ECONOMIC INTEGRATION OF CHEMICAL AND NON-CHEMICAL WEED CONTROL UNDER HERBICIDE RESISTANCE IN CONTINUOUS CROPPING

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Summary. Even under threat of herbicide resistance, inclusion of pasture into continuous cropping systems will not be acceptable or even advisable in all situations. However there is a range of other non-chemical control options available, including cultivation, burning and choice of wheat cultivar. In this study we investigate the optimal combination of chemical and non-chemical control of ryegrass under threat of herbicide resistance. Our model is a dynamic non-linear programming model representing a continuous cropping system infested with ryegrass in Western Australia. We investigate the impact which herbicide resistance has on the optimal combination of chemical and non-chemical control and estimate the cost of failing to respond optimally to the threat of resistance.

INTRODUCTION

There have been a number of studies of the economics of pesticide resistance in insects and diseases (2) but almost no research on the economics of herbicide resistance. In this paper we address the economics of herbicide resistant weeds in Western Australian dryland agriculture, a mixed farming system producing livestock and various crops. Our focus is on the management of herbicide resistance before it reaches high levels rather than on responses to a high existing level of herbicide resistance.

By far the greatest number of occurrences of herbicide resistance in Australia has been for annual ryegrass (*Lolium rigidum*) growing as a weed in continuous cropping rotations (usually wheat/lupins) treated with selective grass herbicides (1,5). This reflects the frequency with which selective herbicides are usually used in continuous cropping. This system is the focus for our study.

The Management Options. Resistance develops after a number of years of chemical use, whereas costs of the various management responses are incurred in the preceding years. Evaluating management strategies to prevent herbicide resistance requires comparison of costs and returns incurred over time. Discounting both future costs and future benefits is a method used to determine the "net present value" of a strategy. A strategy with the highest net present value is most beneficial to the farmer.

Of the many strategies proposed for prevention of herbicide resistance two strategies are evaluated in this paper The first strategy is the use of a non-chemical weed control method, such as mechanical cultivation. The second strategy is the application of lower dosages of the herbicide. Our case study is for a situation where continuous cropping is the most profitable land use prior to development of herbicide resistance.

The cost of non-chemical control varies for different methods. In the case of mechanical cultivation there are the costs of machinery usage as well as potential costs from soil erosion and a reduction in crop yields if planting must be delayed to allow cultivation. The benefits of this strategy are that the weed population can be controlled without applying selective pressure for weeds that are resistant to selective herbicides. The strategy of reducing herbicide dosage has the benefit of lower chemical costs, less phytotoxic damage to the crop and reduced selective pressure for resistant weeds. The costs of this strategy are reduced weed control and therefore lower crop yields in the short run and greater weed seed numbers the following year. Since the choice of one strategy (i.e. cultivation or reduced herbicide rates) affects the profitability of the other, it is necessary to take an integrated approach to select the appropriate combination of the two strategies.

Model description. We model the build-up of resistance to diclofop-methyl by annual ryegrass (*Lolium rigidum*) in wheat crops in Western Australia. The model is implemented as an annual time-step simulation in a microcomputer spreadsheet. Statistical estimation methods, data sources and specific functions used are not presented here. This information is available from the authors. The model draws on that developed by Maxwell *et al.* (3) but parameters and several of the functions are specific to Australian conditions.

The model includes the following functions:

1. Density of susceptible weeds surviving herbicide application as a function of herbicide dose and pre-treatment weed density.
2. Proportional phytotoxic damage to the wheat crop as a function of herbicide dose.
3. Wheat yield loss from competition with both susceptible and resistant weeds.
4. Autonomous natural mortality of weed seeds over summer.
5. Weed mortality from non-chemical control.
6. Carry-over of weed seeds (susceptible and resistant) from one season to the next.
7. Seed production per weed as a function of intra- and inter-specific competition.

Parameter values assumed for the analysis were as follows:

Initial density of susceptible weeds:	100/square m;
Initial frequency of resistant weeds:	0.000001;
Weed-free wheat yield:	600 kg/ha;
Price of wheat:	$120/tonne;
Price of herbicide:	$55/kg a.i.;
Other costs of crop production:	$89/ha;
Cost of extra cultivation for weed control including indirect costs such as soil degradation and erosion:	$10/ha;
Gross margin of grazing sheep:	$25/ha.

Due to the variation in effectiveness and costs of non-chemical weed control we look at three different levels of effectiveness, where cultivation kills either 25%, 50% or 75% of all weeds. For convenience, mechanical cultivation will be assumed to be the non-chemical weed control method in this paper. Cultivation is a typical non-chemical weed control method which farmers in Western Australia use in conjunction with chemical weed control. For simplicity we assume that the land is cropped with wheat each year until the number of weeds resistant to herbicide is so great that livestock grazing of pasture is more profitable than further cropping. We also assume that weeds other than ryegrass are well controlled.

RESULTS AND DISCUSSION

We calculated the net present values of 12 different management scenarios representing different combinations of chemical and non-chemical weed control (Table 1). The three herbicide dosages in Table 1 correspond to 50 percent, 75 percent and 100 percent of the label recommended rate for control of ryegrass with dichlofop-methyl. These herbicide dosages are consistent with current farmer practices in Western Australia. Four different levels of effectiveness of cultivation are considered: Zero, 25 percent, 50 percent and 75 percent weed mortality. Thus the first line of results is for a strategy relying totally on herbicide for weed control. The other three lines are for strategies which include non-chemical control.

Table 1. Net present value of agricultual production (A$/ha over 30 years at 5 percent real discount rate)

Weeds killed by cultivation (%)	Herbicide dosage (kg active ingredient/ha)		
	0.188	0.281	0.375
0	496	660	686
25	540	685	666
50	703	778	726
75	1058	975	886

If no cultivation is used lowering the herbicide rate below 0.375 kg/ha reduces farm profitability (Table 1). However a cultivation which kills as few as 25 percent of the weeds makes it profitable to reduce the herbicide dose by 25 percent. If cultivation can be 75 percent effective at controlling weeds, it would be profitable to cut herbicide dosage by 50 percent. Thus the lower herbicide dosages shown in Table 1 can be considered when at least 25 percent of weeds have been killed by other means such as cultivation. A lower weed density following cultivation means that the yield loss prevented by applying herbicide is lower, so that the highest rate of herbicide is not warranted. Pannell (4) showed that the optimal herbicide dose is positively related to weed density, so a lower density prior to spraying is associated with a lower optimal herbicide dose.

Table 2. The number of years of crop before pasture becomes a more profitable land use

Weeds killed by cultivation (%)	Herbicide dosage (kg active ingredient/ha)		
	0.188	0.281	0.375
0	3	7	7
25	4	9	7
50	9	9	9
75	16	16	16

Table 2 shows the number of years of crop which can be grown before the density of weeds reaches a level at which crop is less profitable than pasture. Pasture is assumed to be $88/ha less profitable than a weed-free crop. At the lowest dosage of herbicide and zero to 25 percent effectiveness for cultivation the population of non-resistant weeds very quickly builds up to such high densities that cropping is less profitable than pasture.

Table 3 shows that if the lowest herbicide dose is used and cultivation achieves a weed kill of 50 percent or less, then at the time when cropping is abandoned, the proportion of weeds which are resistant to herbicide is still very low. At the higher herbicide dosages, susceptible weeds are contained, but eventually selection pressure precipitates the onset of resistance. If the farmer relies solely on rate cutting to delay the build-up of resistance, herbicide dosage has to be reduced so much that the population of susceptible weeds increases to the point where crop yields are decreased substantially.

Table 3. The proportion of herbicide-resistant weeds present after the cropping phase indicated in Table 2.

Weeds killed by cultivation (%)	Herbicide dosage (kg active ingredient/ha)		
	0.188	0.281	0.375
0	0.00006	0.54	0.98
25	0.0002	0.53	0.99
50	0.15	0.98	1.0
75	1.0	1.0	1.0

Effectiveness of cultivation is the main determinant of years of cropping before resistant weed density reaches a critical level. Herbicide dosage affects the net present value but does not substantially affect the time to resistance build-up. This result depends on the simple genetic assumptions implicit in our model and does need some empirical verification. Results of this study show that it is not sufficient to consider individual control strategies without examining their interaction. Furthermore the evaluation of the impact of control measures on resistant weeds should account for the population of susceptible weeds.

ACKNOWLEDGEMENTS

This project was partly funded by the Grains Research and Development Corporation and the Australian Research Council.

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