Paper presented at the
38th Annual Conference of the
Australian Agricultural Economics Society.
Wellington, New Zealand.
February 8–10 1994.

Economics of Herbicide Resistant Weeds

Carmel Schmidt[A,C], David Pannell[B,C] and Vanessa Stewart[C]

[A]*Department of Agriculture, Western Australia*
[B]*University of Western Australia*
[C]*Centre for Legumes in Mediterranean Agriculture*

Summary

Herbicide resistant ryegrass (*Lolium rigidum*) is having a dramatic impact on the continuous cropping systems of Australia, resulting in serious economic losses. Ryegrass has exhibited cross resistance, (ie it has the ability to develop resistance to one herbicide group and then to exhibit resistance to herbicides which differ chemically and which have different modes of action), and hence use of the major herbicide groups as the predominant means of weed control is being ruled out. In this paper we discuss the development of HR, its cost and implications for farm management. Increasing non chemical control delays resistance, but does not prevent complete resistance development. The introduction of pasture into the rotation to delay the development of resistance results in large income losses on all soil types. Where farmers wish to maintain a continuous cropping system, weed control strategies that included a range of control methods such as burning, cycloning and early sowing give the optimum return.

Introduction

Over the last decade substantial increases in crop yields have been made possible by the use of herbicides as the main method of weed control. While the level of herbicide use has increased, dependence on tillage and grazing for weed control have declined as farmers have chosen direct drilling and continuous cropping as the most profitable farming options. However, the repeated use of herbicides has resulted in several weed species developing resistance to the major chemical groups currently used for their control, leading to substantial losses to farmers.

In Australia, herbicide resistance (HR) is already a bigger problem than in any other country. Of the plant species that have developed herbicide resistance, that of Annual ryegrass (*lolium rigidum*) is of most significance in Australia, where the reliance on chemical weed control in continuous cropping rotations (usually wheat/lupins) has lead to rapid development of this problem.

Annual ryegrass has a wide distribution and has demonstrated a remarkable capacity for rapid development of HR. In many cases, the evolution by ryegrass of resistance to one herbicide has immediately endowed resistance to other herbicides. This development of cross resistance to different herbicide groups with different modes of action means that the options for control of ryegrass with herbicides are limited, and an integrated weed management strategy of control is needed. Thus HR seems destined to radically transform the management practices of grain growers, especially in southern Australia.

The initial response of many farmers to increasing problems of HR is to change the rate or frequency of chemical application and revert to cultivation as a means of weed control. While cultivation is the most obvious alternative, it can have long-tern detrimental effects on soil structure, and may not control the problem adequately or economically.

An alternative means of control is the introduction of pasture phases into the rotation so that resistant weeds can be controlled by spray topping (spraying with gylphosate, to which there is currently no HR, prior to seed set) or grazing. The profitability of this alternative is dependant on the prices of wheat and wool plus the rate of pasture growth and hence this option is not always suitable.

Farmers who wish to remain in a continuous cropping system must consider other methods of weed seed control. These may include burning, seed catching or cycloning, or preventing seed set by cutting the crop for hay or green manuring. Inclusion of any of these options in the system will involve a cost, and one method alone may not provide the optimal solution.

This paper examines the economic implications of adopting the above methods for control of the rapidly growing problem of HR, and considers the optimal management responses prior to and after the development of resistance.

Model

In this paper, results are presented from a number of models. Apart from the results from the MIDAS model (Kingwell and Pannell, 1987), each of the models includes the following elements.

Crop yield (Y) is represented using the following general form.

$$Y=Y_0[1-D(W)] \quad (1)$$

Where Y_0 is yield with no weeds present and D is the damage function representing the proportion of yield lost at weed density W. W includes both herbicide resistant and herbicide susceptible weeds (W_R and W_S respectively). W_S is a function of W_{S0}, pre-treatment density of susceptible weeds, K(H), the proportion of weeds killed at herbicide rate H, and N, the proportion of weeds killed by non-chemical means.

$$W_S = W_{S0}\,[1 - K(H)][1 - N] \qquad (2)$$

The kill functions K and N must be bounded by zero and one. Resistant weeds are unaffected by herbicide, so their density depends on N but not K.

$$W_R = W_{R0}\,[1 - N] \qquad (3)$$

There are links from one season to the next via seed pools in the soil. There are separate pools for susceptible and resistant weeds. Seed production of each type depends on the total weed density. In the following season, the density of weed seedlings depends on the number of seeds and the levels of natural mortality or removal of seeds.

Profit (π) is given by

$$\pi = P_y\,Y - P_h H - A - F \qquad (4)$$

where P_h is herbicide unit cost, A is herbicide application cost and F represents costs from all other inputs which are assumed to be fixed. A consists of costs of labour and machinery use which are incurred only if herbicide is applied but which are independent of the application rate, H.

Results and Discussion

If farmers change rotations to delay HR, what is their short term cost?

The implications of introducing pasture into the cropping rotation so as to delay the development of HR have been examined for the Eastern wheat belt of W.A. The use of a bioeconomic model MIDAS (Kingwell and Pannell 1987) identified the most profitable crop rotation on soil type S2 (Sandplain) as cereal, lupin (CL), while on soil types S3 (Gravely duplex) and S4 (Duplex) it was CCL . Any alteration from this rotation to include pasture will therefore come at a cost (Table 1).

These losses are based on average returns per hectare over the length of the rotation, and do not directly allow for the impact of the rotation on herbicide resistance.

Table 1. The cost of including pasture in the rotation (\$/ha)
(Wheat price \$170/t wool 350c/kg)

		Soil type	
Rotations	S2	S3	S4
PPPCLCL	18	11	18
PPCLC	17	8	14
PLC	18	16	24

The above results indicate that the introduction of a pasture phase into continuous cropping rotations can be very costly because of poor pasture growth and the need for broad leaf weed control in the cereal phase of the rotation. The profitability is also very dependant on soil type and product price. Given the low profit margins in the eastern wheatbelt region these decreases in profit are substantial, and therefore pasture is only likely to be a viable strategy for delaying resistance on soil types which show similar profits for pasture and crops.

Low pasture density after cropping is a primary contributor to the relatively low profitability of pasture–cereal–lupin rotations. There are various means by which pasture production may be improved, including plant breeding, grazing management and re–seeding. However, even if pasture production in the above table could be increased by 20% substantial losses still occur (Table 2). Only on soil type S3 was a break even situation approached. If the long pasture rotations on S3 allow good resistant weed control then the cost of HR looks low, but on S2 and S4 the cost is still high, the results differing because of different soil types. For similar reasons, the impact of including pasture in the rotation will vary between regions.

Table 2. The cost of including pasture in the rotation ($/ha) if pasture yield increased by 20% in all months

	Soil type		
Rotations	S2	S3	S4
PPPCLCL	16	5	17
PPCLC	16	3	12
PLC	17	15	23

If farmers maintain continuous crop rotations, how long will it be before profitability collapses?

Because of the losses involved in introducing pasture into the rotation to delay HR, farmers are likely to avoid taking this step until continuous cropping is less profitable than a system that includes pasture. The advantage of pasture in a HR system is that it allows the use of animals and spray topping for weed control. Table 3. shows results from a simulation model giving 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 (Abadi et al. 1993).

Table 3. The number of years of crop before pasture becomes a more profitable land use in the eastern wheatbelt of Western Australia.

% Weeds killed by non chemical control	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

The effectiveness of non chemical control is the main determinant of years of cropping before resistant weed density reaches a critical level. At the lowest herbicide dosage and zero to 25% effectiveness of non chemical control the population of non-resistant weeds very quickly builds up to such high densities that cropping is less profitable than pasture.

How does non-chemical control affect the optimal herbicide dose?

For each result in Table 3, the simulation model calculates densities of susceptible and resistant weeds, crop yields and profits over time. Table 4 shows net present values for each combination of chemical and non-chemical control.

Table 4. Net present value of agricultural production (A$/ha over 30 years at 5% real discount rate) in the eastern wheatbelt of Western Australia.

% Weeds killed by non chemical control	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

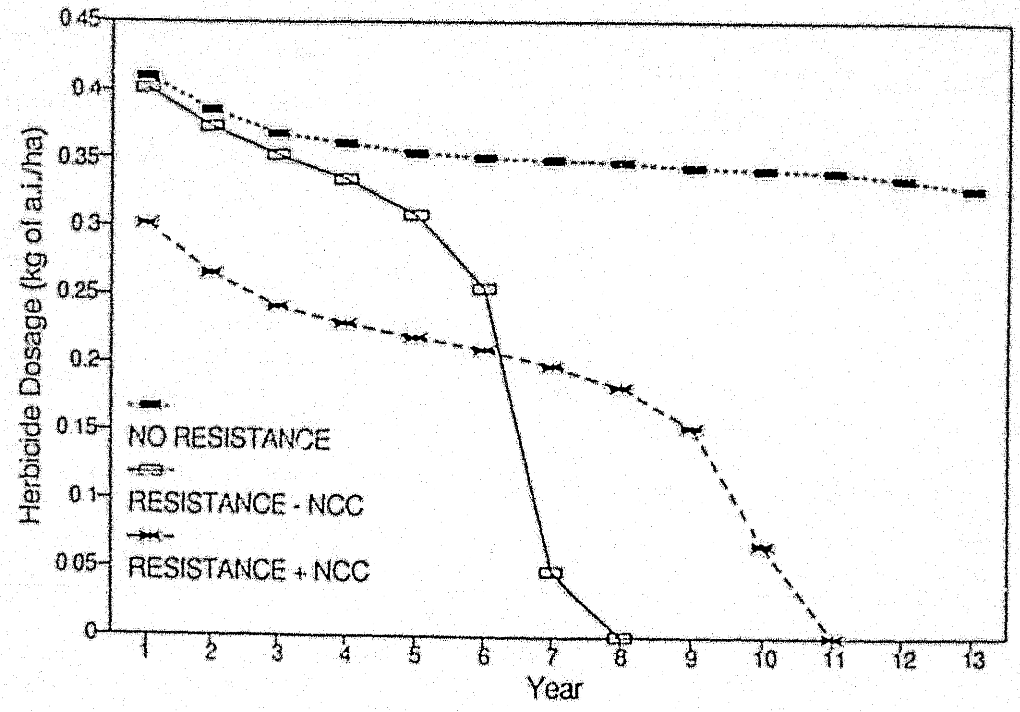
Non chemical control which kills as few as 25% of the weeds makes it profitable to reduce the herbicide dose by 25%, while if non chemical control can be 75% effective at controlling weeds, it would be profitable to cut herbicide dosage by 50%. A lower weed density following non chemical control means that the yield loss prevented by applying herbicide is lower so that the highest rate of herbicide is not warranted (Pannell 1990). The reduction in herbicide rate is not the main cause of the delay in the development of HR. It is the increased non chemical control which has the delaying effect. While these results indicate that in the short term continuous cropping using a combination of chemicals and non chemical control is profitable, returns to the farmer gradually decline.

What is the optimal time path of herbicide usage?

Gorddard et al. (unpublished) used a dynamic optimisation model to determine optimal chemical dosage and levels of non-chemical weed control. They identify an economic balance between current control of herbicide resistant weeds and future development of resistance.

Figure 1 shows the time path of herbicide use under scenarios with and without resistance and with and without the use of other non chemical control options. (Non chemical control in this example assumes a 50% weed kill).

Figure 1. Optimal herbicide dosages over time for resistant and non resistant weed control, with and without non chemical control.



Where herbicide resistance is present the dosage falls away rapidly in the last years of cropping as the level of resistance increases. There are several reasons for the fall in dosage·

1) Weeds in a field crop are not all at the same stage of growth when spraying occurs, so herbicide dose can determine the rate of weed survival. More mature weeds require a higher dose than smaller weeds, so the larger the dose of herbicide applied the greater the number of weeds killed. However, once the crop is infested with resistant weeds the yield of the crop declines and it no longer pays to apply higher herbicide doses as any resulting yield increase will not cover this increased cost.

2) lower dose levels mean the survival of susceptible plants which can then compete with resistant plants, thus delaying resistance development, but this is likely to be small.

3) lower doses result in reduced phytotoxic damage to the crop

These results indicate that even with non–chemical weed control methods such as cultivation, if herbicides are used, herbicide resistance will eventually develop.

If weeds become totally resistant, can a continuous cropping rotation be maintained?

Given that cultivation and pastures provide only a partial solution to this problem, other methods of weed control must be considered. We have used a multi–period simulation model to consider the impact of a combination of a variety of weed control methods on wheat and lupin yields in a wheat, wheat, lupin rotation in the central wheat belt of Western Australia (Stewart, 1993).

Weed control methods in the model are:

delayed sowing,
early tickle (ie early shallow cultivation),
cutting for hay, green manuring,
total burning,
seed catching with the seed being either burnt or removed, and
cycloning with the windrow only being burnt, or with a total burn

The weed control efficacy of each of the control methods was determined from weed densities data collected from field trials. A number of strategies involving combination of the control measures were defined.

Of the 22 control strategies investigated, a strategy that integrated six different non-chemical weed control techniques provided the highest NPV of A$712 /ha over 20 years (Table 5).

Table 5. Net Present values of the 5 best strategies and of 2 non optimal strategies for weed control in a continuous cropping system in the central wheat belt of Western Australia.

Place	Strategy No.	Strategy	NPV ($/ha)
1	13	Hay year zero, then 1 year in 4, Total burn when lupins and W1 cut for hay W1 delayed sowing, early tickle, seed catching, total burn W2 delayed sowing, seed catching, windrow burnt Lupins cyclone with total burn, early tickle.	712
2	18	As strategy 13 but hay every 5th year	703
3	12	As strategy 13, but early tickle in W2	679
4	17	Hay every 5th year Total burn of W1 and Lupin stubbles W1 and W2 seed catching, windrow burnt, delayed sowing and tickle Lupins, cyclone, total burn	672
5	8	W1 seed catching, total burn, delayed sowing and early tickle W2 seed catching, windrow burnt only, delayed sowing, early tickle Lupins cyclone with a total burn, early tickle	656
	22	Green manure year 2 and 16, Hay every 4th year from year 2 W1 seed catching, total burn, early tickle W2 seed catching, windrow burnt only, delayed sowing Lupins cyclone, total burn	441
	5	Lupins, cyclone, seed collection, Wheat total burn all years	279

W1 = first wheat crop grown in rotation after a lupin crop
W2 = second wheat crop grown in rotation after a lupin crop

While strategy 13 gave the greatest net profit over 20 years, both weed survival and annual net return were highly variable. For this reason strategy 8 with a slightly lower NPV/ha but less variable annual return may be preferred by risk averse farmers.

Strategies 5 and 22 (Table 5), are examples of weed control methods with low returns. Strategy 22 involves a large income loss in years where green manuring practices are implemented, while strategy 5 illustrates the losses incurred when only a few control techniques for weed control are utilised. This is also evident in the fact that "early tickle" or "delayed sowing" options, (both using cultivation for weed control), which are most commonly identified as the solutions to the problem of HR, did not, on their own, rank in the five best strategies as determined by this model. Thus, these results highlight the fact that the reliance on a single control agent for weed management is not appropriate.

Improving the efficiency of any of the control methods may result in a different optimal solution. Over the 20 years, strategies which had lower average weed survival had lower cumulative weed densities and consequently higher cumulative returns.

Because rainfall and grain yields are generally higher in the central than in the eastern wheat belt, a direct comparison of the costs of including pasture in the rotation with the cost of continuous cropping using the above weed control strategies is not possible in this paper.

Conclusion

Continuous cropping systems are under threat because of the increasing problem of HR. Serious economic losses are faced by farmers as the problem increases, and alternative weed control methods must be considered.

The inclusion of a pasture phase in the rotation to delay the development of HR allows for a period of non chemical control, however the economic losses associated with this method can be high, and are dependant on soil type and commodity prices.

Farmers who wish to remain in a continuous cropping system must therefore adopt strategies for weed control that include a wide range of weed control methods, no one method alone provides the optimum solution. Regardless of the method adopted, there will be a reduction in income to cover the cost of the strategy adopted. However the corresponding reduction in the reliance on chemicals may help to enhance our "clean" farming image.

The development of a MIDAS model which allows the optimisation of all HR control methods mentioned in this paper forms part of the continuing work on this problem in Western Australia.

References

Abadi AK, Pannell DJ and Gorddard RJ (1993). Economic integration of chemical and non-chemical weed control under herbicide resistance in continuous cropping. *Proceedings 10th Australian and 14th Asian-Pacific weed conference. Brisbane, Australia. p480-484.*

Gorddard RJ, Hertzler GL and Pannell DJ (unpublished). An optimal control model for integrated weed management.

Kingwell RS and Pannell DJ (1987). MIDAS, a bioeconomic model of a dryland farm system. Wageningen: Pudoc.

Maxwell BD, Roush ML and Radosevich SR (1990). Predicting the evolution and dynamics of herbicide resistance in weed populations. *Weed Technology* 4, 2-13.

Pannell DJ (1990) An Economic response model of herbicide application for weed control in crops. *Australian Journal of Agricultural Economics*. 34, 223-241.

Stewart VA (1993) Economics of integrated strategies for managing herbicide resistant ryegrass under continuous cropping. BSc (Agric) thesis. University of Western Australia. 69pp.