 groups of Maku lotus plants, 15 to 47 days after pollination in 1982/83.

Group	Days after pollination								
	15	19	23	27	31	35	39	43	47
1	0.086	0.178	0.279	0.566	0.678	0.702	0.721	0.757	0.710
2	0.080	0.081	0.256	0.546	0.535	0.695	0.641	0.633	0.698
3	0.096	0.096	0.296	0.605	0.772	0.696	0.781	0.724	0.731
4	0.080	0.090	0.220	0.542	0.591	0.722	0.692	0.733	0.691
\bar{X}	0.086	0.111	0.263	0.565	0.644	0.707	0.709	0.712	0.708
SE (mean)	0.004	0.023	0.016	0.014	0.052	0.013	0.029	0.027	0.009

Appendix 4 Moisture percentage of 1000 seeds for 4 groups of Maku lotus plants, 15 to 47 days after pollination in 1982/83.

Group	Days after pollination								
	15	19	23	27	31	35	39	43	47
1	79.4	81.9	77.5	68.5	62.1	60.6	32.8	11.9	18.1
2	81.3	90.0	77.6	69.1	61.7	62.1	30.2	23.5	11.6
3	86.7	90.7	81.1	70.0	67.0	60.6	42.8	18.4	17.4
4	79.5	89.8	76.9	70.0	69.1	61.4	58.7	31.5	14.7
\bar{X}	81.7	88.1	78.3	69.4	64.9	61.2	41.1	21.3	15.5
SE (mean)	1.72	2.08	0.95	0.37	1.83	0.36	6.46	4.14	1.48

Appendix 5 Germination percentage of normal seedlings of fresh Maku lotus seeds for 4 groups of plants, harvested 15 to 47 days after pollination in 1982/83.

Group	Days after pollination								
	15	19	23	27	31	35	39	43	47
1	-	-	-	32.0	62.0	52.0	38.0	14.5	4.0
2	-	-	-	34.0	44.7	34.5	60.5	56.0	33.0
3	-	-	-	16.0	50.0	53.5	36.0	8.0	0.0
4	-	-	-	29.3	42.7	53.0	48.5	23.5	6.5
\bar{X}	-	-	-	27.8	49.9	48.3	45.8	25.5	10.9
SE(mean)	-	-	-	4.06	4.33	4.59	5.63	10.65	7.50

Appendix 6 Germination percentage of abnormal seedlings of fresh Maku lotus seed for 4 groups of plants, harvested 15 to 47 days after pollination in 1982/83.

Group	Days after pollination								
	15	19	23	27	31	35	39	43	47
1	-	-	-	35	26.7	10.5	11.5	6.5	2.5
2	-	-	-	32	34.7	22.5	17.5	16.5	12.5
3	-	-	-	14.5	36	19	15.5	4	0.5
4	-	-	-	18.7	40.7	16.5	26	12.5	2.5
\bar{x}	-	-	-	25.1	34.5	17.1	17.6	9.9	4.5
SE (mean)	-	-	-	4.99	2.91	2.53	3.08	2.84	2.71

