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Are high lupin seeding rates more risky in the Western Australian wheatbelt?

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Abstract. A seeding rate aimed at establishing 45 plants/m^2 has been the long-standing recommendation for lupin crops in Western Australia. However, contrary to recommendations, many farmers in low rainfall areas of the state use a seeding rate that results in densities as low as 25–30 plants/m^2, claiming that these rates give more reliable yields. Current recommendations for optimal lupin seeding rates are based solely on maximisation of expected profit and risk preferences have not been considered. The present study tested the hypothesis that optimal lupin seeding rates are lower if the farmer is averse to risk. A risk analysis of lupin yields in response to seeding rates was conducted to determine whether optimal seeding rates are lower for farmers who are risk averse. The analysis was based on results from field trials from various locations in Western Australia in various years. Lupin yields were not less reliable at high seeding rates and therefore risk aversion does not materially reduce the optimal seeding rate. Farmers who used a seeding rate lower than the recommended rate forewent profit without lowering risk. In the low and medium rainfall areas, the average reduction in expected gross margin from using a suboptimum seeding rate (25–30 plants/m^2) is AU$4–10/ha. Farmers in the high rainfall zone who aim for 25–30 plants/m^2 could forego in excess of $30/ha, particularly in situations where high yields are possible.

Additional keywords: plant density, risk aversion.

Introduction

It has been estimated that for most lupin growing areas in Western Australia a plant density of 45 plants/m^2 will, on average, maximise profits. Growers achieving yields in excess of 1.5 t/ha may benefit from slightly higher plant densities, while growers in low yielding environments should aim for plant densities of 30–35 plants/m^2 (Nelson and Delane 1991; French *et al.* 1994). Despite extension of these findings, some growers in dry areas use seeding rates that result in establishment of 25–30 plants/m^2. They claim that these densities produce more reliable yields (Nelson *et al.* 1990; French *et al.* 1994). The discrepancy between recommendations and farmer practice has been the source of much discussion and debate. One criticism expressed by growers has been that there are large 'edge effects' in the narrow trial plots used by researchers. They argued that the plants on the edge of the plot are at a lower density and thus distort results. In response to this criticism, researchers conducted a series of farm trials using conventional equipment and the results of these trials were consistent with the results from earlier narrow trial plots (Nelson *et al.* 1990).

One factor that has not yet been considered in the analysis and modelling of lupin seeding rates is the risk preference of the farmers. There is a common perception among farmers that increasing crop inputs leads to increased production risk, and this discourages farmers from using input levels that maximise expected profit (Smith and Umali 1985). It may be that higher lupin seeding rates are more profitable on average, but also more risky. This study was designed to test the hypothesis that optimal lupin seeding rates are lower once risk and risk aversion are considered. If true, this may account for the observed discrepancy between research recommendations and farmer practice.

The issue of optimal seeding rate has gained renewed importance with the widespread development of resistance to selective chemical herbicides by annual ryegrass (*Lolium rigidum*) in the continuous cropping systems of Western Australia (Schmidt and Pannell 1996*a*). Increasing crop seeding rates has been proposed as a key component of 'Integrated Weed Management' strategies to combat resistant weeds in the presence of herbicide resistance (e.g. Schmidt and Pannell 1996*b*). If risks of yield failure are increased by this strategy, the recommendation may not necessarily be in the best interest of the farmers.

Materials and methods

Data source

The data used in this work are the results of trials conducted from 1987 to 1990 and again in 1993. The trials were situated at various locations throughout the Western Australian wheatbelt in zones of high, medium and low rainfall and were conducted by the Western Australian

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Department of Agriculture. Average annual rainfall for the high rainfall zone is more than 450 mm, and average annual rainfalls for the medium and low rainfall zones are 325–450 mm and less than 325 mm respectively. In most of the experiments, 6 rates of seeding were used, ranging from 30 to 200 kg/ha. The cultivars used were Gungurru, Danja, Yorrel and a reduced branching line, 75A/329. Lupin seed was sown at traditional 18-cm row spacing, and in most cases the soil chosen was one that was locally suited to lupin-growing (French *et al.* 1994). A range of measurements was taken from the trial sites. Of particular relevance to this study were the measurements of yield and established plant density at each seeding rate in the trials.

Model of lupin yield response to seeding rate

In order for optimal seeding rates to be calculated it was necessary to model lupin yield as a function of seeding rate. Several functional forms were evaluated. The functional form chosen was the 'quadratic divided by linear'. This form has great flexibility across a range of responses. It can peak at a maxima if necessary or plateau to an asymptote. The quadratic by linear function is

$$E(Y(S)) = a + b/(1 + dS) + cS,$$

subject to the constraint that $a = -b(1)$ where Y is yield, S is seeding rate, a, b, c and d are parameters, and E() is the expectations operator (Genstat 1996).

There were large fluctuations in yield potential between trials. In order to allow comparison between trials, all yields were standardised. This was done by dividing each observation in a trial by the maximum fitted yield of that trial. Maximum fitted yield was taken as the maximum value of a quadratic divided by linear production function fitted to the trial data set. Standardised yield response to seeding rate for each cultivar in each rainfall zone was estimated by fitting the quadratic divided by linear function to the data for each of 33 individual trials. Microsoft Excel Solver was used in each case to calculate the values of a, b, c and d that minimised the sum of squared deviations of actual data from the fitted response. In view of the large number of trial results and their limited interest, they are not presented here but are available from the authors in a technical appendix.

It was also necessary to develop a model that described standard deviation of yield as a function of seeding rate. Data for all cultivars (standardised as above) were pooled for each rainfall zone (high, medium and low) and linear regression used to describe the relationship between seeding rate and standard deviation of yield. Results are shown in equations 2, 3 and 4 for high, medium and low rainfall zones, respectively.

$$\sigma_H = 0.1620 + 0.0006701S \text{ (adjusted } R^2 = 0.51) \quad (2)$$
$$(0.0002073)$$

$$\sigma_M = 0.1870 - 0.0001297S \text{ (adjusted } R^2 = -0.056) \quad (3)$$
$$(0.0002864)$$

$$\sigma_L = 0.1598 - 6.075 \times 10^{-5} \times S \text{ (adjusted } R^2 = -0.10) \quad (4)$$
$$(0.000223)$$

where σ_H, σ_M and σ_L are standard deviations of standardised yields for high, medium and low rainfall zones, S is seeding rate in kg/ha, and values in parentheses are standard errors of the estimated parameters. P-values for the slope coefficients were 0.012, 0.66 and 0.79, respectively.

In the case of the high rainfall zone, there was a strong relationship between seeding rate and standard deviation of yield. For the medium and low rainfall zone it was concluded with a high degree of confidence that there was no relationship between seeding rate and standard deviation of yield. Therefore, the standard deviation of yield was assumed to be constant in the medium and low rainfall zones.

In addition, linear regressions were used to describe the relationship between seeding rate and established plant density for each cultivar in each rainfall zone. There was a strong relationship between seeding rate and established plant density under all scenarios tested. Equations 5, 6 and 7 show the regression results for the data set pooled by rainfall zone. Individual regression results for each cultivar in each region are in the technical appendix available from the authors.

$$D_H = 5.084 + 0.3494S \text{ (adjusted } R^2 = 0.69) \quad (5)$$
$$(0.008168)$$

$$D_M = 4.410 + 0.4368S \text{ (adjusted } R^2 = 0.85) \quad (6)$$
$$(0.008093)$$

$$D_L = 5.166 + 0.4201S \text{ (adjusted } R^2 = 0.77) \quad (7)$$
$$(0.007943)$$

where D_H, D_M and D_L are established plant densities (plants/m^2) for high, medium and low rainfall zones, and the values in parentheses are standard errors of the estimated parameters.

The risk model

There are various approaches to representation of risk aversion in decision problems. Of those that are practically useful, the approach that is considered the most theoretically respectable is the 'expected utility' approach (Anderson *et al.* 1977; Hardaker *et al.* 1997). This approach is based on a set of intuitively reasonable axioms that have been used to derive a 'utility function', which represents the satisfaction or psychological benefit that a decision maker gains from different possible outcomes of their decisions. For risk-averse decision makers, the shape of the utility function is such that they give a greater weight to relatively bad outcomes than to relatively good outcomes. The objective of the decision maker is to make the choice that results in the highest value of the statistical expected value of utility (or the maximal expected utility for short).

The degree of risk aversion of the decision maker affects the shape of his or her utility function, and can be quantified as a 'risk aversion coefficient', which is a parameter of the utility function. The measure of risk aversion used in this study is known as 'relative risk aversion'. Empirical studies have shown that most Australian farmers are either risk neutral (relative risk aversion = 0) or slightly risk averse (relative risk aversion less than 1.0) (Bond and Wonder 1980; Bardsley and Harris 1987). In this study, relative risk aversion coefficients ranging from 0 up to 1.6 were investigated.

For this study, the decision problem is to choose the value of S which maximises E(U(π)), where U(π) is utility as a function of profit and E() is the expectations operator. The functional form of the decision problem is

$$\text{Max E(U}(\pi)) = \sum_{i=1}^{n} \text{U}[W + (PY_i(S) - SC - I)A]\text{prob}(i) \quad (8)$$

where W is initial wealth, P is output price per unit of output, C is the cost per unit of seed, I is cost per unit area of inputs other than seed, A is area, and prob(i) is the probability of yield i. For the purpose of this analysis we assumed an initial wealth, W, of AU$250000 and an area of lupins, A, of 800 ha. The price per unit of output, P, used in the analysis was based on the average of pool returns paid to Western Australian lupin growers for the 5 years from 1997 to 2001, less deductions for freight, storage, handling and research levies. The cost per unit of seed, C, was taken as the opportunity cost of seed plus the cost of treatments (including grading, inoculation and treatment for disease), while the cost of inputs other than seed, I, was calculated as the cost of planting, spraying and harvesting a lupin crop using current recommended practices. The values assumed for P, C and I are provided in Table 1.

Utility is represented by the following functional form:

$$U = k + m\pi^{(1-R)} \quad (9)$$

where R is relative risk aversion and k and m are constants that do not affect the ranking of options. The risk model represents yield and price

Table 1. Assumptions for the values of price of output, cost of seed and cost of other inputs used in the analysis

	Price of output (cents/kg)	Cost of seed (cents/kg)	Cost of other inputs ($/ha)
Low rainfall zone	15.58	28.58	100
Medium rainfall zone	15.88	28.88	125
High rainfall zone	16.18	29.18	150

as discrete random variables of n possible levels, where $n = 1000$. A random number generator was used to generate the normal scores for the yield and price distributions. Each of the random observations was assigned a probability of 0.001 for the analysis on the assumption that prices and yield are not correlated. Thus, at any seeding rate, there are 1000 possible yield–price combinations in the model, each of which has a corresponding profit, a utility value and a probability. These are combined to calculate the expected utility for that seeding rate. The values of expected utility at different seeding rates are compared with find the optimal rate. This procedure was repeated for a range of different levels of risk aversion.

The risk model assumes that the probability distributions of price and yield at a given seeding rate are about normal. The validity of this assumption was tested for yield by subjecting pooled data for each rainfall zone to chi-squared goodness of fit tests (Mead *et al.* 1994). In 35 of 37 data sets the normal distribution was found to adequately represent the distribution of yields for a given seeding rate ($P<0.01$). The 2 failures of the goodness of fit test were due to 2 outliers in the data, and repeating the tests after removing these observations showed the normal distribution to be adequate. The authors are aware that the true distribution of these variables cannot be normal (e.g. they are truncated at zero) but from the tests conducted and visual inspection we believe that the assumption of normality is a good approximation in this case.

Results and discussion

Table 2 shows results for optimal seeding rates in the cases of risk neutrality ($R = 0$) and high risk aversion ($R = 1.6$). Results for other levels of risk are not shown. Optimal seeding rates were calculated on the basis of a yield (at the yield-maximising seedling rate) of 1000, 1500 and 2000 kg/ha for the low, medium and high rainfall zones respectively. A yield of 1500 kg/ha is considered realistic for much of the Western Australian wheatbelt (French 1989), which in large part falls into the medium rainfall zone (325–450 mm). The inclusion of the lower and higher yield potentials reflects the different production environments of the low and high rainfall zones.

In the low and medium rainfall zones, a change in seeding rate did not change yield variability when the latter was expressed as a standard deviation. Therefore it is not surprising that a farmer with an aversion to risk would select seeding rates almost identical to those preferred by a risk-neutral farmer, as seen from a comparison of the first and third columns of Table 2. The results are not identical since the impact of stochastic prices reduces the optimal level of an input (Sandmo 1971), albeit only slightly in this case.

In the high rainfall zone, where higher seeding rates were found to increase yield variability, the impact of risk aversion on optimal seeding rates was modest. The biggest impact was a reduction of 14 kg/ha and in all cases the optimal plant density remained above 45 plants/m^2. These results are all the more robust since our assumptions relating to initial

Table 2. The effect of risk aversion on optimal lupin seeding rate and plant density

	Risk neutral farmer ($R = 0$)		Risk averse farmer ($R = 1.6$)		Risk averse farmer ($R = 1.6$)[A]	
	Seeding rate (kg/ha)	Plant density (plants/m^2)	Seeding rate (kg/ha)	Plant density (plants/m^2)	Seeding rate (kg/ha)	Plant density (plants/m^2)
	Low rainfall zone (yield potential 1000 kg/ha)					
All cultivars pooled	75.5	36.9	75.3	36.8	73.7	36.1
Gungurru	76.0	37.3	75.8	37.3	75.0	36.9
Danja	75.5	37.5	75.3	37.4	73.7	36.7
Yorrel	84.1	38.8	83.7	38.6	81.2	37.6
75A/329	54.7	28.7	54.4	28.6	52.8	28.1
	Medium rainfall zone (yield potential 1500 kg/ha)					
All cultivars pooled	85.3	41.7	84.8	41.5	80.9	39.7
Gungurru	92.8	46.4	92.0	46.0	85.7	43.2
Danja	85.3	41.8	84.8	41.6	80.9	39.3
Yorrel	100.7	38.2	100.0	37.9	93.8	35.8
75A/329	92.6	40.3	92.2	40.2	88.5	38.9
	High rainfall zone (yield potential 2000 kg/ha)					
All cultivars pooled	132.9	51.5	124.6	48.6		
Gungurru	153.7	55.3	139.8	50.8		
Danja	132.9	53.8	124.6	50.7		
Yorrel	n.d.	n.d.	n.d.	n.d.		
75A/329	125.9	63.0	120.1	60.3		

[A]Final 2 columns show results for the hypothetical case where yield variability in low and medium rainfall zones is positively related to seeding rate, using the same relationship as for the high rainfall zone. n.d., not determined.

wealth, *W*, and area of lupins, *A*, were conservative and tended to exaggerate the impact of risk aversion on lupin seeding rate. The fact that the impact of risk aversion remains small despite our conservative assumptions emphasises how unimportant risk is in the lupin seeding rate decision.

This result is similar to recent findings for optimal seeding rates for upright beans (*Phaseolus vulgaris* L.) in Canada (Saindon *et al.* 1995). In the past there has been a perception that using a high seeding rate in upright beans increases the level of risk of yield due to a greater likelihood of white mold disease associated with reduced air flow through the crop. As a consequence, bean growers have been using seeding rates that reduce yields by up to 10–20%. Contrary to popular belief it has been found that upright beans can be grown at a high seeding rate without a great increase in the level of risk of white mold disease, especially when the chosen cultivar is erect. The optimal seeding rate is close to that calculated on the basis of expected profit maximisation (Saindon *et al.* 1995).

The results of the present study also parallel research into the effect of risk aversion on optimal rates of nitrogen fertiliser. While there is often a positive relationship between nitrogen rate and yield variability, several studies have shown that optimal nitrogen rates under risk aversion are only slightly less than optimal rates for risk neutral farmers, and that risk aversion alone does not account for the low rates used by some farmers (e.g. Smith and Umali 1985; Roumasset *et al.* 1989).

The results presented here also support previous results of research that showed that higher seeding rates are required to exploit environments with higher yield potentials. Optimal lupin seeding rates in high yielding environments are typically 40–80 kg/ha higher than for low yielding environments. In addition, there is evidence of differences in optimal seeding rate between cultivars. For example, in high rainfall areas Gungurru lupins yield more than Danja. Optimal seeding rates reflect this, with the rates for Gungurru being higher than Danja. Similarly, of the 3 conventional lupin cultivars used in this study, Yorrel is the best adapted to short growing conditions and to drought conditions (Cowling *et al.* 1994). These abilities are reflected in low rainfall areas where the optimal seeding rate (and target plant densities) calculated for Yorrel in this study was slightly higher than for Gungurru and Danja. This finding is consistent with previous work that suggests that cultivars with a higher yield potential at a particular site will have a higher optimal seeding rate (French *et al.* 1994).

In addition, the seeds of Yorrel are 10% bigger than those of Gungurru and Danja (Cowling *et al.* 1994). This means that when establishing a crop of Yorrel lupins a greater weight of seed is required to establish a certain number of plants compared with Danja or Gungurru. The results in Table 2 are consistent with this. For example, in the low rainfall zone the ratio of seeding rate to established plant density is 2.0 for Danja and Gungurru, and 2.2 for Yorrel. Likewise, in the medium rainfall zone, the ratios are 2.0 for Danja and Gungurru, and 2.6 for Yorrel.

A possible explanation for the reduced seeding rates in the low and medium rainfall zone is that some farmers perceive (apparently incorrectly) that yield risk increases with increasing seeding rate. To test whether this was a plausible explanation, the relationship between seeding rate and yield variance observed in the data for the high rainfall zone was applied to the low and medium rainfall zones.

We did not assume that farmers in the low–medium rainfall zones actually believe that the high rainfall relationship applies precisely in their area. The intention of this analysis was to examine whether a quite plausible misperception of this type would be sufficient to explain observed farmer behaviour. The results of the hypothetical analysis are shown in the final column of Table 2. Risk aversion reduced the optimal seeding rate, but at the assumed level of risk aversion it did not reduce the optimal seeding rate by an amount large enough to explain the very low seeding rates used by some growers. We conclude that risk aversion at realistic levels is not sufficient to explain the discrepancy between recommendations and farmer practice. Even assuming an unrealistically strong relationship between seeding rate and yield variability, risk aversion levels much stronger than previously measured for most farmers would be needed to account for observed low seeding rates. It appears that the explanation is a combination of the following possibilities: (i) levels of risk aversion of farmers are greater than previously measured, (ii) farmers' perceptions of the relationships between seeding rate and yield variability are strongly erroneous, and (iii) decision-making processes of farmers are not consistent with the economic model used in this study.

Without conducting a detailed and complex survey of individual farmers, it is not possible to determine which of these 3 possibilities apply, or to what extent. Given the possibility that explanation (ii) applies, it is worth reflecting on possible reasons for the exaggerated perceptions of the levels of risk that are associated with some crop inputs. It was noted earlier in this paper that this has been observed in a number of previous studies. A potential explanation for the observation is a failure to clearly identify sources of risk. Without environment-specific information on the sources of risk there can be large inaccuracies in estimation of optimal inputs (Rosegrant and Roumasset 1985). This can be clearly seen in the study of Hanus and Schoop (1989), in which exaggerated perceptions of risk surrounding the use of nitrogen fertilisers on cereals were identified. Increased use of nitrogen fertiliser was risky when necessary changes to crop husbandry were not made. However, when appropriate management strategies were adopted in conjunction with increased nitrogen fertilisation (e.g. control of fungal diseases and accurate control of irrigation), increases in yield

Table 3. Expected gross margin at optimal seeding rate ($/ha), expected gross margin when target plant density is 27.5/m^2 ($/ha) and expected gross margin foregone when a suboptimal seeding rate (27.5 plants/m^2) is used ($/ha)

	Expected gross margin at optimal seeding rate ($/ha)	Expected gross margin when target plant density is 27.5 plants/m^2 ($/ha)	Expected gross margin foregone ($/ha)
	Low rainfall zone (yield potential 1000 kg/ha)		
All cultivars pooled	20	16	4
Gungurru	28	21	7
Danja	20	16	4
Yorrel	17	13	4
75A/329	27	26	1
	Medium rainfall zone (yield potential 1500 kg/ha)		
All cultivars pooled	81	75	6
Gungurru	85	78	7
Danja	81	75	6
Yorrel	82	78	4
75A/329	81	71	10
	High rainfall zone (yield potential 2000 kg/ha)		
All cultivars pooled	132	101	31
Gungurru	128	96	32
Danja	132	97	35
Yorrel	n.d.	n.d.	n.d.
75A/329	130	70	60

variability were greatly reduced or even avoided (Hanus and Schoop 1989). It is clear that nitrogen was not the only source of risk in this situation. Instead, a failure to adapt management to increased nitrogen was responsible for much of the increased risk in yield.

Cost of using suboptimal lupin seeding rates

We have concluded that, for whatever reason, many farmers use suboptimal seeding rates in lupin crops. To examine the cost of this practice the expected gross margin gained from using a seeding rate that aimed to establish 27.5 plants/m^2 was determined and compared against the expected gross margin realised when the optimal rate was used. The results of this analysis are shown in Table 3.

The expected gross margin foregone by using a seeding rate aimed at establishing 25–30 plants/m^2 is AU$4–10/ha in the low and medium rainfall zones. These amounts are relatively modest, although for farmers planting large areas of lupins, the total returns foregone could become significant. Use of suboptimal seeding rates is particularly costly in the high rainfall regions. For crops with a potential yield of 2000 kg/ha the forgone amount is in excess of $30/ha, and represents a significant reduction in returns.

Conclusion

Risk aversion alone cannot account for the practice of some Western Australian farmers to use a lower than optimal lupin seeding rate. Farmers who use a lower than optimal seeding rate forego profit while avoiding little or no risk. This study supports previous recommendations to use a seeding rate for lupin crops that aims to establish at least 45 plants/m^2, with room for adjustments up or down by 5–10 plants/m^2 depending on yield potential. The results of this study also support previous research that has found differences in optimal seeding rate between cultivars and site yield potentials.

There is potential for this type of research to be applied to a range of crops. In most research, optimal input levels for crops have been determined purely on the basis of expected profit maximisation. However, if higher input levels are more risky, risk preferences become a very real consideration. On the other hand this type of work also has a role in dispelling false ideas about agronomic practices. It has been shown that there are false or exaggerated perceptions of risk associated with several inputs into crop systems. If farmers are using suboptimal input levels on the basis of risk avoidance, and yet in doing so are not avoiding any risk, then a formal approach can help identify the sources of risk and aid the decision making process.

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