Model-based evaluation of yield performance and agronomic options for lupins in the southern wheatbelt, Western Australia

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Abstract

Currently, narrow-leafed lupin (Lupinus angustifolius L.), the largest grain legume crop in Western Australian (WA), is mainly grown in the northern agricultural region. However, due to a cooler and longer growing season yield potential may be higher in the southern wheatbelt. Our capacity to assess this experimentally is limited by the lack of vernalisation insensitive long season varieties. This study used a modelling approach to test this hypothesis by comparing six selected locations in high, medium and low rainfall zones in the northern and southern WA wheatbelt. On average, simulated lupin yields in the medium and low rainfall zones in the southern region were 15% higher than in the medium and low rainfall zones in the northern region. However, lupin yield in the southern high rainfall zone was slightly lower due to less solar radiation. Lupin may potentially be integrated into farming systems in the south if longer maturity varieties become available. Overall in the medium and high rainfall zones in southern WA, higher yield would be obtained when sown in early April with late-maturity cultivars, while in the low rainfall zone, lupin crops would benefit more from early-maturity cultivars when sown later than mid-April, if opening rains occur. While, further assessment of lupin agronomy, production and the balance with other crops in terms of economic and environmental performances should be performed, this preliminary work suggests that breeders should pay attention to developing varieties with a longer maturity for the southern wheatbelt of WA.

Key words

Yield potential; Sowing date; Vernalisation sensitivity; APSIM

Introduction

Narrow-leafed lupin (*Lupinus angustifolius* L.) has been the predominant grain legume in Western Australia (WA), producing grain totalling 500,000-1,000,000 t yr^{-1} (French and Buirchell, 2005). The majority of lupins in WA are grown in the northern wheatbelt (van Gool, 2009). Due to a lack of vernalisation-insensitive long season varieties adapted to the WA environment (Berger et al., 2012), lupin has not been widely incorporated into farming systems in the southern-wheatbelt (Howieson and O'Hara, 2008), where lupins may benefit from a longer growing season and lower evaporation rates. It is important to understand the yield potential of lupin in this region to develop sustainable agricultural systems. Furthermore, matching crop phenology with climate conditions, through combining improved varieties and sowing dates, is one of the key factors to improve and stabilize crop production (Farré et al., 2002). The optimum combination of cultivars and sowing date for lupin should be identified to match growth to available water in the southern wheatbelt of WA. Because of our lack of access to vernalization-insensitive long season varieties, this is not feasible at the moment. However the implications of such a crop can be explored using simulation modelling, which can be used to ask, if such varieties existed, how would they perform in the southern agricultural region?

The objectives of this paper are to use a simulation modelling approach to investigate lupin production potential in the southern wheatbelt of WA and examine the patterns of lupin yield responses to changes in sowing dates and varieties.

Materials and Methods

Study locations

Six study locations, Badgingarra, Eradu, Mullewa, Manjimup, Katanning and Lake King, were selected (Table 1). A major consideration for site selection is the contrasting rainfall conditions. Badgingarra, Eradu and Mullewa are located in the high, medium and low rainfall zones in northern agricultural region of WA, respectively; while Manjimup, Katanning and Lake King are located in the high, medium and low rainfall zones in southern agricultural region, respectively.

Table 1 Details of study sites

Site	Lat. (°S)	Lon. (°E)	Annual mean temperature	Growing season mean temperature[1]	Annual rainfall	Growing season rainfall
Badgingarra	30.40	115.55	18.9	16.0	549	496
Eradu	28.65	115.05	20.1	17.2	356	314
Mullewa	28.54	115.51	20.1	16.8	342	281
Manjimup	34.33	116.00	15.2	13.0	934	837
Katanning	33.67	117.60	15.8	13.2	471	396
Lake King	33.09	119.69	16.5	13.9	337	253

[1]Growing season is from May to October

Model parameterisation and application

APSIM (Holzworth et al., 2014) was used to evaluate lupin productivity and agricultural management options. Model parameters were determined using lupin data obtained from historical variety trials conducted at the experimental sites of Badgingarra in 2006, Eradu in 2005 and Mullewa in 2005 (Berger et al., 2012). Four lupin cultivars, namely Mandelup, Quilinock, Chittick and Jindalee were evaluated, which differ in maturity (Berger et al., 2012). All the data were used to derive crop model parameters through iterative adjustments. Model performance was evaluated by comparing observed and simulated values in terms of the root mean squared error (RMSE) and the coefficient of determination (r^2).

The tested model was then used to simulate lupin yield at the six study sites (Table 1) to explore lupin yield performance at the southern agricultural region of WA, using cv. Jandalee (late maturity). The model was also used to investigate the effects of cultivar and sowing date on lupin production to identify the potential agronomic management alternatives at the three southern locations. Two lupin cultivars (early maturity: Mandelup; late maturity: Jindalee) were selected to sow on 20 April and thereafter at 10 day intervals until 20 June over the period of 1961-2013, assuming opening rains occurred for each sowing window. Aside from maturity all other parameters were the same for these two cultivars.

Results

Model performance

Both flowering time and lupin grain yield were reasonably well predicted. APSIM accounted for 98% of variations for flowering time and 97% for grain yield (Figure 1). The RMSE for flowering time and grain yield were 3.0 days and 136.1 kg ha^{-1}, respectively.

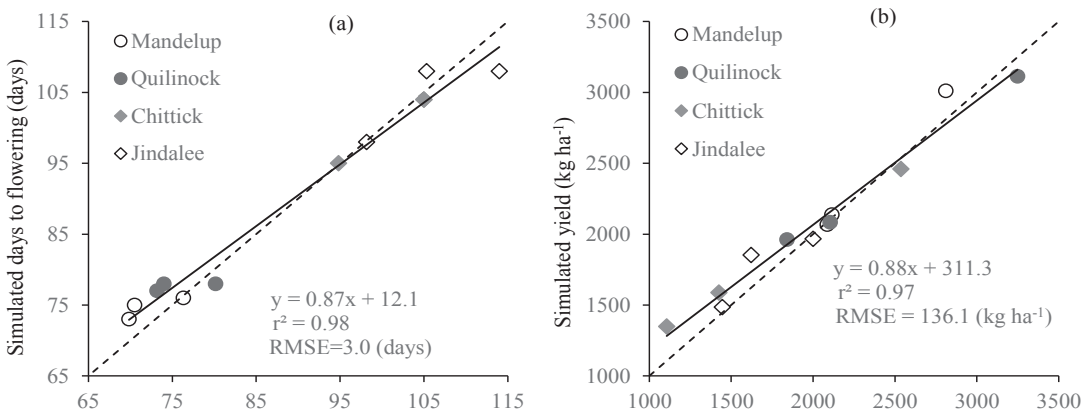

Fig. 1 Relations between simulated and measured days to flowering (a) and yield (b) for four lupin cultivars at Badgingarra, Eradu and Mullewa.

Variability in lupin yield at six sites

Figure 2 shows the cumulative probabilities of simulated yields of lupin with cv. Jindalee sown on 10 May each year between 1961 and 2013 at six locations. In the high rainfall zone, due to lower solar radiation as a result of higher rainfall during lupin growing season and lower latitude, the range and average of simulated lupin yield at Manjimup in the southern agricultural region of WA was smaller than that at Badgingarra in the northern agricultural region. In the medium rainfall zone, simulated lupin yield at Katanning in the southern

agricultural region showed less variation than that at Eradu in northern agricultural region, as indicated by the steeper slope of the cumulative probabilities. At Katanning about 90% of year had yields larger than 2000 kg ha^{-1}, while at Eradu only about 65% of years had this amount. In the low rainfall zone, simulated yield was larger than 2000 kg ha^{-1} in less than 20% of years at Mullewa, while it was larger than 2000 kg ha^{-1} in more than 40% of years at Lake King in the southern agricultural region. In the medium and low rainfall zones in the southern agricultural region, the cooler growing season temperature together with average higher rainfall increased lupin productivity with a fairly high probability. On average, simulated lupin yield in the southern two rainfall zones was 15% higher than the two northern rainfall zones.

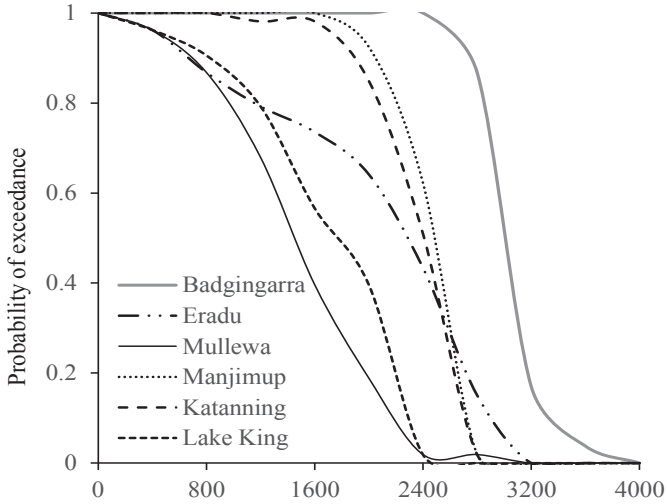

Fig. 2 Cumulative distribution of simulated lupin yield for cv. Jindalee at six sites (Badgingarra and Manjimup at high rainfall zone, Eradu and Katanning at medium rainfall zone, Mullewa and Lake King at low rainfall zone).

The response of lupin yield to the combined changes in sowing date and variety

A marked cultivar × sowing time interaction was evident at all three locations in the southern wheatbelt (Fig. 3). At Manjimup (high rainfall zone), lupin yield of the early-maturity variety increased with delayed sowing. However, for a late-maturity cultivar to achieve higher yield it needed to be sown earlier than 30 May (Fig. 3a). This is because the late-maturity cultivar could take advantage of ample water resources in the high rainfall zone. While at Katanning in the medium rainfall zone, there was a crossover of lupin yield between early-maturity and late-maturity cultivars in the mid-May, indicating that late-maturity cultivars should be sown before mid-May and cultivars with early maturity should be sown after then (Fig. 3b). In the low rainfall zone, early-maturity and late-maturity cultivars had little difference if they were sown early, but varieties with early maturity should be considered if sowing was later than late April (Fig. 3c).

Conclusions

A preliminary test of the APSIM model showed that it could reasonably reproduce lupin development and yield in the study area. Simulation results using the tested model combined with historical climate data showed that, if a lupin cultivar that was grown in northern agricultural region was sown in southern agricultural region, on average it would have higher grain yield. In the medium and low rainfall zones of the southern agricultural region, yields increase because the growing season is longer and temperatures are lower. In the high rainfall zone, the benefit of this effect was somewhat offset by the lower solar radiation. Overall in the high and medium rainfall zones in southern agricultural region of WA, higher yields would be obtained from late-maturity cultivars when sown before late April if opening rains occur. In low rainfall zone, sowing in early April was preferable with either early- or late-maturity cultivars. This preliminary work suggests that breeders should pay attention to releasing lupin varieties that address longer growing season potential in areas such as southern WA. Further research should be performed to assess breeding of vernalisation-insensitive long season varieties, lupin agronomy, production and its balance with other crops in terms of economic and environmental performance.

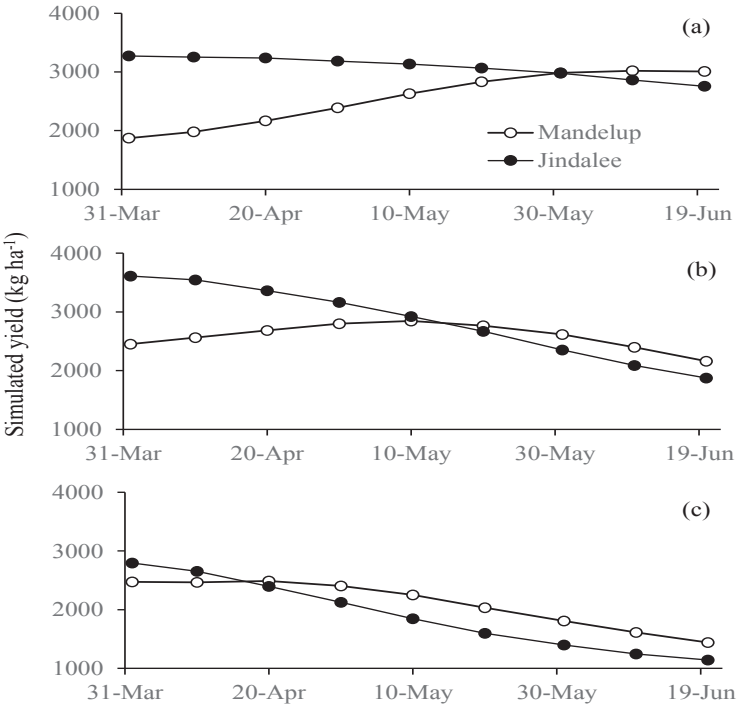

Fig. 3 Simulated lupin yield for cv. Mandelup (early maturity); cv. Jindalee (late maturity) under different sowing dates during 1961-2013 at Manjimup (a), Katanning (b) and Lake King (c).

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