

HARVEST WEED SEED CONTROL FOR THE SOUTHERN HIGH RAINFALL ZONE



GRDC
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CORPORATION

SOUTHERN REGION



TITLE:

Harvest weed seed control for the southern high rainfall zone

GRDC CONTRACT CODE:

SFS00032

ACKNOWLEDGEMENTS:

The research undertaken as part of this project was made possible by the significant contributions of growers through both trial cooperation and the support of GRDC. The author James Manson would like to thank the following individuals for their continued support:

Southern Farming Systems	Paul Breust, Jon Midwood
Riverine Plains	Kate Coffey
Mackillop Farm Management Group	Felicity Turner
FarmLink	Kellie Jones, Eva Moffatt
CSIRO Floreat	Dr Roger Lawes
GRDC	Dr Leigh Nelson, Dr Jason Emms

ISBN: 978-1-921779-93-0 (print)

ISBN: 978-1-921779-94-7 (online)

<https://grdc.com.au/harvest-weed-seed-control-for-the-southern-high-rainfall-zone/>

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COVER PHOTO:

Mature annual ryegrass seed heads standing in a wheat crop at Skipton, Victoria.
Photo: Paul Breust, SFS

PUBLISHED OCTOBER 2019

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Background

What is harvest weed seed control?

Harvest weed seed control (HWSC) is an umbrella term that refers to a range of technologies and practices that capture and destroy weed seeds at harvest. These include chaff carts, narrow windrow burning, chaff lining, chaff tramlining (chaff decks) and weed seed impact mills. While each of these technologies differ in the specific way that weed seeds are destroyed, they are all designed to capture weed seeds via the sieves during harvest operations and eliminate them before they can germinate in the following season.

Why should HWSC be taken seriously?

HWSC is an important tool to consider for weed management because it is a late-season cultural control tactic. Annual ryegrass (*Lolium rigidum*) is particularly difficult to control in the southern high rainfall zone (HRZ) because of the long growing season. In this region, annual ryegrass (ARG) continues to germinate into late winter, enabling it to avoid the residual activity of pre-emergent herbicides. Other than HWSC, there are few options for controlling this cohort of weeds.

Resistance to a range of important herbicides continues to develop in weed populations in the southern HRZ. Even if new herbicide options become available, any resistance to older products remains costly, both on-farm and to the agricultural sector. Incorporating cultural weed control options such as HWSC into integrated weed management (IWM) systems is essential to maintaining the lifespan of herbicides. HWSC can improve the level of weed control in an intensively cropped system and maintain the efficacy of chemical control options.

Of the range of cultural control options available, HWSC has received a lot of attention because it has been shown to be extremely effective. For example, weed seed impact mills can destroy 95 to 99 per cent of the seeds that enter the front of the harvester (Walsh et al. 2017). A study in WA showed that as much as 60 to 80 per cent of ARG seeds can be captured at harvest (Walsh et al. 2014). If most of these remaining seeds can be destroyed by HWSC then a significant reduction in ryegrass numbers will be achieved. This effect has been confirmed across Australia.

What are the critical factors for effective HWSC?

Four factors are generally considered essential for an effective HWSC strategy. The first relies on the efficacy of the technology itself. Weed seed impact mills and chaff carts can kill or remove nearly all weed seeds that are captured and other technologies can destroy the majority of the captured seeds, but efficacy may vary depending on environmental and harvest conditions. Information about specific technologies is available online. The GRDC and Australian Herbicide Resistance Initiative (AHRI) websites have useful resources and video content:

- <https://grdc.com.au>

- <https://ahri.uwa.edu.au/research/management/>

The second factor for HWSC efficacy is that it is essential that the targeted weed species retains its seed in the seed head after maturity, rather than shedding seed before harvest. The third critical factor is that the weed plant remains upright after maturity, keeping its seed head off the ground. The fourth factor is that the harvester must be set up properly to prevent weed seeds from being missed inside the machine.

Where the first factor is about the efficacy of the specific HWSC technology, the second, third and fourth factors relate to how much weed seed is captured by the harvester. Without an adequate capture rate HWSC will not be effective, regardless of the technology used.

Why should HWSC be studied in the southern HRZ specifically?

The southern HRZ is a unique agroecological region in Australia. Not only does it have a high yield potential, it is also cool with a longer growing season. Both characteristics may affect the role that HWSC should have in this region's farming systems.

It has been recommended that harvesters cut at 15 centimetres above ground height when using HWSC to maximise the amount of weed seeds captured (Walsh et al. 2014). However, high-yielding environments produce heavy stubble loads that hinder harvest operations. These environments also produce crops with large biomass that cause ARG plants to grow taller and develop seed heads higher above the soil surface (Walsh et al. 2018). This raises a question about the practicality of using HWSC in the southern region and whether it is necessary to cut as low as 15cm.

The southern HRZ's cool climate extends the growing season and, as a result, cereals are harvested through December and January (much later than in other parts of Australia). This may provide ARG with enough time to shed seeds before harvest. This is a critical question in understanding the efficacy of HWSC.

While research on HWSC has been conducted across Australia and in a range of rainfall zones, not as much has been done in the southern HRZ. It is uncertain if the findings from other parts of the country apply. This GRDC investment – Harvest weed seed control for the southern high rainfall zone – was undertaken to address this knowledge gap.



FIGURE 1 A Case IH 9120 header harvesting wheat.



FIGURE 2 Seed heads of an upright annual ryegrass plant in a mature wheat crop.

Project overview

The research project had three major components addressing three key questions. Together, these components will explain the role that HWSC should have in southern HRZ cropping systems.

1 Is HWSC effective? Small-plot experiments were conducted in Victoria (Lake Bolac, Rutherglen, Yarrawonga), SA (Conmurra) and Tasmania (Cressy) from 2015 to 2017. All trials except for Rutherglen were conducted for two to three consecutive years on the same experimental plots. Sowing date, crop cultivar choice and harvest cut height were hypothesised to affect the efficacy of HWSC. HWSC was simulated by catching all harvest trash from plot headers and taking it off-site (Figure 3).

2 Is HWSC practical? On-farm trials were conducted from 2015 to 2017 in Victoria, SA and southern NSW to test the practicality of using some available HWSC technologies, ground-truth their efficacy and measure operating costs.

3 Is HWSC profitable? The data from these trials was pooled to recalibrate a farm systems model called LUSO (Lawes and Renton 2010), which was used to explore the long-term economic impact of adding HWSC to a wheat/barley/canola rotation.



FIGURE 3 Plot harvester with a bulker bag attached to capture harvest trash, simulating HWSC.



FIGURE 4 A prototype weed seed impact mill used in on-farm trials in 2015.

How effective is HWSC in the southern HRZ?

Key messages

- A realistic target for ARG seed capture in cereals in the southern HRZ is 30 per cent
- 50 per cent of ARG seeds shed before cereals are harvested
- 20 per cent of ARG seeds are below a 15cm or 30cm harvest cut height
- HWSC is a useful tool that can help control, but not drastically reduce, ARG numbers

The efficacy of HWSC and the key issues

This research showed that a realistic target for ARG seed capture at harvest of cereals in the southern HRZ is 30 per cent. This is in contrast to a capture rate of about 70 per cent for ARG observed in other parts of the country. The value of 30 per cent is based on the rate of seed capture that was calculated for every plot

from every treatment in every trial site from 2015 to 2017 and the median value of this dataset being 29 per cent. The rate of seed capture was highly variable, with half of the data falling between a capture rate of 46 per cent and 10 per cent.

The lower capture rate was caused by two key issues. The first and most important issue was that 51 per cent of the ARG seed had shed before harvest of wheat or barley. Again, there was a high degree of variability in the amount of seed shed before harvest, but a bell curve can be seen in Figure 6 that peaks about 50 per cent.

The harvest dates for each small-plot trial are presented in Table 1. The harvest dates range from 4 December to 5 January of a given trial year and are representative of the region. ARG seed shedding was observed from late November and through December.

The second cause of the low seed capture rate was that about 20 to 25 per cent of the ARG seed that was still attached to the seed head was located below both a 15cm and 30cm harvest cut height, with no significant difference between the two heights (see next section for more information). This resulted from either the ARG stalk having lodged and fallen to the ground or from the seed head breaking off the ARG stalk.

TABLE 1 The development of annual ryegrass in small-plot experiments in the southern HRZ.

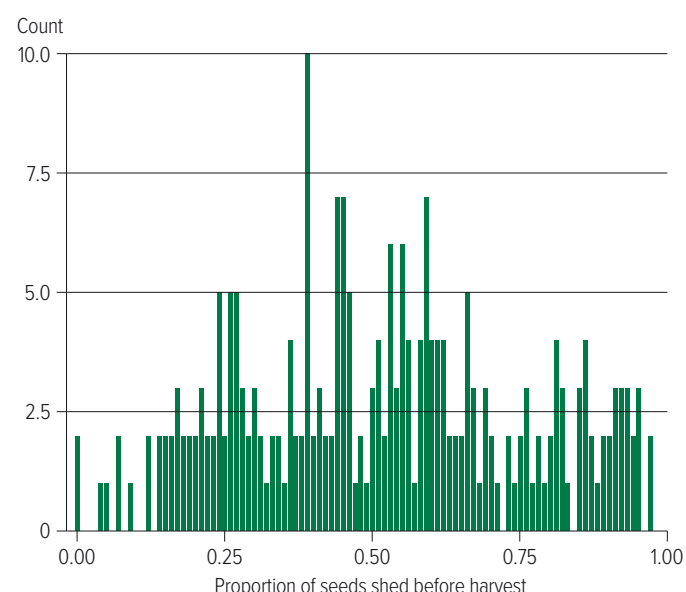
Site	Year	Crop sowing date(s)	ARG mid-anthesis	First recorded ARG shedding	Crop harvest date
Conmurra	2015	15 May, 3 June, 26 June	28 October	—	22 December
Lake Bolac	2015	20 April, 15 May, 17 June	—	26 November	4 Dec (TOS1) or 23 Dec (TOS2,3)
Conmurra	2016	17 May	23 November	19 December	4 January
Lake Bolac	2016	25 May	21 November	30 November	23 December
Yarrawonga	2016	28 April	—	11 November	11 December
Cressy	2016	12 April, 10 May	—	15 December	5 January
Conmurra	2017	22 May	10 November	24 November	4 January
Yarrawonga	2017	12 May	—	10 November	10 December

TOS – time of sowing

FIGURE 5 The location of small-plot experiments (green) and on-farm trials (orange) that were part of the research project.



FIGURE 6 The distribution of seed shedding rates in small-plot experiments in the southern HRZ.



The impact of HWSC in a southern HRZ cropping system

The ability to capture and destroy 30 per cent of ARG seeds, although lower than the rate observed elsewhere, is nevertheless substantial. It is therefore still worth considering the long-term impact of adding HWSC to a cropping system in the southern HRZ.

Method

The data from the research was pooled and used to adjust a farming systems model called LUSO. This model was used to examine the long-term impact of adding HWSC to 12 years of a wheat/barley/canola rotation under four scenarios. The scenarios were based on whether there was a low or high starting weed burden and whether herbicides were effective. The low starting weed burden was 100 seeds/m², resulting in approximately 15 plants/m² in late winter; the high starting weed burden was 500 seeds/m² or approximately 75 plants/m² in late winter. 'Effective herbicide' use was represented by killing 95 per cent of ARG plants before harvest, the standard LUSO value, and 'ineffective herbicide' use (whether due to reduced application efficacy or herbicide resistance) was represented by 90 per cent of ARG plants killed before harvest. The HWSC technology examined was a weed seed impact mill (WSM) because its high efficacy is well established.

Results

After 12 years, a similar pattern in ARG control was observed when the starting seedbank was 100 or 500 seeds/m² (see Figure 7). Populations increased exponentially if only 90 per cent of weeds were killed by herbicides and a WSM was not used. Adding a WSM to this 'ineffective herbicide' situation significantly reduced weed population growth but the final number of weed seeds in the seedbank still grew after 12 years. Increasing herbicide efficacy to 95 per cent of ARG weeds killed, the default LUSO value, largely achieved this on its own. Only when the weed kill rate was 95 per cent and a WSM was used did ARG numbers decline in absolute terms – by about 30 per cent over 12 years.

Discussion

This modelling work shows that by itself HWSC cannot drastically reduce ARG numbers in the way that has been reported in other parts of the country. However, it does reduce ARG population growth; alongside effective herbicides, it can degrade ARG numbers over time. This means that HWSC cannot act as an 'emergency handbrake' for weed control in the southern HRZ. It will not by itself bring ARG numbers under control. This was confirmed in the small-plot trials where the herbicide programs were not intended to achieve maximum control of ARG and the weed numbers remained constant or increased over two to three years. However, by reducing the potential weed seedbank by 30 per cent each year, HWSC assists weed control, acting as an additional way to put pressure on the normal 'footbrake' of weed control in cropping systems.

FIGURE 7 Final seedbank after 12 years of a wheat/barley/canola rotation with 90% or 95% of weeds killed by herbicides and with/without a weed seed impact mill (WSM), starting at 100 seeds/m² or 500 seeds/m².

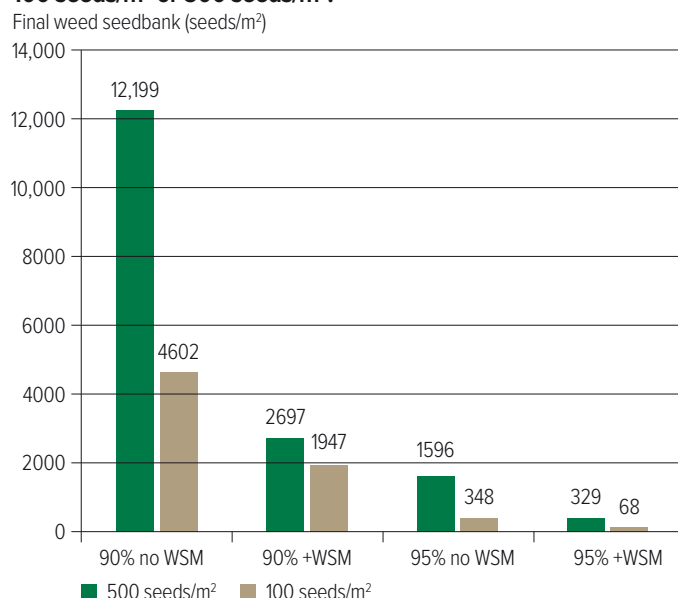


FIGURE 8 Annual ryegrass seed on the soil surface after shedding.



FIGURE 9 Annual ryegrass seed captured in a small-plot experiment to measure the degree of seed shedding.

Can the efficacy of HWSC be increased?

Key messages

- The growing season in the southern HRZ is too long to prevent significant amounts of ARG seed shedding before typical cereal harvest dates, so focus on maximising crop yield potential.
- In a crop with large biomass a harvest cut height of 30cm may be as effective as 15cm, so consider a slightly higher cut height when using HWSC in bulky crops.

High ARG weed numbers (100 plants/m²) were not brought under control by HWSC in the small-plot experiments after two or three years. Further, no experimental treatments that were hypothesised

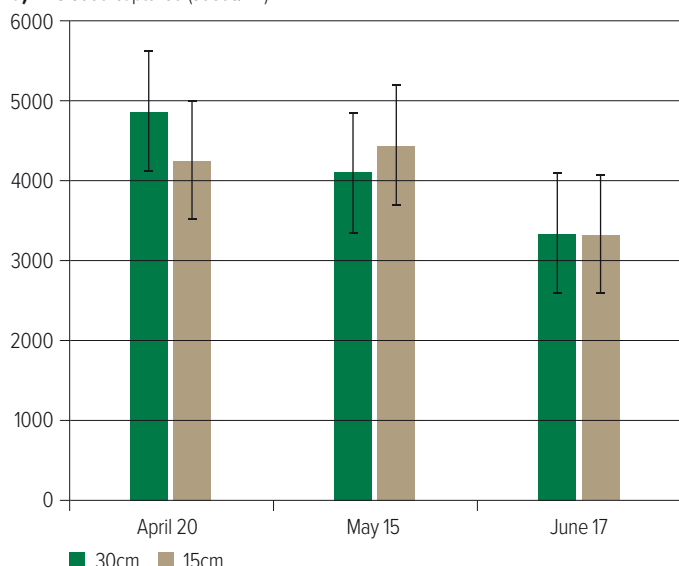
to improve HWSC reduced ARG germination in the following year. This was true of all trial sites across trial years.

Case study – Lake Bolac, Victoria, 2015

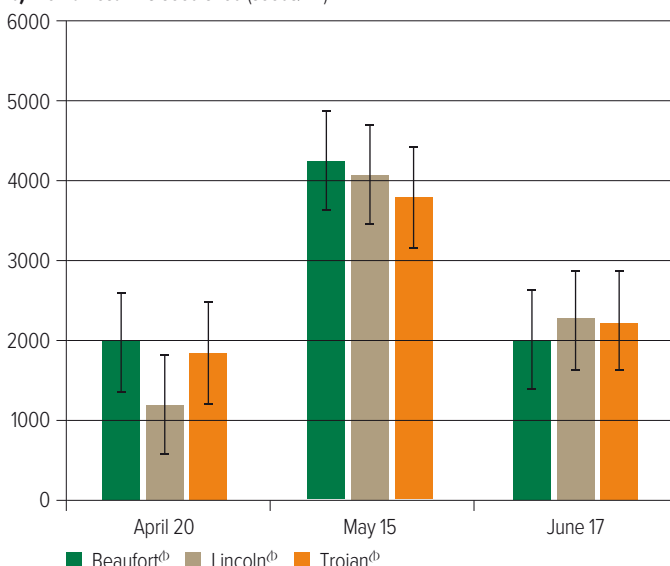
The data from Lake Bolac in 2015 can be taken as a case study for the research project. This experiment tested the interaction of sowing date (20 April, 15 May, 17 June), crop cultivar (LongReach Beaufort[®], LongReach Lincoln[®], LongReach Trojan[®]) and harvest cut height (15cm, 30cm) for the efficacy of HWSC. It was hypothesised that a later sowing date might delay ARG maturity and therefore reduce shedding, and a low cut height of 15cm instead of 30cm might increase the amount of seed captured for

FIGURE 10 Data from a small-plot experiment at Lake Bolac in 2015: a) the number of ARG seeds captured, relative to time of sowing and cut height; b) the number of ARG seeds shed before harvest, relative to time of sowing and variety; c) the proportion of ARG seed shed before 4 December, relative to time of sowing and variety; d) the proportion of ARG seed shed before harvest, relative to time of sowing and variety.

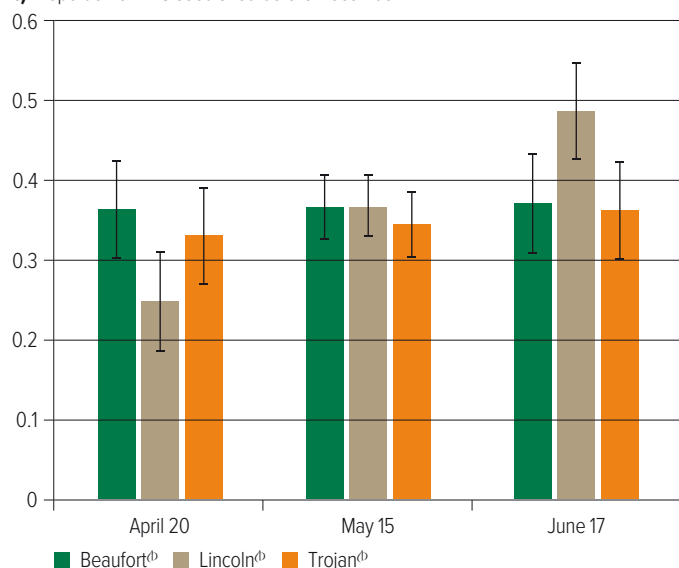
a) ARG seed captured (seeds/m²)



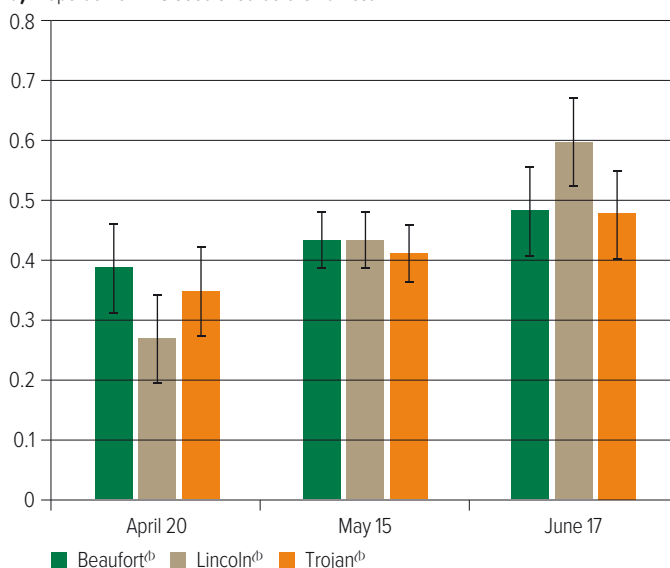
b) Pre-harvest ARG seed shed (seeds/m²)



c) Proportion of ARG seed shed before December 4



d) Proportion of ARG seed shed before harvest



HWSC. The 20 April treatments were harvested on 4 December, and the 15 May and 17 June treatments were harvested on 23 December.

On average 2600 ARG seeds/m² were shed before harvest (see Figure 10b). The sowing date had a significant impact on ARG establishment in that year, where there were 125 weeds/m² in the 15 May treatments compared with 21 or 34 weeds/m² in the 20 April or 17 June treatments. This was the result of the different timings of pre-emergent herbicides.

The difference in weed numbers is reflected in the difference in total seeds shed. Delayed sowing did not change ARG development to reduce shedding – a similar proportion of seeds were shed from the start of shedding until 4 December (the first harvest date) for all treatments. Harvesting earlier, on 4 December as opposed to 23 December, may have slightly reduced the total amount of shedding by preventing the shedding that occurred in December (see Figure 10d).

A low harvest cut height of 15cm did not increase ARG seed capture compared with a 30cm cut height in any sowing date treatment. There was no interaction between cut height and sowing date despite the fact that crop height was reduced by delayed sowing, as was crop yield (data not presented). Because of the effect of ARG seed shedding, and without significant treatment effects, the number of seeds captured for HWSC was similar between treatments (Figure 10a).

Research findings

The results from the Lake Bolac trial are typical for the project:

- Sowing date affected ARG establishment because of how the timing of the herbicide applications related to ARG germination events (effects that disappeared by harvest in several trials).
- Large amounts of seed were shed before harvest, regardless of sowing date.
- Weed seed capture was slightly better with earlier harvest dates.
- The 15cm harvest cut height did not improve ARG seed capture compared with 30cm.

Two things can be learned from these trends. First, the growing season is too long to prevent ARG seed shedding before the typical harvest dates of cereals. At Lake Bolac, delaying sowing as late as June did not compress the growing season enough to delay ARG development and reduce seed shedding. Second, a harvest cut height of 30cm may be as effective as 15cm in the southern HRZ. It has been shown that competition from vigorous crops increases the height at which ARG seeds are located in the canopy, therefore improving HWSC. Given the high productivity of the southern HRZ, this is likely to be the reason there was no long-term significant difference between a 15cm and 30cm cut height for ARG control. Cutting higher at 30cm might also increase harvest efficiency where there are heavy stubble loads, reducing the extra costs associated with HWSC.



FIGURE 11 Stubble remaining after a 15cm (left) or 30cm (right) harvest cut height in a small-plot experiment at Lake Bolac.

Is HWSC profitable in the southern HRZ?

Key messages

- Despite only capturing 30 per cent of ARG seeds, the extra costs of HWSC can still be justified for farm businesses in the southern HRZ.
- Where weeds are under control, HWSC must incur less than \$34/ha in extra costs to be profitable.
- The profitability of HWSC in the southern HRZ is driven by the region's high yield potential.

The question

Data from the small-plot experiments and on-farm trials were used to modify a farming systems model called LUSO for the southern HRZ to explore HWSC's potential profitability. To be assessed properly, the question, 'Is HWSC profitable in the southern HRZ?' needs to be viewed in a long-term time frame. HWSC does not increase the gross margin for the season that is being harvested; its benefits will be seen in later years.

Further, when HWSC is added to a farming system it will change the following year's weed germination with flow-on effects to weed numbers throughout the rotation. The question also has its complexities. Many factors affect weed survival and reproduction. To answer the question, therefore, a scenario analysis of the long-term effect of HWSC on farm profit is needed. This is provided by the modified LUSO, making it possible to demonstrate how HWSC might fit into southern HRZ farming systems.

Method

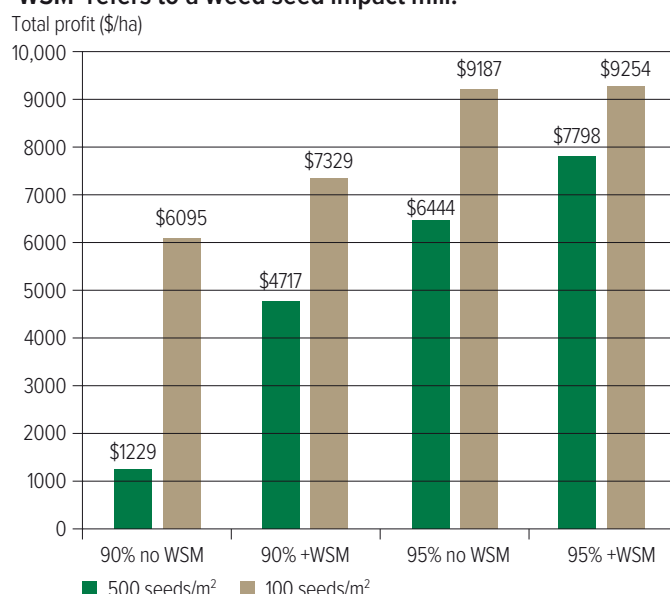
The consequence of adding a weed seed impact mill (WSM) to a farming system was examined alongside two factors: initial weed burden and herbicide efficacy. A low starting point is represented by 100 seeds/m², or about 15 ARG plants/m² in late winter, and a high starting burden is represented by 500 seeds/m², or about 75 ARG plants/m² in late winter. Ineffective herbicides are represented by 90 per cent of weeds killed mid-season, whereas effective herbicides are represented by 95 per cent of weeds killed mid-season, the default LUSO value.

In 2017, an on-farm demonstration was conducted at Wolseley, SA, comparing two New Holland CR8090 headers – one with an integrated Harrington Seed Destructor (iHSD) and one without. Wheat was harvested at 15cm with both machines and the extra cost of running the WSM was estimated at \$34/ha. This is comparable to the value estimated by the Kondinin Group for a 6 tonnes per hectare crop (White, Guimelli and Saunders 2018). Grain prices are the long-term average grain prices from the Geelong port taken from the Grain and Graze 3 website, variable costs are based on the PIRSA Gross Margin Guide 2019, and other inputs were based on expert agronomic knowledge for the region (Table 2).

TABLE 2 Values used in LUSO for the economic analysis of a WSM in a 12-year wheat/barley/canola rotation.

Enterprise	Yield potential (t/ha)	Grain price (\$/t)	Variable cost (\$/ha)	N required (kg/ha)
Wheat + WSM	8	300	635	180
Wheat	8	300	600	180
Feed barley + WSM	8	260	585	150
Feed barley	8	260	550	150
Canola + WSM	3	580	635	100
Canola	3	580	600	100

FIGURE 12 Total profit after 12 years of a wheat/barley/canola rotation starting at 100 seeds/m² or 500 seeds/m². '90%' or '95%' refers to the number of weeds killed before harvest. 'WSM' refers to a weed seed impact mill.



Results

Total profit after 12 years of a wheat/barley/canola rotation was severely reduced when 90 per cent of weeds survived until seed set and no WSM was used under the 100 and 500 initial seeds/m² scenarios. For both initial seedbanks, adding a WSM significantly increased profit when herbicides were ineffective, but effective herbicides recovered profit to an even greater degree. A difference occurred in profit when 95 per cent of weeds were killed. When starting at 500 seeds/m² with 95 per cent of weeds killed by herbicides, adding a WSM increased profit, but when starting at 100 seeds/m² there was only a small profit gain (Figure 12).

Discussion

This modelling shows that even more expensive HWSC technologies have a place in the farming systems of the southern HRZ if there is a pre-existing weed problem. By 'weed problem', it is meant that either herbicides have lost some efficacy due to resistance (90 per cent of weeds are killed instead of 95 per cent) and/or the initial weed burden is high.

However, when herbicides were effective (95 per cent of weeds killed) and the initial weed burden was low (initial seedbank of 100 seeds/m²) using a WSM did not significantly increase profit over 12 years. Another way of looking at this is that for a farming system where weeds are under control, the HWSC technology used must be \$34/ha or less in extra costs to have a place in a farm business.

This rough break-even point applies to WSMs and other HWSC technologies that remove 95 to 99 per cent of captured weed seeds. The break-even point of extra costs is lower for technologies that are less effective (increasing their need to be affordable), but higher if there is a pre-existing weed problem (making it easier to justify extra costs).

It must be noted that the models of the WSMs used in this research program from 2015 to 2017 will be replaced by improved technology. Improved WSM models that reduce extra harvest costs will make it likely that they will cost significantly less than \$34/ha. Further, most HWSC technologies are cheaper than WSMs so other HWSC options may have a place in southern HRZ farm businesses. It is essential to accurately understand the effectiveness of weed control, the extra costs of each technology considered and to pay special attention to the reduction in harvest speed any may cause.

The importance of a high yield potential

It is surprising that even though only 30 per cent of ARG seed was available for capture in the southern HRZ, HWSC was still profitable in the long term in several situations. Even extra costs of \$34/ha could be justified in a weedy paddock or where there was herbicide resistance. The reason is that although HWSC achieves lower weed control in the southern HRZ, weed control is worth more in the southern HRZ than might be expected.

The small-plot experiments established that a given number of weeds reduces crop yields by the same percentage value in the high rainfall zone as they do in the low rainfall zone. If there are 50 ARG plants/m², it will cause a yield penalty of about 10 per cent to the yield potential. Where the yield potential is 3t/ha, this weed burden reduces yield by 0.3t/ha. If the yield potential is 6t/ha, the same number of weeds reduces yields by 0.6t/ha.

Therefore, because of the high yield potential, the southern HRZ has more to gain per weed controlled than the LRZ in terms of yield and income. It is for this reason that the extra costs of HWSC can be justified in a southern HRZ farming system despite being less effective than in other parts of the country.



Conclusion: How should HWSC be used in the southern HRZ?

Findings

By itself, HWSC only decelerates the population growth of ARG in the southern HRZ. HWSC must be combined with consistently effective herbicides and other weed management options to reduce weed numbers in absolute terms, and even then the reduction in ARG seedbanks will be small and slow. However, with an efficacy of 30 per cent, a weed seed impact will decelerate ARG population growth in every LUSO-modelled scenario.

It is difficult to increase the efficacy of HWSC. In small-plot trials, sowing date, crop cultivar and a 15cm harvest cut height did not increase HWSC efficacy. In a long-season environment where cereal harvest does not start before December, there is little that can be done to delay ARG development and reduce shedding. In a high-yielding environment, crop biomass forces ARG to grow taller, reducing the need for very low harvest heights.

HWSC is valuable to farm businesses because the high yield potential of the southern HRZ drives a high return for weed control, making HWSC more valuable than might be anticipated.

The profitability of an expensive HWSC technology depends on several factors. In weed-free paddocks with no herbicide resistance HWSC, must cost less than \$34/ha in extra costs. If weed numbers are not under control, the technology can cost much more than this and still be profitable.

Implications

Since there is a high return for weed control in the southern HRZ, HWSC has a place in its farming systems. With only 30 per cent of ARG seeds available for capture at harvest, HWSC cannot be relied upon in the southern HRZ to drastically reduce ARG numbers. However, HWSC can support IWM packages by decelerating ARG population growth.

Given that expensive HWSC options (\$34/ha) do not contribute to farm profitability when weeds are already under control, a strategic approach to HWSC may be needed.

Given that no experimental treatments increased the efficacy of HWSC, effort should be made to maximise yield potential and it may be unnecessary to cut lower than 30cm at harvest in an average year.

Recommendations

- Consider adding HWSC to IWM packages for the southern HRZ.
- Take a strategic approach to HWSC. Find ways to reduce the operating costs of HWSC technologies, consider only using expensive HWSC options on problem paddocks and consider only using cheaper options in clean paddocks with low resistance levels.
- Maximise yield and crop biomass to reduce the need to cut low at 15cm. Early sowing of appropriate high-yielding cultivars and cutting at 30cm was the best option in small-plot trials.
- Estimate the extra costs associated with HWSC before investing. Consider the efficacy on the target weeds, extra fuel usage, extra wear-and-tear costs and depreciation. Any decrease in harvest speed caused by a HWSC technology should be carefully estimated.

HWSC is not an 'emergency handbrake' for weed control in the southern HRZ. Rather, it is a 'footbrake' that helps decelerate weed population growth.



APPENDIX

References and further reading

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Useful links

- <https://weedsmart.org.au/the-big-6>
- <https://ahri.uwa.edu.au/hwsc-cost>
- <https://ahri.uwa.edu.au/chaff-lining-too-good-to-be-true>

Notes

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