'Grasslands Maku' Lotus (*Lotus pedunculatus* (Cav.)) Seed Production 1. Development of Maku Lotus Seed and the Determination of Time of Harvest for Maximum Seed Yields[1]

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ABSTRACT

Seed development investigations showed that the optimum time to commence harvesting 'Grasslands Maku' lotus (*Lotus pedunculatus* (Cav.), syn. *L. uliginosus* (Schkuhr.)) was 2-4 days after seed maturity when the seeds had 35% moisture content, the pods were light brown and 3-4% pod shatter had occurred. Pollination to seed maturity (maximum 1000 seed dry weight; 0.70g 1982, 0.71g 1983) took 27 days in 1982 and 35 days in 1983. Pod color was the best indication of seed maturity and seed moisture content in both years.

Additional index words: seed development; harvesting time, germination, hardseededness.

INTRODUCTION

The main reasons for low harvested seed yields from potentially high yielding crops of 'Grasslands Maku' lotus (*Lotus pedunculatus* (Cav.)), syn. (*L. uliginosus* (Schkuhr.)) are the indeterminate flowering and unpredictably of 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).

Optimum times for harvest of herbage legume seeds can be determined by monitoring the changes which occur during seed development. Studies of several herbage legumes have shown that maximum viability was reached 4-7 days before seeds reached maturity (Hyde et al., 1959; Win Pe, 1978; Kowithayakorn and Hill, 1982). Thus by mowing or desiccating the crop shortly after seed maturity and allowing the seed to dry in the sward, pod shatter may be reduced and seed yields increased, as Wiggans et al. (1956) showed in *Lotus corniculatus*. The problem is to identify reliably this stage. 'Seed maturity' is the point at which maximum dry weight is first reached (Hyde, 1950; Anderson, 1955). 'Seed viability' is the capacity of the seed to resume growth after having been dried (Hyde, 1950). '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).

The aim of this work was to see if changes in moisture content, dry weight and germination capacity of Maku lotus seed could be related to pod color changes and pod shattering, so that the optimum time for seed harvest could be defined.

MATERIALS AND METHODS

The trial was conducted at Lincoln College, Canterbury (43°S) over the 1981/82 and 1982/83 summer seasons. Plants were sown in November 1980 on a Wakanui soil complex and in August 1981 were thinned to a population of one plant per square meter for the trial and the field closed until seed harvest. The soil profile overall was of variable texture with sand and silt lenses at various depths. The soils were susceptible to water-logging during the winter and dried out rapidly and cracked during the summer. A soil quick test (Cornforth and Sinclair, 1982) in January 1982 gave a pH of 6.1 and an Olsen P of 24.

Umbel development from bud appearance through to pollination was observed on one tagged umbel on each of 10 plants. On 14 December 1981 and 17 December 1982, 20 pollinated umbels on each of 30 plants (total of 600 umbels) were tagged by wrapping colored wire around the peduncles at main flowering.

Main flowering was deemed to have been reached when 50% of the umbels on the plants had yellow flowers. Umbels were deemed to have been pollinated when 30 to 90% of the florets were open and the petals were slightly wilted.

Every four days from 19 days (1981/82) and 15 days (1982/83) after pollination two tagged umbels per plant were collected. In 1982/83 the plants were divided into 4 groups in order to determine standard errors of mean between groups. The following observations were made in both seasons:

i Pod color
ii Pod number per umbel
iii Shattered pod number per umbel
iv Seed fresh weight, dry weight and moisture percentage
v Germination percentage
(a) 1981/82. Five replicates of 100 seeds per petri dish were germinated on top of blotting paper in a

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growth cabinet at 20 C with 16 hours light and 8 hours darkness. Germination counts were made at 9 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 4 days and then germinated on top of blotting paper at 20 C in darkness. Germination counts were made at 4, 12 and 20 days. Normal and abnormal seedlings, hard and ungerminated inbibed seed were recorded. Normal seedlings were those with a good radicle, long hypocotyl and 2 cotyledons, including those in which the testa still covered the cotyledons at the end of the test period (Wellington, 1970).

RESULTS

Umbel Development

Umbel buds first appeared between 10 and 15 November in both years. Development from the green bud stage to pollination took 30 to 35 days (Table 1). At pollination (as described in Methods) the yellow flowers were fully open, petals slightly wilted, and some lower keel petals in the umbel were pushed out slightly by expanding pods. Pollination to the dark brown pod stage took 31 days in 1981/82, but in 1982/83 it took over 47 days. All pods were shattered by 47 days in 1981/82, compared with only 13% in 1982/83. Over both seasons it took 75-90 days for all umbels to develop from green buds to brown pods (Tables 1 and 2).

Table 1. 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
Brown bud stage	Sepals brown.	10
Orange bud stage	Peduncle elongates from leaf axil. Yellow standard petals with orange tips protrude from calyx.	10
Yellow flower stage	Six to 16 florets (mean 10) attached by short pedicels to a long solitary peduncle, 60-100 mm in length.	10
Pollination	Yellow flowers fully open, petals slightly wilting, keel petals pushed slightly out by expanding pods in lower flowers of umbels.	2

[1]Mean of 1981 and 1982 years.

Table 2. Pod color and stage of seed development from 19 to 47 days after pollination.

Days after pollination	Color 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 and dry weight 63% moisture	Maximum fresh weight 70% moisture
31	Light brown all over pod	Dark purple on top, green underneath	20% moisture 4% pod shatter	65% moisture
35	Light brown all over pod	Purple to light brown top, yellowish green underneath	9.3% moisture 7% pod shatter	Maximum dry weight 61% moisture
39	Dark brown all over pod. Pods crisp and snap easily	Light brown on top, yellowish green underneath	9.5% moisture 44% pod shatter	41% moisture 2% pod shatter
43	As above	Light brown all over pod	8.3% moisture 88% pod shatter	20% moisture 8% pod shatter
47	As above	Dark brown all over pod	100% pod shatter	15.5% moisture 13% pod shatter

In both years umbels were tagged towards the top of the plant canopy. When tagged in the second year new vegetative growth appeared in December which resulted in tagged umbels becoming buried in the middle of the plant canopy. Thus, umbels experienced drier weather in the first than in the second season, especially from 27 to 43 days after pollination (Figures 1,2,3).

Seed Development

Fresh weight: In both seasons maximum fresh weight of Maku lotus seeds was reached 27 days after pollination (Figure 4). Maximum 1000 seed fresh weight was 1.9g (63% moisture) in 1982 and 1.85g (70% moisture) in 1983. In 1982 the rapid decline in fresh weight from 27 to 31 days after pollination, appeared to be caused by the very high vapor pressure deficits and high temperatures for that period especially on day 30 in 1982 when the maximum temperature was 33.5 C and the vapor pressure deficit was 2.26 kPa (Figures 1 and 2).

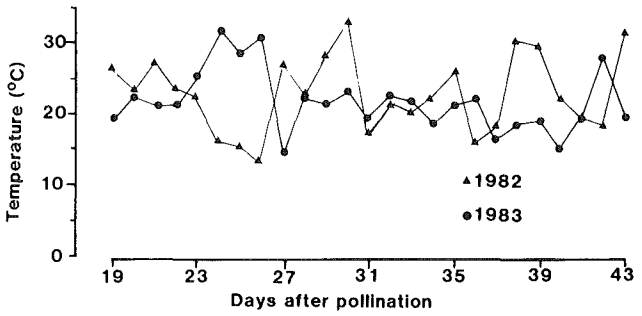

Figure 1. Maximum temperatures from 19 to 43 days after pollination.

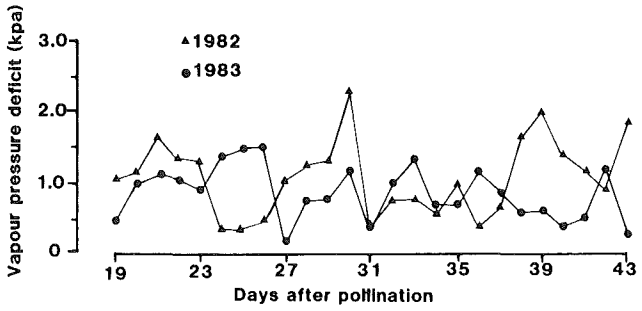

Figure 2. Average daily vapor pressure deficits from 19 to 43 days after pollination.

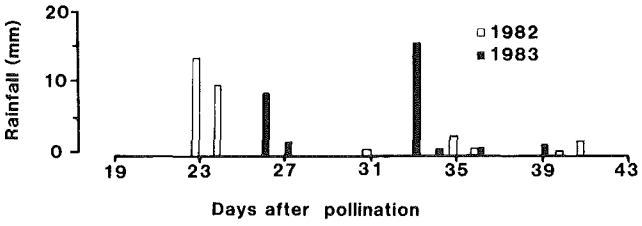

Figure 3. Daily rainfall from 19 to 43 days after pollination.

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 5).

Maximum 1000 seed dry weight was 0.70g in 1982 and 0.71g in 1983. Seed moisture percentage when seeds attained maximum dry weight was 63% in 1982 and 61% in 1983.

Moisture percentage: In both seasons, rapid seed drying did not occur until maximum dry weight was reached. In 1982 the moisture percentage of seeds declined rapidly at 6.7% per day from 27 to 35 days after pollination (Figure 6). In 1983 the moisture percentage declined by 5% per day over the 8 day period following maximum dry weight, day 35 to day 43.

Pod color and shattering: Pod color progressed from green to purple on the top surface to a light brown below

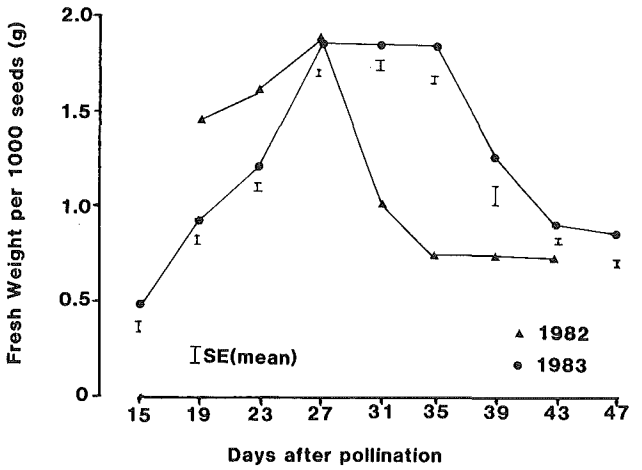

Figure 4. Maku lotus 1000 seed fresh weight from pollination.

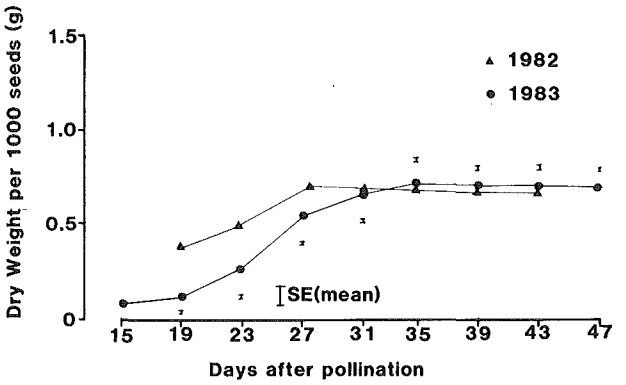

Figure 5. Maku lotus 1000 seed dry weight from pollination.

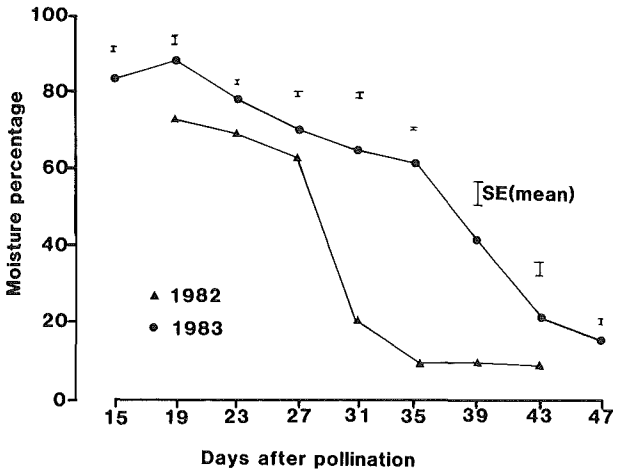

Figure 6. Moisture percentage of Maku lotus seed from pollination.

20% moisture and to a dark brown when pods shattered (Table 2). Maximum dry weight was reached in both years when pods were purple to light brown on top and yellowish

green underneath. Pods remained green and seed retained moisture longer in 1983 than in 1982. Pod color changes were more rapid in 1982. For both seasons the onset of pod shattering appeared to be consistent with seed approaching 20% moisture (Table 2, Figure 7).

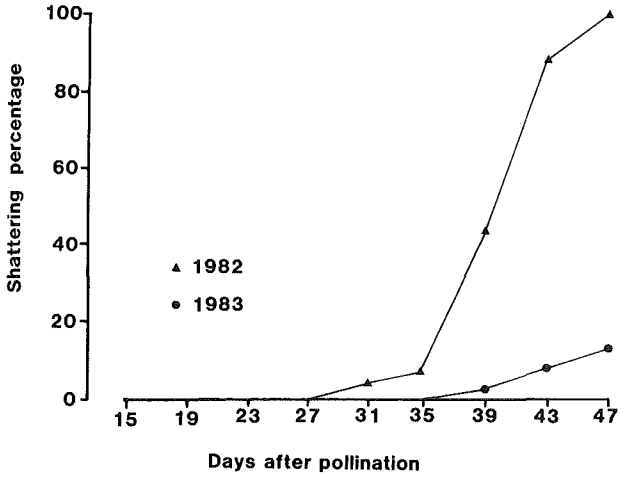

Figure 7. Pod shattering percentage of Maku lotus from pollination.

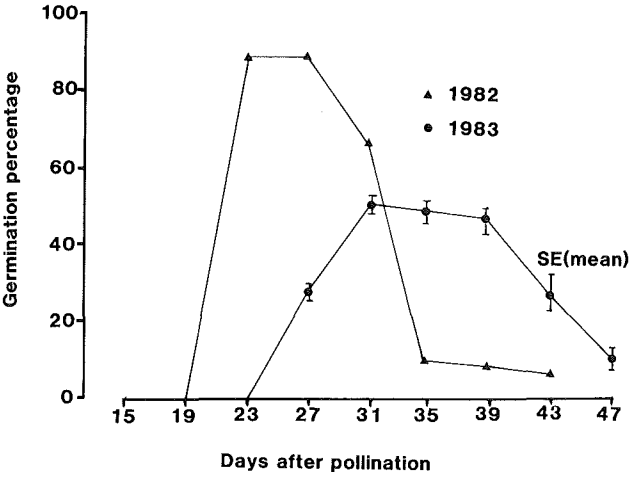

Figure 8. Germination percentage of Maku lotus fresh seed from pollination.

In 1982 pod shattering increased rapidly from 7% at day 35, to 44% at day 39, to 88% at day 43. From day 35 to day 43 pods shattered at a rate of 10% per day. These losses occurred when the seed moisture percentage was below 10%. By contrast, seed moisture percentage in 1983 did not drop below 15.5% resulting in only 13% pod shatter by day 47.

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 4, 8). At this stage the seed was 71% of its final dry weight in 1982 and 90% in 1983 (Figures 6, 8).

Hardseededness appeared as the moisture content decreased below 40% (Figure 6, 9). Over 90% of seeds were observed to be hard in 1982 at moisture percentages of 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 hard (Figure 9).

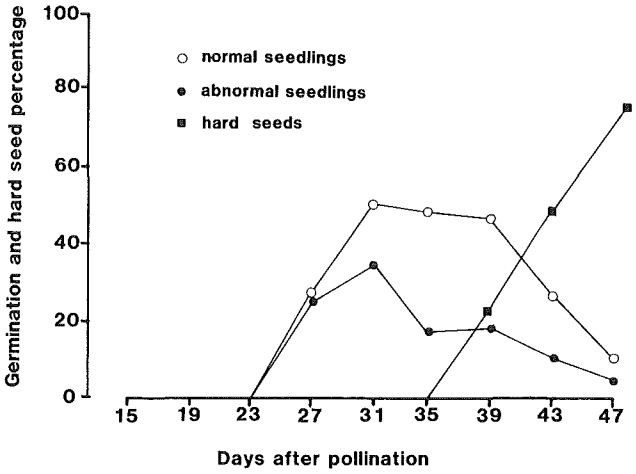

Figure 9. Seed quality components of Maku lotus fresh seed in 1983.

DISCUSSION

Seed Development

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

Seed development in Maku lotus appeared to follow three stages, the growth stage, the food reserve accumulation stage and the ripening stage, similar to those described in other herbage legumes (Table 3).

In Maku lotus the growth stage was the period of seed development up to 19 days after pollination in 1982 and 23 days in 1983. The seed moisture content during this phase was very high (70-90%) and seed was non-viable. The duration of the growth stage was similar to the 22 days in *Medicago sativa* (Kowithayakorn and Hill, 1982), but twice as long as the 10 day growth stage found in white and red clovers (Hyde et al., 1959; Win Pe, 1978).

The second stage of food reserve accumulation in Maku lotus ended when seeds reached a maximum dry weight on day 27 in 1982 and day 35 in 1983. Seeds became viable early in this stage but germination capacity declined during the later parts of the stage, with the increase of hard seeds.

Table 3. Duration of stages of seed development in five herbage legumes

Herbage legume	Growth stage	Food reserve accumulation stage	Ripening stage
	(days)		
Maku lotus, 1982	19	8	8
Maku lotus, 1983	23	12	12
White clover (Hyde et al., 1959)	10	10-14	3-7
Hamua red clover (Hyde et al., 1959)	10	10-14	3-7
Pawera red clover (Win Pe, 1978)	10	16	10-14
Lucerne (Kowithayakorn and Hill, 1982)	22	17	35

The changes outlined for Maku lotus during this stage have also been reported by other workers for other herbage legumes but with variation in the rate of development. Hyde et al. (1959) found that the food reserve accumulation stage in white and red clovers took 10-14 days (similar to the 8-12 days for Maku lotus), but Win Pe (1978) with Pawera red clover, and Kowithayakorn and Hill (1982) with lucerne, found that this stage took 16 or 17 days (Table 3). Since none of the above workers clearly stated the weather conditions for the duration of their studies, it is impossible to attribute these differences to weather or species.

In Maku lotus the ripening stage took 8 days in 1982 and 12 days in 1983. 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 6% more moisture than in 1982 but were still suitable for harvest at 15% moisture, as dry weight was constant.

Hot dry weather clearly accelerated ripening in Maku lotus in 1982 and cooler weather delayed ripening in 1983. Hyde et al. (1959) reported a 3 to 7 day ripening period for white and red clover which compares with the 8 day ripening period in Maku lotus in 1982. Win Pe (1978) found that a 10 to 14 ripening period was required for Pawera red clover, which was similar to the 12 days Maku lotus ripened in 1983 (Table 3).

Maximum seed viability of Maku was reached during the food reserve accumulation stage, 4 days before seed maturity was reached. A similar result was found by Hyde et al. (1959) and Win Pe (1978) in white and red clover. By contrast in *L. corniculatus* maximum seed viability was found at or just after seed maturity (Anderson, 1955; McKersie, 1982). These differences are probably due to technique. Germination of Maku lotus and white and red clover was tested on freshly harvested seed, but in *L. corniculatus* dry seed stored for several weeks was used.

The contrasting conditions under which Maku lotus seeds were germinated in 1982 and 1983 may explain why 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. uliginosus* seeds should be germinated in darkness. All Maku lotus seedlings in 1983 were very weakly developed and a large percentage were abnormal. No radicle developed. Radicles in normal seedlings were small and the seed testa still covered nearly all of the cotyledons. 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/8 hour dark period be used.

Hardseededness first occurred in Maku lotus after seed maturity was reached when seed moisture percentage began to decline rapidly. Win Pe (1978) and Kowithayakorn and Hill (1982) also found hardseededness developed after seed maturity, when seeds were tested immediately after harvest.

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

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 vapor pressure deficit exceeded 0.90 kPa ten times (1983, five times) and the maximum temperature exceeded 25 C seven times (1983, once). Metcalfe et al. (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. Vapor pressure deficit, however, is a better indicator of atmospheric drying (J.N. Gallagher, Lincoln College pers. comm.).

Optimum time to harvest

Observations of changes in umbel formation and pod color of Maku lotus will give farmers a reliable indication of the optimum time to harvest. 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 1 to 2 days earlier, have extended keel petals caused by expanding pods. Lower flowers on an umbel may be 2 to 3 days more advanced in development than flowers towards the top of the umbel.

Pod color was the best indication of seed maturity and seed moisture content of Maku lotus 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 this stage. The optimum time to mow the crop, in preparation for harvest, was after seed maturity, when the pods had just started to turn light brown and about 2 to 3% pod shatter had occurred. At this stage seed dry weight was constant and seed moisture was 35%.

Two years study of Maku lotus showed that pod color changes, seed moisture and some pod shatter correlated well with the production of seed of high weight and quality. This is in contrast to a 3 year study, by Klein and Harmond (1971) which found that in other grass and small legume seeds, moisture content was the only property that correlated well with obtaining maximum yields of pure live seed.

By superimposing Figures 5, 6 and 7 upon one another, optimum harvesting times for 1982 (Figure 10) and 1983 (Figure 11) can be predicted. This is done by finding the time when the seed was ripe (constant dry weight) and only minimal pod shatter had occurred. The first stage of harvesting is mowing or chemical desiccation; this stage would be on day 29 in 1982 and day 35 in 1983. The light brown pod color would give farmers a clear visual indication of this stage. After 2 to 3 days in 1982 and 8 days drying in 1983 the seed crop could be harvested.

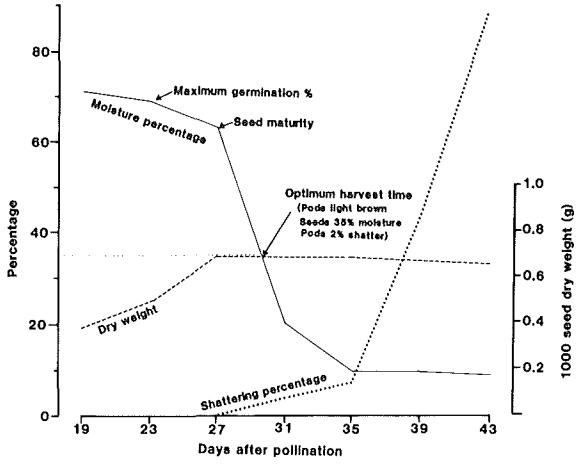

Figure 10. Optimum harvest times in 1982 according to changes in seed moisture percentage, pod shattering percentage, and 1000 seed dry weight.

Farmers must be able to predict seed development to mow or chemically desiccate the crop at the appropriate time. First, the time of main flowering must be judged. Maku lotus has a prolonged and indeterminate flowering pattern particularly during moist weather. By counting open yellow flowers in small quadrats, once the first flush of flowers appear, farmers will be able to record when main flowering and pollination have occurred. Seeds from pods formed during the main flowering period will give the highest seed yields.

Second, the weather must be watched from day 27 after pollination. Farmers can then predict when pod color changes and pod shattering will occur. If strong drying

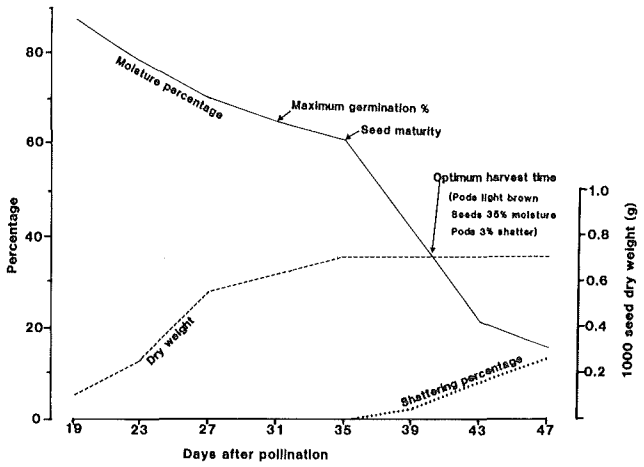

Figure 11. Optimum harvest times in 1983 according to changes in seed moisture percentage, pod shattering percentage, and 1000 seed dry weight.

winds are blowing and the temperatures are above 25 C then seed will ripen rapidly and pods will dry, even if vapor pressure deficits are not known. As soon as the pods turn light brown and some pod shattering begins, mowing must take place.

Use of chemical desiccation will depend on the density of the crop and farmer preference. With chemical desiccation there is a danger of very rapid pod drying, before the stems dry, leading to extensive pod shattering and seed loss. Most Maku lotus seed growers favor mowing. The time taken to dry the sward in the windrow after mowing or in the stand after chemical desiccation will again depend on weather. Mowing and desiccating at the appropriate time reduces risk of pod shatter and allows for a longer stem drying time. However, an equally large amount of seed can be lost because of poor seed fill if Maku lotus is cut too soon when seed moisture is above 50%. Unlike white and red clovers, Maku lotus seeds cease further development once the crop is cut (P.T.P. Clifford, DSIR, Lincoln, pers. comm.). Therefore, there is no finishing process continuing in the curing stage of the swath; instead, crumpled seeds occur.

CONCLUSION

The results in this paper substantiate the view that it is not necessary to delay harvesting until Maku lotus seeds are fully ripe in order to obtain maximum yields of high quality seed. Maku lotus seeds are viable and mature several days before seed ripeness, so that seed quality will not be affected by mowing or chemical desiccation soon after seed maturity. Mowing and /or desiccation at this time 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.

Optimum harvest time can be judged by counting the days from pollination and observing seed pod color. After 27 days from pollination, crops must be inspected daily and the weather monitored. Under hot dry conditions the period

between seed maturity and pod shattering is only 4 to 5 days, but timely operations by well prepared farmers will maximize seed yields.

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