Sowing dates, phenology and yield in lupins (*Lupinus angustifolius*)

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ABSTRACT

A field experiment was conducted to investigate the relationship between sowing dates and flowering dates in narrow-leafed lupin (*L. angustifolius)* at Wagga Wagga. The results showed that flowering date can be well described by temperature and day-length after sowing. The relationship between grain yield of lupin and sowing date was examined using various published and unpublished data from eastern Australia. It was found that grain yields (expressed as a percentage of yield obtained in an April-May sowing, usually the maximum yield for the year) were well described by sowing date and annual rainfall. In a high annual rainfall season or location, the sowing date can be delayed considerably. An analysis of climate variability using the weather data at Wagga Wagga from 1945 to 1999 showed that the latest sowing date is not determined by the risk of high temperature-induced poor seed-set. It was concluded that the latest economically-acceptable sowing date may be determined from predicted crop yield based on rainfall and sowing date.

KEY WORDS

Climate, first flowering, genotypes, temperature, rainfall, climate variability.

INTRODUCTION

Narrow-leafed lupin (*Lupinus angustifolius* L.) is an important crop in Australia as the inclusion of a pulse in crop rotations can be beneficial to following cereal crops and the rotation as a whole (1). However, if the crop is sown too early it may suffer some frost damage, while late sowing could result in poor seed-set when the temperature exceeds 27?C, or water stress occurs during grain filling (2). It is important to select cultivar and sowing date suited to the local climate and the farmers' situation, to maximise yield and profitability. Although it is generally recommended that lupins be sown in April-May (3), the precise relationships between sowing date, flowering date and crop yield in eastern Australia are not available. Further, due to climate variability from year to year at any location, sowing recommendations should also be considered in conjunction with climate information.

This paper describes the use of flowering time data derived from a time of sowing trial to generate parameters for a photo-thermal model to forecast flowering time for six varieties of lupins. We go on to examine the possibility of using these parameters with other varieties within similar maturity classes, and to evaluate the impact of frost and high temperature risk and time of sowing and seasonal rainfall on yield.

MATERIAL AND METHODS

Experimental

An experiment was conducted at the Wagga Wagga Agricultural Institute in 1998 (latitude 35.03?S, longitude. 147.35?E). Six genotypes of narrow-leafed lupins (Merrit, Wonga, Myallie, WL478, WL652, WL318) were sown at six sowing dates (1 April, 5 May, 25 May, 16 June, 8 July, 4 August). Each variety was sown in 3 rows by 1 metre long in two replications and was protected under two 5x40 m bird net cages. Flowering time was defined as the day on which first flowering appeared on 50% of plants. Temperature data were automatically recorded in the cages. Day-length was calculated (4).

Flowering model

Reader *et al.* (5) showed that the time to flowering in lupins was best described by the photo-thermal model:

$$1/f = a + b\overline{T} + c\overline{P} \quad (1)$$

where *f* is the number of days from sowing to the flowering date, $\overline{T}$ is the mean pre-flowering temperature (?C), $\overline{P}$ is mean pre-flowering photoperiod ($h.d^{-1}$) and *a*, *b* and *c* are genotype-specific constants. Experimental data from 1998 were fitted to Eq (1) to determine the constants (a, b and c) for the six lupin varieties. Flowering occurs when the cumulative daily development rate (DDR) from sowing equals 1. The model was validated against the data of Landers (unpublished data), which included the six genotypes listed above plus Chittick, Illyarrie, Unicrop and Uniharvest observed in 1985 at Wagga Wagga. After the constants a, b, c and d were determined, DDR for a day was calculated by $a+bT+cP$, where *T* and *P* are mean temperature and the photoperiod at the day, respectively.

Yield model

We developed an empirical model to describe the yield losses from late sowing. Yield data were obtained from the genotypes Unicrop and Uniharvest sown in 1977, 1978 and 1979 at Trangie (6) and in 1973 at Rutherglen (7); Danja, Gungurru, Geebung and 75A/330 sown in 1989 and 1990 at Wagga Wagga (1); WL318 sown in 1995, 1997, 1998 and 1999 at Wagga Wagga (D. Luckett, unpublished data), and Uniwhite sown in 1974 at Rutherglen (7). The model described relative yield as a function of sowing dates and rainfall in the form:

$$y = \frac{100}{1 + [Z/(a + bR)]^{(c+dR)}} \quad (2)$$

where *y* is relative yield, expressed as a percentage of maximum yield achieved in early season (April-May) sowing, and $Z = D/(D_{mx} - D)$, *D* is day of the year at sowing, ie. *D*=1 for January 1st, D_{mx} is number of day for a year, ie. D_{mx}=365 or 366 for a leap year, *R* is annual rainfall (mm), and *a*, *b*, *c* and *d* are constants. Z gives an exponential shape with D. The model outputs a revised logistic curve as illustrated in Figure 1.

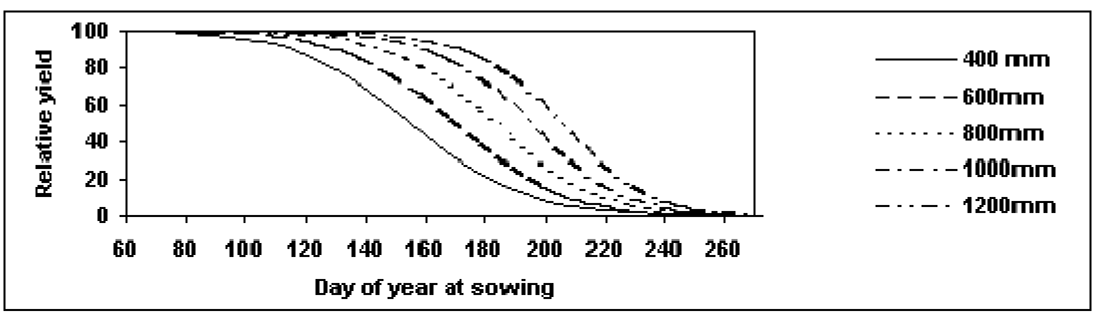

Figure 1. Relative yield as a function of day of year at sowing and rainfall as shown in Eq (2). Parameter values are: a=0.45747, b=0.000699, c=3.9626, and d=0.001806.

Climate risk analysis

The risk of frost damage is defined by the probability of occurrence $P(T_\alpha)$ at the critical temperature (T_α), which is specific to the genotype. Thus, $D_{P(T\alpha)}$ denotes the critical day of year for the earliest sowing under the *P* % probability of frost damage. Sowing the crop earlier than $D_{P(T\alpha)}$ may result in frost damage with a probability higher than $P(T_\alpha$, while sowing dates later than $D_{P(T\alpha)}$ may have a frost damage probability lower than $P(T_\alpha)$. Similarly, $D_{P(T_\beta)}$ is defined as the latest day of the year at which the chance of a specified high temperature (T_β) causing poor seed-set may occur ($D_{P(T_\beta)}$). The latest recommended sowing date is then determined by consideration of both $D_{P(T_\beta)}$ and a target crop yield. Temperature and rainfall data from 1945 to 1999 for Wagga Wagga were obtained from Metaccess (8) and used in the climate risk analysis.

RESULTS AND DISCUSSION

The time to flowering in all the six genotypes tested at Wagga Wagga in 1998 was well described by the photo-thermal model (Eq 1), which accounted for 95%, 96%, 99%, 97%, 97% and 99% of the total observed variance for Merrit, Wonga, Myallie, WL478, WL652 and WL318, respectively.

To test if the parameters can be applied to other genotypes that were not involved in the regression analysis, the flowering dates predicted by the parameters determined in this study were compared against the observations of Landers (unpublished data) (Fig 2). The result showed that the later flowering genotype Uniharvest was close to the prediction from the model of the later flowering cultivars, WL478 and WL318. The two additional early flowering cultivars, Illyarrie and Unicrop, were well predicted by the early flowering group, particularly by Wonga. The mid flowering type, Chittick, was set between the early and late flowering types. There may exist a set of parameters that is common and can be used for genotypes from the same flowering group. Further work is needed to test the hypothesis using data from a wide range of environments.

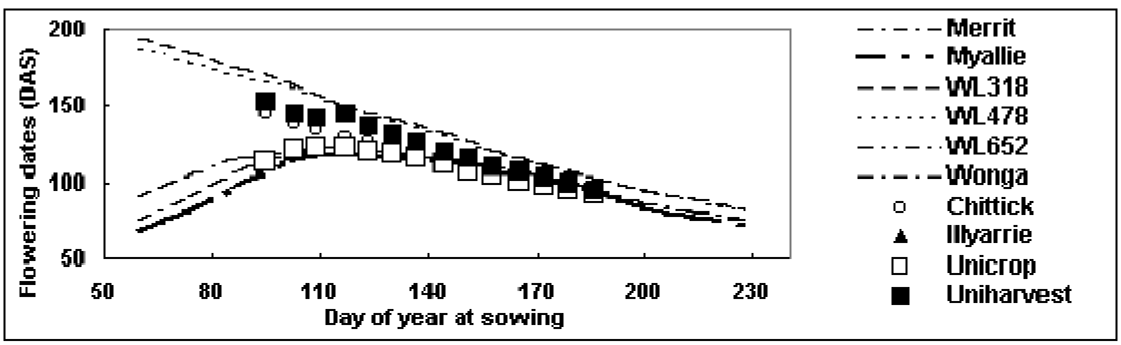

Figure 2. Comparison between the predicted flowering dates in 1985 using the parameters developed for six genotypes in 1998 (lines) and the observed flowering dates of four genotypes (symbols) in 1985 at Wagga Wagga.

Using the relative yield of lupins obtained in 1973 and 1974 at Rutherglen (7) Eq 2 accounted for 91% and 88%, respectively, of the total observed variance (Fig. 3). The analysis was based on rainfall data for a single year, hence, two single constants were used to replace $a+bR$ and $c+dR$. Furthermore, Eq 2 accounted for 83% of the total variance in relative yield for a wide range of data (6, 2, D. Luckett, unpublished data).

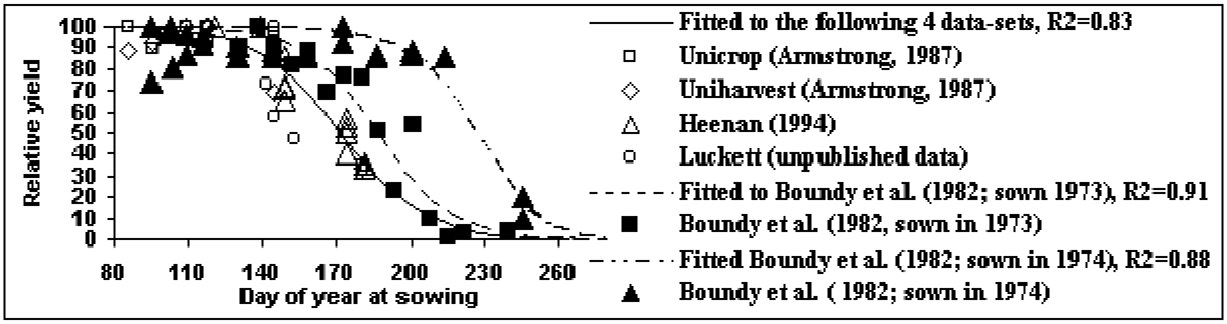

Figure 3. Comparison between the observations of relative lupin yield (symbols) and the predicted relative yield by Eq. (2) (lines). Left solid line is fitted with the data of Armstrong (6), Heenan (2) and D. Luckett (unpublished data). Annual rainfall for those data sets ranged between 372 mm and 705 mm. The mid broken line and right broken line were fitted to the data of Boundy et al., (7) for lupins sown in 1973 (annual rainfall 960mm) and 1974 (annual rainfall 1342mm), respectively.

Taking all of the above data, together with their respective rainfall in those years (rainfall range from 372 mm to 1342 mm), the analysis of Eq 2 showed that the regression coefficient (R^2) was 84%. A relationship between the predicted yield (y_p) and the observed yield (y_o) for the pooled data was $y_p = 0.028(\pm 0.04) + 0.94(\pm 0.05)\, y_o$. Therefore, relative yield can be well predicted by sowing date and annual rainfall.

It should be noted that as annual rainfall was used in Eq. 2, the model may be improved if the actual in-season rainfall were used. Furthermore, the success of late sowing may most likely depend on the spring rainfall (2). However, annual rainfall is the most commonly used in practice. Annual rainfall in Eq (2) may be acting as a surrogate for length of growing season.

The phenology model and yield model were integrated with weather data and risk analysis into a model called SOWMAN (Decision Support System for Winter Crop Sowing Dates Management). Figure 4A and 4B show the results obtained from SOWMAN.

When lupins, using WL318 as an example, are sown on 1 April in Wagga Wagga, the time to flowering varied between 157 and 188 days after sowing, depending on seasons, while when sowing on 30 July the time to flowering was between 100 and 116 days after sowing (Fig. 4A). At T_α=2°C and $P(T_\alpha$=2°C)=20%, the earliest safe sowing date was the 92nd day of the year, ie. 2 April (Fig. 4B).

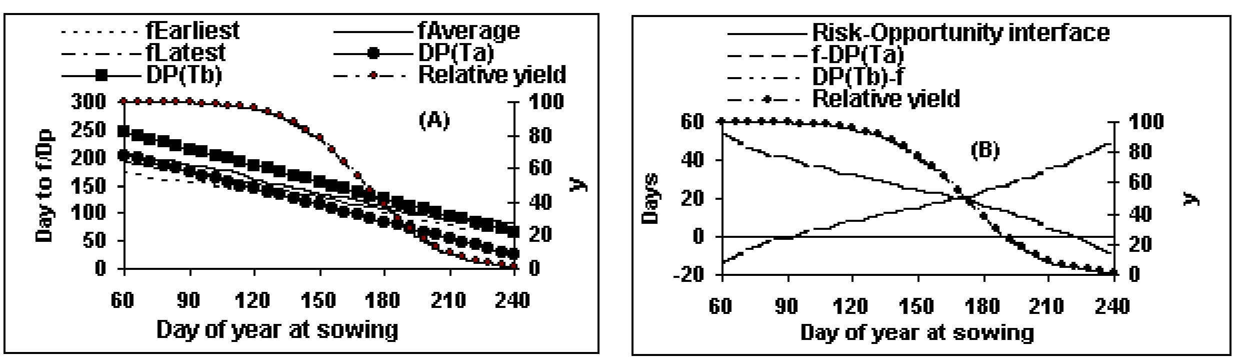

Figure 4. Average relative yield (%), earliest flowering dates ($f_{Earliest}$), average flowering dates ($f_{Average}$) and latest flowering dates (f_{Latest}) for lupin sowings between 60 and 240 days of year in the year 1945 to 1999 at Wagga Wagga (A). Difference in days between flowering dates and critical dates (B). T_α=2°C, T_β=27°C, P(T_α)=20.0%, P(T_β)=20.0%.

At a given value of *P*(T_β =27?C)=20%, the latest sowing dates is the 222nd day of the year (10 August). However, yield is predicted to be only about 5% of that achieved by sowing in April-May. If one targets 70% yield, or above, of the April-May-sowing yield, the sowing date should be no later than the 160th day of the year (9th June). From the yield model, we can see that with an annual average rainfall of 550 mm, every week of sowing delay after 10th June reduces the yield by 8%. Heenan (2) showed that at Wagga Wagga, lupins sown on 23rd June 1989 had a yield of only 50% of those sown on 21st April and those sown on 30 June 1990 had a yield of only 36% of those sown on 1 May. The annual rainfall at Wagga Wagga was 705 mm in 1989 and 565 mm in 1990

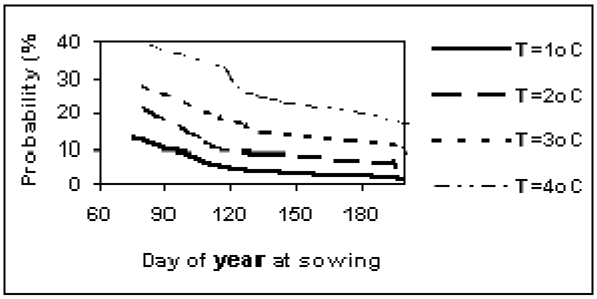

Figure 5. Relationship between probability (%) of frost damage and day of year at sowing with various T_α at Wagga Wagga.

With the analysis of the historical weather data,we can estimate the probability of frost damage at a particular site, *P*(T_α), which may be useful for decision making. Figure 5 shows the probability of various $T_\alpha$levels against sowing dates. Critical $T_\alpha$value may vary with genotype. The lower the $T_\alpha$is, the lower the probability of frost damage. Consequently, low $T_\alpha$genotypes should be selected for areas with a high probability of frost damage.

CONCLUSION

The study showed that yield in narrow-leafed lupins in eastern Australia is well related to sowing date and rainfall. The higher the rainfall, the later the crop can be sown. Therefore, the latest sowing date for lupins can vary considerably, depending on rainfall. It is further concluded that decisions on the latest sowing date suitable for narrow-leafed lupins should be based on predicted crop yield with linkage to historical weather data and current year weather forecasting, not on the risk of high temperature-induced poor seed-set.

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