Economic Assessment of a New Grain Legume for Low Rainfall Environments*

Nicole A. Free[1,2], David J. Pannell[2] and Greg G. Shea[3]

[1]Agriculture Western Australia, 3 Baron-Hay Court, South Perth WA 6151,
[2]Agricultural and Resource Economics, Faculty of Agriculture, University of Western Australia, Nedlands WA 6907,
[3]Agriculture Western Australia, Avon Districts Agricultural Centre, Lot 12 York Road, Northam WA 6401.

Abstract

Cropping on yellow earth soils in the eastern wheatbelt of Western Australia can be restricted by subsoil acidity. There are approximately one million hectares of yellow earth soils in Western Australia, some of which are extremely unproductive due to acidity and high concentrations of available aluminium. The best crop rotation on yellow earth soils includes wheat and narrow-leafed lupins, but this is not economically viable on those soils with high aluminium concentrations.

It is known that the yellow lupin (*Lupinus luteus*) is more tolerant to toxic levels of subsoil aluminium than the narrow-leafed lupin (*Lupinus angustifolius*). Research has shown that the yellow lupin has a very high level of resistance to *Pleiochaeta* root rot and brown leaf spot (*Pleiochaeta setosa*) compared to the narrow-leafed lupin. Evidence from field trials has shown that the advantage of the yellow lupin over the narrow-leafed lupin is greatest on the soils with a high level of extractable aluminium.

The potential role of yellow lupins in the Western Australian eastern wheatbelt farming system is assessed using the whole farm bioeconomic model, MIDAS (Model of an Integrated Dryland Agricultural System).

Keywords: yellow lupin (Lupinus luteus), MIDAS, whole farm model, sensitivity analysis

Introduction

In Western Australia, cropping on the yellow earth soils in the low rainfall eastern wheatbelt can be restricted by subsoil acidity. There are approximately one million hectares of yellow earth soils in Western Australia, some of which are extremely unproductive due to high concentrations of available aluminium associated with subsoil acidity. The best crop rotation on yellow earth soils includes wheat and narrow-leafed lupins. Narrow-leafed lupins are an important component of the sandplain farming system in Western Australia. Generally they are most profitable when grown in rotations which include a high proportion of wheat. Without the benefits which narrow-leafed lupins have for production in cereal crops, their production would be substantially lower than it is (Pannell, 1994). A rotation including narrow-leafed lupins and wheat, however, is not economically viable on those more acidic sandplain soils, due to toxic levels of aluminium in the subsoil restricting both narrow-leafed lupin and wheat yields. Hence, most farmers currently use the acidic sandplain soils for continuous pasture which is unimproved.

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The high aluminium concentrations of the acidic sandplain soils extremely restrict wheat yields. Narrow-leafed lupins (*Lupinus angustifolius*) appear to be more tolerant than wheat to subsoil aluminium toxicity, but narrow-leafed lupin yields are still restricted on these soils. Hence, they are not an economically viable option. It has been shown that the yellow lupin (*Lupinus luteus*) is more tolerant to toxic levels of subsoil aluminium than the narrow-leafed lupin (Carr, 1994). The yellow lupin is better able to maintain root elongation in the presence of increasing concentrations of toxic aluminium in the subsoil.

Pleiochaeta setosa is known world-wide as the cause of brown leaf spot of lupins. The same fungus causes a serious root disease of young seedlings when roots contact spores of *P. setosa* in soil previously cropped with lupins. These two diseases are the most widespread and important lupin diseases of the wheatbelt of Western Australia. Research has shown that the yellow lupin is tolerant to brown leaf spot and extremely resistant to *Pleiochaeta* root rot (Sweetingham, 1994).

The yellow lupin has the potential to play a useful role in the eastern wheatbelt farming system, particularly on the acidic sandplain soils. It has the ability to substantially outyield the narrow-leafed lupin on the acidic sandplain soils due to its tolerance of high aluminium concentrations in the subsoil. The yellow lupin also has the advantage of being tolerant to brown leaf spot and extremely resistant to *Pleiochaeta* root rot. In addition, the yellow lupin has a protein content significantly higher than the narrow-leafed lupin with a higher content of important amino acids. Therefore, there is potential for this commodity to attract relatively high prices in the stockfeed market (Shea *et al.*, 1996[b]).

This paper uses the whole farm bioeconomic model, MIDAS (Model of and Integrated Dryland Agricultural System), to evaluate the role of yellow lupins within the eastern wheatbelt farming system, in particular its contribution to whole farm profit. MIDAS is a mathematical programming model designed for agricultural systems analysis (Morrison, 1986). MIDAS is the most appropriate tool available to be used in this analysis given its ability to account for the large number of interdependencies between enterprises on the farm. MIDAS has three components: (1) An objective to be maximised or minimised, in this case, maximisation of whole-farm profit; (2) Activities which can be viewed as different ways of meeting the objective (in the case of MIDAS, these are different land uses and other farm management practices); and (3) Constraints which limit the activities (limited resources of land, finance and labour, and limitations imposed by the biology of the system) (Morrison, 1991). For a more detailed description of MIDAS refer to Kingwell and Pannell (1987).

In all models, parameters are more-or-less uncertain (Pannell, 1996). The modeller is not only likely to be unsure about their future values, but also their current values. This applies to factors such as prices, costs, productivity and technology. When parameters are uncertain, the use of sensitivity analysis can give information such as: how robust the optimal solution is in the face of different parameter values; under what circumstances the optimal solution would change; how the optimal solution changes in different circumstances; and how much worse off the decision maker would be if he or she ignored the changed circumstances and stayed with the optimal strategy or some other strategy (Pannell, 1996). Hence, sensitivity analysis is used here to assess the role of yellow lupins in the eastern wheatbelt farming system with MIDAS.

The aim of this paper is to determine which parameters yellow lupins are most sensitive to in terms of the optimal area of yellow lupins selected to be sown on the farm, and the extra profit to be made by including yellow lupins on the farm.

Method

The Eastern Wheatbelt Model of MIDAS was used for the analysis. The version used was MER96-02, which is an updated version of that documented by Pannell and Bathgate (1994). The model farm has 2500 ha of arable land and is made up of seven different soil types. Table 1 contains the soil mix of the farm and a description of each of the soil types. Soil types 1, 2 and 3 are those which are included in the term yellow earth soils, soil type 1 being that referred to as the acidic sandplain soil.

Table 1: Definition and Soil Mix of the MIDAS farm

Soil Type	Description	pH Range ($CaCl_2$)	Area (ha)
1 Acid Sands	Yellow loamy or gravelly sands.	< 5.5	500
2 Good Sandplain	Deep, yellow brown, loamy sands.	5.5 - 6.0	500
3 Gravelly Sands	Yellow brown, gravelly sands and sandy gravels.	5.5 - 6.0	250
4 Duplex	Grey sandy loams, loamy sands, gravelly sands and sand, over white clay with yellow or red mottles.	5.5 - 6.5	250
5 Medium Heavy	Red brown, sandy loam over clay subsoil.	6.0 - 7.0	375
6 Heavy	Dark red brown, sandy clay loams.	> 6.5	500
7 Heavy (Friable)	As for soil 6, but better structured and higher yielding, possibly due to gypsum application	> 6.5	125

Trials were carried out in 1994 and 1995 throughout the West Australian wheatbelt to determine the comparative yields of narrow-leafed lupins and yellow lupins across a range of soil types, rotations and disease pressures. The results were averaged and scaled down from trial yields to "paddock" yields and used for analysis with MIDAS. These yield assumptions appear in Table 2 below. The yield assumptions for the various cereal crops are shown in Table 3. Note that yellow lupins are only suitable to be grown on the yellow earth soils, and thus only yields for soil types 1, 2 and 3 are given.

Table 2: Base level yield assumptions for lupins on the yellow earth soils (kg/ha).

Soil Type	Type of Lupin	CCL	CL	CPL
S1	Yellow Lupin	800	775	787.5
	Narrow-leafed Lupin	500	450	475
S2	Yellow Lupin	850	823.75	768.5
	Narrow-leafed Lupin	1050	997.5	1050
S3	Yellow Lupin	800	768.5	800
	Narrow-leafed Lupin	900	837	900

Note that C = cereal, L= Lupin (yellow or narrow-leafed), P = Pasture
ie: CCL = cereal:cereal:lupin rotation

Table 3: Base level cereal yield assumptions for first cereal crop after lupin crop on the yellow earth soils (kg/ha).

Cereal Type	Soil Type S1	S2	S3
Wheat	950	1400	1400
Barley	-	1260	1260
Oats	1093	-	-
Triticale	1093	-	-

The standard or base level gross grain prices in MIDAS for the cereals, narrow-leafed lupins and yellow lupins were as follows and represent medium term prices (3-5 years):

Wheat	$200/t
Manufacturing Barley	$200/t
Feed Barley	$180/t
Oats	$150/t
Triticale	$150/t
Narrow-leafed lupins	$200/t
Yellow Lupins	$200/t

The wool price used in the analysis was 360 c/kg greasy net on farm.

Costs of production for yellow lupins and narrow-leafed lupins are assumed to be the same, other than there being no phosphate application to yellow lupins. This makes the cost of production of yellow lupins around $25/ha less than that for narrow-leafed lupins.

The analysis involved carrying out sensitivity analysis around several parameters in order to test the robustness of the optimal solution in the face of different parameter values. The parameters which were included in the sensitivity analysis were: yellow lupin yield, yellow lupin price, narrow-leafed lupin price, wheat price, wool price and phosphorus application. Pannell (1996) suggests that when selecting the parameter levels which will be used in a sensitivity analysis, the levels selected for each parameter should encompass the range of possible outcomes for that variable, or at least the "reasonably likely" range for that variable. He states that what constitutes "reasonably likely" is an arbitrary choice of the modeller, and suggests that one possible approach is to select the maximum and minimum levels such that the probability of an actual variable being outside the selected range is 10 percent. Given Pannell's (1996) suggestion, the authors subjectively selected a low and a high level for each of the parameters (except phosphorus application). In the case of phosphorous application, the base level is zero, so only a high level was selected. Probabilities were subjectively assigned to each level of each parameter as suggested by Pannell (1996). Parameter levels and their assigned probabilities appear in Table 4.

A complete factorial experimental design was used. Hence, the model was solved for all possible combinations of the parameters included in the sensitivity analysis. The effect of these different parameter values on the optimal area of yellow lupins sown on the farm, and the extra profit attributed to incorporating yellow lupins on the farm, was observed.

Table 4: Parameter levels for sensitivity analysis

Parameter	Low level (Probability 0.1)	Base level Probability (0.8)	High level Probability (0.1)
Yellow lupin yield	-25%	0.8 t/ha*	+25%
Yellow lupin price	-40%	$200/t	+25%
Narrow-leafed lupin price	-40%	$200/t	+25%
Wheat price	-40%	$200/t	+25%
Wool price	-22%	360 c/kg g.n.o.f.	+44%
Phosphorus application		0 kg/ha**	+50 kg/ha

*Yield is different for each rotation on each soil type
**As there is no low level, the probability of the base level is 0.9

By assigning probabilities to each of the parameter levels, and assuming statistical independence of the parameters, the probability of each scenario was easily calculated. For example, the scenario which included the low level yellow lupin yield, the high level yellow lupin price, and the base levels of all other parameters would have a probability of $0.1 \times 0.1 \times 0.8 \times 0.8 \times 0.8 \times 0.9 = 0.004608$. A cumulative probability curve was constructed for the extra profit made due to the inclusion of yellow lupins on the farm.

Sensitivity indices were calculated for the parameters with respect to optimal yellow lupin area, and the extra profit due to the inclusion of yellow lupins in the farming system. A simple index proposed by Hoffmann and Gardiner (1983) is as follows:

$$SI = (D_{max} - D_{min})/D_{max}$$

where D_{max} is the output result when the parameter in question is set at its high level and D_{min} is the result for the low parameter value. A slight variation of this equation was used in this analysis. The equation used was:

$$SI = (D_{max} - D_{min})/D_{mean}$$

where D_{mean} is the mean statistical expected value over the 486 scenarios.

Results

Given the underlying assumptions for this analysis, the optimal farm management strategy when all parameters are set at their base levels, includes yellow lupins on the yellow earth soils (Table 5, Figure 1). The inclusion of yellow lupins in the farming system on these soils leads to an increase in overall farm profitability (Table 5, Figure 2).

The aims of this paper were to evaluate the effect of changes in key parameters on the optimal area of yellow lupins selected, and estimate the increase in farm profit due to yellow lupins being incorporated into the farming system. The sensitivity analysis considered changes in 6 different parameters. Of these 6 parameters, 5 had 3 levels for sensitivity analysis, and one had two levels.

Hence, the sensitivity analysis generated 486 different scenarios (3 x 3 x 3 x 3 x 3 x 2). Table 5 presents examples of four of these scenarios, and presents results for the optimal area of yellow lupins and the increase in farm profit due to yellow lupins, for the particular individual scenario. Note that columns 2 and 3 of Table 5 include results for the single base-case scenario, while columns 4 and 5 show results for the mean results over the 486 scenarios.

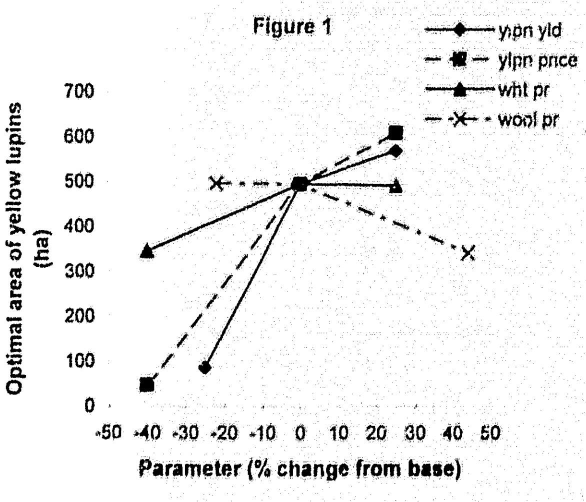
The first scenario which appears in Table 5 is the "best bet" scenario, in which all parameters are at their base level. The expected optimal area of yellow lupins for this scenario is 495 ha, leading to an expected increase in farm profit of $10,524. We consider that these results are a better indication of the likely impacts than the single base-case results.

Table 5: Example of results for four individual scenarios

	*Optimal area of yellow lupins (ha)	*Extra profit due to yellow lupins ($)	***Expected area of yellow lupins, all scenarios considered (ha)*	***Expected extra profit due to yellow lupins, all scenarios considered ($)*
Standard solution	[illegible]	11,414	*495*	*10,524*
Standard with high phos applic	[illegible]	5,185	*437*	*6,681*
Standard, low Y. lupin yield	0	0	*86*	*1,300*
Standard, low Y. lupin price	0	0	*47*	*599*

* The single solution for an individual scenario. Probability of the particular scenario occurring is not taken into account.

**Statistical expected value over 486 scenarios.



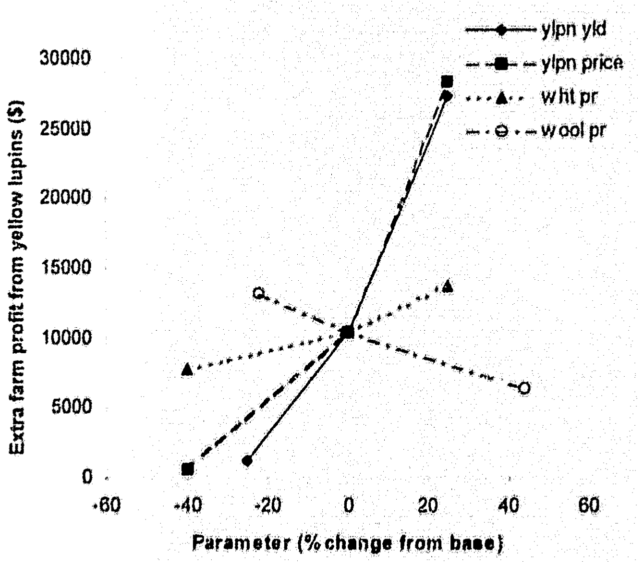
Results of the sensitivity analysis highlighted that the optimal area of yellow lupins is most sensitive to changes in yellow lupin price and yield (Figure 1, Table 6). For wheat price, a decrease of 40 percent led to the optimal area of yellow lupins decreasing by around 150 ha. However an increase in wheat price of 25 percent was not enough to lead to any substantial change in the optimal area of yellow lupins because of the limited availability of some of the soils. The opposite was the case with wool price, for which an increase in wool price of 44 percent led to the optimal area of yellow lupins decreasing by around 150 ha, but a 22 percent decrease in wool price did not alter the area of yellow lupins (Figure 1). Yellow lupin price and yield also had the largest effect on the profit generated from incorporating yellow lupins into the farming system (Figure 2, Table 6).

A 25 percent increase in wheat price led to an increase in economic gain from including yellow lupins in the farming system (Figure 2). Although the optimal area of yellow lupins did not change substantially with an increase in wheat price of this magnitude (Figure 1), the extra farm profit due to yellow lupins being included in the farming system does. This appears to be due to low probability-high return scenarios influencing the expected benefits. On the other hand, as expected, a decrease in wheat price of 40 percent led to a decrease in the extra income due to yellow lupins (Figure 2), as the optimal area of yellow lupins was decreased (Figure 1).

Table 6: Sensitivity indices of optimal yellow lupin area and extra profit due to the inclusion of yellow lupins in the farming system

Parameter	Sensitivity index of optimal area	Sensitivity index of extra profit due to yellow lupins
Yellow lupin yield	0.98	2.47
Yellow lupin price	1.13	2.63
Narrow leaf lupin price	-0.26	-1.55
Wheat price	0.29	0.57
Wool price	-0.31	-0.65
Phosphorous application	-0.09	-0.58

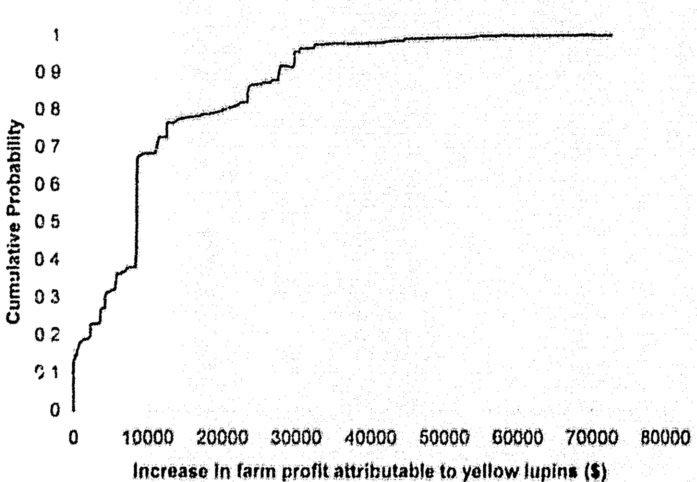
Figure 2



As was seen in Figure 1, if wool price increases by 44 percent, the area of yellow lupins decreases by about 150 ha. Hence this increase in wool price will lead to a decrease in the extra farm profit attributed to yellow lupins, as there is a smaller area of yellow lupins (Figure 2). Although a 22 percent decrease in wool price does not lead to the optimal area of yellow lupins increasing, the extra profit due to yellow lupins increased slightly (Figure 2), again due to the impact of extreme scenarios on the expected benefit of yellow lupins.

For purposes of clarity, the narrow-leafed lupin price parameter curve has been left out of Figures 1 and 2. It is expected that yellow lupin price and narrow-leafed lupin price will be similar, and follow similar trends and, if anything, that yellow lupin price will be slightly higher than that of narrow-leafed lupins.

Figure 3



The phosphorous application parameter has also been omitted from Figures 1 and 2, as it only had two levels. This parameter had only a very small effect on the optimal area of yellow lupins being selected in the optimal solution (Table 6). When Phosphorous application was increased from zero to 50 kg/ha, the optimal area of yellow lupins decreased by only 58 ha (Table 5). The increase in farm profit due to yellow lupins decreased by $4,655 when phosphorous application increased from zero to 50 kg/ha on yellow lupins (Table 5). This difference in profit is made up of the cost of applying the phosphorous (compared to applying none), in addition to the change in profit due to the very small reduction in yellow lupin area.

Figure 3 indicates that the most likely increase in profit from incorporating yellow lupins into the farming system is close to $10, 000. However, the vertical section of the curve at the origin also indicates that it is likely there will be no increase in profit due to yellow lupins. The probability of this occurring is around 0.16 (Figure 3). This would correspond to the probability of a scenario occurring in which the optimal area of yellow lupins selected is zero. The probability of farm profit increasing by somewhere between 0 and $10, 000 due to the incorporation of yellow lupins into the farming system is around 0.23 (Figure 4). There is a probability of about 0.31 that farm profit may increase beyond $10,000 by incorporation of yellow lupins in the farming system. Hence, there is a probability of 0.84 that incorporating yellow lupins into the farming system, will lead to some increase in overall farm profit.

Discussion

The analysis with MIDAS indicated that the inclusion of yellow lupins on the yellow earth soils of the low rainfall eastern wheatbelt farming system of Western Australian increases farm profit. By adopting the methodology of sensitivity analysis suggested by Pannell (1996), it was possible to determine that the majority of the scenarios generated by the sensitivity analysis included yellow lupins in the optimal solution.

Given the assumed probabilities and sensitivity levels for the parameters included in the sensitivity analysis, 84 percent of scenarios included yellow lupins in their optimal solutions, and 61 percent of the scenarios resulted in an increase in farm profit of more than $10,000 due to the incorporation of yellow lupins on the farm. Of the remaining 39 percent of scenarios, 16 percent did not include yellow lupins in their optimal solution. For the other 23 percent, although yellow lupins were included in their optimal solution, the increase in profit made from doing so was less than $10,000.

The sensitivity analysis revealed that changes in yellow lupin price and yellow lupin yield had the largest effect on the area of yellow lupins selected in the optimal solution, and hence, the extra farm profit due to yellow lupins. Although decreases in wheat price and increases in the wool price also effect the optimal area selected, the optimal area of yellow lupins selected when wheat price decreased by 40%, or wool price increased by 44% still resulted in an increase in farm profit of $7,000. Therefore, given that in 61 percent of scenarios the inclusion of yellow lupins in the farming system led to increased farm profit of $10,000 or more, the optimal strategy would be to include yellow lupins in the farming system on the yellow earth soils.

This analysis indicated that the introduction of a rotation including yellow lupins on the acidic sandplain is likely to be a more profitable option than the traditional option of leaving this soil type in continuous pasture. This is due to the fact that yellow lupins are able to tolerate the lower pH and higher aluminium concentration of this soil, and hence are significantly higher yielding than narrow-leafed lupins on the acidic sandplain soils. However, results indicated that yellow lupins are unlikely to be grown purely for their returns in the year that they are grown. This was demonstrated by the area of yellow lupins, and hence, the increase in farm profit due to the incorporation of yellow lupins into the farming system decreasing when wheat price decreased. The indirect benefit of legumes, such as nitrogen carryover and cleaning crop effects, in addition to the value of the harvested grain, make yellow lupins a potentially important component of the optimal rotation on the yellow earth soils.

The role of yellow lupins was thought to be most promising on the acidic sandplain, due to the yield advantage yellow lupins have over narrow-leafed lupins on this soil type. On soil types 2 and 3 the yield of narrow-leafed lupins and yellow lupins are comparable. Costs of production however, are lower for yellow lupins on all three soil types, as yellow lupins do not require phosphate application. Shea *et al* (1996[a]) found that the rotational profit increases on these soil types when yellow lupins are included in the rotation, but not to the extent that it does on soil type 1, the acidic sandplain.

An issues not taken into account in this analysis is the introduction of serradella (a pasture legume tolerant of acidic soils) on the acidic sandplain soil. Serradella improves the carrying capacity of this soil type, and hence it is expected that it would compete with yellow lupins to be the most profitable option on soil type 1, particularly in times of high wool prices. Additionally, wheat varieties that are tolerant of low levels of subsoil aluminium are being bred in Western Australia and this technology could complement yellow lupins on some acidic soils.

Another issue not taken into account in this analysis is the comparative yield variability of yellow lupins versus narrow-leafed lupin. Being disease resistant (and determinant in its growth pattern) it is expected that the yellow lupin should have less variable yields compared to narrow leaf lupin when grown in the wheatbelt.

Conclusions

The analysis with MIDAS indicates that there is likely to be a role for yellow lupins in the low rainfall eastern wheatbelt farming system of Western Australia. Given the underlying assumptions of the analysis, it is suggested that the optimal strategy involves incorporating yellow lupins into the farming system on yellow earth soils, particularly the acidic sandplain.

The use of sensitivity analysis was found to be a useful method for assessing the role of a new crop such as yellow lupins in the farming system. Assigning probabilities to the scenarios in the sensitivity analysis provided useful information about the probability of yellow lupins being selected in the optimal solution, and the probability distribution of the increase in farm profit generated by including yellow lupins on the farm.

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