Variability in lupin yield due to climate in Western Australia

Imma Farre[1*], Michael Robertson[2], Senthold Asseng[1], Robert J. French[3], Miles Dracup[4]

[1] CSIRO Plant Industry, Private Bag No 5, Wembley, WA 6913 Email Imma.Farre@csiro.au
[2] CSIRO Sustainable Ecosystems/Agricultural Production Systems Research Unit, Long Pocket Laboratories, Indooroopilly,
Qld 4068
[3] Department of Agriculture, PO Box 432, Merredin, WA 6415
[4] Department of Agriculture, Locked Bag 4, Bentley, WA 6983

Abstract

Yield variability in lupin due to variable rainfall and delay in sowing is a key constraint to lupin production in the agricultural region of Western Australia. A lupin simulation model has been developed using the APSIM legume template. Initial testing of the model for Western Australian conditions has shown good performance for phenology, shoot biomass and yield. The model was linked to long-term weather data to simulate yield for two soil types and two sowing decisions rules in a low and high rainfall location. Simulated yields were very variable and declined with delay in sowing. Simulated yields were higher on a loamy sand soil than on a sandy soil. The impact of seasonal variability and sowing decisions on lupin yields was quantified for different rainfall locations in Western Australia.

Key words

Simulation model, narrow-leafed lupin, sowing date, rainfall, Western Australia

Introduction

Lupin is an important grain legume crop in Australia, with over 1 million ha sown every year. Most of it is narrow-leafed lupin (*Lupinus angustifolius* L.) and is grown in Western Australia. It is widely grown due to its adaptation to the common sandy and acidic soils of Western Australia, for rotational benefits and for adding significant amounts of fixed nitrogen to soils. In the mediterranean environment of Western Australia the seasonal rainfall varies from year to year, both in total amount and in distribution. Moreover, the beginning of rains in autumn, and therefore the sowing date, varies from year to year. All these factors contribute to the high season-to-season variability of lupin yields, which is one of the main concerns of growers. The effect of seasonal rainfall and sowing date on yield differs depending on factors such as location and soil type and their interaction. A large number of experiments would be required to study all combinations of factors affecting yield and profitability. A crop simulation model, once tested for the conditions under which it will be used, provides a tool for assessing agronomic and management options. The wheat and the canola crop modules of the APSIM family have been tested for Western Australian conditions (1, 2).

The aims of this paper are: 1) to report on the development and testing of the lupin model for Western Australian conditions for inclusion as a module in the cropping systems simulator, APSIM and 2) to perform a simulation experiment with long-term weather data to illustrate the potential of a lupin model for studying and improving lupin crop management.

Methods

Model development

The lupin crop module in APSIM is being developed from a template using the framework described in detail by Robertson *et al*. (3). The phenology model predicts flowering assuming a long-day photoperiod response until floral initiation. Model parameters for phenology were obtained using datasets with observed flowering dates for 2 years, 4 locations and 4 sowing dates (R.J. French, unpublished) and published data by Dracup *et al.* (4). Phenology parameters were derived for three lupin cultivars, namely Belara, Merrit and Wodjil. The traditional two-step process of calibration-testing was not used, but rather all the data were used to derive phenology parameters, by using an optimisation program (5).

A number of crop parameters were derived from our experimental data, while other parameters were sourced from the literature. Parameters for leaf and branch development were obtained from Dracup and Kirby (6, 7). Base (0 ?C) and optimum (20 ?C) temperatures were obtained from Dracup and Kirby (6). Some of the parameters for biomass partitioning among organs and demand for grain yield (harvest index increase) were derived from detailed experimental studies (7, 8). Values for the crop extinction coefficient (0.85), radiation use efficiency (0.80 g/MJ solrad; for above-ground biomass) and transpiration efficiency coefficient (0.0055 pa) were obtained from the literature (9, 10).

Model evaluation

The first stage of model evaluation was to test the performance of the model on the datasets that were used for deriving the phenology parameters. While this is not a completely independent test of the module, it is a first step to test whether the derived parameters, when used in the module, reproduce the datasets from which they are derived.

Initial testing of the model for phenology, shoot biomass, yield and soil water content was performed with independent data from two field experiments in Western Australia. Experiment 1 was carried out in Beverley in 1993, on a duplex soil (11), experiment 2 was carried out in Moora in 1995 and 1996, on a sandy soil (12).

Simulation experiment

The APSIM-lupin model was used in simulation experiments with historical weather data from 1960 to 1999 to simulate grain yield. Two major soil types in the lupin growing area were used, a sand and a loamy sand (55 mm and 130 mm plant-available soil water in the root zone, respectively). Two contrasting locations, in the high (Moora) and low rainfall zone (Merredin) were chosen. Simulations were done for the cultivar Merrit (early-mid maturity type). The soil water profile was re-set at the lower limit at 1 January (DOY 1) each year. Sowing time was controlled by a sowing rule. A sowing window was set between 15 April and 30 June. The first sowing opportunity occurred when at least 15 mm of rainfall had accumulated within 5 days. Two sowing dates were simulated, sowing 1: sowing occurring at the first sowing opportunity every year, and sowing 2: sowing occurring 21 days later.

Results and discussion

Model development and testing

Observed days to flowering varied from 71 to 107. The estimated number of days from sowing to flowering, obtained from the phenology parameters derived using the optimisation procedure, gave values of Root Mean Square Deviation (RMSD) of 4.1, 3.4 and 4.4 days for Belara, Merrit and Wodjil, respectively.

Initial testing of the model with independent data from two experiments, resulted in a reasonably good performance of the model for phenology, shoot biomass, yield and soil water content. Observed and simulated values for shoot biomass, grain yield and soil water content for experiment 1 are shown in Fig. 1. Observed yields from experiment 2 were 2000 kg/ha in 1995 and 1700 kg/ha in 1996 and simulated yields were 2370 kg/ha in 1995 and 1740 kg/ha in 1996. Measured evapotranspiration in the period from 2 July to 15 September 1996 was 178 mm and the simulated value was 147 mm.

Simulation experiment

The sowing rule produced a range of sowing dates over the 40 years simulated, depending on rainfall patterns pre-sowing. There were no significant interactions between soil type and location or sowing date, with yields on loamy sand being on average 5-12% higher than on sandy soils, due to the higher soil water holding capacity. Lupin yields were highly variable because of their dependence on seasonal rainfall (Fig. 2). The delay in sowing date reduced the simulated yield in both locations (Fig. 2). However, in the high rainfall location the delay in sowing did not reduce yields significantly for a range of sowing dates from beginning of April until end of May, and yield reduction only occurred for very late sowings (June sowings) (Fig. 2a), and no differences between soil types were observed. In contrast, in the low rainfall location, for the whole range of sowing dates any delay in sowing reduced yields (average yield reduction of 6%/week delay or 18 kg/ha/d) (Fig. 2b). The yield reductions obtained by the model agreed with work by Reader *et al.* (13), who found that lupins are only partly able to compensate for late sowing by flowering earlier and, thus, late-sown lupins face terminal drought with less time available for grain filling. Late sowing also increases the risk of heat stress during the grain filling period in spring. The risk of heat stress has been reported by Reader *et al.* (14), who found significant yield reductions in lupin caused by hot temperatures during grain filling. The simulation results also agreed with findings by Eastham *et al.* (15), who found that early sowing in lupin was associated with increased early growth and larger canopies and thus higher yields.

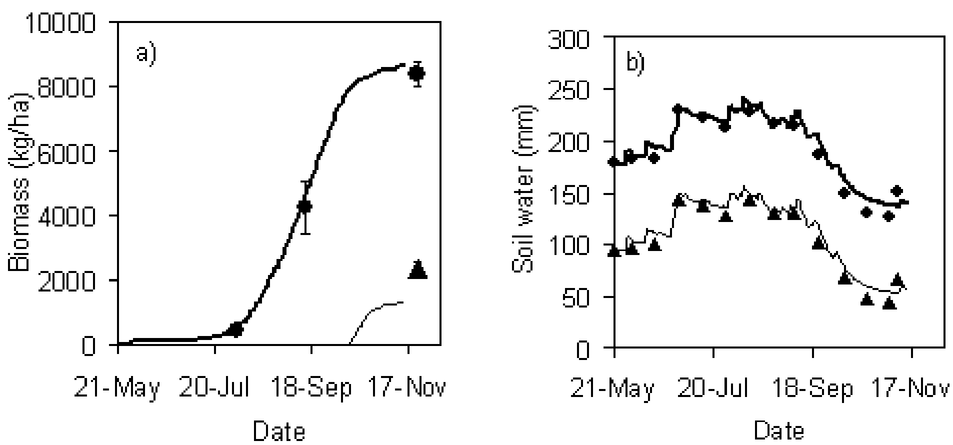

Figure 1. Simulated (lines) and observed (symbols) of (a) above ground biomass (●) and grain yield (▲), (b) soil water in 0-0.7 m depth (▲) and in 0-1.1 m depth (●), in Experiment 1 (year 1993 in Beverley). Observed data after Gregory (11).

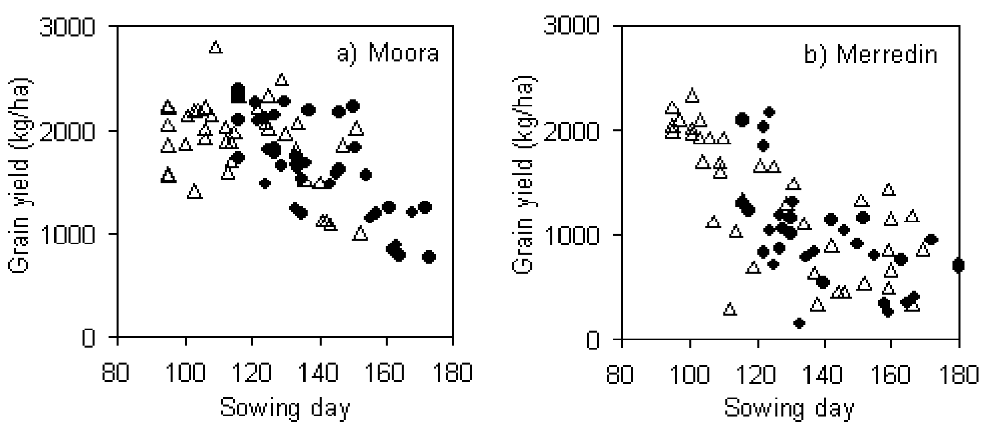

Figure 2. Simulated yields for lupin *cv*. Merrit on a sandy soil for sowing at the first sowing opportunity (Δ) and sowing 21 days later (●) in (a) Moora (high rainfall zone) and (b) Merredin (low rainfall zone), Western Australia.

Simulated long-term average yields were higher in the high rainfall location than in the low rainfall location both when sown at the first opportunity and 21 days later (Fig. 3). Average yields from the first sowing opportunity were 13% higher than from sowing 21 days later in the high rainfall location (17% on sand, 8% on loamy sand) and 32% higher in the low rainfall location (35% on sand, 29% on loamy sand) (Fig. 2). The 25% and 75% percentiles represent the yields exceeded in 1 out of 4 and 3 out of 4 years, respectively (Fig. 3). The variability in yield was larger in the low rainfall (cv% 49) than in the high rainfall location (cv% 27) (Fig. 3). In the high rainfall location, yields were less variable when sown at the first sowing opportunity (cv% 20) than when sown 21 days later (cv% 33) whereas in the low rainfall location yield variability was high for both sowing decisions (cv% 47 and 51) (Fig. 3). The results emphasize that location (rainfall zone) and sowing date are important factors determining yield. Early sowing is an important determinant of lupin yield, especially in water limited environments, where late sowing reduces the period for biomass accumulation before the terminal drought.

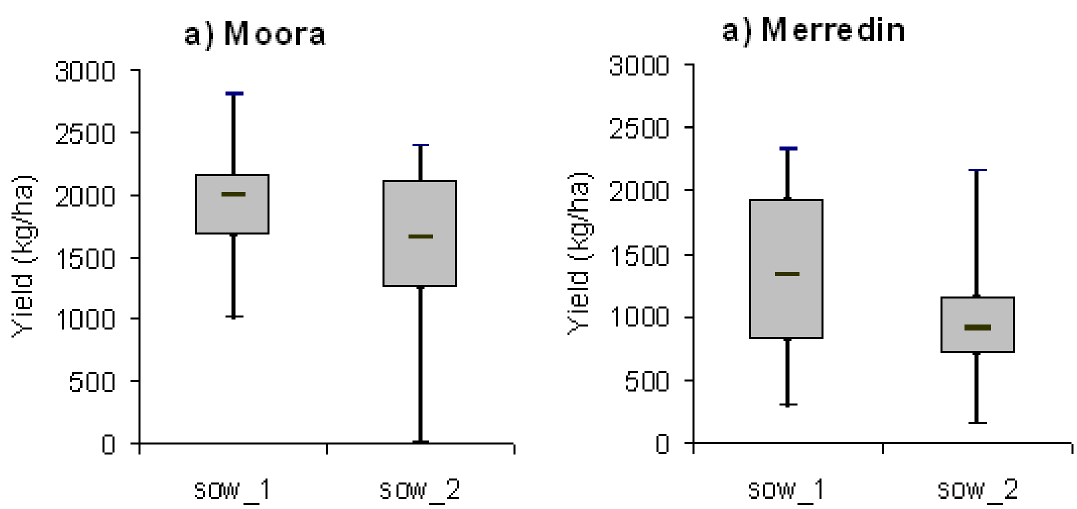

Figure 3. Simulated lupin yields on a sandy soil for (a) Moora (high rainfall zone) and (b) Merredin (low rainfall zone) for sowing at the first sowing opportunity (sow_1) and sowing 21 days later every year (sow_2). Error bars show range of simulated values. Solid bars show the 25% and 75% percentiles and the median (50% percentile) (solid line within the bar).

Conclusions

A new lupin model is being developed using the APSIM-legume template. Initial testing of the model has shown a reasonably good performance for phenology and yield. The application of the model indicated substantial yield loss due to delayed sowing and an additional loss in relation to the 21 days delay. In the mediterranean environment of Western Australia, late sowing restricts biomass accumulation and exposes the crop to unfavourable grain filling conditions with high temperatures and water deficit, which reduces yield and crop profitability. The modelling approach allowed the quantification of the effect of variable growing season rainfall and sowing decisions on lupin yield.

References

(1) Asseng S, Keating BA, Fillery IRP, Gregory PJ, Bowden JW, Turner NC, Palta JA, Abrecht DG (1998) Field Crops Res. 57, 163-179.

(2) Farre I, Robertson MJ, Walton GH, Asseng S (2002) Aust. J. Agric. Res. (in press).

(3) Robertson MJ, Carberry PS, Huth NI, Turpin JE, Probert ME, Poulton PL, Bell M, Wright GC, Yeates SJ, Brinsmead RB (2002) Aust. J. Agric. Res. 53, 429-446.

(4) Dracup M, Thomson B, Reader M, Kirby EJM, Shield I, Leach J (1998) Aust. J. Agric. Res. 49, 1047-1055.

(5) Carberry PS (1996) Final report to Grains Research and Development Corporation, Project CSC9 33 pp.

(6) Dracup M, Kirby EJM (1993) Field Crops Research 34, 209-225.

(7) Dracup M, Kirby EJM (1996) Lupin Development Guide. UWA Press, Nedlands,WA 97 pp.

(8) Dracup M, Reader MA, Palta JA (1998) Aust. J. Agric. Res. 49, 799-810.

(9) Gregory PJ, Eastham J (1996) Aust. J. Agric. Res. 47, 427-447.

(10) Thomson BD, Siddique KHM (1997) Field Crops Res. 54, 189-199.

(11) Gregory PJ (1998) Aust. J. Agric. Res. 49, 21-32.

(12) Anderson GC, Fillery IRP, Dolling PJ, Asseng S (1998) Aust. J. Agric. Res. 49, 329-343.

(13) Reader MA, Dracup M, Kirby EJM (1995) Aust. J. Agric. Res. 46, 1063-1077.

(14) Reader MA, Dracup M, Atkins CA (1997) Aust. J. Agric. Res. 48, 1169-1178.

(15) Eastham J, Gregory PJ, Williamson DR, Watson GD (1999) Agric. Water Management 42, 205-218.