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Research article

From resistance to resilience: A bioeconomic evaluation of integrated weed management of glyphosate-resistant ryegrass in dryland cropping systems

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A B S T R A C T

Weeds cost Australian crop growers over AUD 4.0 billion annually in lost yield revenue and weed control expenditure. When new weed species invade or herbicide resistance develops, existing herbicide-based practices are often ineffective leading to costly reactive management. This study seeks to quantify the cost of a resistant weed incursion and assess the value of having a diverse integrated weed management (IWM) strategy already in place to reduce those costs and increase cropping system resilience. Using the RIM model, we evaluate the bioeconomic implications of glyphosate-resistant annual ryegrass in broadacre cropping systems under six IWM scenarios. Herbicide-resistant annual ryegrass is the most problematic weed in Australian cropping systems due to its abundance, high fecundity and outcrossing, with multiple resistance to a range of herbicides. Outcomes were compared with and without weed seed control practices, based on a typical crop rotation in the Riverina and Sunraysia (Mallee) regions of southeastern Australia. Modelling revealed that the cost of acquiring glyphosate resistance was lower when diverse weed control practices were in place, including rotating cereal crops with break crops such as canola and legumes, using competitive crops like barley, and early (dry) sowing of break crops. An IWM program achieving 80% weed seed control efficacy reduced the cost of gaining glyphosate resistance by up to AUD 18.0 per hectare, demonstrating its important role in building resilience to new weed challenges. These findings highlight the value of an IWM strategy, not only for profitable weed management, but also for mitigating the costs of future resistance development and weed incursions. Farm-level adoption of diverse IWM practices that reduce the seed set of a new and potentially mobile weed may then also improve resistance management by limiting potential for spread at the broader landscape scale.

1. Introduction

The cost of weeds to Australian grain production has risen to well over AUD 4.0 billion (Australian dollars) annually, with the majority being attributable to weed control costs (Ouzman et al., 2025). The invasion of new weed species or rising herbicide resistance can be expensive to manage if not effectively controlled by current methods. Improved management of these problematic weeds at the farm level could prevent costly outbreaks and stop further spread across cropping regions.

With the widespread adoption of conservation agriculture systems that minimize or eliminate regular tillage (Kassam et al., 2018; Llewellyn et al., 2012; Walsh et al., 2020), growers have increasingly relied on repeated herbicide applications in place of traditional physical weed control methods, such as cultivation and grazing. This shift has created strong selection pressure for herbicide resistance (Owen et al., 2007). Across the agricultural regions of southern Australia, the most problematic weed is annual ryegrass (*Lolium rigidum* Gaudin), owing to its high abundance, prolific seed production, extensive herbicide resistance driven by outcrossing, and effective dispersal mechanisms (Beckie et al., 2020b; Broster et al., 2019, 2022; Gill, 1996a, 1996b; Llewellyn et al. 2016; Preston et al., 2022). Notably, annual ryegrass often dictates a grain grower's herbicide program and typically incurs greater management costs than all other weeds species combined (Beckie et al., 2020a, b; Llewellyn et al. 2016).

With the decline of tillage, ryegrass populations developed resistance to in-crop selective herbicides, and the adoption of herbicide tolerant crops further intensified this shift, increasing reliance on the non-selective herbicide glyphosate (herbicide mode of action Group 9). As a result, glyphosate-resistant ryegrass populations, along with other weeds, are increasing in frequency in the major cropping regions of Australia (Beckie, 2011; Neve et al., 2003; Owen and Powles, 2017;

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Preston et al., 2022) and the globe (Brunharo et al., 2022; Peterson et al., 2018; Reboud et al., 2017).

The development of resistance in annual ryegrass to selective herbicides was the major driver of adoption of integrated weed management (IWM) practices by Australian grain growers (Llewellyn et al., 2007). The key principle behind IWM is that integrating weed control strategies, including chemical and non-chemical options, can delay or prevent the evolution of herbicide resistant weed populations by avoiding over-reliance on herbicides that have the same mode of action on plants, while sustaining profitable production (McGillion and Storrie, 2006; Preston, 2019). An example of highly effective components of IWM with increasing levels of grower adoption are Harvest Weed Seed Control (HWSC) technologies (Somerville et al., 2018; Walsh et al., 2017b), which significantly reduce weed seed set at harvest. Nationally, 52% of farms utilize one or more HWSC technologies (GRDC, 2021).

The impact of adopting IWM to address emerging herbicide resistant ryegrass populations has been previously evaluated through bioeconomic modelling, particularly in Western Australia (WA) (Doole and Pannell, 2008; Doole et al., 2009; Monjardino et al., 2004a, 2004b, 2005). Some of these studies also examined the economic cost of losing access to non-selective herbicides, such as glyphosate, in mixed farming systems (Beckie et al., 2020a,b; Walsh and Kingwell, 2021). Several of these analyses employed the Ryegrass Integrated Management (RIM) model – a decision support tool developed for Australian farmers and advisors to assess the long-term profitability of alternative ryegrass strategies (Pannell et al., 2004; Lacoste and Powles, 2014, 2015).

While the economic cost of losing access to glyphosate has also received substantial international attention (e.g., Finger et al., 2023; Kudsk and Mathiassen, 2020), emerging glyphosate resistance has not been investigated widely in other cropping systems contexts, particularly through the lens of valuing IWM practices that may already be in place e.g. after being adopted for management of other weed and resistance challenges. This is timely since findings from a recent area-wide weed management survey revealed that glyphosate-resistant ryegrass ranks as the most concerning weed threat to growers in the Sunraysia and Riverina cropping zones of southeastern Australia (Graham et al., 2020). This study seeks to quantify the cost of managing a glyphosate-resistant weed population and thereby assess the value of a diverse IWM program in increasing resilience of a cropping system comprised of cereals as well as break crops such as canola and an occasional legume crop.

2. Materials and methods

2.1. Focus regions

To test a farming system scenario where glyphosate-resistant annual ryegrass is acquired and affects a cropping sequence over a 10-year period, we selected a typical cropping rotation that is common to the Riverina (New South Wales, NSW) and Sunraysia (Victorian Mallee) regions (Fig. 1). Both regions in southeastern Australia's agricultural zone are facing an emerging threat of glyphosate-resistant annual ryegrass in winter crops. The Riverina, with an average annual rainfall of 380 mm, dedicates 37% of its land to crops, primarily wheat, canola and barley (Australian Bureau of Statistics, 2020a). Although the region is renowned for its irrigated rice, citrus and nut production, crops such as cotton, canola, and oranges generate the highest gross value (Australian Bureau of Statistics, 2020b). The Sunraysia region receives an average annual rainfall of 292 mm, with 83% of its land dedicated to cropping, primarily cereal and legume crops (Australian Bureau of Statistics, 2020a) but also high-value irrigated almonds and grapes (Australian Bureau of Statistics, 2020b). A recent survey found high levels of annual ryegrass dispersal within and across these regions (Hereward et al., 2022). In this study we represent a typical rain-fed farming system that is relatively common across both regions, as described in section 2.3.

2.2. The RIM model

The bioeconomic simulation analysis was conducted using the RIM

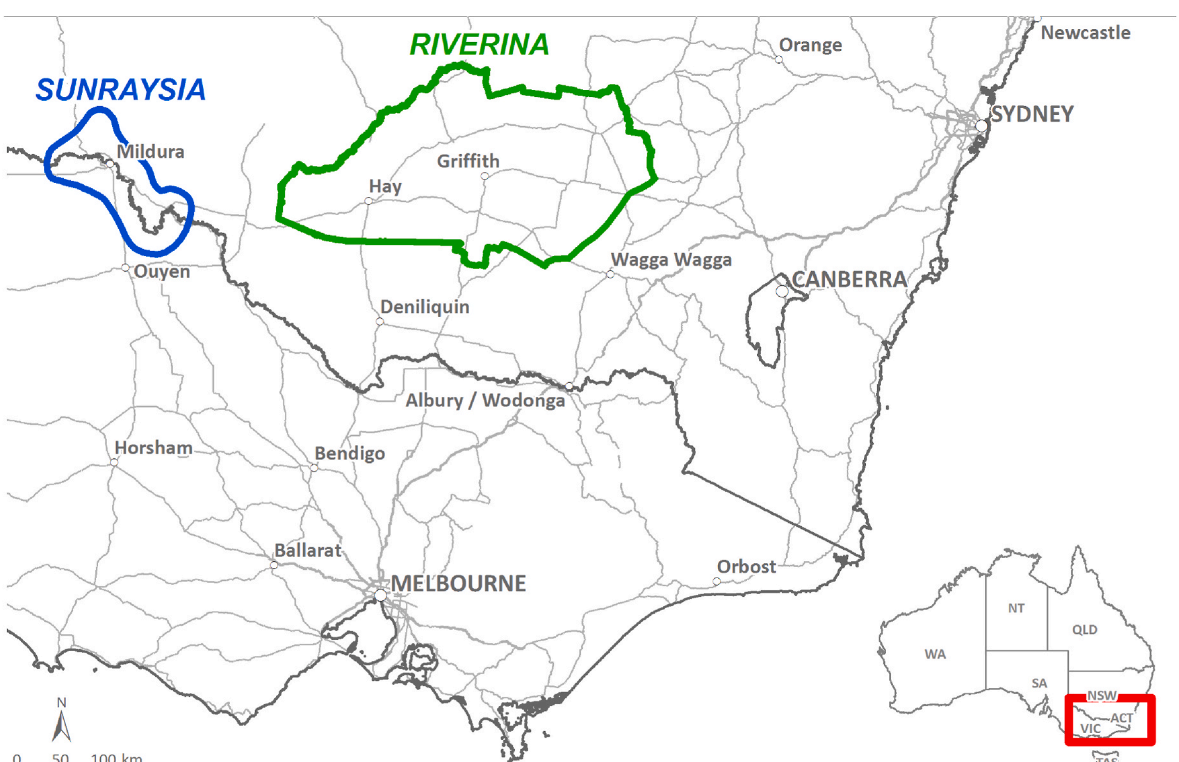

Fig. 1. Map of the focus regions of Riverina (NSW) and Sunraysia (Victorian Mallee). Source: C. Ratcliff (CSIRO).

model version developed for a typical cropping system in eastern Australia (https://www.ahri.uwa.edu.au/our-research/wim-weed-management-models/rim-ryegrass-integrated-management/). In brief, RIM users choose a crop/pasture sequence for a 10-year period and develop a viable agronomic strategy that integrates various chemical and non-chemical practices throughout the growing season, guided by predefined control efficacy values and associated costs.

Chemical control methods include pre-sowing knockdown herbicides such a glyphosate (mode of action – MOA – Group 9), pre-emergence herbicides like chlorsulfuron (Group 2) and trifluralin (Group 3), post-emergence herbicides including diclofop (Group 1), and in-crop topping with glyphosate (Group 9) in spring to supress seed set. Non-chemical practices included in RIM involve tillage options, rotating crop types and pastures to disrupt weed cycles, using competitive crops such as barley, adjusting sowing times, modifying crop seeding rates to improve competition against weeds, grazing to reduce weed biomass, producing hay or silage or incorporating weedy crops (green manuring), swathing in spring, and implementing HWSC techniques at harvest.

Long-term calculations compute net present values for machinery repayments and for the 10-year average economic return. The economic calculations integrate bank interest, inflation rate, tax, potential yield increases, and discounting. The model outputs financial gross margins (AUD/ha, in Australian dollars) and weed plant and seed density (i.e. number of weed plants and seeds per hectare), which vary based on the chosen strategy. Additional outputs include weed control costs and income for each enterprise. Fig. 2 depicts the structure and relationships of the main components of the RIM model. For a more detailed description, refer to Lacoste and Powles (2014, 2015). The original RIM (Pannell et al., 2004) has been adapted to various weed species, farming systems, and geographical locations in Australia and around the world (Torra and Monjardino, 2020), including the recent adaptation for Italian ryegrass (*Lolium multiflorum*) in Danish cropping systems (Sonderskov et al., 2020).

RIM is implemented in Microsoft Excel, supported by VBA macros. The model has undergone multi-level validation (Lacoste and Powles, 2014, 2015). Specifically, the biological outputs from the WA version of Ryegrass RIM (Pannell et al., 2004) have been compared against field data (Draper and Roy, 2002). Furthermore, sensitivity analysis serves as a valuable method for assessing the impact of data limitations and guiding targeted research efforts (Pannell, 1997). Users also have the flexibility to adjust biological and economic parameters to reflect their specific conditions.

2.3. Scenario analysis

2.3.1. Cropping system

We focus on a typical low rainfall cropping system relevant to the Sunraysia as well as to dryland winter cropping in the lower rainfall areas of the Riverina. An average cropped area of 2000 ha was assumed for this analysis. The no-tillage system was assumed to grow a typical crop rotation, common to both the Sunraysia and the Riverina, based on cereals (wheat and barley) and break crops such as canola and an occasional legume crop. Including a legume in the rotation has system-wide benefits, such as disease break and soil fertility (Kirkegaard et al., 2008).

The long-term average weed-free grain yields used in RIM for a standard rotation were: 2.5 t/ha for wheat, 2.8 t/ha for barley, 1.3 t/ha for canola and 1.0 t/ha for a legume crop, in line with the upper range of Victorian-New South Wales regional weed-free yield levels estimated in J Ouzman et al. (2025). The average farm-gate prices (i.e., excluding transport costs) for grain used were: 270, 220, 550 and 400 AUD/t for wheat, barley, canola, and legume, respectively (Ag Commodity Prices, 2020). Due to the lack of region-specific data for our study area, we assumed an average initial ryegrass density of 20 plants/m^2 in the spring prior to the study treatment period across all scenarios which is likely to be in the upper range of starting densities (Ouzman et al., 2025). This estimate is then used in model parameters (Lacoste and Powles, 2015) developed for annual ryegrass under comparable no-tillage farming systems (Goggin et al., 2012), recognizing that multiple factors in addition to climate affect weed seed dormancy and potential germination at a field scale in the following season (Owen et al., 2011).

The break crops (canola and legume) were assumed to be dry sown

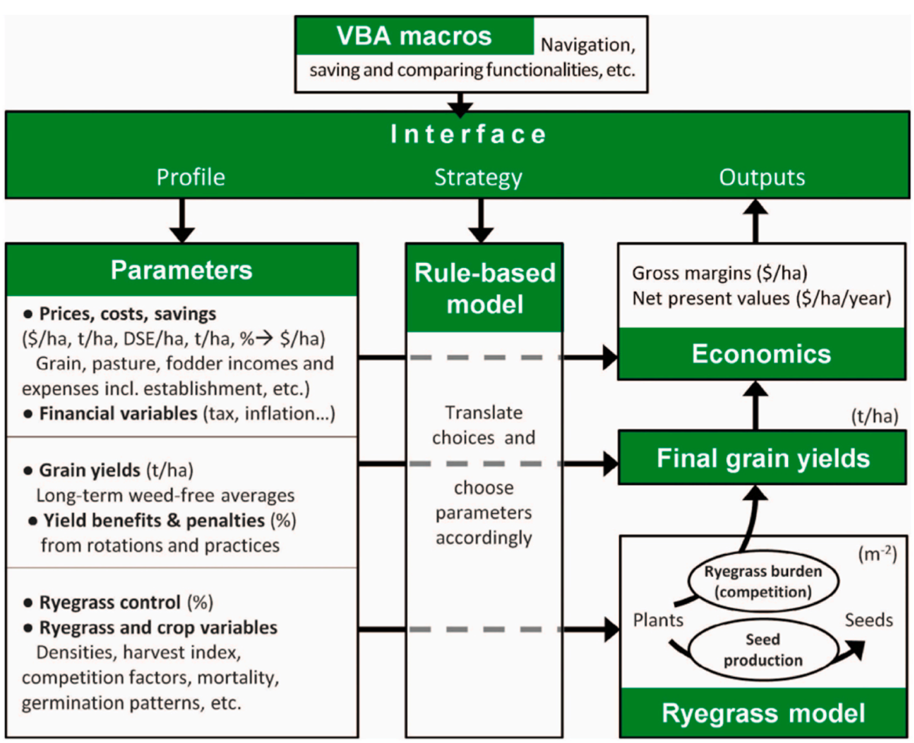

Fig. 2. Structure and relationships of the main RIM components. Source: Lacoste and Powles (2015).

(Fletcher et al., 2016), whereas cereals were sown after the season break (e.g. 1-2 weeks delayed sowing after the season break rainfall). A standard crop seeding rate was used for all crops: 60, 70, 3 and 100 kg/ha for wheat, barley, canola, and legume, respectively.

2.3.2. Weed management

The economic cost – measured in terms of additional weed-related costs and weed seedbank load – was assessed for two established weed management systems: i) a system with no specific weed seed management practices, and ii) a system with an IWM strategy in place that includes substantial HWSC practices (Walsh et al., 2017b). Both systems incorporate IWM practices beyond herbicides and HWSC, including rotating cereal crops with break crops such as canola and legumes, and using competitive crops like barley.

In the RIM model, weed seed control options were assumed to achieve an average 80% seed control and include HWSC technologies (Walsh et al., 2017b), such as i) Chaff cart: A cart trailing behind the harvester collects the chaff, which is then strategically dumped for burning, grazing, or removal; ii) Narrow-windrow burning: Chaff and straw are concentrated into narrow windrows (500 to 600 mm wide) during harvest and later burned to destroy weed seeds; iii) Chaff tramlining: Chaff is concentrated on dedicated tramlines during harvest, used in a controlled traffic system; iv) Seed Destructor (HSD): a mill attachment to the harvester that destroys weed seeds. Several HWSC practices have been shown to have similar levels of cost-effectiveness (Walsh et al., 2017a).

In terms of resistance risk, the baseline no-tillage scenario presumes glyphosate efficacy at 95% with a strong reliance on pre-emergence and in-crop selective herbicides. In a second scenario, glyphosate remains part of the program due to its cost-effectiveness against non-ryegrass weeds, even as resistance reduces its efficacy on ryegrass from 95% to 40%. For comparative analysis, scenarios without glyphosate – both with and without seed control – were also explored. Given the large range of pre-emergence herbicide options now available to Australian grain growers with multiple modes of action and currently low levels of resistance (Busi et al., 2021), it has been assumed that in-crop effectiveness of weed control can be maintained across the study period.

A summary of the six RIM-modelled weed management scenarios is listed below and outlined in Table 1.

1. Glyphosate at 95% efficacy, No weed seed control
2. Glyphosate at 95% efficacy, Weed seed control
3. Glyphosate at 40% efficacy, No weed seed control
4. Glyphosate at 40% efficacy, Weed seed control
5. No glyphosate, No weed seed control
6. No glyphosate, Weed seed control

3. Results and discussion

3.1. System profitability

Simulation results over a 10-year period – comparing scenarios with glyphosate efficacy on annual ryegrass at 95% (baseline), 40%, and complete absence of glyphosate for ryegrass control – are presented in Table 1 and Fig. 3. Each scenario was evaluated under IWM systems both with and without weed seed control at harvest.

Results show that in a typical cropping system – where pre-emergence and in-crop selective herbicides were applied annually, break crops were dry-sown in four out of 10 years, and glyphosate knockdown was used in cereals in the remaining six years – a decline in glyphosate efficacy against the winter weed target, annual ryegrass, from 95% to 40% due to resistance resulted in an estimated economic loss of approximately AUD 14.0 per hectare. The economic cost of glyphosate being totally lost to growers for annual ryegrass control would be closer to AUD 20.0 per hectare (Table 1, Fig. 3). This relatively low decrease in profitability is due to a high reliance on selective herbicides including pre-emergence herbicides.

The results are also consistent with the increasing shift by growers to early dry seeding (Fletcher et al., 2016), which essentially means electing to forego use of glyphosate as a knockdown on a significant portion of crop land in order to achieve greater overall systems and yield potential benefits (Hunt et al., 2019) However, while there are multiple pre-emergence herbicide options with a number of modes of action not yet affected by widespread resistance (Busi et al., 2021), these herbicides are at risk of resistance developing when placed under increased intensity of use so it should be noted that this usage may not be sustainable past the 10-year horizon studied here.

3.2. Weed control

Increasing annual ryegrass densities under reduced glyphosate efficacy highlight the growing risk of herbicide resistance. If glyphosate resistance develops and efficacy declines to 40% on ryegrass (while remaining effective on other weed species), seedbank levels rise sharply from 7 to 53 seeds per m^2. In addition, the number of mature ryegrass plants setting seed also increases in the absence of supplementary weed seed control measures (Scenario 3).

Removing glyphosate from the system (without weed seed control) would critically increase the seedbank to 146 ryegrass seeds per m^2 (Scenario 5, Table 2, Fig. 3).

If weed seed control practices are in place that can control 80% of ryegrass seed set, then the decline of glyphosate efficacy leads to similar profitability and similar plant numbers (Scenario 4, Table 2, Fig. 3). Importantly, the use of the HWSC measures enables this level of profitability without heavy reliance on the resistance-prone in-crop selective herbicides, provided glyphosate remains available. Under these

Table 1
Ryegrass Integrated Management (RIM) model assumptions for the six weed management and glyphosate resistance scenarios analysed in the Riverina/Sunraysia region of southeastern Australia, all with the 10-year crop rotation wheat-barley-canola-wheat-barley-pulse-canola-wheat-barley-canola.

Assumptions	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
	Glyphosate at 95% efficacy, No weed seed control	Glyphosate at 95% efficacy, Weed seed control	Glyphosate at 40% efficacy, No weed seed control	Glyphosate at 40% efficacy, Weed seed control	No glyphosate, No weed seed control	No glyphosate, Weed seed control
Glyphosate (herbicide MOA Group 9)	6	6	6	6	0	0
Pre-emergent herbicides (Group 2 and Group 3)	10	10	10	10	10	10
Number of years of dry seeding	4	4	4	4	4	4
In-crop selective herbicides (Group 1)	10	7	10	7	10	10
Weed seed control (HWSC, crop-topping)	0	6	0	6	0	6

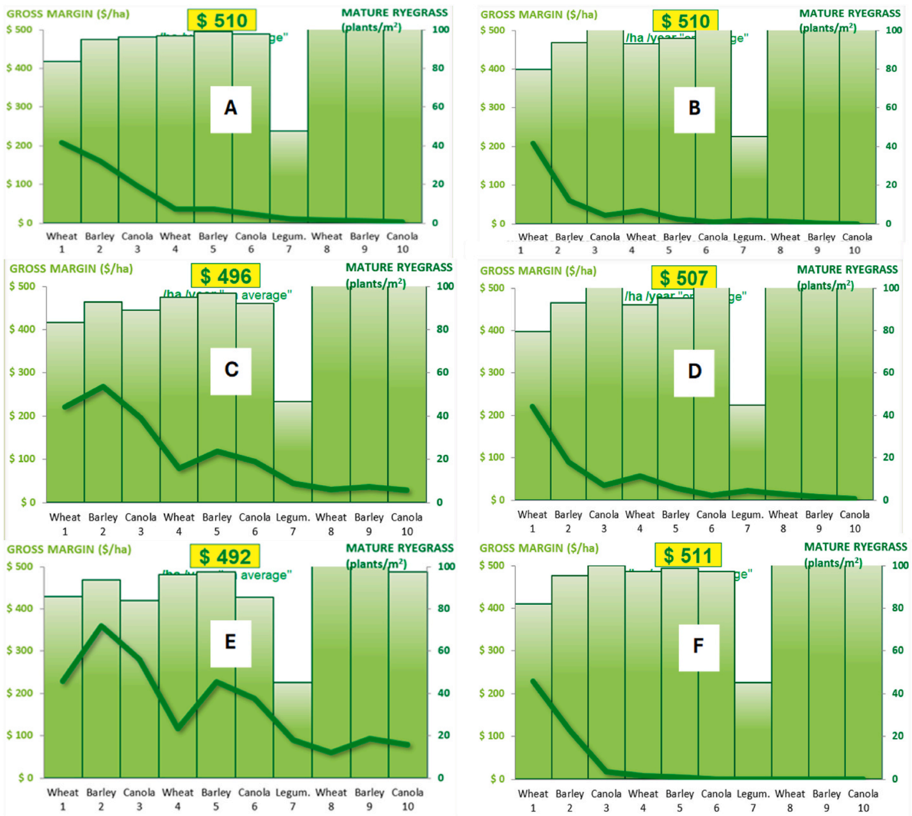

Fig. 3. RIM simulation results for the six scenarios as described in Table 1, showing ryegrass plant density and gross margin (in Australian dollars) over the 10-year crop rotation wheat-barley-canola-wheat-barley-pulse-canola-wheat-barley-canola in the Sunraysia/Riverina area. **A)** Glyphosate at 95% efficacy, no weed seed control; **B)** Glyphosate at 95% efficacy, weed seed control; **C)** Glyphosate at 40% efficacy, no weed seed control; **D)** Glyphosate at 40% efficacy, weed seed control; **E)** No glyphosate, no weed seed control; **F)** No glyphosate, weed seed control.

Table 2
Ryegrass Integrated Management (RIM) model results for the six weed management and glyphosate resistance scenarios analysed in the Riverina/Sunraysia region of southeastern Australia, all with the 10-year crop rotation wheat-barley-canola-wheat-barley-pulse-canola-wheat-barley-canola.

Results	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
	Glyphosate at 95% efficacy, No weed seed control	Glyphosate at 95% efficacy, Weed seed control	Glyphosate at 40% efficacy, No weed seed control	Glyphosate at 40% efficacy, Weed seed control	No glyphosate, No weed seed control	No glyphosate, Weed seed control
Ryegrass density after 10 years (plants/m^2)	1	0	6	1	16	0
Seeds in soil next autumn (seeds/m^2)	7	6	53	22	146	0
Average gross margin (AUD/ha/year)	510	510	496	507	492	511

conditions, the use of in-crop herbicides can be reduced to seven applications over the 10-year period (Table 1). Even in the complete absence of glyphosate, profitability is maintained, primarily due to lower overall herbicide costs (assumed average AUD 10.0 ha in RIM) and the effective reduction of the weed seedbank (Scenario 6).

In regions where a dominant winter weed, such as annual ryegrass, drives resistance dynamics, the RIM tool offers a valuable framework for evaluating optimal control strategies, especially when herbicide resistance has emerged or is at risk of developing. In this analysis, where glyphosate resistance in ryegrass reduces its efficacy to just 40%, or is potentially completely lost, IWM practices that achieve an average 80% weed seed set control can reduce the cost of losing glyphosate as an effective option.

These practices can also reduce reliance on other herbicides and consequent resistance selection pressure to these herbicides. Pre-emptive adoption of these weed seed set-focused practices can not only reduce on-farm resistance selection pressure but also increase resilience of the cropping system to the risk of spread of new forms of resistance. In addition to these weed seed set control practices providing field-level benefit, they can also potentially reduce risk of weed or resistance spread to neighbouring fields.

3.3. Study limitations

Our results focus on a single winter weed species in southern cropping systems and are influenced by the cropping system assumptions and the simulated scenarios; therefore, they should be interpreted with caution. Using average values for crop yields, grain prices, input costs, and weed control efficacy may lead to overestimation of IWM benefits in specific years, given the variability of these factors over time. Likewise, outcomes can vary depending on initial weed densities. We also assume summer fallow weed control is not affected by the loss of glyphosate efficacy.

Furthermore, as previously noted, herbicides continue to develop resistance under intensive cropping regimes, which could significantly reduce their effectiveness within the next decade and/or they may be substituted by new alternative herbicides (Broster et al., 2022). However, the low rainfall region represented in this study - which extends over approximately 8.0 million ha of Australian grain cropping land - typically has lower existing levels of resistance, and thereby more existing herbicide options, than some other higher rainfall cropping regions (Broster et al., 2022). There is also a suite of available effective pre-emergence herbicide options currently available (Busi et al., 2021) but increasing selection pressure over a decade could lead to increased risk of resistance and additional management costs beyond the 10-year horizon of this analysis.

It should also be noted that not all possible IWM practices were included in this simulation. The analysis could be expanded to incorporate additional practices that are often applied tactically, such as hay (and pasture) phases, which have the potential to profitably control resistant weeds (Doole and Pannell, 2008; Doole et al., 2004b, 2009). Likewise, it would be valuable to assess the inclusion of a glyphosate-resistant crop like canola in the rotation (Monjardino et al., 2005). Finally, the recent trend in grower adoption of early sowing into warmer soil that leads to more competitive early season crops and potential yield benefits (Hunt et al., 2019) is expected to further contribute to the success of IWM in increasing system resilience to new resistant weed incursions.

3.4. Implications for sustainable weed management

The risk of reduced herbicide options over time suggests that more sustainable (and potentially more costly) changes would be required to maintain low weed seed banks to minimize population proliferation and the evolution of resistance. This highlights the need to take a longer-term view when evaluating potential costs of gaining a resistant weed problem within cropping systems.

Our findings are broadly consistent with a previous RIM-based study by Beckie et al. (2020a,b), which reported that the profit margins were not substantially reduced under a no-glyphosate scenario for in-season weed control compared with the current practice of knockdown and some pre-harvest glyphosate applications in no-tillage cereal-based rotations in WA. However, when assessing the economic implications of the total loss of glyphosate for all weed control purposes and also the loss of the alternative non-selective herbicide paraquat in a crop-livestock farm context in WA (using the whole-farm MIDAS model), Walsh and Kingwell (2021) concluded that it could lead to larger declines in farm profit due to increased costs of crop production and a shift towards more grazed pasture. When comparing to other studies, it is important to note that unlike many analyses that examine the cost of complete loss of glyphosate as a management tool in cropping systems (e.g. Finger et al., 2023) here we consider resistance in just one weed species and also represent reduced levels of efficacy.

While the RIM model provides valuable insights into weed management strategies, its assumption of fixed average yields, grain prices, weed densities, and control efficiencies over a 10-year horizon simplifies the complex realities of farming systems. Seasonal yield variability, market price fluctuations, and dynamic weed population changes can substantially alter economic outcomes. Moreover, herbicide resistance progression is inherently non-linear, with control efficiencies declining over time, which may affect model outcomes. Acknowledging these sources of variability clarifies the limitations of the model and highlights the need for future work incorporating stochastic elements or scenario-based approaches.

Overall, consideration needs to be given to the fact that growers often have a diverse range of management options for a diverse range of weeds. The addition of another weed species that can be controlled by existing practices such as IWM, or an extra form of resistance that can be managed through adapted or alternative practices, may not always have a large economic cost when a diverse range of options (herbicide, non-herbicide, and crop sequence) remain available to the grower (Monjardino et al., 2003). Similarly, the expected marginal cost of a new weed problem may not be large if growers also expect new control options to become available in the future (e.g., new herbicides or other technology). Weed management options that offer similar on-farm profitability but also offer reduced risk of weed seed set and potential mobility are options that are likely to offer value to potential adopters.

There may be future opportunities to empirically examine the relationship between IWM adoption – often driven by herbicide resistance development on farms over past decades – and findings from a recent national study by Broster et al. (2022), which observed that certain resistance types in some regions have shown little increase. Future work will seek to use more time series and temporal data and aim to integrate this with development of resistance data to look at the 'history of IWM use' and its ability to explain resistance status over time.

4. Conclusion

This study employed the RIM model to assess the bioeconomic consequences of glyphosate-resistant annual ryegrass development within a low-rainfall winter cropping system in southeastern Australia. We evaluated novel scenarios involving glyphosate use under varying levels of resistance within cropping systems that included a range of IWM.

Our findings indicate that high additional costs of managing a new form of herbicide resistance can be avoided, provided growers have a diverse set of weed control measures in place, such as strategic rotations with break crops, use of competitive crops and emphasis on reducing return of weed seeds to the seedbank though effective use of weed seed control practices. IWM strategies that can achieve an average 80% weed seed control play a critical role in improving the resilience of cropping systems. Growers who are using diverse, weed seed-focused IWM strategies to manage existing weed problems can also benefit from lowering the economic costs and agronomic risks of resistance development and spread.

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CRediT authorship contribution statement

Marta Monjardino: Writing – original draft, Methodology, Formal analysis, Conceptualization. **Rick Llewellyn:** Writing – review & editing, Conceptualization.

Consent to participate

Not applicable.

Ethics approval

Not required.

Consent for publication

Not applicable.

Availability of data and material

The modelling scenarios generated during the current study are available from the corresponding author on reasonable request.

Code availability

The RIM model is available online for free downloading: https://www.ahri.uwa.edu.au/our-research/wim-weed-management-models/rim-ryegrass-integrated-management/

Declaration of competing interest

None do declare.

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Data availability

Data will be made available on request.

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