

The economic value of pasture phases in the integrated management of annual ryegrass and wild radish in a Western Australian farming system

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Abstract. Most cropping farms in Western Australia must deal with the management of herbicide-resistant populations of weeds such as annual ryegrass (*Lolium rigidum* Gaudin) and wild radish (*Raphanus raphanistrum* L.). Farmers are approaching the problem of herbicide resistance by adopting integrated weed management systems, which allow weed control with a range of different techniques. One important question in the design of such systems is whether and when the benefits of including pasture in rotation with crops exceed the costs. In this paper, the multi-species resistance and integrated management model was used to investigate the value of including pasture phases in the crop rotation. The most promising of the systems examined appears to be so-called 'phase farming', involving occasional 3-year phases of pasture rather than shorter, more frequent and regular pasture phases. This approach was competitive with the best continuous cropping rotation in a number of scenarios, particularly where herbicide resistance was at high levels.

Additional keywords: herbicide resistance, weed control.

Introduction

Herbicide resistance in weeds has become a major problem in dryland cropping in Western Australia as a consequence of the widespread use of herbicides. Contributing factors include the adoption of minimum and no-tillage systems, and reduced areas of pasture in favour of intensive cropping rotations. Within this system there is little diversity, especially in weed control practices. Persistent herbicide use without the diversity of weed control provided by cultivation and grazing has resulted in high selection pressure for herbicide resistance, particularly in the 2 principal crop weeds: annual ryegrass and wild radish (Llewellyn and Powles 2001; Walsh *et al.* 2001). For several reasons, including resistance, these 2 species are the most widespread and economically damaging weeds in the Western Australian cropping region.

Farmers can manage herbicide-resistant weed populations by adopting more diverse integrated weed management (IWM) systems, which allow weed control with a range of non-herbicide techniques along with changed herbicide usage (Powles *et al.* 1997). Non-herbicide methods include the use of pasture, which can help in effective weed control by allowing a combination of grazing, and other methods such as application of non-selective herbicides and cutting for hay or silage before infesting weeds can produce seed.

This study used a recently created bio-economic simulation model Multi-species Resistance and Integrated Management (RIM) to investigate both the value of including pasture in a rotation for managing herbicide resistance and the value of using alternative pasture management tactics within a cropping-based system involving the integrated management of ryegrass and wild radish (Monjardino *et al.* 2003).

Materials and methods

The multi-species RIM model

Multi-species RIM is a bio-economic model that simulates the population dynamics of annual ryegrass and wild radish over a 20-year period. It is a decision support tool designed specifically for the evaluation of various management strategies to control herbicide-resistant weeds in dryland agriculture. The model includes a detailed representation of the biology of weeds, crops and pasture as well as the financial costs and returns of agricultural production and management. The user specifies the cropping and pasture and management sequences for the 20-year period and the model calculates the consequences with respect to crop yields, weed populations, resistance status and profitability (Monjardino *et al.* 2003).

Weed biology. In the multi-species RIM model, both weed seed production and expected crop yield after competition with the other species are calculated through the following equation:

$$Y = \frac{m \times P_1}{a + P_1 + (k_{2,1} \times P_2) + (k_{3,1} \times P_3)} \quad (1)$$

applied in-crop. Yield benefits provided by rotation with legume crops or pasture (due to nitrogen fixation) are also accounted for (Monjardino *et al.* 2003; Pannell *et al.* 2004). Levels of production from crops and pastures are typical of a dryland environment (Mediterranean-type climate) receiving 325–450 mm annual average rainfall.

Weed control. In the multi-species RIM model there are 50 herbicide and non-herbicide control options available (for more details on each method, see Monjardino *et al.* 2003):

(i) 27 crop-selective herbicide options for grass and broadleaved weeds (herbicides of high and moderate selection pressure);

(ii) 6 non-selective herbicides (herbicides of low resistance risk);

(iii) 17 non-herbicide methods, including cultivation, delayed sowing, seed catching and stubble burning. Grazing during a pasture phase is another important non-herbicide option. Heavily weed-infested crops or pasture can be cut for hay or silage or used for green manuring.

The effect of each control strategy on weed mortality and seed set is specified for each enterprise (Monjardino *et al.* 2003). Gill and Holmes (1997), Gorddard *et al.* (1996), Matthews (1996), Powles *et al.* (1997) and Schmidt and Pannell (1996) suggest that no single method available provides the optimal weed management strategy. Instead, a combination of a range of weed control methods can achieve very effective and sustainable weed control. Because control methods are conducted at different times, their combined impacts are considered to be multiplicative rather than additive (Pannell *et al.* 2004). However, where 2 herbicides are applied in a tank mix at the same time, there may be additive impacts (Kudsk 1989).

The multi-species RIM model allows the user to specify the initial herbicide resistance status of ryegrass and wild radish with respect to each of 9 herbicide groups (modes of action).

Economic values. The model calculates costs, revenues, profit and net present value. It also includes complexities such as tax and long-term trends on prices and yields. Costs associated with cropping, pasture and various weed control options have been specified in detail. They account for costs of input purchasing; costs of machinery operating, maintenance and repayment; costs of contracting of labour for hay and silage making; and costs of crop insurance. There are also costs of crop yield penalty due to practices such as green manuring and delayed sowing, or due to contamination of the grain with wild radish seeds. Resource degradation costs associated with some non-herbicide methods such as cultivation and burning are also represented in the model. Economic returns from crops are based on sale prices for grain and hay. Net returns from sheep are specified as a long-term trend of gross margin per dry sheep equivalent (\$11/DSE), combining returns from wool and meat.

Because the model is run over 20 years (t), annual net profit (ANP) must be discounted to make them comparable at the start of the modelled period. A real discount rate (r) of 5% per year is used for this purpose. The sum of discounted net profits or net present value (NPV) is the main economic criterion used to compare weed management strategies (equation 2). In results presented later it is expressed in an annualised form on a per hectare basis (annuity).

$$NPV = \sum_{t=1}^T \frac{ANP}{(1+r)^t} \quad (2)$$

Weed management scenarios

Enterprise sequences. The value of including pasture in the rotation as well as the value of alternative pasture management tactics were investigated for the following examples of enterprise sequences.

(a) A pasture–pasture–wheat–wheat rotation (PPWW), with self-regenerating subterranean clover pasture.

(b) A barley–pasture–wheat–wheat rotation (BPWW), with volunteer pasture.

(c) A barley–pasture–pasture–wheat–wheat rotation (BPPWW), with self-regenerating subterranean clover pasture.

(d) A barley–pasture–pasture–pasture–wheat–wheat rotation (BPPPWW), with self-regenerating subterranean clover pasture.

(e) A barley–lupin–wheat–wheat rotation (BLWW), the non-pasture control scenario.

(f) A barley–lupin–wheat–wheat rotation with a single 3-year French serradella pasture phase in years 9–11 (BLWW + PPP).

(g) A lupin–wheat rotation with a single 3-year French serradella pasture phase in years 9–11 (LW + PPP).

(h) A lupin–wheat–wheat rotation with a single 3-year French serradella pasture phase in years 9–11 (LWW + PPP).

Thus the sequences examined included pasture proportions in the rotation varying from 25 to 50% (a , b , c and d), or occasional 3-year pasture phases in long-term crop rotations (f , g and h). The chosen sequences are considered practical, relevant and a good representation of all pasture types modelled (different crop–pasture rotations were selected to investigate other issues related to herbicide resistance, Monjardino 2002).

The model was set at 400 ryegrass and 100 wild radish seeds/m² at the start of the simulation for all weed management scenarios. These densities are considered average in the field. The impact of different initial weed seed densities is investigated later in the paper.

Herbicide use. All crop and pasture rotations were investigated for a scenario of herbicide use where a maximum of 2 herbicide applications of groups A and B (each) were available before complete herbicide resistance evolved in both ryegrass (groups A and B) and wild radish (group B). It was assumed that there were up to 10 applications available of each moderate-risk herbicide group (C, D, F and G) and up to 15 applications available of each low-risk herbicide group (I, L and M). These assumptions about herbicide resistance status assume a past history of herbicide use in the field. Resistance status is varied later in the paper.

Non-herbicide methods. Complementing the strategies of pasture and herbicide application, many combinations of other control methods were investigated in order to find the best management systems. The range of IWM methods employed across the 8 rotational strategies is listed in Table 4.

These strategies were identified in a simulation process of ‘trial and error’ and were selected on the basis of the optimal 20-year profit. For the purpose of this study, the term ‘optimal’ is used to refer to the strategy that produces the highest long-term profit (annuity) from within the dataset.

Results and discussion

In the rotational sequences investigated, most applications of groups A and B were used except in PPWW, where no use of group A was economical (Table 4). The use of simazine (group C) was greatest in rotations with a higher proportion of pasture and lupins. No more than 5 uses of Group F, 4 uses of group D (trifluralin) and zero uses of group G were selected in the economically preferred management systems identified. In regard to the non-herbicide methods, the weed management strategy remained relatively constant across all rotations. However, a decrease in the practice of delayed seeding was obvious when more lupins were grown, due to the advantages of early sowing of this crop.

The average annual returns over 20 years (annuities) and the final weed plant densities across all systems considered in this study are shown in Table 5. The best rotation in financial terms was the continuous cropping sequence, BLWW (\$117/ha.year), closely followed by the same

Table 4. Economically optimal combinations of weed management options, by rotation (number of applications)

IWM methods	PPWW	BPWW	BPPWW	BPPPW	BLWW	BLWW + PPP	LW + PPP	LWW + PPP
Glyphosate-knockdown (M)	9	10	10	7	12	4	2	3
Group A herbicides	0	2	2	1	2	2	2	2
Group B herbicides	2	2	2	2	2	2	2	2
Group C herbicides	8	2	6	10	8	10	9	10
Group D herbicides	1	2	0	1	1	2	4	3
Group F herbicides	0	2	2	1	2	0	5	5
Group I herbicides	13	13	11	11	15	13	10	13
High crop seeding rate	10	15	11	10	19	15	15	15
Tickle + 20-day delay seeding	6	9	9	6	4	3	2	3
Sustainable grazing	5	0	4	3	0	1	1	1
High-intensity grazing	5	5	4	6	0	2	2	2
Pasture spray-topping (L/M)	10	5	8	9	0	3	3	3
Lupins crop-topping (L)	0	0	0	0	5	4	7	3
Swathing	0	5	4	4	4	3	0	0
Seed catching + burning	8	10	4	0	11	9	8	12
Windrowing + burning	0	2	0	2	8	6	8	4
Residues burning	3	5	2	3	0	1	1	1

BLWW rotation and by the LWW rotation, both with a 3-year pasture phase once during the 20-year simulation (\$113 and \$111/ha.year, respectively). Overall, the shorter, more regular cereal–pasture rotations proved less profitable (\$73–84/ha.year) than the combined cropping sequence and the phase farming systems. Final weed numbers were low in all scenarios.

Weed densities

Even though all pasture rotations had similarly low finishing weed numbers (Table 5), weed population patterns varied over the 20-year period. Wild radish density was kept very low across most years and rotations, but the density of ryegrass had peaks as high as 10 and 12 plants/m² under PPWW (Figs 1 and 2). This is because it was not economical to use any group A herbicide in that particular scenario. Years of higher ryegrass density (years 8 and 16) corresponded to a second consecutive wheat year. Those ryegrass peaks were then brought under control by effective control tools employed in the following pasture phases. Inclusion of

pasture phases as long as 3 years led to excellent ryegrass control over the whole period. This was due to more frequent and intense grazing and a sequence of 10 simazine (group C) applications in those rotations (75% kill).

Net value of pasture

Initial weed seed densities. Because existing weed densities vary widely between farms and are hard to predict, the value of pasture in the rotation was evaluated across a range of weed infestation levels. For that reason, the value of each pasture sequence was subjected to a sensitivity analysis exploring variations in the initial seed density of annual ryegrass (0, 100, 400 and 1600 seeds/m²) and wild radish (0, 25, 100 and 400 seeds/m²). The net value of including a range of pasture phases in the rotation was calculated as the difference between the 20-year annuity of that rotation and the annuity of the most profitable continuous cropping sequence or control scenario (BLWW).

Table 5. Annuities and final weed densities across all rotations

Rotations	Annuity (\$/ha.year)	Ryegrass density in year 20 (plants/m ²)	Radish density in year 20 (plants/m ²)
PPWW	84	3	<1
BPWW	76	4	<1
BPPWW	73	2	1
BPPPW	76	3	<1
BLWW (control)	117	4	<1
BLWW + PPP	113	1	1
LW + PPP	105	2	1
LWW + PPP	111	3	1

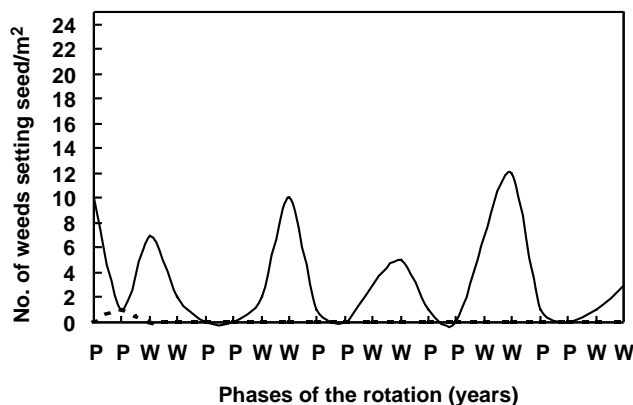


Figure 1. Weed densities (— annual ryegrass; --- wild radish) over 20 years for a pasture–pasture–wheat–wheat rotation.

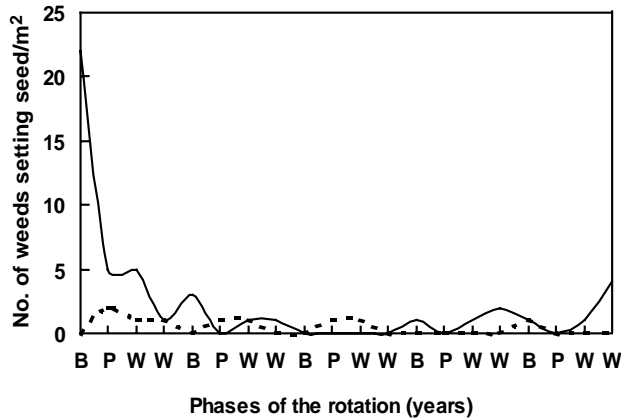


Figure 2. Weed densities (— annual ryegrass; --- wild radish) over 20 years for a barley–pasture–wheat–wheat rotation.

Given the assumptions about herbicide resistance status and market conditions underlying these results, the net value of including pasture in the rotation was mostly negative, ranging from $-\$45$ to $\$3$ /ha.year (Table 6). Volunteer pasture was a relatively unattractive option, with a negative value of up to $-\$42$ /ha.year despite being grazed at high intensity.

The sequences with one 3-year French serradella pasture phase were by far the most profitable pasture options because it provides significant weed-control benefits without foregoing crop revenues in many years (net values range from $-\$14$ to $\$3$ /ha.year). PPWW was the best subterranean clover pasture rotation analysed ($-\$34$ to $-\$28$ /ha.year), followed by BPPPWW ($-\$45$ to $-\$36$ /ha.year) and then by BPPWW ($-\$45$ to $-\$41$ /ha.year).

In most cases, the pasture phase becomes marginally more valuable as the weed burden increases. For example,

under the scenario of 1600 ryegrass and 400 radish, the value of these pasture phases was $\$1$ to $\$4$ /ha.year greater than for the 1600 ryegrass and 0 radish scenario. Similarly, the value was $\$1$ to $\$3$ /ha.year greater than under the 0 ryegrass and 400 radish scenario.

Herbicide resistance status. In order to determine how the degree of herbicide resistance to all herbicide groups affects the value of pasture, several scenarios of herbicide applications left before full resistance (an indication of the resistance status) were investigated for the BLWW rotation with one 3-year French serradella pasture phase.

In comparison with the default scenario of herbicide use (I), the value of pasture initially decreased (by $\$8$ /ha.year in scenario II) and then increased considerably (by $\$22$ /ha.year in scenarios III and IV) as herbicide use was reduced (Table 7). The initial reduction in pasture value is likely to be a direct consequence of less group C herbicides being available, for many of the original 10 simazine applications were used in the pasture phase. However, a further decrease in herbicide use identifies pasture as a crucial weed control tool due to other methods specifically employed in this phase (e.g. grazing, spray-topping, burning). The lower values obtained for pasture in the last 2 scenarios (V and VI) result from a general low level of returns for both rotations, as weed control becomes very difficult to achieve with hardly any herbicides available. These results show that a pasture phase can make a significant contribution to long-run profitability in situations of low herbicide availability due to herbicide resistance. Furthermore, the inclusion of a pasture phase in the rotation along with more diverse management practices may potentially delay the onset of herbicide resistance.

Pasture phase length and frequency. A small sensitivity analysis was conducted to determine how the length and

Table 6. Net value ($\$/ha.year$) of different pasture phases across a range of initial weed seed densities

Ryegrass initial seed density ^A (seeds/m ²)	Radish initial seed density ^A (seeds/m ²)	PPWW	BPWW	BPPWW	BPPPWW	BLWW + PPP	LW + PPP	LWW+ PPP
0	25	-33	-41	-44	-44	-3	-13	1
0	100	-33	-41	-44	-43	-4	-13	1
0	400	-30	-38	-42	-39	-5	-10	3
100	0	-34	-41	-44	-44	-3	-13	-2
100	25	-34	-41	-45	-44	-4	-13	-2
100	100	-33	-41	-45	-43	-4	-13	-2
100	400	-30	-38	-43	-39	-5	-10	0
400	0	-34	-41	-44	-43	-3	-13	-6
400	25	-34	-41	-45	-43	-4	-13	-7
400	100	-33	-41	-44	-42	-4	-12	-6
400	400	-30	-38	-42	-38	-5	-10	-4
1600	0	-31	-39	-43	-41	-2	-10	-10
1600	25	-31	-39	-43	-41	-3	-11	-10
1600	100	-31	-39	-43	-40	-3	-10	-10
1600	400	-28	-36	-41	-36	-4	-7	-6

^A These numbers apply at the start of year 1. Later seed densities depend on the simulated seed dynamics.

Table 7. Effect of herbicide use on the net value of pasture (\$/ha.year) for rotation BLWW with a 3-year French serradella pasture phase

Each column (I–VI) corresponds to a scenario involving a defined number of applications left before full resistance of each herbicide group (rows A to M)

Herbicide groups	Herbicide resistance scenarios (no. of applications remaining before full resistance)					
	I	II	III	IV	V	VI
A	2	2	0	0	0	0
B	2	2	0	0	0	0
C	10	4	4	2	0	0
D	10	4	4	2	0	0
F	10	4	4	2	0	0
I	15	15	5	5	5	0
L	15	15	5	5	5	0
M	15	15	5	5	5	0
Net value of pasture (\$/ha.year)	–4	–12	18	18	15	14

frequency of pasture in the rotation would affect the value of pasture. The BLWW rotation was investigated by including 1 and 2 French serradella pasture phases, each varying from 1 to 5 years. This analysis was conducted for a scenario of low herbicide use (scenario IV of Table 7).

The value of pasture steadily increases as more pasture years are included in the rotation (Table 8). This increase is more accentuated for 2 pasture phases (\$43/ha.year) than for the scenario with 1 pasture phase (\$15/ha.year). These results confirm that including pasture phases in the rotation may be a profitable long-term management decision where herbicide resistance is a major problem.

Break-even values. An indication of the potential for pasture to become a profitable inclusion in the land-use sequence is the increase in pasture profitability needed for the value of the pasture rotations to equal the value of the cropping rotation (BLWW, \$117/ha.year). Such increases might occur either by increasing the number of sheep (dry sheep equivalent, DSE) carried per hectare (currently 1–6 DSE/ha, depending on the type and year of the pasture phase and the grazing intensity) or by increasing the gross margin per head (currently \$11/DSE). The increases required to match the net returns of the continuous cropping sequence (with default parameters) are shown in Table 9.

Increasing the stocking rates results in an increase in grazing pressure. Here, it was assumed that the higher

stocking rates of Table 9 each result in 100% control of ryegrass and radish, regardless of the pasture type. Another assumption was that a higher livestock density leads to a drop in sheep gross margin of about \$2/DSE (from \$11/DSE to \$9/DSE), due to loss of animal condition.

Overall, stocking rates would have to increase by between 3.5 and 13.3 DSE/ha in order for each pasture rotation to reach a profitability of \$117/ha.year. The required increases in gross margin per DSE appear quite feasible in at least 2 of the cases examined, BLWW and LWW with PPP. Indeed, at the time of writing, these increases have been more than achieved due to an improvement in market conditions. The increases required for the other options appear unlikely to occur. These other rotations would require a combination of favourable circumstances for pasture to be competitive with the best continuous cropping rotation.

Although many of the results do not favour pasture, it should also be noted that most farmers do maintain some pasture on land capable of being used for cropping. There are a number of factors that contribute to this:

(i) limits on capacity of farm resources (machinery, finance, labour) to handle 100% cropping;

Table 9. Break-even values of sheep gross margin for each pasture rotation

Pasture rotation	Increase in stocking rate ^A (DSE/ha)	Increase in sheep gross margin (\$/DSE)
PPWW	7	15.5
BPWW	13.3	98
BPPWW	12	27
BPPPWW	9.5	17
BLWW + PPP	4	5
LW + PPP	7	14
LWW + PPP	3.5	7

^AOn top of existing values across pasture types and years.

Table 8. Effect of phase length and frequency on the net value of pasture (\$/ha.year) relative to BLWW

Phase length (number of years)	Phase frequency	
	1	2
1	6	–2
2	10	3
3	18	15
4	19	33
5	21	41

- (ii) complementarity between pastures and crop residues as joint sources of animal feed at different times of the year;
- (iii) diversification of income to reduce risks;
- (iv) different relative yields in different regions and on different soil types (we have only examined 1 soil type in 1 region);
- (v) reductions in soil degradation in years of pasture (e.g. increased organic matter).

By focusing on management at the single-field level, the RIM model does not capture these factors. The results for pasture phases must therefore be interpreted with caution when extrapolating to whole-farm management. In cases where farmers do wish to grow pasture, the results of this analysis suggest that an occasional pasture phase of 3 years may be more profitable in the long run than a regular rotation involving more frequent pasture phases.

Conclusion

The multi-species RIM model was used to evaluate the value of including pasture in the rotation. For this farming system, the most promising of the strategies examined appears to be so-called 'phase farming', involving occasional 3-year phases of pasture rather than shorter, more frequent and regular pasture phases. This approach was competitive with the best continuous cropping rotation in a number of scenarios, particularly where herbicide resistance was at high levels.

Break-even analyses showed that for short rotations, the increase in livestock returns or stocking rates required to make pasture phases economically attractive were substantial. On the other hand, 3-year phases of pasture performed relatively well financially, and in situations of high herbicide resistance they performed particularly well.

It is important to appreciate that the model used, while detailed in many respects, excludes some issues that would tend to favour inclusion of some pasture. For example, RIM is limited to a paddock or field scale but there are some relevant issues that only come into play at the whole farm level (e.g. related to management of livestock feed and crop machinery). For farmers giving weight to these issues, the RIM model still provides useful information about the ranking of alternative pasture strategies.

Acknowledgments

The authors acknowledge the contributions of M. Ewing and C. Revell in reviewing this paper. The Western Australian Herbicide Resistance Initiative is funded by the Grains Research and Development Corporation. The Cooperative Research Center for Australian Weed Management provided partial financial support for M. Monjardino.

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Received 19 February 2003, accepted 27 July 2003