Section 1: Economic benefits of IWM

Adoption of integrated weed management (IWM) is economically beneficial in many Australian cropping systems. Not only is IWM essential for the management of herbicide resistance, but it also plays an important role in minimising the size of weed seedbanks over time and has clear benefits for managing the risk of weed control failure due to adverse seasonal conditions. Using a range of tactics in an IWM plan is essential for the effective, long-term management of weeds.

The economic benefits of adopting integrated weed management

IWM has short-term costs and short- and long-term benefits, including positive impacts on weed numbers and crop production. The challenge is to realise and estimate the long-term benefits, both physical and fiscal, rather than focus on the short-term financial pressures.

Returns of an individual enterprise in the short-term are usually measured through a gross margin budget, which is determined by subtracting factors such as the cost of weed control (both herbicide and non-herbicide) and other inputs (eg seed and fertiliser) from gross income (calculated as crop yield multiplied by grain price). Crop yield is directly influenced by weed density, which itself is a function of weed control.

For short-term decision making the goal of the grower managing a weed problem is to determine the optimal level of herbicide and non-herbicide inputs for a given weed density that will maximise the crop gross margin.

Key finding #1

Weed seed carryover in the soil seedbank has a huge impact on returns in future years.

In the long-term, determining the optimal level of herbicide and non-herbicide inputs for a given weed density that will maximise the crop gross margin ignores a critically important economic factor. This approach to measuring returns from weed management does not consider the impact of weed seed carryover in the soil seedbank.

Each weed control decision not only has an impact on returns for the current crop, but affects yields and the cost of weed management in later years (for good or bad) due to its impact on the weed seedbank.

Key finding #2

Calculating returns over the long term (eg 10 years) is the best approach for determining the value of the economic benefits of IWM.

Net present value (NPV) is one measure of calculating returns over the long-term. In this instance future gross margins are summed and discounted back to a present day value. The discounted average annual return, obtained by dividing the NPV by the time period, can also be used.

The term ‘discounting’ means converting future gross margins to a present day dollar value so as to account for factors such as inflation and the opportunity cost of capital.

This approach is able to account for important economic factors such as changes to the weed seedbank from one year to the next due to weed management actions and herbicide resistance. The benefits of all potential agronomy targeting weed control (eg a change in crop sequence) and IWM tactics (eg green manuring where there is a loss of income in the year of activity) can be included.

Estimating the economic benefits and costs of IWM

Guidelines illustrating the economics of individual IWM practices can be provided based on a realistic IWM scenario, although the true economics will vary significantly between and within regions, farms and seasons. A summary of the elements of the economic costs and benefits affecting the net value of the IWM tactics identified in this manual is presented in Table E1.

The net value of each individual tactic is the difference in the 20-year equivalent annual profit for the base IWM strategy calculated by including and excluding that particular tactic. A series of RIM (resistance and integrated weed management) model simulations led to the identification of the base IWM strategy, which was the most profitable combination of tactics over a 20-year period. For further information on the RIM model concept see Pannell et al (2004) and *Simulation model 3: RIM model* in this section.

Table E1 Elements of the economic costs and benefits for some individual tactics presented in Section 4

Tactic group	Tactic	Average annual application cost/ha ($)[a]	Elements of economic cost	Elements of economic benefit[b]	Net value ($/ha/year)[c]
1. Deplete weed seed in the target area soil seedbank	1.1 Burning residues	5.00	Fire risk, soil degradation	20–98% weed control, increased soil fertility	–1
	1.2 Encouraging insect predation of seed	#	Stubble management, reduced tillage practices	20–80% weed control	1
	1.3 Inversion ploughing	40.00	Mechanical operation, soil degradation	95% weed control, increased soil fertility and crop yield	9
	1.4 Autumn tickle	4.00	Mechanical operation	50% weed control	–1
	1.5 Delayed sowing (seeding)	0.01	Mechanical operation, 5–30% crop yield penalty for each week of delay	5% weed control	7
2. Kill weed(s) (seedlings) in the target area	2.1 Fallow and pre-sowing cultivation	3.15	Mechanical operation, soil degradation	80% weed control	–3
	2.2a Knockdown (non-selective) herbicides for fallow and pre-sowing control	7.50–14.50	Herbicide use, mechanical operation, low resistance risk	97% weed control, easy application	26
	2.2b Double knockdown or ’double knock’	22.00	Herbicide use, mechanical operation, low resistance risk	100% weed control, prevention/delay of resistance	–4
	2.2c Pre-emergent herbicides	12.50–25.50	Herbicide use, mechanical operation, medium/high resistance risk, phytotoxicity	75–90% weed control	71
	2.2d Selective post-emergent herbicides	6.00–27.00	Herbicide use, mechanical operation, high resistance risk, phytotoxicity	>98% weed control, early yield boost	40
	2.3 Weed control in wide-row cropping	#	Herbicide use, mechanical operation, low resistance risk	90% weed control, small yield loss	0
	2.4 Spot spraying, chipping, hand roguing and wiper technologies	#	Herbicide use, mechanical operation, low resistance risk	Targeted weed control/eradication	#
3. Stop weed seed-set	3.1a Spray-topping with selective herbicides	5.00–20.00	Herbicide use, mechanical operation, high resistance risk, phytotoxicity	90% weed control	#
	3.1b Crop-topping with non-selective herbicides	6.50	Herbicide use, mechanical operation, low resistance risk, yield loss/phytotoxicity	75–80% weed control	1
	3.1c Wiper technology	7.50	Herbicide use, mechanical operation, low resistance risk, yield loss/phytotoxicity	70–98% weed control	–4
	3.1d Crop desiccation and windrowing	3.00–5.00	Machinery investment, herbicide use, mechanical operation, fire risk (if burn dumps)	40–50% weed control	10

	3.2	Pasture spray-topping	4.50	Herbicide use, mechanical operation, low resistance risk	75–90% weed control	7
	3.3	Silage and hay – crops and pastures	70.50–77.50	Herbicide use, mechanical operation, contract labour, crop loss	90–98% weed control, fodder value	–12
	3.4	Renovation crops and pastures – green manuring, brown manuring, mulching and hay freezing	25.00	Herbicide use, mechanical operation, crop loss	98% weed control, increased soil fertility, 10% following crop yield boost, fodder value	–11
	3.4(i)	Mowing pasture and crops	37.00	Mechanical operation, herbicide use, contract labour	98% weed control	–3
	3.5	Grazing – actively managing weeds in pastures	66.00	Running sheep, seed burial/spread	60–95% weed control	15
4. Prevent viable weed seeds within the target area being added to the soil seedbank	4.1	Weed seed collection at harvest	4.50–6.50	Initial investment, mechanical operation, harvest slow-down, fire risk (if burn dumps)	60–95% weed seed removal, reduced spread of herbicide resistant seed	4
	4.2	Grazing crop residues	#	Running sheep, seed burial/spread	15–95% weed control, fodder value	0
5. Prevent introduction of viable weed seed from external sources	5.1a	Sow weed-free seed	#	Prevention of new weed infestations generally requires extra time and labour input	Minimisation of unnecessary weed seed addition to the seedbank	15
	5.1b	Manage weeds in non-crop areas	#			#
	5.1c	Clean farm machinery and vehicles	#			#
	5.1d	Manage livestock feeding and movement	#			#

[a] Based on figures from the resistance and integrated weed management (RIM) model for average application costs across a range of crops and pasture types.

[b] Weed control ranges correspond to the average percentage weed kill/seed-set reduction across a range of weeds, crops and pasture types.

[c] The net value of each tactic corresponds to the difference between the RIM-generated 20-year annuity of the base IWM strategy with and without that particular tactic.

No specific cost item

The base IWM strategy was built on the following set of assumptions:

1. a crop–pasture rotational sequence of wheat–barley–lupin–wheat–barley–pasture (French serradella, *Ornithopus sativus* cv Cadiz)
2. a herbicide resistance status of two applications of Group A and Group B herbicides, five applications of Group C and Group D herbicides, and 15 applications of Group L and Group M herbicides left available before the onset of resistance
3. an initial annual ryegrass seedbank density of 500 seeds/m^2
4. default biological and economic values represented in the annual ryegrass RIM model.

Simulations with and without each tactic meant that some tactics were deliberately evaluated in one particular year only (eg inversion ploughing, wiper technology, hay/silage, green manuring, mowing pasture), while others were evaluated in set years (eg spray-topping and grazing in all pasture years, windrowing in all barley years) and some were applied whenever possible and profitable (eg most herbicides, autumn tickle/cultivation, delayed sowing, windrowing, seed-catching). The use of high crop sowing rates was the only tactic economically used every year.

Key finding #1

Herbicides are the most cost-effective weed management option, providing the most reliable weed control.

When considering the economic value of individual tactics (Table E1) the use of herbicides was by far the most economically valuable tactic. Selective pre-emergent herbicides showed a net value of \$71/ha/year, followed by selective post-emergent herbicides with a net value of \$40/ha/year and non-selective herbicides at \$26/ha/year.

Both high-intensity pasture grazing and high crop sowing rates also proved to be profitable tactics at \$15/ha/year.

Furthermore, windrowing (\$10/ha/year), inversion ploughing (\$9/ha/year), delayed sowing and pasture spray-topping (\$7/ha/year), seed collection at harvest (\$4/ha/year) and encouraging seed predation and crop-topping to prevent seed-set (\$1/ha/year) were all of positive value, as most provided very effective weed control.

All other tactics were slightly unprofitable, with green manuring and silage/hay crops, not surprisingly, the least valuable of all at –\$11 and –\$12/ha/year, respectively. This is consistent with the findings of Monjardino et al (2004b), who concluded that non-cropping phases, such as haying and green manuring of crops, were generally found to reduce profits due to the high cost of sacrificing the entire crop, despite excellent weed control. The most promising prospects for such tactics appear to be in cases of extreme herbicide resistance, involving the ineffectiveness of all selective herbicides. Here, a simple break-even analysis on the sale price of hay indicates that it would have to increase from \$40/tonne (model default price) to \$85/tonne for the hay scenario to be as profitable as the base strategy.

Estimating the economic benefits of IWM using simulation models

This section discusses a number of published studies that have considered the economic benefits of IWM and their key findings. There is a strong Western Australian focus in these case studies due to the high incidence of herbicide resistance in that state, which has necessitated research aimed at determining the many factors, costs and cost-benefits associated with implementing IWM.

Simulation model 1: Dynamic optimisation model

Key finding #1

The dynamic optimisation model (with a limited number of IWM tactics included) suggests that including non-chemical IWM options has economic value only for the 'with resistance' case.

A dynamic optimisation model was used to determine optimal combinations of chemical and non-chemical tactics, taking into account the trade-off between short-term profit and long-term level of herbicide resistance (Gorddard et al 1995).

The model focused on two options for delaying resistance: the inclusion of non-chemical control and the reduction of the herbicide dose. In this model it was assumed that increasing the herbicide dose had no effect on the level of weed control, which would be the case where target-site resistance dominates. Therefore, it was 'economically optimal' to reduce the herbicide rate as the level of resistance in the weed population increased and the crop yield was reduced.

A continuous cropping system was assumed until the herbicide resistant weed population increased to a point where cropping was no longer economically feasible, and the system then converted to pasture production. The study did not consider issues such as rotating herbicide groups or rotation of crop and pasture between years.

The results of the analysis were reported for resistant and non-resistant scenarios, and for chemical-only control (non-IWM) and non-chemical plus chemical control (IWM) (Table E2). The results are reported in terms of NPV calculated over 30 years using a 5% real discount rate. In addition to the economic returns, the number of years before cropping was abandoned in favour of pasture is also presented in the table.

The model suggests that the presence of resistance at the rate of one plant per million (annual ryegrass) in the first year substantially reduces the NPV by $594/ha for non-IWM and $678/ha for IWM scenarios.

Table E2 Benefits of non-chemical weed control options (Gorddard et al 1995)

	NPV[a] ($/ha)	Years of cropping[b]
Non-resistant, chemical-only control	1,445	30
Non-resistant, non-chemical and chemical control	1,445	30
Resistant, chemical-only control	767	7
Resistant, non-chemical and chemical control	851	12

[a] Net present value (NPV) over 30 years using 5% real discount rate

[b] Number of years before resistance reaches a level where cropping is less profitable than pasture

Simulation model 2: Combining a range of IWM tactics targeting annual ryegrass

Key finding #1

A strategy which integrated six different tactics provided the highest net present value according to the simulation model developed by Schmidt and Pannell (1996).

Key finding #2

Growers who wish to remain in a continuous cropping system must include a wide range of weed control methods as no single method provides the optimal solution.

The simulation model (later to be known as RIM) included a much larger number of IWM tactics than was considered in simulation model 1. The weed control tactics included delayed sowing, shallow cultivation, cutting crop for hay to remove weed seed heads, green manuring, seed-catching at harvest, crop-topping and increased plant densities.

A large number of strategies involving combinations of these tactics with post-emergent herbicides were examined. Of the control strategies investigated, a strategy which integrated six different tactics provided the highest NPV (Table E3). The strategies with the highest average NPV included a broader combination of tactics than is currently used in mainstream agriculture. The last two strategies in Table E3 highlight the importance of employing a combination of several non-chemical control methods.

Table E3 Net present values (NPV) of alternative weed control strategies in a 20-year continuous cropping (wheat–lupin) rotation in the central wheat belt of Western Australia (Schmidt and Pannell 1996)

Modelling (target weed – annual ryegrass)	NPV ($/ha)
Model 1 • pre-sow glyphosate in wheat • simazine in lupins • increase crop plant densities (lupins from 40 to 60 plants/m^2, wheat from 100 to 200 plants/m^2) • crop-top lupins with paraquat • windrow lupin and wheat crops • burn windrows in autumn	985
Model 2 • pre-sow glyphosate in wheat • simazine in lupins • increase crop plant densities (lupins from 40 to 60 plants/m^2, wheat from 100 to 200 plants/m^2) • crop-top lupins with paraquat • windrow lupin and wheat crops • collect crop residue (seed-catch) at harvest	955
Model 3 • pre-sow glyphosate in wheat • simazine in lupins • crop-top lupins with paraquat • windrow lupin and wheat crops • burn windrows in autumn	159
Model 4 • pre-sow glyphosate in wheat • simazine in lupins • increase crop plant densities (lupins from 40 to 60 plants/m^2, wheat from 100 to 200 plants/m^2) • total autumn burn	255

Simulation model 3: RIM model – herbicide resistance, annual ryegrass and IWM

Key finding #1

The benefits of IWM extend beyond herbicide resistance management, also applying to the case of long-term weed population management.

The RIM (resistance and integrated weed management) model was developed from the earlier models, 1 and 2, and is described by Pannell et al (2004).

This model expanded the number of chemical and non-chemical tactics available and also included the effects of different pasture phases on herbicide resistance and economic returns. The model allowed for resistance to herbicides with different modes of action, represented by the herbicide groups. Each group was allocated a number of applications, or 'shots', before full herbicide resistance was assumed to have developed.

A number of scenarios with differing levels of availability of a selective herbicide were evaluated over a 10-year period for a wheat–lupin rotation in Western Australia (Table E4). Included in the results are non-herbicide options of increasing crop sowing rates, seed-catching at harvest and shallow cultivation with delayed sowing; as well as the option of crop-topping (a non-selective application of the herbicide paraquat to lupins during grain fill). As herbicide availability increases, the total number of weed treatments other than selective herbicides falls. However, it is apparent from the results that it is economical in the long-term to include IWM options when herbicide resistance is not an issue so as to achieve a high level of control of weed populations.

Simulation model 4: Multi-species (annual ryegrass and wild radish) RIM model

Key finding #1

The most promising of the strategies examined appeared to be 3 years of pasture ('phase farming' in Western Australia) rather than the more commonly practised 1 year of pasture between crops.

Monjardino et al (2003) extended the original single species (annual ryegrass) RIM model to include wild radish and additional weed management practices to control this species (multi-species RIM model).

The implications of several rotational sequences with different crop–pasture phases, where the level of selective herbicide availability was held constant, were evaluated (Table E5). The first two rotations are continuous

Table E4 Consequences of restricting usage of selective herbicides over 10 years (assuming a Western Australian lupin–wheat rotation) (Pannell et al 2004)

Applications of selective herbicide available	Profitable treatments (other than selective herbicide) forming part of the integrated strategies[a]	Equivalent annual profit ($/ha)
2	• use high crop sowing rates (10) • crop-top lupins with paraquat (5) • use seed-catching cart, burn dumps (10) • delay seeding 20 days and apply glyphosate (10)	64
4	• use high crop sowing rates (10) • crop-top lupins with paraquat (5) • use seed-catching cart, burn dumps (10) • delay seeding 20 days and apply glyphosate (6)	76
6	• use high crop sowing rates (10) • crop-top lupins with paraquat (4) • use seed-catching cart, burn dumps (10) • delay seeding 20 days and apply glyphosate (2)	83
8	• use high crop sowing rates (10) • crop-top lupins with paraquat (2) • use seed-catching cart, burn dumps (10) • delay seeding 20 days and apply glyphosate (1)	91
10	• use high crop sowing rates (6) • crop-top lupins with paraquat (1) • use seed-catching cart, burn dumps (10)	93

[a] The number of years in which this treatment was applied is shown in parentheses.

Table E5 Choice of crop–pasture rotation sequence and weed control practices over a 20-year period in Western Australia (Monjardino et al 2003)

Rotation[a]	Profitable control options other than selective herbicides[b]	Equivalent annual profit ($/ha)
WWL	• delayed sowing (1) • high sowing rates (19) • crop spray-topping (6) • windrowing (3) • seed-catching + burning (11) • windrowing + burning (6)	137
WWC	• delayed sowing (2) • high sowing rates (19) • crop spray-topping (0) • windrowing (6) • seed-catching + burning (10) • windrowing + burning (9)	114
WWL+PPP	• delayed sowing (0) • high sowing rates (16) • crop spray-topping (9) • seed-catching + burning (10) • windrowing + burning (3) • burning (1) • grazing (1) • high-intensity grazing (2)	124

[a] Abbreviations: W – wheat; L – lupin; C – canola; P – pasture (French serradella).

[b] The number of years in which this treatment was applied is shown in parentheses.

cropping based on wheat (with either lupins or canola), and the last rotation is a wheat–wheat–lupin sequence with a 3-year French (pink) serradella *(O. sativus)* pasture phase in years 9 to 11 of a 20-year simulation.

The economic results indicate that IWM options were selected as optimal for each rotation system considered. All three rotations were found to provide good weed control. The types of control methods selected for the two cropping-only rotations were broadly similar, although practices such as delayed sowing, windrowing and seed-catching were slightly less attractive in the lupin rotation. The rotation that included pasture had a different mix of control options as the pasture phase itself allowed for grazing as an additional weed control method. Importantly, the inclusion of a pasture phase with these extra weed control options made it economically optimal to use fewer applications of selective herbicide. In a different study by Monjardino et al (1999), the inclusion of pasture in a cropping rotation increased the attractiveness of a long-term herbicide conservation strategy (versus rapid exploitation of the same selective herbicide) by reducing the early net losses from conservation.

Monjardino et al (2004a) evaluated the net value of a broader range of crop–pasture sequences against different factors such as initial weed seed densities, level of herbicide use, pasture phase length and frequency. The most promising of the strategies examined appeared to be the 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.

Simulation model 5: Multi-species (annual ryegrass and wild radish) RIM model and GM glyphosate-resistant canola crop

Key finding #1

The value of glyphosate-resistant canola as a break crop to manage weeds is significantly higher than that of triazine-resistant canola, which currently dominates Western Australian plantings.

Key finding #2

The glyphosate-resistant canola technology package needs to be highly effective in order for its use to be justified in the management of annual ryegrass and wild radish infestations.

The multi-species RIM model was again used, this time to evaluate the economic value of including a genetically modified (GM) crop in the system. The example used was glyphosate-resistant canola to replace triazine-resistant canola in a typical Western Australian cropping system (Monjardino et al 2005). The analysis focused on a continuous cropping rotation of wheat–wheat–canola–wheat–lupin (WWCWL). The assumption was that glyphosate can be sprayed in-crop once or twice, and that this may reduce reliance on, and thus help prolong the life of, selective herbicides to which annual ryegrass and wild radish can be highly resistant. Glyphosate-resistant canola was also assumed to have a yield advantage compared to triazine-resistant canola, although its seed is likely to cost more due to a technology fee.

Evaluation of these trade-offs led to the conclusion that the value of glyphosate-resistant canola is significantly higher than that of triazine-resistant canola, which currently dominates Western Australian plantings (Table E6). The benefits of glyphosate-resistant canola accrue from its yield advantage relative to triazine-resistant canola (10–20%) and from the inexpensive, effective weed control obtained with glyphosate. However, the results of this analysis indicate that the glyphosate-resistant canola technology package needs to be highly effective in order for its use to be justified in the management of annual ryegrass and wild radish infestations. This estimate would be higher if wild radish alone had been considered in the analysis and lower if the focus were on annual ryegrass.

The adoption of glyphosate-resistant canola could result in a substantial increase in farm profit, as well as greater flexibility in managing weeds and the likely extension of the life of selective herbicides.

Despite public debate on the potential impacts of GM crops, the risks of gene flow from glyphosate-resistant canola, the development of ‘super-weeds’ and the potential problems with volunteer weeds have all been found to be very low or negligible. Furthermore, the impact on the environment of growing glyphosate-resistant canola is likely to be positive as a result of reduced usage of residual triazine herbicides in favour of safer glyphosate. However, if glyphosate-resistant canola is widely adopted, there is a threat of increased evolution of resistance to glyphosate in a range of weed species as glyphosate will be used in-crop as well as during the fallow phase, thus reducing its profitability and availability to farmers over time. The impact of GM canola products on human health is not expected to be significant as no traces of GM material are usually found in canola oil. Nevertheless, ongoing risk assessment research is required in these areas.

Simulation model 6: WeedRisk model – inclusion of variability and uncertainty

The simulation studies already discussed assume certainty with respect to efficacy of the weed control options. However, variability in seasonal conditions is an important source of risk to farmers in terms of yields and potential impacts on the efficacy of weed control.

Key finding #1

Given that IWM aims to spread the risk of control failure and increase the probability of success, and because integrated weed control options are mutually supportive, ignoring risk may undervalue some control practices.

Because the success of weed control is often determined by weather, the use of particular technologies will affect the risk of agricultural production. The influence of seasonal conditions on the performance of a weed management technology and the potential strategic and tactical responses by farmers to the uncertain outcomes, are central in evaluation of the benefits of IWM. Essentially, any IWM strategy will vary in its impact according to the conditions (eg soil moisture, temperature and light) and thus have a distribution around it, since the variability is a function of the probability distributions of these uncertain inputs.

Jones and Medd (2005) used a climatically and biologically driven simulation model (WeedRisk) to determine the impact of IWM options on weed seedbanks, plant densities and crop yields for different population densities of wild oats and wild radish.

Table E6 Equivalent annual profits and weed densities for two scenarios, and net value of glyphosate-resistant canola ($/ha/year), for a wheat–wheat–canola–wheat–lupin rotation over a 20-year period in Western Australia

	Equivalent annual profit ($/ha/yr)	Annual ryegrass density (plants/m^2)	Wild radish density (plants/m^2)
Scenario with glyphosate-resistant canola	153	< 1	1
Scenario with triazine-resistant canola	142	< 1	2
Net value of glyphosate-resistant canola	11		

The strategies in this simulation model involved the use of a post-emergent herbicide plus various combinations of the IWM options of pre-season tillage (eg autumn tickle), increased competition (eg increased sowing rate, competitive crops) and late season herbicide application (eg crop-topping, selective spray-topping).

Key finding #2

IWM options that target the seedbank recruitment stage of the weed life cycle (Tactic Group 3) had the greatest impact in terms of reducing the size of seedbanks.

The use of post-emergent herbicides was found to be critical when trying to minimise wild oat density and maximise crop yields in any given year. Similar results were obtained in the case of wild radish.

Using the same mix of weed control options, Jones et al (2006) estimated the economic benefits of IWM under deterministic (zero risk) and stochastic (full risk) assumptions. The benefits of a non-IWM scenario (ie post-emergent herbicide only) for wild oats over a 20-year simulation period were a gain in NPV of 6%. However, when variability in seasonal conditions and the efficacy of the alternative options were taken into account, the NPV of the IWM scenario was 80% greater than the non-IWM scenario.

Key finding #3

The benefit of the IWM scenario was largely attributable to options that reduced replenishment of the seedbank (eg crop-topping, selective spray-topping) as they were able to compensate for years of failure of post-emergent herbicides due to adverse seasonal conditions.

To explore the benefits of IWM further, the WeedRisk model was tested for a range of rotational and IWM options over a 20-year period for three key cropping weeds; wild oats, wild radish and annual ryegrass (Table E7). The systems included a continuous cropping system and a rotation involving a 4-year crop phase followed by a 3-year perennial pasture phase for a southern New South Wales cropping system. The calculated benefits from IWM are conservative as the analysis does not consider the impacts of development of herbicide resistance from continual use of the post-emergent herbicide.

Key finding #4

The economic returns averaged over a 20-year period for IWM are greater than for non-IWM in all cases, usually by a considerable margin, primarily due to lower seedbank numbers in IWM systems.

Contributors

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References

Gorddard, R.J., Pannell, D.J. and Hertzler, G. (1995). An optimal control model for integrated weed management under herbicide resistance. *Australian Journal of Agricultural Economics* **39**: 71–87.

Jones, R.E. and Medd, R.W. (2005). A methodology for evaluating risk and efficacy of weed management technologies. *Weed Science* **53**: 505–514.

Jones, R.E., Cacho, O. and Sinden, J. (2006). The importance of seasonal variability and tactical responses to risk on estimating the economic benefits of integrated weed management. *Agricultural Economics* **35**: 245–256.

Monjardino, M., Pannell, D.J. and Powles, S. (1999). Managing herbicide resistance: should you conserve or exploit your herbicides? *In Proceedings of 43rd Australian Agricultural and Resource Economics Society and 6th New Zealand Agricultural Resource Economics Society Conference*, 19–22 January 1999, Congress Centre, Christchurch, New Zealand.

Table E7 The economic impact ($/ha) of different crop and IWM systems on mean[a] annualised discounted returns for wild oats, wild radish and annual ryegrass in a southern New South Wales cropping system

	Economic return ($/ha)					
	Wild oats		Wild radish		Annual ryegrass	
Continuous cropping						
– IWM	268	± 35	– 9	± 27	284	± 34
+ IWM	332	± 38	315	± 37	335	± 38
Crop + pasture rotation						
– IWM	288	± 29	157	± 25	284	± 28
+ IWM	319	± 32	300	± 30	320	± 31

[a] The values following ± are the standard deviation.

Monjardino, M., Pannell, D.J. and Powles, S.B. (2003). Multispecies resistance and integrated management: a bioeconomic model for integrated management of rigid ryegrass *(Lolium rigidum)* and wild radish *(Raphanus raphanistrum)*. Weed Science **51**: 798–809.

Monjardino, M., Pannell, D.J. and Powles, S.B. (2004a). The economic value of pasture phases in the integrated management of annual ryegrass and wild radish in a Western Australian farming system. *Australian Journal of Experimental Agriculture* **43**: 265–271.

Monjardino, M., Pannell, D.J. and Powles, S.B. (2004b). The economic value of haying and green manuring in the integrated management of annual ryegrass and wild radish in a Western Australian farming system. *Australian Journal of Experimental Agriculture* **44**: 1195–1203.

Monjardino, M., Pannell, D.J. and Powles, S.B. (2005). The economic value of glyphosate-resistant canola in the management of two widespread crop weeds in a Western Australian farming system. *Agricultural Systems* **84**: 297–315.

Pannell, D.J., Stewart, V., Bennett, A., Monjardino, M., Schmidt, C. and Powles, S.B. (2004). RIM: a bioeconomic model of integrated weed management of *Lolium rigidum* in Western Australia. *Agricultural Systems* **79**: 305–325.

Schmidt, C.P. and Pannell, D.J. (1996) Economic issues in management of herbicide-resistant weeds. *Review of Marketing and Agricultural Economics* **64**: 301–308.

Further reading

GM Canola Technical Working Group. (2001). *Genetically Modified Canola in Western Australia: Industry Issues and Information* – A summary of Western Australian canola production in relation to biotechnology and genetic modification issues. GM Canola Technical Working Group, Perth.

Jones, R., Alemseged, Y., Medd, R. and Vere, D. (2000). *The distribution, density and economic impact of weeds in the Australian annual winter cropping system*. Technical Series No. 4. CRC for Australian Weed Management, Adelaide.

Llewellyn, R.S., Lindner, R.K., Pannell, D.J. and Powles, S.B. (2002). Resistance and the herbicide resource: perceptions of Western Australian grain growers. *Crop Protection* **21**: 1067–1075.

Llewellyn, R.S., Lindner, R.K., Pannell, D.J. and Powles, S.B. (2004). Grain grower perceptions and use of integrated weed management. *Australian Journal of Experimental Agriculture* **44**: 993–1001.

Neve, P., Diggle, A.J., Smith, F.P. and Powles, S.B. (2003a). Simulating evolution of glyphosate resistance in *Lolium rigidum*. I. Population genetics of a rare resistance trait. *Weed Research* **43**: 404–417.

Neve, P., Diggle, A.J., Smith, F.P. and Powles, S.B. (2003b). Simulating evolution of glyphosate resistance in *Lolium rigidum*. II. Past, present and future glyphosate use in Australian cropping. *Weed Research* **43**: 418–427.

Pannell, D.J. and Zilberman, D. (2000). Economic and sociological factors affecting growers' decision making on herbicide resistance. SEA Working paper 00/07.

Rieger, M.A., Potter, T.D., Preston, C. and Powles, S.B. (2001). Hybridisation between *Brassica napus* L. and *Raphanus raphanistrum* L. under agronomic field conditions. *Theoretical & Applied Genetics* **103**: 555–560.

Rieger, M.A., Preston, C. and Powles, S.B. (1999). Risks of gene flow from transgenic herbicide-resistant canola *(Brassica napus)* to weedy relatives in southern Australian cropping systems. *Australian Journal of Agricultural Research* **50**: 115.

Sinden, J., Jones, R., Hester, S., Odom, D., Kalisch, C., James, R., Cacho, O. and Griffith, G. (2005). The economic impact of weeds in Australia. *Plant Protection Quarterly* **20**: 25–32.