

Weed control

Key messages

- Cereal rye is extremely competitive and has an aggressive root system, so it competes well against weeds.¹
- Because cereal rye matures earlier than other cereal crops, strict harvest and grazing-management procedures are important to prevent it from becoming a weed.²
- Consider Integrated Weed Management (IWM) practices when controlling weeds.
- When selecting a herbicide, it is important to know the crop growth stage, weeds present and plant-back period. Herbicides must be applied at the correct stage of crop growth, or significant yield losses may occur.
- Check product labels for up-to-date registrations and application methods.
- Use practices that minimise the risk of development of herbicide resistance.

Weeds such as annual ryegrass (Photo 1) are estimated to cost Australian agriculture AU\$2.5–4.5 billion per annum. For winter cropping systems alone, the cost is \$1.3 billion. Consequently, any practice that can reduce the weed burden is likely to generate substantial economic benefits to growers and the grains industry.



Photo 1: Annual ryegrass (*Lolium rigidum*) is one of the most problematic weeds in Australia (left).

Source: [FarmPress](#)

6.1 Cereal rye: a weed suppressor

Rye is one of the best cool-season crops for outcompeting weeds, especially small-seeded, light-sensitive annuals (Photo 2). Weed biomass has been found to decrease with increasing rye residue, with weeds completely suppressed at residue levels over 1500 g per m².³ Rye can effectively suppress weeds by shading, competition and allelopathy.

Based on research from southern New South Wales, the competitiveness of crops against annual ryegrass populations at 300 plants per m² was in the order oats > cereal rye > triticale > oilseed rape > barley > wheat > field pea > lupin.⁴

¹ UVM Extension Crops & Soils Team (2011) Cereal rye. Northern Grain Growers Association. <http://northerngraingrowers.org/wp-content/uploads/RYE.pdf>

² Atlas of Living Australia. Ryecorn, <http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2905471>

³ MR Ryan, SB Mirsky, DA Mortensen, JR Teasdale, WS Curran (2011) Potential synergistic effects of cereal rye biomass and soybean planting density on weed suppression. *Weed Science* 59, 238–246.

⁴ D Lemerle, B Verbeek, N Coombes (1995) Losses in grain yield of winter crops from *Lolium rigidum* competition depend on crop species, cultivar and season. *Weed Research* 35, 503–509.



Photo 2: Weed-free cereal rye paddock in Mallee trials.

Source: [Agronomy Matters](#)

IN FOCUS

Rye residues contribute weed suppression in no-tillage cropping systems

The use of allelopathic cover crops in reduced-tillage cropping systems may provide an ecologically sound and environmentally safe management strategy for weed control. Growers often plant winter rye for increased soil organic matter and soil protection. In a study in the United States, spring-planted living rye reduced weed biomass by 93% compared with plots without rye. Residues of autumn-planted–spring-killed rye reduced total weed biomass compared with bare-ground controls. Rye residues also reduced total weed biomass by 63% when poplar excelsior was used as a control for the mulch effect, suggesting that allelopathy, in addition to the physical effects of the mulch, did contribute to weed control in these systems. In greenhouse studies, rye root leachates reduced tomato dry weight by 25–30%, which is additional evidence that rye is allelopathic to other plant species.⁵

6.1.1 Allelopathic effects

Cereal rye produces several compounds in its tissues and releases root exudates that apparently inhibit germination and growth of weed seeds. These allelopathic effects, together with cereal rye's ability to smother other plants with cool weather growth, make it a good choice for weed control (Photo 3).

However, allelopathic compounds may also suppress germination of small-seeded vegetable crops as well if they are planted shortly after the incorporation of cereal rye residue. Large-seeded crops and transplants rarely are affected. There is some evidence that the amount of allelopathic compounds in tillering plants is lower than in seedlings.⁶

⁵ JP Barnes, AR Putnam (1983) Rye residues contribute weed suppression in no-tillage cropping systems. *Journal of Chemical Ecology* 9, 1045–1057. doi:10.1007/BF00982210

⁶ V Grubinger (2010) Winter rye: A reliable cover crop, <https://www.uvm.edu/vtvegandberry/factsheets/winterrye.html>



Photo 3: Field trial on allelopathic cover crops preceding a tomato crop in a biological farm. Left panel: Plot with rye mulch left on the soil surface, showing the good weed suppression ability. Right panel: Control plot without cover crop, split in two treatments: left side, untreated subplot in which tomato plants are almost completely overgrown by weeds; right side, subplot with mechanical control by cultivations. ⁷

Source: Schulz et al. 2013

The allelopathic effects of rye have been shown in field and laboratory studies to inhibit germination of some triazine-resistant weeds (barnyard grass, willow herb, horseweed). ⁸

Rye was also found to reduce total weed density by an average of 78% when rye residue covered more than 90% of soil in a no-till study in Maryland, United States. ⁹

Growers can increase rye's weed-suppressing effect by planting rye with an annual legume. However, do not expect complete weed control, and complement with weed-management measures. Thick stands ensure excellent weed suppression. To extend rye's weed-management benefits of the rye, allow its allelopathic effects to persist longer by leaving killed residue on the surface rather than incorporating it. Allelopathic effects usually taper off after about 30 days.

After killing rye, wait three–four weeks before planting small-seeded crops. Rye seedlings have a greater quantity of allelopathic compounds than more mature rye residue. Allelopathic effects usually lasting about 30 days. Transplanted vegetables and larger seeded species, especially legumes are less susceptible to the allelopathic effects of rye. In one study, use of a mechanical under-cutter to sever roots when rye was at mid–late bloom, and leaving residue intact on the soil surface (as whole plants), increased weed suppression compared with incorporation or mowing.

If weed suppression is an important objective when planting a rye–legume mixture, plant early enough for the legume to establish well. If not, a pure stand is likely to work better. ¹⁰

CASE STUDY

Managing land classes for better feed utilisation

Location: Midgee, north of Cowell, South Australia.

⁷ M Schulz, A Marocco, V Tabaglio, FA Macias, JM Molinillo (2013) Benzoxazinoids in rye allelopathy—from discovery to application in sustainable weed control and organic farming. *Journal of Chemical Ecology* 39, 154–174.

⁸ T Przepiorkowski, SF Gorski (1994) Influence of rye (*Secale cereale*) plant residues on germination and growth of three triazine-resistant and susceptible weeds. *Weed Technology* 8, 744–747, https://www.istor.org/stable/3988190?seq=1#page_scan_tab_contents

⁹ JR Teasdale, CE Beste, WE Potts (1991) Response of weeds to tillage and cover crop residue. *Weed Science* 39, 195–199, http://www.istor.org/stable/4044915?seq=1#page_scan_tab_contents

¹⁰ A Clark (Ed.) (2007) Managing cover crops profitably. 3rd edn. SARE Outreach Handbook Series Book 9. National Agricultural Laboratory, <http://www.sare.org/publications/covercrops.htm>

SECTION 6 CEREAL RYE

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FEEDBACK

Aim: to increase soil cover for erosion protection on the site by fencing off the sandy rises to help manage grazing and establish an appropriate perennial pasture.

Because of the high risk of unfavourable conditions for pasture establishment on this site, perennial veldt grass was established over a two-year period. The paddock had been planted to wheat in 2010 and was left as a ley pasture paddock with summer weeds dominating during 2011.

In June, half of the paddock was sown with a mixture of Bevy cereal rye (20 kg/ha) and veldt grass (2 kg/ha) at 22.5 cm row spacings with 40 kg/ha of 18:20 fertiliser using a disc air-seeder and press-wheels. The remainder of the paddock was sown to 60 kg/ha wheat with 55 kg/ha of 18:20. Winter rainfall totaled only 150 mm prior to August and there was no rain received in the six weeks from August. Despite the low rainfall, the cereal rye and wheat grew very well. However, there was a very poor germination of veldt grass and the lack of rain, combined with moisture competition from the cereal rye, resulted in poor growth.

At harvest the wheat yield averaged 1.1 t/ha, and despite the low cereal rye seeding rate, it yielded ~0.6 t/ha (64 t of which was sold at \$282/t).

Despite competition for moisture from the cereal rye, a surprising amount of grass had survived. However, this was mostly in the areas that only had a low density of cereal rye. The plants that were present were very small and had suffered obvious moisture stress.

What problems were encountered?

The main problem was the limited establishment of perennial veldt grass. Although the cereal rye provided good protection for the soil against wind erosion, it was highly competitive. Where the cereal rye was the thickest; there was little or no veldt grass.

Actively growing cereal rye competed vigorously with the veldt grass for moisture. To minimise this competition it may be feasible to sow veldt grass into standing stubble, or if there is no stubble on the paddock, only sow the cover crop with a very light seeding rate (10 kg/ha) so the paddock is protected from wind erosion without the competition for moisture during the veldt grass establishment.¹¹

¹¹ Natural Resources SA (2014) Producer case study. Managing land classes for better feed utilisation. [Natural Resources SA, http://www.naturalresources.sa.gov.au/files/e7e04254-1bae-4763-9400-a38700980519/managing-land-classes-for-better-feed-utilisation-walsh-case-study-gen.pdf](http://www.naturalresources.sa.gov.au/files/e7e04254-1bae-4763-9400-a38700980519/managing-land-classes-for-better-feed-utilisation-walsh-case-study-gen.pdf)

Remove cereal rye early to avoid problems from its allelopathic effect

The decaying green substance ('ooze') from cereal rye, rather than the herbicide used to kill the rye, can create problems for germinating grasses (e.g. maize) (Photo 4). This toxic effect of the dying rye makes it a good cover-crop choice for organic producers. A good rye stand reduces weed problems while it is growing. Producers then roll down the rye to terminate it (no herbicide is used) and then plant their broadleaf crop. The decaying rye affects the germinating grasses, greatly reducing grass weed pressure while the crop is becoming established. The cover provided by the rye also reduces weed pressure by providing a mulch and by keeping the sun off the soil surface until the crop canopy forms.

When using a cereal rye cover crop in a no-till situation, it is preferable to spray out the rye two–three weeks before planting maize, so that the rye is brown before planting. Rye should not be sprayed out five–ten days before planting, assuming glyphosate is being used, because the rye will be decaying as the maize is germinating. For a shorter window before spraying and planting, use a different herbicide to kill the cereal rye more quickly so that it is dead and brown sooner.

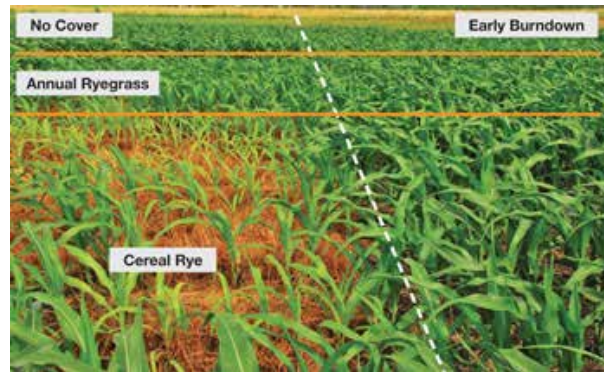


Photo 4: Effects of a late kill of cereal rye on maize plants. The impact appears to be from a combination of the carbon penalty and allelopathy exerted by the cereal rye.

Source: [AgWeb](#)

Some producers say that germination problems are minimal if there is no rain to leach the substance down to the germinating seed during this establishment time. Others report that the germination problems can be reduced by planting deeper.¹²

6.1.2 Volunteer rye

Volunteer rye may contaminate wheat, oats and barley.¹³

Rye is not always a tall, robust plant, and under stressful conditions, such as those found in tilled and chemical fallow fields, grassy field edges and roadsides, it can still grow and produce seed despite only attaining heights of less than 25 cm (Photo 5).

¹² P Jasa P (2012) Kill rye early to avoid problems from its allelopathic effects. Cropwatch. University of Nebraska, <http://cropwatch.unl.edu/kill-cereal-rye-early-avoid-problems-its-allelopathic-effect>

¹³ Manure \$ense (2009) Cereal rye: Manure and livestock's new best friend. Midwest Cover Crops Council, http://mccc.msu.edu/wp-content/uploads/2016/09/MI_2009_CerealRyeManure.pdf



Photo 5: Shorter stands of cereal rye can still produce seed heads.

Source: [NebGuide](#)

Preventative methods are a critical part of an IWM control system for volunteer rye. Eliminating potential seed sources for rye establishment is a priority.

To eliminate seed sources:

1. Plant clean seed. Volunteer rye seed is often found in cereal seed, especially winter wheat. It is difficult to separate volunteer rye seed from winter wheat seed; therefore, growers should be aware of their winter wheat seed source or buy only certified seed.
2. Destroy any volunteer rye before it produces seed. Rye may germinate as late as mid-April and still experience sufficient cold weather to vernalise and produce seed. Rye plants as short as 20 cm can produce viable seed.
3. Thoroughly clean combines before moving between paddocks.
4. Make sure that all rye is kept out of roadside ditches and other areas that may contaminate the fields. This task may be aided by covering all trucks transporting winter wheat grain.

Burning frequently results in soil erosion and has other adverse environmental impacts. Also, fire is usually not hot enough to kill a high percentage of volunteer rye seed. The amount of crop residue, the temperature, and the length of burn greatly limit fire as a potential weed-control method.¹⁴

Growers can improve winter wheat's competitiveness with volunteer rye by using cultural practices that stimulate rapid emergence and vigorous seedling growth. For example, deep-banding of nitrogen (N) fertiliser near wheat seeds at planting, planting larger sized wheat seeds, increasing wheat seeding rates, reducing wheat-row spacing, and planting taller wheat cultivars that tiller profusely are all cultural practices that have been reported to improve wheat's competitiveness with weeds.

Tillage or chemical control of volunteer rye during the fallow period can reduce subsequent populations in the winter wheat crop similarly over a two-year period.

Post-emergence, non-selective herbicides such as glyphosate or paraquat can control volunteer rye and other winter annual grasses found in fallow fields. Glyphosate and paraquat do not provide residual weed control; therefore, any volunteer rye plants that emerge after treatment will not be controlled. Both of these herbicides are inactivated on contact with soil, meaning that all weed plants should be emerged prior to application. The effectiveness of both herbicides on volunteer rye decreases as plant size and maturity increase. Glyphosate is labelled for volunteer rye control in wheat as a wiper application. This technique requires at least a 25-cm height differential between the wheat and volunteer rye. Care must be taken

¹⁴ D Lyon, R Klein (2014) Rye control in winter wheat. University of Nebraska Extension, <https://web.archive.org/web/20140413144910/http://www.ianrpubs.unl.edu/pages/publicationD.jsp?publicationId=106>

to prevent any herbicide from contacting the wheat. Any herbicide that drops on or otherwise contacts wheat will result in death.¹⁵

6.2 Integrated weed management

The Grains Research and Development Corporation (GRDC) supports IWM, which is a system for managing weeds over the long term, particularly the management and minimisation of herbicide resistance. There is a need to combine herbicide and non-herbicide methods into an integrated control program. Given the additional costs associated with implementing IWM, the main issues for growers are whether it is cost-effective to adopt the system and whether the benefits are likely to be long-term or short-term in nature.

Download the [Integrated Weed Management Manual](#).

The IWM manual examines these issues and breaks them down into seven clear sections, assisting the grower in the development of an IWM plan.

Effective strategic and tactical options are available to manage weed competition that will increase crop yields and profitability. Weeds with herbicide resistance are an increasing problem in grain cropping enterprises. Industry and researchers advise that growers adopt IWM to reduce the damage caused by herbicide-resistant weeds.

The following five-point plan will assist in developing a management strategy in each paddock:

1. Review past actions and history.
2. Assess current weed status.
3. Identify weed-management opportunities.
4. Match opportunities and weeds with suitably effective management tactics.
5. Combine ideas into a management plan. Use of a rotational plan can assist.

An integrated weed management plan should be developed for each paddock or management zone.

In an IWM plan, each target weed is attacked by using tools from several tactic groups (see links below). Each tactic provides a key opportunity for weed control and is dependent on the management objectives and the stage of growth of the target weed. Integrating tactic groups reduces weed numbers, stops replenishment of the seedbank and minimises the risk of developing herbicide-resistant weeds.

IWM tactic groups:

- [Reduce weed seed numbers in the soil](#)
- [Control small weeds](#)
- [Stop weed seedset](#)
- [Practice hygiene—prevent weed seed introduction](#)
- [Use agronomic practices and crop competition](#)

Successful weed management also relies on the implementation of best agronomic practices to optimise crop growth. Basic agronomy and fine-tuning of the crop system are the important steps towards weed management.

Several agronomic practices can improve crop environment and growth, along with the crop's ability to reduce weed competition. These include crop choice and sequence, improving crop competition, planting herbicide-tolerant crops, improving pasture competition, and using fallow phases and controlled traffic or tramlining.¹⁶

¹⁵ S Miller, C Alford, W Stump. Feral rye: A serious threat to high quality wheat. University of Wyoming Extension, <http://www.wyoextension.org/agpubs/pubs/B1157.pdf>

¹⁶ DAFWA (2016) Crop weeds: Integrated Weed Management (IWM). Department of Agriculture and Food Western Australia, <https://www.agric.wa.gov.au/grains-research-development/crop-weeds-integrated-weed-management-iwm>

6.2.1 Five-point plan

1. Review past actions

Knowledge of the historical level of selection pressure can be valuable information to predict which weeds or Mode-of-Action (MoA) groups are at greatest risk in terms of resistance development. Such knowledge can prompt more intensive monitoring for weed escapes when a situation of higher risk exists. Picking up newly developing resistance issues while patches are still small, before they spread, can make a big difference to the cost of management over time.

From all available paddock records, calculate or estimate the number of years in which different herbicide MoAs have been used. The number of years in which a herbicide MoA has been used is of far greater relevance than the total number of applications. For most weeds, use of a herbicide MoA in two consecutive years presents a far greater selection pressure for resistance than two applications of the same herbicide MoA in the one year. If the entire paddock history is unavailable, record what is known and estimate the rest. Collate separate data on MoA use for summer and winter weed spectrums. Further subdivide these into broadleaf and grass weeds.

Account for double-knocks. Where survivors of the first tactic would have been largely controlled by the second tactic, reduce the number of MoA uses accordingly. For example, trifluralin (Group D) may have been used 20 times, but during six years, in-crop Group A selectives were used, and during several more years, in-crop Group B products targeting the same weed as the trifluralin were used. These in-crop herbicides effectively double-knocked the trifluralin, thus somewhat reducing the effective selection pressure for resistance to trifluralin.

Review the data you have collected and identify which weeds and MoA groups have been selected for at a frequency likely to lead to resistance in the absence of a double-knock. Trifluralin typically takes about 10–15 years of selection for resistance to occur (Table 1). Thus in the above example, a ‘watching brief’ would be in place for trifluralin and other Group D MoA herbicides.

Paddock history can also be useful information when evaluating the likely reasons for herbicide spray failures, in prioritising strategies for future use, and when deciding which paddocks should receive extra time for scouting to find potential patches of weed escapes.

Information on history of MoA use should be added to paddock records.

Table 1: Typical number of years of use to develop resistance to Mode-of-Action (MoA) groups.

MoA Group	Typical years of application	Resistance risk
A (fops, dims, dens)	6–8	High
B (SUs, IMIs)	4	High
C (triazines, subst. ureas)	10–15	Medium
D (trifluralin, Stomp®)	10–15	Medium
F (diflufenican)	10	Medium
I (phenoxies)	>15	Medium
L (paraquat, diquat)	>15	Medium
M (glyphosate)	>12	Medium

2. Assess the current weed status

Record the key broadleaf and grass weed species for summer and winter and include an assessment of weed density, with notes on weed distribution across the paddock. Include GPS locations or reference to spatial location of any key weed patches or areas tested for resistance.

Include any data, observations or information relating to the known or suspected herbicide-resistance status of weeds in this paddock.

Grass weed seeds can be submitted for herbicide resistance testing against the range of herbicides and herbicide groups. Growers can register and submit samples to [Plant Science Consulting](#) (all sampling information and instructions are available on the website). Growers should consider spending 1–2% of the chemical budget on herbicide resistance testing.

Add all of this this information to paddock records.

3. Identify weed management opportunities within the cropping system

Identify which different herbicide and non-herbicide tactics could be cost-effectively added to the system and where in the crop sequence these can be added. For information on the different integrated weed management tactics, see [IWM: Section 4: Tactics for managing weed populations.](#)

4. Fine-tune your list of options

Which are your preferred options to add to current weed-management tactics to add diversity and help drive down the weed seed bank?

5. Combine and test ideas

Computer-simulation tools can be useful to run a number of scenarios to investigate potential changes in management and the likely effect of weed numbers and crop yield. Two simulation tools being used are the [Weed Seed Wizard](#) and [RIM—Ryegrass Integrated Management](#).

Combine ideas by using a rotational planner, or test them by using decision support software such as RIM and/or Weed Seed Wizard.

Weed Seed Wizard

The Weed Seed Wizard helps growers understand and manage weed seedbanks on farms across Australia's grain-growing regions.

It is a computer simulation tool using paddock management information to predict weed emergence and crop losses. Different weed-management scenarios can be compared in order to show how different crop rotations, weed-control techniques, irrigation, grazing and harvest management tactics can affect weed numbers, the weed seedbank and crop yields.

The Wizard uses farm-specific information, and users enter their own farm-management records, paddock soil type, local weather and one or more weed species. The Wizard has numerous weed species to choose from including annual ryegrass, barley grass, wild radish, wild oat, brome grass and silver grass in the southern states, and liverseed grass, barnyard grass, paradoxa grass, feathertop Rhodes grass, bladder ketmia, fleabane, sowthistle, sweet summer grass, cowvine, and bellvine in the north.

MORE INFORMATION

[Weed seed wizard](#)

i MORE INFORMATION

AHRI: [Ryegrass Integrated Management](#)

▶ VIDEOS

WATCH: Managing herbicide resistant ryegrass with IWM.



Ryegrass integrated management

RIM provides insights into the long-term management of annual ryegrass in dryland broadacre crops facing development of herbicide resistance. RIM enables alternative strategies and tactics for ryegrass management to be compared for profit over time and impact on weed numbers. The software's underlying model integrates biological, agronomic and economic considerations in a dynamic and user-friendly framework, at paddock scale and over the short and long term.

The tool tracks the changes through time on a 10-year crop cycle for ryegrass seed germination, seed production and competition with the crop. Financial returns are also estimated annually and as a 10-year average return.

RIM allows you to try out many different combinations of weed treatments and observe their predicted impacts on ryegrass populations, crop yields and long-term economic outcomes. A wide variety of chemical and non-chemical weed treatment options are included, so that as chemicals are lost to herbicide resistance, the next best substitute can be identified.

To do this by trial and error in the real world, rather than in a computer simulation, would take many years and may leave farmers with a major weed problem they could have avoided. With RIM, farmers and others can conduct virtual experiments with a vast range of treatment options before they put real dollars at risk.

RIM can help farmers to tackle questions such as:

- How much income will I lose once resistance develops?
- Which combination of strategies provides the best overall system once resistance is present?
- Is it worth trying to delay the onset of resistance by using herbicides less frequently?
- Is it economically viable to maintain a continuous cropping rotation once resistance is present?
- If a pasture phase is included, how long should it be?

6.2.2 IWM in the Southern Region

Grain growers in Victoria, South Australia and Tasmania can beat costly weeds by driving down the weed seedbank through an aggressive 'stacked' approach. By combining five essential measures and repeating the exercise year after year, growers can run down seedbanks even when experiencing high levels of herbicide resistance on their farms.

Very high weed seedbanks can be eroded to low, near-zero levels by committing to a simple strategy. The components of a successful strategy are:

1. A double knock of herbicides.
2. Mixing and rotating chemicals.
3. Competitive crops.
4. Stopping seedset.
5. Harvest weed-seed control (HWSC).

Double-knock is not so much about the seedbank but preserving the usefulness of glyphosate. If double-knock is implemented every year, glyphosate resistance should not be an issue. However, if glyphosate resistance is already present and you try to double-knock, you are essentially applying a single knock of paraquat, and then

paraquat resistance will arise. The best time to start using a double-knock strategy is before any glyphosate resistance.

It is also important to use herbicide mixtures. If two herbicides are mixed together at full rates, then a weed that is resistant to one product will be killed by the other product before seedset, because it is almost impossible for a weed to have two resistance mechanisms before herbicide selection pressure has occurred.

Crop competition involves four aspects—seeding rate, row spacing, orientation and cultivars. Growers need to adopt appropriate recommendations for at least one (preferably two) of these, in terms of encouraging crop competition.

HWSC has been a focus of research and development efforts of the Australian Herbicide Resistance Initiative (AHRI). Several options are available, depending on the situation:

- In mixed farming systems with sheep, using a chaff cart for HWSC is recommended.
- For continuous croppers in high-production areas, the Harrington Seed Destructor is recommended.
- Putting chaff on tramlines is cheap and there is nothing to do after harvest.
- Chaff-lining is another option, leaving it in the windrow to rot.
- Windrow burning is a popular option, with more people windrow-burning than any other HWSC activity, but it does have issues. The other HWSC tools can be used in every crop every year, but that is not always the case with windrow burning.
- Bale direct involves towing a baler behind the harvester. This is a good option where a large market for straw bales exists close to the farm.

Competitive crops improve HWSC. Competitive crops support the ryegrass and other weeds so that they can be caught in the header. HWSC works better on low-density ryegrass. If the seedbank is low and HWSC is used, it is particularly effective.

Many weeds are becoming more dormant. Later germination, which avoids knock-down and pre-emergent herbicides, is being selected in weeds such as ryegrass, barley and brome grasses. However, it can be an advantage to growers because a competitive crop can be sown early to compete with the weeds.

When all components of weed-seed management are stacked together and growers commit to the regime for at least six years, the outcome can be dramatic.¹⁷

South Australian Weed Control app

The free [South Australian Weed Control app](#) provides essential information about the control of weeds declared in South Australia under the Natural Resources Management Act 2004. It is produced by Biosecurity SA in partnership with the eight Natural Resource Management regions.

The app includes:

- control recommendations for >132 declared plants
- chemical and non-chemical treatments
- information on the safe use of herbicides
- colour photographs of each species for identification.

The app provides information from the [Weed Control Handbook for Declared Plants in South Australia](#).

In addition, app users can:

- record the location of weeds
- keep a personal log of control activities
- phone or email regional Natural Resource officers

¹⁷ S Watt (2016) Odds of beating weeds stacked in favour of grain growers. GRDC Media Centre, March 2016, <https://grdc.com.au/Media-Centre/Media-News/South/2016/03/Odds-of-beating-weeds-stacked-in-favour-of-grain-growers>

i MORE INFORMATION

PIRSA: [Weed control handbook for declared plants in South Australia.](#)

PIRSA: [Declared plants in SA—are they on your land?](#)

PIRSA: [SA weed risk management guide.](#)

- send photos and text of high-risk weeds.

The app is updated annually as chemical uses and plant declarations change.

Download app from [Google Play \(for Android devices\)](#) or iTunes App Store.

6.2.3 Cover cropping for weed management

The critical period for weed suppression by the cover crop is typically the first 30 days of cover-crop growth. A cover crop's ability to suppress weeds is generally correlated with the cover crop's early season biomass production rather than its biomass at maturity. Cover crops such as cereal rye maximise light interception with a dense canopy early in the season are the best at suppressing weed growth and weed-seed production (Photo 6).¹⁸

IN FOCUS

Overcoming weed management challenges in organic rotational no-till soybean production based on cover cropping

Organic rotational no-till soybean production based on cover cropping has attracted attention from farmers, researchers, and other agricultural professionals because of the ability of this system to enhance soil conservation, reduce labor requirements, and decrease diesel fuel use compared to traditional organic production. This system is based on the use of cereal rye cover crops that are mechanically terminated with a roller-crimper to create *in situ* mulch that suppresses weeds and promotes soybean growth. This study reports on experiments conducted in the United States on cover crop-based organic rotational no-till soybean production, and outlines current management strategies and future research needs. The study focused on maximising spring groundcover and biomass of cereal rye because of the crucial role of this cover crop in weed suppression. Soil fertility and timing of cereal rye sowing and termination affect biomass production, and these factors can be manipulated to achieve levels less than 8,000 kg/ha, a threshold identified for consistent suppression of annual weeds. Cereal rye seeding rate and seeding method also influence groundcover and weed suppression. In general, weed suppression is species-specific, with early-emerging summer annual weeds, high weed seedbank densities (e.g. 10,000 seeds/m²) and perennial weeds posing the greatest challenges. Because of the challenges of maximising the weed-suppression potential of cereal rye, the practice of high-residue cultivation may be an additional means to improve weed control. In addition to cover crop and weed management, progress has been made with planting equipment and planting density for establishing soybean into a thick cover-crop residue. Future research will focus on integrated multi-tactic weed management, cultivar selection, insect pest suppression, and nitrogen management as part of a systems approach to advancing this new production system.¹⁹

¹⁸ R Smith, RL Bugg, M Gaskell, O Daugovish, M Van Horn (Eds) (2011) Cover cropping for vegetable production: a grower's handbook. Publication no. 3517. UCANR Publications.

¹⁹ SB Mirsky, MR Ryan, JR Teasdale, WS Curran, CS Reberg-Horton, JT Spargo, JW Moyer (2013) Overcoming weed management challenges in cover crop-based organic rotational no-till soybean production in the Eastern United States. *Weed Technology* 27, 193–203. <http://www.bioone.org/doi/abs/10.1614/WT-D-12-00078.1>

VIDEOS

WATCH: [Over the Fence: IPM delivers 'unexpected' pest control benefits.](#)



Photo 6: Effect of seeding rate on weed suppression of a 90% legume and 10% cereal rye mixed cover crop. The higher seeding rate (left) was more effective in suppressing weeds than the lower seeding rate (right), which saw the emergence of weeds.²⁰

Source: Smith et al. 2011

Suppression of annual ryegrass by wheat, triticale and rye was compared in field trials at Wagga Wagga, NSW, in 1993. Cereal rye and triticale were more competitive than wheat, with a biomass of annual ryegrass at maturity of 70 g/m² with triticale compared with 170 g/m² with wheat. Early seedling vigour, superior height and broad leaves appeared to influence the greater competitive ability of triticale and cereal rye.²¹

6.3 Key weeds in Australia's cropping systems

Click on the weed name below to view further information on this weed:

- [Annual ryegrass \(*Lolium rigidum*\)](#)
- [Barley grass \(*Hordeum* spp.\)](#)
- [Barnyard grasses \(*Echinochloa* spp.\)](#)
- [Black bindweed \(*Fallopia convolvulus*\)](#)
- [Bladder ketmia \(*Hibiscus trionum*\)](#)
- [Brome grass \(*Bromus* spp.\)](#)
- [Capeweed \(*Arctotheca calendula*\)](#)
- [Doublegee \(*Emex australis*\)](#)
- [Feathertop Rhodes grass \(*Chloris virgata*\)](#)
- [Fleabane \(*Conyza* spp.\)](#)
- [Fumitory \(*Fumaria* spp.\)](#)
- [Indian hedge mustard \(*Sisymbrium orientale*\)](#)
- [Liverseed grass \(*Urochloa panicoides*\)](#)
- [Muskweed \(*Myagrum perfoliatum*\)](#)
- [Paradoxa grass \(*Phalaris paradoxa*\)](#)
- [Silver grass \(*Vulpia* spp.\)](#)
- [Sweet summer grass \(*Brachiaria eruciformis*\)](#)
- [Turnip weed \(*Rapistrum rugosum*\)](#)
- [Wild oats \(*Avena fatua*, and *A. ludoviciana*\)](#)

²⁰ R Smith, RL Bugg, M Gaskell, O Daugovish, M Van Horn (Eds) (2011) Cover cropping for vegetable production: a grower's handbook. Publication no. 3517. UCANR Publications.

²¹ D Lemerle, K Cooper (1996) Comparative weed suppression by triticale, cereal rye and wheat. In Triticale: Today and tomorrow. pp. 749–750. Springer Netherlands.

Wild radish (*Raphanus raphanistrum*)

Windmill grass (*Chloris truncata*)

Wire weed (*Polygonum aviculare*, *P. arenastrum*)²²

6.3.1 Annual ryegrass management in the Southern Region

South Australian trial

Herbicide resistance in annual ryegrass is on the increase, with higher levels of chemical tolerance recorded in the south-east of South Australia. A survey in 2013 found that 16% of paddocks in the region contained glyphosate-resistant ryegrass (Photo 7).



Photo 7: *Glyphosate-resistant ryegrass in a crop paddock.*

Source: [Weekly Times](#)

A three-year trial by the University of Adelaide at Roseworthy, in South Australia's mid-north, found that strategic use of oaten hay was the best tool for rapidly reducing the seedbank of annual ryegrass. However, another year of seedset control is vital for keeping populations low.

Three weed-management strategies were used for ryegrass control in a four-year trial. Cutting oaten hay in the first year reduced the seedbank of ryegrass by 86%, from 4819 to 692 seeds/m² in one year. Field peas were sown in the following year and three spray options used across three sections.

- When trifluralin was used alone, seedbank levels increased from 692 to 8319 seeds/m².
- When Select® (clethodim) was applied after trifluralin, the ryegrass seedbank slightly increased from 692 to 806 seeds/m².
- When Select® was applied and the field peas were crop-topped with Roundup® (glyphosate), the seedbank declined to less than 500 seeds/m².

This shows the importance of a second year of seedset control in managing annual ryegrass.

Growers should be cautious about chemical use because resistance to Select® is on the increase in South Australia—a major concern given the herbicide's importance for providing effective control of ryegrass in pulse and canola break crops.

Crop-topping after Select® application, even if there are only a few weeds left in the paddock, decreased the risk of resistance emerging.

²² GRDC (2014) Section 8. Profile of common weeds of cropping. Integrated weed management manual. GRDC Integrated Weed Management Hub, <https://grdc.com.au/Resources/IWMhub/Section-8-Profiles-of-common-weeds-of-cropping>

Where two years of seedset control had been used, the annual ryegrass seedbank in the following wheat crop continued to decline, even where Boxer Gold® was the only herbicide used.²³

Victorian trial

From 2012, a trial at Southern Farming Systems' Lake Bolac site, which has a history of resistant annual ryegrass, assessed the effectiveness and applicability of cultural control practices before seeding, in combination with pre-emergent herbicides, on management of herbicide-resistant annual ryegrass in the Victorian high-rainfall zone (HRZ).

The cultural control practices included mouldboard ploughing, stubble burning, stubble incorporation with light cultivation and retained stubble with direct sowing. These were followed up with pre-emergent options of low cost (such as trifluralin mixtures), or medium and high cost (such as Sakura® (pyroxasulfone) + Avadex® Xtra (trilalate) mixtures in wheat).

Mouldboard ploughing

Although mouldboard ploughing is expensive, early results were promising, despite some wild radish germinating in the ploughed area. In a long-season scenario where there is plenty of rain, any ryegrass that germinates late, after treatments have been applied, will produce a great deal of seed. In the HRZ, this is a problem. If growers do not stop ryegrass seedset, it will quickly replenish the seedbank.

Pre-emergent herbicides

If using pre-emergent herbicides, stubble should not be burnt rather than incorporated. Incorporating stubble moves the ryegrass away from the herbicides, limiting their effectiveness.

If post-emergent resistant ryegrass is present, growing wheat and barley is not an effective management option. Even with the best treatments, resistant ryegrass numbers are still increasing.

The cheapest pre-emergent herbicide strategies were the least effective. The mid-cost strategy was better and the expensive strategy best.

To contain the ryegrass in the cereal part of the rotation in the HRZ, more expensive herbicide options are needed to achieve length of persistence, such as the Sakura® + Avadex® Xtra mix.

Narrow windrow burning

When attempting to windrow-burn barley in these trials, the burn was too fast and did not burn the windrows all the way down to the ground, leaving streaks of ryegrass across the site. Barley may be the most difficult crop for windrow burning.²⁴

6.3.2 Brome grass and barley grass in the Southern Region

Increasing incidence of brome grass and barley grass in cropping paddocks in southern Australia is likely to be associated with selection of more dormant biotypes because of weed-management practices used by growers.

Brome grass

Control of brome grass is becoming increasingly difficult throughout south-eastern Australia's cropping zone owing to high levels of herbicide resistance, increasing seed dormancy, and spread of the weed from its traditional low-rainfall area to other regions (Photo 8).

23 D Lush (2013) Consistent weed control needed to combat ryegrass. GRDC Ground Cover Issue 106, <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-106-Sept-Oct-2013/Consistent-seed-control-needed-to-combat-ryegrass>

24 A Lawson (2015) HRZ trial yields lessons in resistant ryegrass management. GRDC Media Centre, January 2015, <https://grdc.com.au/Media-Centre/Media-News/South/2015/01/HRZ-trial-yields-lessons-in-resistant-ryegrass-management>

Currently, brome grass management in cereals relies heavily on Group B herbicides, especially the Clearfield™ technology. Delaying onset of resistance to these herbicides will require identification of effective alternative herbicides.



Photo 8: *Brome grass growing in a cereal crop at a University of Adelaide trial, Balaklava, South Australia.*

Source: [GRDC](#)

Field trials undertaken over four years have investigated various pre-emergence herbicides for brome grass control in wheat. Although Sakura® seems the most active pre-emergent herbicide against brome grass, it lacks the consistency required for long-term population management.

Surveys by the University of Adelaide in an earlier GRDC-funded project showed high levels of resistance to Group B herbicides, with 40–50% resistance to Atlantis® (mesosulfuron-methyl) and Crusader™ (pyroxsulam) in the South Australian Mallee, and 40% resistance to Atlantis® in Victoria.

Pre-emergent control options are no more promising because most common options are ineffective. The most common practice in wheat is use of trifluralin, but these trials have shown that trifluralin may provide only ~50% control in wheat. The combination of Sakura® and Avadex® has been shown to be more effective, but the high cost means that it is often uneconomical.

With herbicide control providing no easy solutions, an IWM strategy is needed to control the problem weed. Where there are severe brome patches in cereals, >50 plants/m², it is recommended that growers patch out the area with a knockdown herbicide such as glyphosate before it can set seed. Where the soil type permits, narrow windrow burning can be a good control method, or options such as chaff carts can help reduce the seedbank.

However, the most effective control will be achieved through use of rotations. For a severe infestation, use a pulse or break crop with a grass-selective herbicide and crop-topping, followed by a Clearfield™ variety using imidazolinone ('imi') chemistry. If there are still some weeds after two years, proceed to barley with trifluralin and metribuzin for a third-step control.

i MORE INFORMATION

GRDC Update papers: [Brome and barley grass management in cropping systems of southern Australia](#)

GRDC Media: [Long-term strategy needed for brome grass control](#)

Full results from the trials are expected in 2017. ²⁵

Barley grass

Field trials confirmed consistently high efficacy of Sakura® against barley grass, especially in situations with good soil moisture. Barley grass management is becoming complicated by evolution of Group A resistance in this species. However, several effective alternatives (e.g. Sakura® and Raptor® (imazamox)) could likely be used for barley grass control in broadleaf crops. ²⁶

Barley grasses are annual species renowned for rapidly germinating in autumn to provide valuable stock feed soon after breaking rain (Photo 9). This speedy establishment has traditionally been seen as a useful clue for early identification, but changes in seedbank dormancy now mean an increasing proportion of the seedbank germinates later in the season.



Photo 9: Seedling of barley grass (*Hordeum leporinum*) (Photo D. Holding).

Source: [GRDC](#)

Barley grass is a problem for several reasons:

- It acts as an alternative host for a number of cereal diseases.
- Seeds of barley grasses cause stock health problems.
- Post-emergent herbicide control is limited in cereals.
- Barley grasses are readily dispersed.
- Populations of barley grasses can develop resistance to herbicides. ²⁷

6.3.3 Emerging flaxleaf fleabane threat

Flaxleaf fleabane (Photo 10) is a major weed in dryland crops in southern Queensland and northern New South Wales, and it is emerging as a problem weed across the entire cereal-cropping belt of southern Australia.

²⁵ R Barr (2014) Long-term strategy needed for brome grass control. GRDC Media Centre, October 2014, <https://grdc.com.au/Media-Centre/Media-News/South/2014/10/Long-term-strategy-needed-for-brome-grass-control>

²⁶ G Gill, L Shergill, B Fleet, P Boutsalis, C Preston (2013) Brome and barley grass management in cropping systems of southern Australia. GRDC Update Papers, February 2013, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Brome-and-barley-grass-management-in-cropping-systems-of-southern-Australia>

²⁷ GRDC (2014). Section 8. Profile of common weeds of cropping. Barley grass. Integrated weed management manual. GRDC Integrated Weed Management Hub, <https://grdc.com.au/Resources/IWMhub/Section-8-Profiles-of-common-weeds-of-cropping/Barley-grass>



Photo 10: *Flaxleaf fleabane.*

Source: GRDC

Previously, fleabane was found mainly on roadsides, particularly where council use of glyphosate created bare ground on which the weed could flourish without competition. However, the weed is highly mobile and soon found its way into adjacent cropping systems.

With the change to minimum tillage and the increasing use of glyphosate, the scene was set for an expansion of this troublesome weed. Wet summers in southern grain regions over the past two years have aided the weed's spread.

Fallow weed control costs have increased markedly because of fleabane, with some no-till growers having to reintroduce cultivation as a last-resort control tactic. Disturbingly, populations of fleabane have recently been confirmed as resistant to eight times the normal rate of glyphosate, earning fleabane the title of Australia's first glyphosate-resistant broadleaf weed.

Control strategy

Although fleabane presents a serious and costly weed challenge, GRDC-funded research has shown that a strategic approach using IWM can significantly reduce the weed's impact on crop production.

The key to controlling fleabane is to attack all parts of the weed's life cycle to keep the seedbank low. An IWM strategy including chemical and non-chemical tactics will result in substantially reduced fleabane problems and fewer resistant populations in subsequent seasons.

Fleabane has the capacity to produce two or three generations each year and 110,000 seeds per plant, so control before it sets seed is critical.

In southern areas and in Western Australia, fleabane often germinates under crops during spring or at harvest. Following harvest, a lack of crop competition combined with summer rain can cause rapid weed growth. By the time there is a window for control, the fleabane plants are often mature, with a large root system, reduced leaf area and high tolerance to most herbicides.

Research across Australia indicates that hitting the weed with herbicide while it is young and actively growing is the best approach. Conversely, delaying herbicide application until the weed is mature and water-stressed can result in poor control.

MORE INFORMATION

GRDC Fact Sheet: [Managing Flaxleaf fleabane](#)

Northern IWM Fact Sheet: [Flaxleaf fleabane: a weed best management guide](#)

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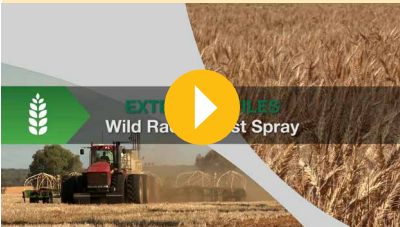
WATCH: GCTV4: [Flaxleaf fleabane.](#)



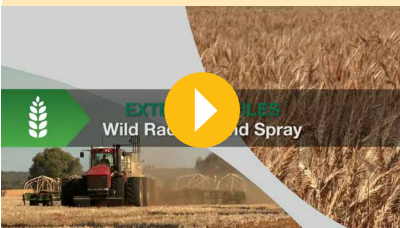
WATCH: GCTV14: [Early control wild radish.](#)



WATCH: GCTV Extension files: [Wild Radish – 1st spray.](#)



WATCH: GCTV Extension files: [Wild radish – 2nd spray.](#)



The double-knock approach, with glyphosate followed by paraquat, has proved a critical component of a fleabane IWM program. This approach, coupled with the use of competitive crops and pastures and strategic cultivations to bury blowouts of seed production, can reduce the weed seedbank to manageable levels within a few seasons. It is also important to target fencelines and roadsides.²⁸

6.3.4 Wild radish herbicide resistance

Growers in the GRDC’s Southern Region should be able to draw on the experience of their western counterparts for developing and implementing proactive control strategies for herbicide-resistant wild radish. Herbicide-resistant wild radish (Photo 11) is becoming a serious threat in the region, but growers in the west have considerable experience keeping this difficult weed in check.



Photo 11: *Herbicide-resistant wild radish plant in cereal paddock.*

Source: [DAFWA](#)

Although wild radish has been present in both regions, the use of a sheep–wheat rotation in southern New South Wales, Victoria, South Australia and Tasmania has helped to keep the weed under control.

By contrast, Western Australia’s intensive cropping system has led to wild radish becoming the number one weed issue, with 60% of wild radish populations developing resistance to some herbicide. Some populations are now resistant to multiple herbicide groups.

The number of resistant wild radish populations in the Southern Region is still significantly lower than in the west; however, enterprise changes are beginning to replicate what has happened in Western Australia, with growers moving towards a more intensive cropping system with fewer sheep and more herbicide applications.

According to University of Adelaide weed scientist Dr Christopher Preston, in 2013 there were more than 20 paddocks across Victoria and South Australia with wild radish resistant to herbicides. Of these, five populations were resistant to Group I herbicides (three in Victoria and two in South Australia) and one was resistant to Group B, Group I and Group F.

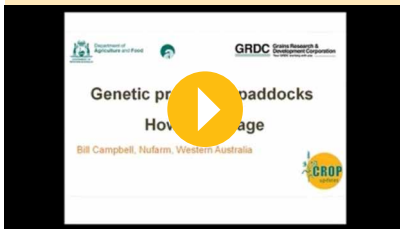
²⁸ M Widderick (2013) Fleabane now a national challenge. GRDC Ground Cover Issue 102, <https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS102/Fleabane-now-a-national-challenge>

SECTION 6 CEREAL RYE

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WATCH: [GRDC Grains Research Updates 6-7 February 2013, Southern Region, Ballarat VIC. Bill Campbell](#)



WATCH: IWM: [Weed seed bank destruction – wild radish seed.](#)



MORE INFORMATION

WeedSmart: [Herbicide resistant wild radish: take back control.](#)

GRDC Fact Sheet: [Wild radish management and strategies to address herbicide resistance](#)

Dr Peter Boutsalis is director of [Plant Science Consulting](#), which carries out annual herbicide-resistance testing on wild radish from paddocks where herbicides have failed. Since 2009, half of the 60 wild radish samples received from growers across south-eastern Australia have been verified as resistant to Group B and Group I herbicides. When poor herbicide control of wild radish is identified, it is critical that the weed seed is tested for herbicide resistance.

GRDC-funded research across the Western and Southern regions has been quantifying the extent of the wild radish problem and developing management systems to lower the weed's on-farm seedbank.

Over the past decade, research by Professor Stephen Powles and his team at [AHRU](#) has unravelled the biology of wild radish and has developed innovative control strategies.

An underlying principle of wild radish management is to keep the weed seedbank in check. More than 90% of seed can be captured at harvest. As long as this seed is destroyed or removed via chaff carts, baling systems, windrowing and subsequent burning, crushing (via the Harrington Seed Destructor) or feeding to livestock, then radish seedbank numbers can be reduced to manageable levels.

When weed seed is not destroyed, it remains in the chaff to be spread back onto the paddock or, worse still, to be transported to another paddock, where wild radish or herbicide-resistant wild radish may not be present.²⁹

6.4 Herbicides explained

When selecting a herbicide, it is important to know crop growth stage, weeds present and plant-back period. For best results, weeds should be sprayed while they are small and actively growing. Herbicides must be applied at the correct stage of crop growth, or significant yield losses may occur. Check product labels for up-to-date registrations and application methods.

6.4.1 Residual and non-residual

Residual herbicides remain active in the soil for an extended period (months) and can act on successive weed germinations. Residual herbicides are absorbed through the roots or shoots, or both. Examples of residual herbicides include imazapyr, chlorsulfuron, atrazine and simazine.

The persistence of residual herbicides is determined by a range of factors including application rate, soil texture, organic matter levels, soil pH, rainfall/irrigation, temperature and the herbicide's characteristics. Persistence of herbicides will affect the sequence chosen (a rotation of crops, e.g. wheat–barley–chickpeas–canola–wheat).

Non-residual herbicides, such as the non-selective paraquat and glyphosate, have little or no soil activity and they are quickly deactivated in the soil. They are either broken down or bound to soil particles, becoming less available to growing plants. They also may have little or no ability to be absorbed by roots.

6.4.2 Post-emergent and pre-emergent

These terms refer to the target and timing of herbicide application. Post-emergent refers to foliar application of the herbicide after the target weeds have emerged from the soil, whereas pre-emergent refers to application of the herbicide to the soil before the weeds have emerged.³⁰

²⁹ J Paterson J (2013) South faces wild radish resistance. GRDC Ground Cover Issue 102, <https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS102/South-faces-wild-radish-resistance>

³⁰ GRDC Integrated weed management, Section 4: Tactics for managing weed populations, <http://www.grdc.com.au/?/media/A4C48127FF8A4B0CA7DFD67547A5B716.pdf>

Herbicides are classified into a number of groups, which refers to the way a chemical works—their different chemical make-up and MoA (Table 2).³¹

Table 2: *Herbicide Mode of Action groups and examples of chemicals and proprietary products in each group.*

Group A	Hoegrass®, Nugrass®, Digrass®, Verdict®, Targa®, Fusilade®, Puma S®, Tristar®, Correct®, Sertin® Grasp®, Select®, Achieve®, Gallant®, Topik®
Group B	Glean®, chlorsulfuron, Siege®, Tackle®, Ally®, Associate®, Logran®, Nugran®, Amber Post® Londax®, Spinnaker®, Broadstrike®, Eclipse®, Renovate®
Group C	Simazine, atrazine, Bladex®, Igran®, metribuzin, diuron, linuron, Tribunil®, bromoxynil, Jaguar®, Tough®
Group D	Trifluralin, Stomp®, Yield®, Surflan®
Group E	Avadex®, BW, EPTC, chlorpropham
Group F	Brodal®, Tigrex®, Jaguar®
Group H	Saturn®
Group I	2,4-D, MCPA, 2,4-DB, dicamba, Tordon®, Lontrel®, Starane®, Garlon®, Baton®, Butress®, Trifolamine®
Group K	Dual®, Kerb®, Mataven®
Group L	Reglone®, Gramoxone®, Nuquat®, Spraytop®, Sprayseed®
Group M	Glyphosate, Glyphosate CT®, Sprayseed®, Roundup CT®, Touchdown®, Pacer®, Weedmaster®

List of commonly used products only. Listing of products does not necessarily imply state registration. Check that product is registered in your state before use. Groups G and J not included.

Source: DPI NSW

VIDEOS

WATCH: GCTV17: [Herbicide partnership.](#)



6.5 Pre-emergent herbicides

Pre-emergent herbicides control weeds between radicle (embryonic root) emergence from the seed and seedling emergence through the soil. Some pre-emergent herbicides may also provide post-emergent control.

Benefits and issues:

- The residual activity of pre-emergent herbicides controls the first few flushes of germinating weeds while the crop or pasture is too small to compete.
- Good planning is needed to use pre-emergent herbicides as an effective tactic. It is necessary to consider weed species and density, crop or pasture type, soil condition, and rotation of crop or pasture species.
- Soil activity and environmental conditions at the time of application play an important role in the availability, activity and persistence of pre-emergent herbicides.
- Positive and negative aspects of using pre-emergent herbicides should be considered in the planning phase.³²

To maximise the efficacy of pre-emergent herbicides while minimising crop damage, it is important to know:

- the position of the weed seeds in the soil
- the soil type (particularly amount of organic matter and crop residue on the surface)
- the solubility of the herbicide; and
- the herbicide's ability to be bound by the soil.

³¹ Agriculture Victoria. Monitoring Tools, <http://agriculture.vic.gov.au/agriculture/farm-management/business-management/ems-in-victorian-agriculture/environmental-monitoring-tools/herbicide-resistance>

³² DAFWA (2016) Herbicides, <https://www.agric.wa.gov.au/herbicides/herbicides?page=0%2C2>

6.5.1 Understanding pre-emergent herbicides

With the increasing incidence of resistance to post-emergent herbicides across Australia, pre-emergent herbicides are becoming more important for weed control. Typically, pre-emergent herbicides have more variables that can influence efficacy. Post-emergent herbicides are applied when weeds are present and the main considerations usually relate to application coverage, weed size and environmental conditions that impact on performance. Pre-emergent herbicides are applied before the weeds germinate; the various pre-emergent herbicides behave differently in the soil and may behave differently in different soil types. It is therefore essential to know the behaviour of the herbicide, the soil type and the farming system in order to use pre-emergent herbicides most effectively.

Pre-emergent herbicides must be absorbed by the germinating seedling from the soil. To do so, these herbicides must have some solubility in water and be positioned in the soil to be absorbed by the roots or emerging shoot. The dinitroaniline herbicides (such as trifluralin) are an exception because they are absorbed by the seedlings as a gas; however, these herbicides still require water in order to be released from the soil as a gas. Therefore, weed control with pre-emergent herbicides will always be lower under dry conditions.

6.5.2 Behaviour of pre-emergent herbicides in the soil

Behaviour of pre-emergent herbicides in the soil is driven by three key factors:

- solubility of the herbicide
- how tightly the herbicide is bound to soil components
- the rate of breakdown of the herbicide in the soil.

Characteristics of some common pre-emergent herbicides are given in Water solubility of herbicides ranges from very low values for trifluralin to very high values for chlorsulfuron. Water solubility influences how far the herbicide will move in the soil profile in response to rainfall events. Herbicides with high solubility are at greater risk of being moved into the crop seed-row by rainfall and potentially causing crop damage. If a herbicide moves too far through the soil profile, it risks moving out of the weed root-zone and failing to control the weed species at all. Herbicides with very low water solubility are unlikely to move far from where they are applied.

Table 3: Water solubility, binding characteristics to soil organic matter (Koc) and degradation half-life for some common pre-emergent herbicides.

Herbicide	Water solubility (at 20°C and neutral pH)		Koc (in typical neutral soils)		Degradation half-life (days)
	(mg/L)	Rating	(mL/g)	Rating	
Trifluralin	0.22	Very low	15,800	Very high	181
Pendimethalin	0.33	Very low	17,800	Very high	90
Pyroxasulfone	3.9	Low	223	Medium	22
Triallate	4.1	Low	3,000	High	82
Prosulfocarb	13	Low	2,000	High	12
Atrazine	35	Medium	100	Medium	75
Diuron	36	Medium	813	High	75.5
S-metolachlor	480	High	200	Medium	15
Triasulfuron	815	High	60	Low	23
Chlorsulfuron	12,500	Very high	40	Low	160

Some rules of thumb for maximising pre-emergent herbicide efficacy while minimising crop damage are:

1. Soils with low organic matter are particularly prone to crop damage from pre-emergent herbicides (especially sandy soils) and rates should be reduced where necessary to lower the risk of crop damage.
2. The more water-soluble herbicides will move more readily through the soil profile and are better suited to post-sowing pre-emergent (PSPE) applications than the less water-soluble herbicides. They are also more likely to produce crop damage after heavy rain.
3. Pre-emergent herbicides need to be present at sufficient concentration at or below the weed seed (except for triallate which needs to be above the weed seed) to provide effective control. Keeping weed seeds on the soil surface will improve control by pre-emergent herbicides.
4. High crop residue loads on the soil surface can inhibit pre-emergent herbicide action because they prevent the herbicide from contacting the seed. More water-soluble herbicides cope better with crop residue, but it is best to manage crop residue so that at least 50% of the soil surface is exposed at the time of application.
5. If the soil is dry on the surface but moist underneath, there may be sufficient moisture to germinate the weed seeds but not enough to activate the herbicide. Poor weed control is likely under these circumstances. The more water-soluble herbicides are less adversely affected under these conditions.
6. Many pre-emergent herbicides can cause crop damage. Separation of the product from the crop seed is essential. In particular, care needs to be taken with disc seeding equipment in choice of product and maintaining an adequate seeding depth.³³

MORE INFORMATION

GRDC Update Paper: [Understanding pre-emergent cereal herbicides](#)

NSW DPI: [Using pre-emergent herbicides in conservation farming systems](#)

WeedSmart: [Gearing up to use pre-emergent herbicides](#)

GRDC Fact Sheet: [Pre-emergent herbicides](#)

GRDC Media Centre: [How pre-emergent herbicides work](#)

6.5.3 Top tips for using pre-emergent herbicides

- Only use pre-emergent herbicides as part of an IWM plan including both chemical and non-chemical weed control practices.
- Preparation starts at harvest. Minimise compaction and maximise trash spreading from the header.
- Minimise soil disturbance, allowing weed seeds to remain on the soil surface. Exclude sheep if possible.
- Leave stubble standing rather than laying it over.
- Knife-points and press-wheels allow greatest crop safety. Avoid harrows.
- If using a disc seeder, understand the machine and the limitations it may carry relative to a knife-point and press-wheel.
- Pay attention to detail in your sowing operation and ensure soil throw on the interrow while maintaining a seed furrow free from herbicide.
- Ensure that the seed furrow is closed to prevent herbicide washing onto the seed.
- Ensure even seed placement, typically 3–5 cm of loose soil on top of seed in cereals for best crop safety.
- Incorporate by sowing (IBS) rather than PSPE for crop safety.
- Understand herbicide chemistry. Choose the right herbicide for the paddock at the right rate.³⁴

6.5.4 Post-sowing pre-emergent (PSPE) herbicide use

Post-sowing pre-emergent herbicide use is the application of pre-emergent herbicides to the seedbed after sowing (but before crop emergence). PSPE herbicides are primarily absorbed through the roots, but there may also be some foliar absorption (e.g. Terbyne®).

³³ C Preston (2014) Understanding pre emergent cereal herbicides. GRDC Update Papers, March 2014, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Understanding-pre-emergent-cereal-herbicides>

³⁴ B Haskins. Using pre-emergent herbicides in conservation farming systems. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

 MORE INFORMATION

NSW DPI Management Guide: [Weed control in winter crops 2016](#) (pp. 44–45)

When applied to soil, best control is achieved when the soil is flat and relatively free of clods and trash. Sufficient rainfall (2–30 mm) to wet the soil through the weed root-zone is necessary within 2–3 weeks of application. Assuming such conditions, best weed control is achieved from PSPE application because rainfall gives the best incorporation. Mechanical incorporation pre-sowing (IBS) is less uniform, and so weed control may be less effective; however, with pre-sowing application and sowing with minimal disturbance, incorporation will essentially be by rainfall after application.

6.5.5 Incorporation by sowing (IBS)

The IBS method is when a herbicide is applied just before sowing (usually in conjunction with a knockdown herbicide such as glyphosate) and then soil-throw from the sowing operation incorporates the herbicide into the seedbed. IBS is the preferred method of applying pre-emergent herbicides in conservation farming systems, as crop safety is maximised, stubble remains standing to protect the seedbed, and soil disturbance is minimised.

The IBS method will often increase crop safety because the sowing operation removes a certain amount of herbicide away from the seed row. However, this can reduce weed control for the same reason, as the chemical is moved out of the seed row. In this case, it is wise to include a water-soluble herbicide into the mix, aiming to have some herbicide wash into the seed furrow.

6.5.6 Control of annual ryegrass and crop safety with use of pre-emergent residual herbicides

Two trials (tyne-planted and disc-planted) were conducted in 2013 to evaluate the crop safety and efficacy of registered residual herbicides for the control of annual ryegrass in wheat. Most treatments were managed by the IBS approach, which specifies the use of narrow-point tynes on the planting equipment. PSPE was also evaluated.

Key findings

Planting method

- The use of a disc planter for IBS of residual herbicides resulted in significantly reduced wheat emergence for all four herbicides evaluated.
- The disc planter set-up actually increased the risk of crop damage (Figure 1).
- These results reinforce the need to use only narrow-point tynes when using residual herbicides with IBS recommendations.

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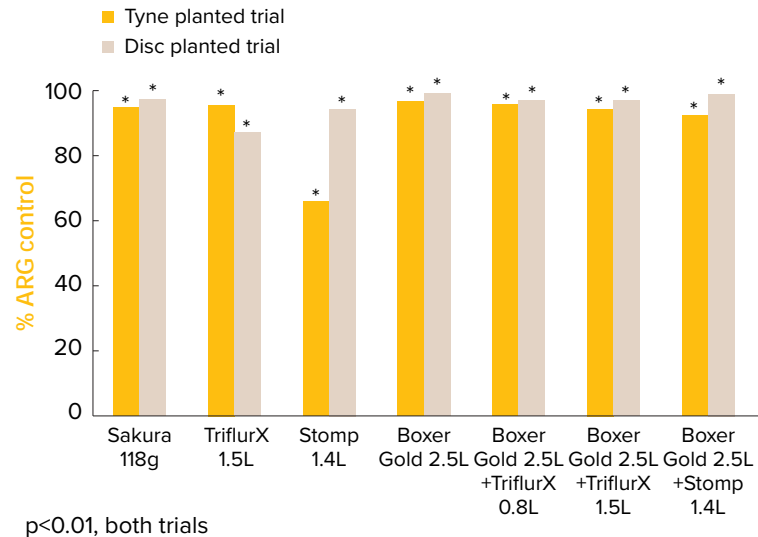


Figure 1: Annual ryegrass (ARG) control based on counts on 22 September 2013, 94 days after planting, as a percentage of the untreated control. All treatments applied in 70 L/ha total volume using AIXR110015 nozzles at 300 kPa. *Significant ($P < 0.05$) weed control compared with untreated within same trial.

Source: GRDC

Herbicide efficacy

- High levels of annual ryegrass control were achieved by most IBS treatments.
- The most consistent products were Boxer Gold® or Sakura®.
- Weed control from Boxer Gold® was significantly reduced in one of the two trials when applied by PSPE.

Conclusions

This work was conducted because of safety concerns for commercial crops arising from the use of residual herbicides at planting for control of annual ryegrass. The two trials highlighted some key points:

1. Crop safety was significantly reduced when a disc planter was used for incorporation.
2. The disc setup appears to have exaggerated crop-safety issues by planting seed in an area with increased herbicide concentration.
3. Observation suggested that small differences in planting depth might have affected crop safety.

This work reinforces some of the difficulties that growers and agronomists face with the use of residual herbicides. Crop safety and efficacy are influenced by a range of factors including planting equipment, planting depth, soil type, stubble load, and rainfall quantity and timing. A more thorough understanding of the impacts from these (and perhaps other) factors is needed to get the best from these important weed-management tools.³⁵

³⁵ R Daniel, A Mitchell (2014) Pre-emergent herbicides; part of the solution but much still to learn. GRDC Update Papers, March 2014, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Pre-emergent-herbicides-part-of-the-solution-but-much-still-to-learn>

6.6 In-crop herbicides: knock-downs and residuals

In-crop herbicides control weeds that have emerged since crop or pasture establishment and they can be applied with little damage to the crop or pasture plants.

Benefits:

- Post-emergent herbicides give high levels of target weed control with the additional benefit of improved crop or pasture yield.
- Observations just prior to application allow fine-tuning of herbicide selection to match weeds present in the paddock.
- Timing of application can be flexible to suit weed size, crop growth stage and environmental conditions.
- Some post-emergent herbicides have pre-emergent activity on subsequent weed germinations.

Issues:

- Careful consideration is needed when selecting the best post-emergent herbicide to use in any one situation.
- Application of post-emergent herbicides to stressed crops and weeds can result in reduced levels of weed control and increased crop damage.
- Crop competition is important for effective weed control using selective post-emergent herbicides.
- The technique used for application must be suited for the situation in order to optimise control.
- Always use the correct adjuvant to ensure effective weed control.
- Selective post-emergent herbicides applied early and used as a stand-alone tactic have little impact on the weed seedbank.
- Choose the most suitable formulation of herbicide for each situation.
- The effectiveness of post-emergent herbicides is influenced by a range of plant and environmental factors.³⁶

MORE INFORMATION

NSW DPI Management Guide: [Weed control in winter crops 2016](#) (pp. 64–68)

6.6.1 Key points for in-crop herbicide application

- Knowledge of a product's translocation and formulation type is important for selecting nozzles and application volumes.
- Evenness of deposit is important for poorly or slowly translocated products.
- Crop growth stage, canopy size and stubble load should influence decisions about nozzle selection, application volume and sprayer operating parameters.
- Robust rates of products and appropriate water rates are often more important for achieving control than the nozzle type, but, correct nozzle type can widen the spray window, improve deposition and reduce drift risk.
- Travel speed and boom height can affect control and drift potential.
- Appropriate conditions for spraying are always important.³⁷

In-crop herbicides will normally require a different set of nozzles from those used in summer fallow spraying and application of pre-emergent herbicides.

In-crop post-emergent herbicides should be applied in the droplet spectrum from upper-end medium to lower-end coarse, depending on the particular herbicide being used. This must be combined with the relevant application volume to obtain enough droplets per cm² on the target for good coverage. Nozzles must also be matched to the spray rig, pump and controller, and desired travel speed.

³⁶ DAFWA (2016) Herbicides. Department of Agriculture and Food Western Australia, <https://www.agric.wa.gov.au/herbicides/herbicides?page=0%2C2>

³⁷ GRDC (2014) In-crop herbicide use. GRDC Fact Sheets, August 2014, <https://grdc.com.au/Resources/Factsheets/2014/08/In-crop-herbicide-use>

Operate within the recommended groundspeed range and apply the product in a higher application volume. The actual recommended application volume will vary with the product and situation, so read the label and follow the directions.

6.6.2 How to get the most out of post-emergent herbicides

- Consider application timing—the younger the weeds the better. Frequent crop monitoring is critical.
- Consider the growth stage of the crop.
- Consider the crop variety being grown and applicable herbicide tolerances.
- Know which species were historically in the paddock and the resistance status of the paddock (if unsure, send plants away for a [Weed Resistance Quick-Test](#)).
- Do not spray a crop stressed by waterlogging, frost, high or low temperatures, drought or (for some chemicals) cloudy or sunny days. This is especially pertinent for grass-weed chemicals with frosts.
- Use the correct spray application:
 - » Consider droplet size with grass-weed herbicides, water volumes with contact chemicals and time of day.
 - » Observe the plant-back periods and withholding periods.
 - » Consider compatibility if using a mixing partner.
 - » Add correct adjuvant.³⁸

MORE INFORMATION

GRDC Fact Sheet: [In-crop herbicide use](#)

6.7 Conditions for spraying

When applying herbicides, the aim is to maximise the amount reaching the target and to minimise the amount reaching off-target areas. This results in:

- improved herbicide effectiveness
- reduced damage and/or contamination of off target crops and areas.

In areas where several agricultural enterprises coexist, conflicts can arise, particularly from the use of herbicides. All herbicides are capable of drift.

When spraying a herbicide, you have a moral and legal responsibility to prevent it from drifting and contaminating or damaging neighbours' crops and sensitive areas.

All grass herbicide labels emphasise the importance of spraying only when the weeds are actively growing under mild, favourable conditions (Photo 12). Any of the following stress conditions can significantly impair both uptake and translocation of the herbicide within the plant, likely resulting in incomplete kill or only suppression of weeds:

- moisture stress (and drought)
- waterlogging
- high temperature, low humidity conditions
- extreme cold or frosts
- nutrient deficiency, especially effects of low N
- use of pre-emergent herbicides that affect growth and root development, i.e. simazine, Balance®, trifluralin, and Stomp®
- excessively heavy dews resulting in poor spray retentions on grass leaves.

Ensure that grass weeds have fully recovered before applying grass herbicides.

38 WeedSmart. Post-emergents, <http://www.weedsmart.org.au/post-emergents/>



Photo 12: Boom spray on crop.

Source: [DAFWA](#)

6.7.1 Minimising spray drift

Before spraying

- Always check for susceptible crops in the area, e.g. broadleaf crops such as grape vines, cotton, vegetables and pulses if you are using a broadleaf herbicide.
- Check sensitive areas such as houses, schools, waterways and riverbanks.
- Notify neighbours of your spraying intentions.

Under the [Records Regulation](#) of the [Pesticides Act 1999](#), when spraying you must record the weather and relevant spray details.

During spraying

- Always monitor weather conditions carefully and understand their effect on 'drift hazard'.
- Do not spray if conditions are not suitable, and stop spraying if conditions change and become unsuitable.
- Record weather conditions (especially temperature and relative humidity), wind speed and direction, herbicide and water rates, and operating details for each paddock.
- Supervise all spraying, even when a contractor is employed. Provide a map marking the areas to be sprayed, buffers to be observed and sensitive crops and areas.
- Spray when temperatures are less than 28°C.
- Maintain a downwind buffer. This may be in-crop, e.g. keeping a boom's width from the downwind edge of the field.
- Minimise spray release height.
- Use the largest droplets that will give adequate spray coverage.
- Always use the least volatile formulation of herbicide available.
- If there are sensitive crops in the area, use the herbicide that will cause no off-target impacts.

Delta T, the relationship between temperature and relative humidity, gives a score for deciding the best times to apply sprays on crops. It is calculated by subtracting the wet bulb temperature from the dry bulb temperature. The ideal is between two and eight. (See: <http://www.spraywisecisions.com.au/Home/Faq>)

6.7.2 Types of drift

Sprayed herbicides can drift as droplets, vapours or particles:

- *Droplet drift* is the easiest to control because under good spraying conditions, droplets are carried down by air turbulence and gravity, to collect on plant or soil surfaces. Droplet drift is the most common cause of off-target damage caused by herbicide application. For example, spraying of fallows with glyphosate under the wrong conditions often leads to severe damage to establishing crops.
- *Particle drift* occurs when water and other herbicide carriers evaporate quickly from the droplet, leaving tiny particles of concentrated herbicide. This can occur with herbicide formulations other than esters. This form of drift has damaged susceptible crops up to 30 km from the source.
- *Vapour drift* is confined to volatile herbicides such as 2,4-D ester. Vapours may arise directly from the spray or evaporation of herbicide from sprayed surfaces. Use of 2,4-D ester in summer can lead to vapour-drift damage of highly susceptible crops such as tomatoes, cotton, sunflowers, soybeans and grapes. This may occur hours after the herbicide has been applied.

In 2006, APVMA, the federal regulators of pesticide use, restricted the use of highly volatile 2,4-D ester. The changes are now seen with the substitution of lower volatility forms of 2,4-D and MCPA. Products with lower risk ester formulations are commonly labelled with 'LVE' (i.e. low volatile ester). Although these formulations have a much lower tendency to volatilise, caution remains because they are still prone to droplet drift.

Vapours and minute particles float in the airstream and are poorly collected on catching surfaces. They may be carried for many kilometres in thermal updraughts before being deposited.

Sensitive crops may be up to 10,000 times more sensitive than the crop being sprayed. Even small quantities of drifting herbicide can cause severe damage to highly sensitive plants.

6.7.3 Factors affecting the risk of spray drift

Any herbicide can drift. The drift hazard, or off-target potential, of a herbicide in a particular situation depends on the following factors:

- Volatility of the formulation applied. Volatility refers to the likelihood that the herbicide will evaporate and become a gas. Esters volatilise (evaporate) whereas amines do not.
- Proximity of crops susceptible to the particular herbicide being applied, and their growth stage. For example, cotton is most sensitive to Group I herbicides in the seedling stage.
- Method of application and equipment used. Aerial application releases spray at three metres above the target and uses relatively low application volumes, whereas ground-rigs have lower release heights and generally higher application volumes, and a range of nozzle types. Misters produce large numbers of very fine droplets that use wind to carry them to their target.
- Size of the area treated. The greater the area treated the longer it takes to apply the herbicide. If local meteorological conditions change, particularly in the case of 2,4-D ester, then more herbicide is able to volatilise.
- Amount of active ingredient (herbicide) applied. The more herbicide applied per hectare the greater the amount available to drift or volatilise.
- Efficiency of droplet capture. Bare soil cannot catch drifting droplets, unlike crops, erect pasture species and standing stubbles.

- Weather conditions during and shortly after application. Changing weather conditions can increase the risk of spray drift.

Volatility

Table 4 is a guide to the volatility of more common herbicide active ingredients that are marketed with more than one formulation.

Table 4: *Relative volatility of herbicides.*

Form of active	Full name	Product example
Non-volatile		
<i>Amine salts</i>		
MCPA dma	Dimethyl amine salt	MCPA 500
2,4-D dma	Dimethyl amine salt	2,4-D Amine 500
2,4-D dea	Diethanolamine salt	2,4-D Amine 500 Low Odour®
2,4-D ipa	Isopropylamine salt	Surpass® 300
2,4-D tipa	Triisopropanolamine	Tordon® 75-D
2,4-DB dma	Dimethyl amine salt	Buttress®
Dicamba dma	dimethyl amine salt	Banvel® 200
Triclopyr tea	Triethylamine salt	Tordon® Timber Control
Picloram tipa	Triisopropanolamine	Tordon® 75-D
Clopyralid dma	Dimethylamine	Lontrel® Advanced
Clopyralid tipa	Triisopropanolamine	Archer®
Aminopyralid K salt	potassium salt	Stinger®
Aminopyralid tipa	Triisopropanolamine	Hotshot®
<i>Other salts</i>		
MCPA Na salt	Sodium salt	MCPA 250
MCPA Na/K salt	Sodium and potassium salt	MCPA 250
2,4-DB Na/K salt	Sodium and potassium salt	Buticide®
dicamba Na salt	Sodium salt	Cadence®
Some volatility		
<i>Ester</i>		
MCPA ehe	Ethylhexyl ester	LVE MCPA
MCPA ioe	Isooctyl ester	LVE MCPA
Triclopyr butoxyl	Butoxyethyl ester	Garlon® 600
Picloram ioe	Isooctyl ester	Access®
2,4-D ehe	Ethylhexyl ester	2,4-D LVE 680
Fluroxypyr M ester	Meptyl ester	Starane® Advanced

Source: Mark Scott, former Agricultural Chemicals Officer, [NSW Agriculture](#)

6.7.4 Equipment and settings for minimising drift

Selection of equipment to reduce the number of small droplets produced is a significant component of minimising spray drift. However, this may in turn affect coverage of the target, and hence the possible effectiveness of the pesticide application. This aspect of spraying needs to be carefully considered when planning to spray.

As the number of smaller droplets decreases, so does the coverage of the spray. A good example of this is the use of air-induction nozzles that produce large droplets

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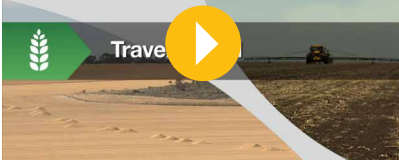
WATCH: [Nozzle Selection.](#)

SPRAY APPLICATION OF HERBICIDES



WATCH: [Travel Speed.](#)

SPRAY APPLICATION OF HERBICIDES



WATCH: [Spray deposition.](#)

SPRAY APPLICATION OF HERBICIDES



that splatter. These nozzles produce a droplet pattern and number unsuitable for targets such as seedling grasses that present a small vertical target.

In 2010, APVMA announced new measures to minimise the number of spray-drift incidents (Table 5). The changes are restrictions on the droplet-size spectrum that an applicator can use, wind speed suitable for spraying and the downwind buffer zone between spraying and a sensitive target. These changes should be evident on current herbicide labels. Hand-held spraying application is exempt from these regulations.

Table 5: *Nozzle selection guide for ground application.*

Volume median diameter: 50% of droplets are less than the stated size and 50% greater. For flat-fan nozzle size, refer to manufacturers' selection charts because droplet size range will vary with recommended pressure; always use the lowest pressure stated to minimise number of small droplets.

Distance downwind to susceptible crop	<1 km	1 to >30 km
Risk	High	Medium
Preferred droplet size (British Crop Protection Council) (to minimise risk)	Coarse to very coarse	Medium to coarse
Volume median diameter (µm)	310	210
Pressure (bars)	2.5	2.5
Flat-fan nozzle size #	11,008	11,004
Recommended nozzles (examples only)	<i>Raindrop:</i> Whirljet® <i>Air induction:</i> Yamaho®, Turbodrop®, Hardi Injet®, AI Teejet®, Lurmark Drift-beta®	<i>Drift reduction:</i> DG TeeJet®, Turbo TeeJet®, Hardi® ISO LD 110, Lurmark® Lo-Drift
CAUTION	Can lead to poor coverage and control of grass weeds. Require higher spray volumes	Suitable for grass control at recommended pressures. Some fine droplets

Adapted from P. Hughes, QDPI
Source: [NSW DPI](#)

Spray release height

- Operate the boom at the minimum practical height. Drift hazard doubles as nozzle height doubles. If possible, angle nozzles forward 30° to allow lower boom height with double overlap. Lower heights, however, can lead to more striping as the boom sways and dips below the optimum height.
- 110° nozzles produce a higher percentage of fine droplets than 80° nozzles, but they allow a lower boom height while maintaining the required double-overlap.
- Operate within the pressure range recommended by the nozzle manufacturer. Production of driftable, fine droplets increases as the operating pressure is increased.

Size of area treated

When large areas are treated, greater amounts of active herbicide are applied and the risk of off-target effects increases due to the length of time taken to apply the herbicide. Conditions such as temperature, humidity and wind direction may change during spraying.

Application of volatile formulations to large areas increases the chances of vapour drift damage to susceptible crops and pastures.

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WATCH: [Water volume with contact sprays.](#)

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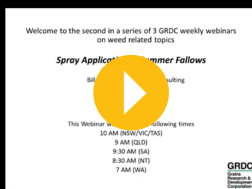
Water volume with Contact sprays

WATCH: [Application volume in stubble.](#)

SPRAY APPLICATION OF HERBICIDES

Application volume in stubble

WATCH: [Advances in weed management – Webinar 2 – Spray application in summer fallows.](#)



Capture surface

Targets vary in their ability to collect or capture spray droplets. Well grown, leafy crops are efficient collectors of droplets. Turbulent airflow normally carries spray droplets down into the crop within a very short distance.

Fallow paddocks or seedling crops have poor catching surfaces. Drift hazard is far greater when applying herbicide in these situations or adjacent to these poor capture surfaces.

The type of catching surface between the sprayed area and susceptible crops should always be considered in conjunction with the characteristics of the target area when assessing drift hazard.

6.7.5 Weather conditions to avoid

Turbulence

Updrafts during the heat of the day cause rapidly shifting wind directions. Spraying should be avoided during this time.

High temperatures

Avoid spraying when temperatures exceed 28°C.

Humidity

Avoid spraying under conditions of low relative humidity, i.e. when the difference between wet and dry bulbs (i.e. Delta T) exceeds 10.

High humidity extends droplet life and can greatly increase the drift hazard under inversion conditions. This results from the increased life of droplets to less than 100 microns.

Wind

Avoid spraying under still conditions. Ideal safe wind speeds are 3–10 km per hour (a light breeze, i.e. when leaves and twigs are in constant motion).

Wind speeds of 11–14 km per hour (a moderate breeze, i.e. when small branches move, dust is raised and loose paper is moving) are suitable for spraying if using low-drift nozzles or higher volume application, say 80–120 L/ha.

Inversions

The most hazardous condition for herbicide spray drift is an atmospheric inversion, especially when combined with high humidity. An inversion exists when temperature increases with altitude instead of decreasing. An inversion is like a cold blanket of air above the ground, usually <50 m thick. Air will not rise above this blanket, and smoke or fine spray droplets and particles of spray deposited within an inversion will float until the inversion breaks down.

Do not spray under inversion conditions.

Inversions usually occur on clear, calm mornings and nights. Windy or turbulent conditions prevent inversion formation. Blankets of fog, dust or smoke and the tendency for sounds and smells to carry long distances indicate inversion conditions.

Smoke generators or smoky fires can be used to detect inversion conditions. Smoke will not continue to rise but will drift along at a constant height under the inversion blanket.³⁹

³⁹ A Storrie (2015) Reducing herbicide spray drift. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/content/agriculture/pests-weeds/weeds/images/wid-documents/herbicides/spray-drift>

6.8 Herbicide tolerance ratings

Within many broadacre crop species, cultivars have been found to vary in sensitivity to commonly used herbicides and tank mixes, thereby resulting in potential grain yield loss and reduced farm profit. With funding from GRDC and state government agencies across Australia, cultivar × herbicide tolerance trials are conducted annually.

The trials aim to provide grain growers and advisers with information on cultivar sensitivity to commonly used in-crop herbicides and tank mixes for a range of crop species including wheat, barley, triticale, oats, lupins, field peas, lentils, chickpeas and faba beans. The intention is to provide data from at least two years of testing at the time of wide-scale commercial propagation of a new cultivar.⁴⁰

The good news is that over 70% of all crop varieties are tolerant to most herbicides. The remaining varieties can experience yield losses of 10–30%, and in some cases, 50% yield loss has been recorded. These results were measured with the use of registered herbicides applied at label rates under good spraying conditions at the appropriate crop growth stage.

To provide growers with clear information about the herbicide interactions of a variety for their region, four regionally based, herbicide-tolerance screening projects have been established. The four projects have now been combined under a national program.⁴¹

In greenhouse trials in the US, cereal rye showed tolerance similar to oats for a range of residual herbicides (based on injury rating). Cereal rye had a higher potential for injury from the Group K herbicide S-metolachlor.⁴²

6.9 Potential herbicide damage effect

6.9.1 Avoiding crop damage from residual herbicides

The herbicide label is the primary source of information on residual activity and cropping restrictions following herbicide application and it should be read thoroughly. The following information provides an explanation of how herbicides break down and extra information on some specific herbicides used in broadacre cropping.

What are the issues?

Some herbicides can remain active in the soil for weeks, months or years. This can be advantageous, as it ensures good long-term weed control. However, if the herbicide stays in the soil longer than intended it may damage sensitive crop or pasture species sown in subsequent years.

For example, chlorsulfuron (Glean®) is used in wheat and barley, but it can remain active in the soil for several years and damage legumes and oilseeds. A problem for growers lies in identifying herbicide residues before they cause a problem.

Growers rely on information provided on the labels about soil type and climate. Herbicide residues are often too small to be detected by chemical analysis, and if testing is possible, it is too expensive to be part of routine farming practice. Once the crop has emerged, diagnosis is difficult because the symptoms of residual herbicide damage can often be confused with, and/or make the crop vulnerable to, other stresses, such as nutrient deficiency or disease.⁴³

An option for assessing the potential risk of herbicide residues is to conduct a bioassay involving hand-planting of small test areas of crop into the field in question.

40 NVT. Herbicide tolerance. GRDC, <http://www.nvtonline.com.au/herbicide-tolerance/>

41 E Leonard (2012) Weed kill without crop damage. GRDC Ground Cover Supplements, November 2012, <https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS101/Weed-kill-without-crop-damage>

42 B Hartzler, M Anderson (2015) Effect of residual herbicides on cover crop establishment. Iowa State University Extension and Outreach, <http://www.weeds.iastate.edu/mgmt/2015/CCherbicides.pdf>

43 DEPI (2013) Avoiding crop damage from residual herbicides. Department of Environment and Primary Industries Victoria, <http://agriculture.vic.gov.au/agriculture/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides>

Which herbicides are residual?

The herbicides listed in Table 6 all have some residual activity or planting restrictions. For example, Glean®, registered in cereal rye, wheat, triticale, and oats, has activity through root and foliar uptake. Plant-back recommendations on alkaline soils are three months for cereal rye.⁴⁴

Table 6: Active constituents (and examples of commercially available herbicide products) that have some residual activity, by herbicide group
List may not include all current herbicides.

Herbicide MoA group and class	Active constituent
Group B: sulfonylureas	Chlorsulfuron (Glean®), iodosulfuron (Hussar®), mesosulfuron (Atlantis®), metsulfuron (Ally®), triasulfuron (Logran®)
Group B: imidazolinones	Imazamox (Raptor®), imazapic (Flame®), imazapyr (Arsenal®)
Group B: triazolopyrimidines (sulfonamides)	Florasulam (Conclude®)
Group C: triazines	Atrazine, simazine
Group C: triazinones	Metribuzin (Sencor®)
Group C: ureas	Diuron
Group D: dinitroanilines	Pendimethalin (Stomp®), trifluralin
Group H: pyrazoles	Pyrasulfotole (Precept®)
Group H: isoxazoles	Isoxaflutole (Balance®)
Group I: phenoxy carboxylic acids	2,4-Ds
Group I: benzoic acids	Dicamba
Group I: pyridine carboxylic acids	Clopyralid (Lontrel®)
Group K: chloroacetamides	Metolachlor
Group K: isoxazolines	Pyroxasulfone (Sakura®)

How to avoid damage from residual herbicides

Select an appropriate herbicide for the weed population. Consider the re-cropping limitations with respect to future rotation options.

Users of chemicals are required by law to keep good records, including weather conditions, but particularly spray dates, rates, batch numbers, rainfall, soil type and pH (including different soil types in the paddock) (Photo 13). In the case of unexpected damage, good records can be invaluable.

If residues could be present, choose the least susceptible crops (refer to product labels). Optimise growing conditions to reduce the risk of compounding the problem with other stresses such as herbicide spray damage, disease and nutrient deficiency. These stresses make a crop more susceptible to herbicide residues.⁴⁵

44 L Lenaghan. Residual herbicides Group B and C carry-over. CropPro, http://www.croppro.com.au/resources/BCGGroupBResidual_herbicides2f11.pdf

45 DEPI (2013) Avoiding crop damage from residual herbicides. Department of Environment and Primary Industries Victoria, <http://agriculture.vic.gov.au/agriculture/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides>

i MORE INFORMATION

NSW DPI: [Herbicide residues in soil and water](#)



Photo 13: Trial plot showing crop damage with pre-emergent herbicides due to poor separation of herbicide and crop seed.

Photo: Dr Christopher Preston. Source: [GRDC](#)

6.9.2 Plant-back intervals

Plant-back periods are the obligatory times between the herbicide spraying date and safe planting date of a subsequent crop.

Some herbicides have a long residual. The residual is not the same as the half-life. Although the amount of chemical in the soil may break down rapidly to half the original, what remains can persist for long periods (e.g. sulfonylureas such as chlorsulfuron). This is shown in the Table 7 where known. Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the sulfonylureas. On labels, this will be shown by plant-back periods, which are usually listed under a separate plant-back heading or under the 'Protection of crops etc.' heading in the 'General Instructions' section of the label (Table 8).

Part of the management of herbicide resistance includes rotation of herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonylureas, triazines, etc.) may be an issue in some paddocks. Remember that plant-back periods begin after rainfall occurs.⁴⁶

⁴⁶ B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

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Table 7: Residual persistence of common pre-emergent herbicides in broadacre trials and from farm paddock situations. ⁴⁷

Herbicide	Residual persistence and prolonged weed control
Logran® (triasulfuron)	High. Persists longer in high-pH soils. Weed control commonly drops off within 6 weeks
Glean® (chlorsulfuron)	High. Persists longer in high-pH soils. Weed control longer than Logran®
Diuron	High. Weed control will drop off within 6 weeks, depending on rate. Has had observed long-lasting activity on grass weeds such as black/stink grass (<i>Eragrostis</i> spp.) and to a lesser extent broadleaf weeds such as fleabane
Atrazine	High. Has had observed long-lasting (>3 months) activity on broadleaf weeds such as fleabane
Simazine	Medium/high. One year residual in high-pH soils. Has had observed long lasting (>3 months) activity on broadleaf weeds such as fleabane
Terbyne® (terbuthylazine)	High. Has had observed long-lasting (>6 months) activity on broadleaf weeds such as fleabane and sowthistle
Triflur® X (trifluralin)	High. 6–8 months residual. Higher rates longer. Has had observed long-lasting activity on grass weeds such as black/stink grass
Stomp® (pendimethalin)	Medium. 3–4 months residual
Avadex® Xtra (triallate)	Medium. 3–4 months residual
Balance® (isoxaflutole)	High. Reactivates after each rainfall event. Has had observed long-lasting (>6 months) activity on broadleaf weeds such as fleabane and sowthistle
Boxer Gold® (prosulfocarb)	Medium. Typically quicker to break down than trifluralin, but tends to reactivate after each rainfall event
Sakura® (pyroxasulfone)	High. Typically quicker breakdown than trifluralin and Boxer Gold®; however, weed control persists longer than Boxer Gold®

⁴⁷ B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

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Table 8: Minimum re-cropping intervals and guidelines for some Group B herbicides.

Class	Herbicide	pH(H ₂ O)	Minimum re-cropping interval (months after application), rainfall and other conditions
Sulfonylurea	Chlorsulfuron: e.g. Glean®, Seige®, Tackle®	<6.5	3 months
		6.6–7.5	3 months, minimum 700 mm
		7.6–8.5	18 months, minimum 700 mm
Sulfonylurea	Triasulfuron: e.g. Logran®, Nugrain®	7.6–8.5	12 months, >250 mm (grain), 300 mm (hay)
		>8.6	12 months, >250 mm (grain), 300 mm (hay)
Sulfonamide	Flumetsulam: e.g. Broadstrike®		0 months
Sulfonylurea	Metsulfuron: e.g. Ally®, Associate®	5.6–8.5	1.5 months
		>8.5	Tolerance of crops grown through to maturity should be determined (small-scale) in the previous season before sowing larger area
Sulfonylurea	Metsulfuron + thifensulfuron: e.g. Harmony® M	7.8–8.5, organic matter >1.7%	3 months
		>8.6 or organic matter <1.7%	Tolerance of crops grown through to maturity should be determined (small scale) in the previous season before sowing larger area
Sulfonylurea	Sulfosulfuron: eg Monza®	<6.5	0 months
		6.5–8.5	10 months

NOTE: always read labels to confirm

Source: [Pulse Australia](#)

Conditions required for breakdown

Warm, moist soils are required to break down most herbicides through the processes of microbial activity. To be most active, soil microbes need good moisture and an optimum range of soil temperature of 18–30°C. Extreme temperatures above or below this range can adversely affect soil microbial activity and slow herbicide breakdown. Very dry soil also reduces breakdown. In addition, when the soil profile is very dry, it requires a lot of rain to maintain topsoil moisture for the microbes to be active for any length of time.

For up-to-date plant-back periods, see the NSW DPI publication: [Weed control in winter crops](#).

MORE INFORMATION

Agriculture Victoria: [Avoiding crop damage from residual herbicides](#)

6.10 Herbicide resistance

6.10.1 Understanding herbicide resistance

Herbicide resistance facts

- Resistance is the inherited ability of an individual plant to survive and reproduce following a herbicide application that would kill a wild type individual of the same species.
- Herbicide-resistant individuals are present at very low frequencies in weed populations before the herbicide is first applied.
- The frequency of naturally resistant individuals within a population will vary greatly within and between weed species.
- Thirty-six weed species in Australia currently have populations that are resistant to at least one herbicide MoA.
- As at June 2014, Australian weed populations had developed resistance to 13 MoAs ([click here](#) for up-to-date statistics).
- A weed population is defined as resistant when a herbicide at a label rate that once controlled the population is no longer effective (sometimes an arbitrary figure of 20% survival is used for defining resistance in testing).
- The proportion of herbicide-resistant individuals will rise (due to selection pressure) in situations where the same herbicide MoA is applied repeatedly and the survivors are not subsequently controlled.
- Herbicide resistance in weed populations is permanent as long as seed remains viable in the soil. Only weed density can be reduced, not the ratio of resistant to susceptible individuals. The exception is when the resistance gene(s) carry a fitness penalty so that resistant plants produce less seed than susceptible ones—but this is rare.

Key messages

Characteristics of resistance:

- Resistance remains for many years, until all resistant weed seeds are gone from the soil seed bank
- Resistance evolves more rapidly in paddocks with frequent use of the same herbicide group, especially if no other control options are used.

Action points:

- Assess your level of risk with the online glyphosate resistance toolkit.
- Aim for maximum effectiveness in control tactics, because resistance is unlikely to develop in paddocks with low weed numbers.
- Do not rely on the same MoA group.
- Monitor your weed control regularly.
- Stop the seedset of survivors.⁴⁸

Herbicide resistance has become far more widespread, reducing the effectiveness of a wide range of herbicide MoAs (Photo 14). Rapid expansion of herbicide resistance and the lack of new MoAs require non-herbicide tactics to be a significant component of any farming system and weed-management strategy. Inclusion of non-herbicide tactics is critical to prolonging the effective life of remaining herbicides, as well as new products and MoAs that have not yet been released or indeed invented. Effective herbicides are key components of profitable cropping systems. Protecting their efficacy directly contributes to the future sustainability and profitability of cropping systems.

48 QDAF (2015) Stopping herbicide resistance in Queensland. Queensland Department of Agriculture and Fisheries, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance>



Photo 14: 2,4-D resistant radish, Wongan Hills.

Photo: A Storrie. Source: [GRDC](#)

i MORE INFORMATION

GRDC: [IWM Hub—Herbicide resistance.](#)

How does resistance start?

Resistance starts in a paddock in several ways. Some rare mutations can occur naturally in weeds already in the paddock, with the frequency varying from 1 plant in 10,000 to 1 in a billion plants, depending on the weed and herbicide. A grower may also import weed seed with the herbicide-resistant gene in contaminated feed, seed or machinery.

Resistance may also be introduced by natural seed spread by wind and water or by pollen, which may blow short distances from a contaminated paddock.

6.10.2 General principles to avoid resistance

Herbicides have a limited life before resistance develops if they are used repeatedly and as the sole means of weed control—particularly in no-till and minimum-till systems.

Resistance can develop within six–eight years for Group A and four–six years for Group B herbicides, 10–15 years for Groups C and D, and after 15 years for Groups L and M herbicides.⁴⁹ Figure 2 illustrates how the use of herbicide can lead to a resistant population. This can be avoided by:

- keeping weed numbers low
- changing herbicide groups
- using tillage
- rotating crops and agronomic practices.

Further insight has been gained into the impact and efficacy of IWM strategy components through a computer-simulated model.⁵⁰

49 QDAF (2015) Stopping herbicide resistance in Queensland. Queensland Department of Agriculture and Fisheries, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance>

50 QDAF (2015) Effectiveness of herbicide resistance management strategies. Queensland Department of Agriculture and Fisheries, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance/effectiveness-of-resistance-management-strategies>

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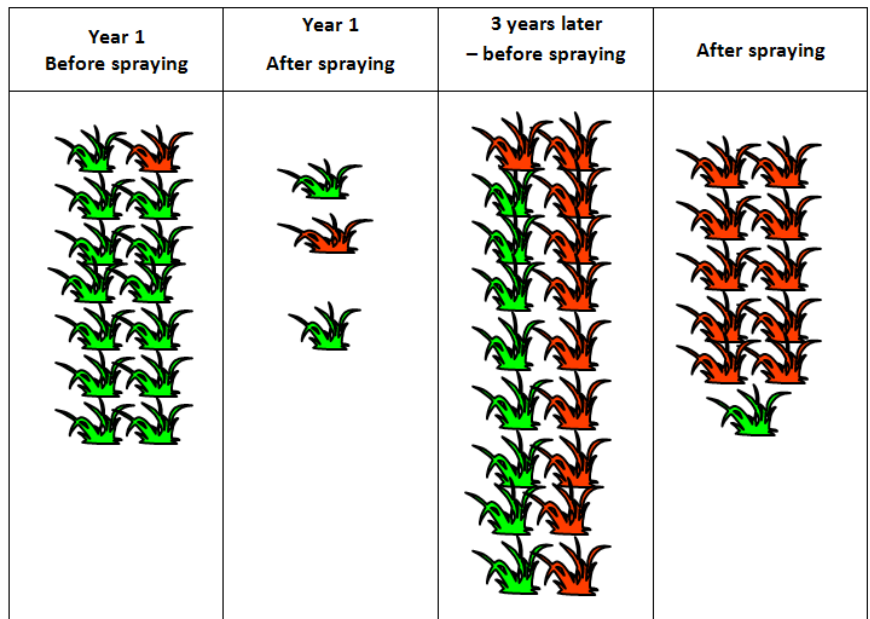


Figure 2: How a weed population becomes resistant to herbicides; red indicates resistant plants.

Source: GRDC

Strategies to prevent or minimise the risk of resistance developing are based on IWM principles as outlined below:

- Ensure that survivors do not set seed and replenish the soil seedbank.
- Keep accurate paddock records of herbicide application and levels of control. Monitor weeds closely for low levels of resistance, especially in paddocks with a history of repeated use of the same herbicide group.
- Rotate between the different herbicide groups, and/or tank mix with an effective herbicide from another MoA group. It is important to use effective 'stand-alone' rates for both herbicides in the mix.
- Aim for maximum effectiveness to keep weed numbers low. The primary aim of weed control is to minimise their impact on productivity, and resistance is much less likely to develop in paddocks with fewer weeds than in heavily infested paddocks.
- Use a wide range of cultural weed-control tools in your weed-management plan. Sowing different crops and cultivars provides opportunities to use different weed-management options on key weeds. Tillage is useful when it targets a major weed flush and minimises soil inversion, because buried weed seed generally persists longer than seed on the soil surface. Competitive crops will reduce seed production on weed survivors.
- Avoid introduction or spread of weeds by contaminated seed, grain, hay or machinery. Also, manage weeds in surrounding non-crop areas to minimise risk of seed and pollen moving into adjacent paddocks.

Guidelines for reducing the risk of glyphosate resistance are outlined in Aim to include as many risk-decreasing factors as possible in your crop and weed management plans.⁵¹

⁵¹ QDAF (2015) Stopping herbicide resistance in Queensland. Queensland Department of Agriculture and Fisheries, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance>

Table 9: Risk factors for weeds developing glyphosate resistance, devised by the national Glyphosate Sustainability Working Group with minor modifications for the Queensland cropping region.

Risk increasing	Risk decreasing
Continuous reliance on glyphosate pre-seeding	Double-knock technique
Lack of tillage	Strategic use of alternative knockdown groups
Lack of effective in-crop weed control	Full-disturbance cultivation at sowing
Inter-row glyphosate use (unregistered)	Effective in-crop weed control
Frequent glyphosate-based chemical fallow	Use alternative herbicide groups or tillage for inter-row and fallow weed control
High weed numbers	Non-herbicide practices for weed seed kill
Pre-harvest desiccation with glyphosate	Farm hygiene to prevent resistance movement

Source: QDAF

Glyphosate-resistant weeds in Australia

Glyphosate resistance was first documented for annual ryegrass in 1996 in Victoria. Since then, glyphosate resistance has been confirmed in 11 other weed species. Resistance is known in eight grass species and four broadleaf species. Four are winter-growing weed species and eight summer-growing weed species. The latter have been selected mainly in chemical fallows and on roadsides (Photo 15).



Photo 15: Winter fallow showing an early glyphosate-resistant sowthistle (*Sonchus spp.*) infestation.

Photo: A Storrie. Source: GSWG

All of the glyphosate-resistant weed populations have occurred in situations where there has been intensive use of glyphosate, often over at least 15 years, few or no other effective herbicides used, and few other weed-control practices used. This suggests that the following are the main risk factors for the evolution of glyphosate resistance:

- intensive use of glyphosate—every year or multiple times a year for ≥ 15 years
- heavy reliance on glyphosate for weed control
- no other weed controls targeted to stop seedset.

MORE INFORMATION

AGSWG: [Australian glyphosate resistance register](#)

GRDC Fact Sheet: [Strategic risk management factsheet](#)

GRDC Fact Sheet: [Farm business management factsheet](#)

AHRI: [RIM model](#)

VIDEOS

WATCH: [Act now: Plan your weed management program.](#)



WATCH: [Chaff carts 101.](#)



WATCH: [Capture weed seeds at harvest: Harrington seed destructor.](#)



WATCH: [Strategic narrow windrow burning.](#)



Farming practices in chemical fallows are dependent on glyphosate for weed control. Therefore, it is highly likely that unconfirmed populations of glyphosate-resistant summer and winter weeds are present in this system.

Likewise, farming practices under the vines in vineyards across Australia are dependent on glyphosate for weed control, so unconfirmed populations of glyphosate-resistant annual ryegrass are very likely present in this system.

These unconfirmed glyphosate-resistant populations are not recorded on the register of glyphosate-resistant populations in Australia.⁵²

The Queensland Department of Agriculture and Fisheries [Glyphosate resistance toolkit](#) enables growers and advisors to assess their level of risk for developing glyphosate-resistant weeds on their farm.

6.10.3 The 10-point plan to weed out herbicide resistance

1. Act now to stop weed seedset.

Creating a plan of action is an important first step of integrated weed management. A little bit of planning goes a long way!

- Destroy or capture weed seeds.
- Understand the biology of the weeds present.
- Remember that every successful WeedSmart practice can reduce the weed seedbank over time.
- Be strategic and committed—herbicide resistance management is not a one-year decision.
- Research and plan your WeedSmart strategy.
- You may have to sacrifice yield in the short term to manage resistance—be proactive.

2. Capture weed seeds at harvest.

Destroying or capturing weed seeds at harvest is the number one strategy for combating herbicide resistance and driving down the weed seed bank.

- [Tow a chaff cart behind the header.](#)
- [Check out the new Harrington Seed Destructor.](#) (Photo 16)
- [Create and burn narrow windrows.](#)
- Produce hay where suitable.
- [Funnel seed onto tramlines in controlled traffic farming \(CTF\) systems.](#)
- Use a green or brown manure crop to achieve 100% weed control and build soil nitrogen levels.

Controlling weed seeds at harvest is emerging as the key to managing the increasing levels of herbicide resistance, which are putting Australia's no-till farming system at risk.

52 C Preston. The Australian Glyphosate Sustainability Working Group, <http://www.glyphosateresistance.org.au>

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burning.



WATCH: [Chaff funnelling onto tramlines.](#)



WATCH: [Capture weed seeds at harvest: Bale Direct System.](#)



WATCH: [IWM: Weed seed destruction – Beer can height.](#)

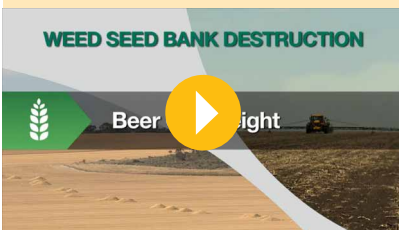


Photo 16: *Harrington Seed Destructor at work in the paddock.*

Source: [GRDC](#)

For information on harvest weed-seed control and its application, see Section 12: Harvest.

3. Rotate crops and herbicide MoA.

Crop rotation is great for farming systems. Make sure weed management is part of the decision when planning crop rotation.

Crop rotation offers many opportunities to use different weed control tactics, both herbicide and non-herbicide, against different weeds at different times.

Rotating crops also gives us a range of intervention opportunities. For example, we can crop-top lupins and pulses, swath canola, and delay sowing some crops (such as field peas).

Rotations that include both broadleaf crops (e.g. pulses and oilseeds) and cereals allow the use of a wider range of tactics and chemistry.

Growers also have the option of rotating to non-crop, e.g. pastures and fallows.

Within the rotation it is also important not to repeatedly use herbicides from the same MoA group. Some crops have fewer registered herbicide options than others, so this needs to be considered too, along with the opportunities to use other tactics in place of one or more herbicide applications, such as harvest weed-seed control.

Repeated use of herbicides with the same MoA is the single greatest risk factor for evolution of herbicide resistance.

4. Test for resistance to establish a clear picture of paddock-by-paddock farm status.
 - Sample weed seeds prior to harvest for resistance testing to determine effective herbicide options.
 - Use the [Quick Test](#) option to test emerged ryegrass plants after sowing to determine effective herbicide options before applying in-crop selective herbicides.
 - Collaborate with researchers by collecting weeds for surveys during the double-knock program.
 - Visit [WeedSmart](#) for more information on herbicide-resistance survey results.

It is clearly too late to prevent resistance evolution for many of our common herbicides. However, a resistance test when something new is observed on-farm can be very useful in developing a plan to contain the problem, and in developing new strategies to prevent this resistance evolving further.

Perhaps the best use for herbicide-resistance tests is in a game-changing situation such as the discovery of a rare resistance gene (e.g. glyphosate resistance), or to determine whether a patch of surviving weeds is any worse than the grower had observed before. This bad patch of weeds gives insight into the future resistance

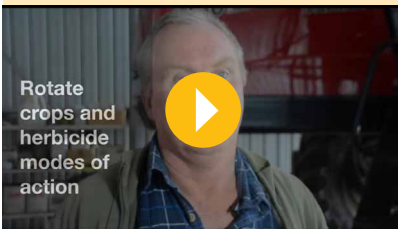
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WATCH: [Crop rotation with Colin McAlpine.](#)



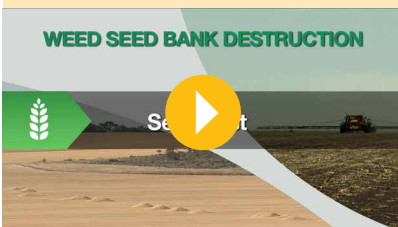
WATCH: [Test for resistance to establish a clear picture of paddock-by-paddock farm status.](#)



WATCH: [IWM: Resistance Testing – Quick test sample collection.](#)



WATCH: [IWM: Seed test – What's involved.](#)



profile of the farm if it is not contained and resistance testing in these situations can be very useful in building preventative strategies.

5. Never cut the rate.

- Always use the label rate
- Weeds resistance to multiple herbicides can result from below the rate sprays.

AHRI researcher Dr Roberto Busi found that annual ryegrass receiving below-the-rate Sakura® evolved resistance not only to Sakura® but also to Boxer Gold® and Avadex®. Imagine developing these multiple-resistant, monster weeds just because you cut the rate!

Aim for 100% control and monitor every spray event:

- Stop resistant weeds from returning to the farming system.
 - Focus on management of survivors in fallows.
 - Where herbicide failures occur, do not let the weeds seed. Consider cutting for hay or silage, fallowing or brown manuring the paddock.
 - Patch-spray areas of resistant weeds only if appropriate.
6. Do not automatically reach for glyphosate.

Glyphosate has long been regarded as the world's most important herbicide, so it is natural to reach for it at the first sign of weeds. But what if it did not work anymore?

Resistance to this herbicide is very high in some areas and now it may fail for growers all across Australia. This is because too much reliance on one herbicide group gives the weeds opportunity to evolve resistance.

To preserve the status of glyphosate as the wonder weed-killer, we need to stop automatically reaching for it. Introduce paraquat products when dealing with smaller weeds, and for a long-term solution, farm with a very low seedbank:

- Use a diversified approach to weed management.
- Consider post-emergent herbicides where suitable.
- Consider strategic tillage.

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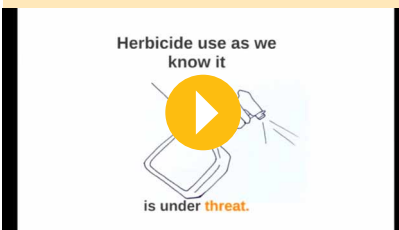
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VIDEOS

WATCH: [Don't cut the rate.](#)



WATCH: [Don't automatically reach for glyphosate.](#)



WATCH: [Manage spray drift.](#)



WATCH: [Plant clean seed into clean paddocks with clean borders.](#)



WATCH: [Best results with double knock tactic.](#)



7. Carefully manage spray events.
 - Use best management practice in spray application.
 - Consider selective weed sprayers such as WeedSeeker® or WEEDit®.

It is important to set up your spray gear to maximise the amount of herbicide applied directly to the target. This makes the spray application more cost-effective by killing the maximum number of weeds possible and it protects other crops and pastures from potential damage and/or contamination.

Spray technology has improved enormously in the last ten years, making it far easier for growers to target the application precisely. Also, many herbicide labels specify the droplet spectrum to be used when applying the herbicide (so take the time to read the label beforehand).

Generally, medium–coarse droplet size combined with higher application volumes provides better coverage of the target. Using a pre-orifice nozzle slows droplet speed, making them are less prone to bouncing off the target.

Using oil-based adjuvants with air-induction nozzles can reduce herbicide deposition by reducing the amount of air in the droplets. These droplets then fail to shatter when they hit the target, which increases droplet bounce.

8. Plant clean seed into clean paddocks with clean borders.
 - It is easier to control weeds before the crop is planted.
 - Plant weed-free crop seed to prevent the introduction of new weeds and the spread of resistant weeds.
 - A recent Australian Herbicide Resistance Initiative (AHRI) survey showed that 73% of grower-saved crop seed was contaminated with weed seed.
 - The density, diversity and fecundity of weeds are generally greatest along paddock borders and areas such as roadsides, channel banks and fence lines.

Keep it clean! With herbicide resistance on the rise, planting clean seed into clean paddocks with clean borders is a top priority.

Controlling weeds is easiest before the crop is planted, so be sure to plant weed-free crop seed to prevent the introduction of new weeds and the spread of resistant ones.

Introducing systems that increase farm hygiene will also prevent new weed species and resistant weeds. These systems could include crop rotations, reducing weed burdens in paddocks or a harvest weed-seed control such as the Harrington Seed Destructor or windrow burning.

Lastly, roadsides and fence lines are often a source of weed infestations. Weeds here set enormous amounts of seed because they have little competition, so it is important to control these initial populations by keeping clean borders.

9. Use the double-knock technique.

To use the double-knock technique, combine two weed-control tactics with different MoA on a single flush of weeds. These two knocks happen in sequential strategies; the second application designed to control any survivors from the first.

One such strategy is the glyphosate–paraquat double-knock. These two herbicides use different MoAs to eliminate weeds and so make an effective team when paired up. When using this combination, ensure that the paraquat rate is high.

The best time to initiate a glyphosate–paraquat double-knock is after rainfall. New weeds will quickly begin to germinate and they should be tackled at this small stage.

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DOUBLE KNOCK APPLICATIONS

A Grower’s Experience

WATCH: [Spray application of herbicides – Double Knock.](#)

SPRAY APPLICATION OF HERBICIDES

Double Knock

WATCH: [Double knock applications - target weed species & application strategy](#)

DOUBLE KNOCK APPLICATIONS

Target Weed Species and Application Strategy

WATCH: [Learn to think outside the drum.](#)

WEED smart
every weed every seed
every farm every year

10. Employ crop competitiveness to combat weeds.

Help your crops win the war against weeds by increasing their competitiveness against them:

- Consider narrow row spacing and seeding rates.
- Consider twin-row seeding points.
- Consider east–west crop orientation.
- Use barley and varieties that tiller well.
- Use high-density pastures as a rotation option.
- Consider brown manure crops.
- Rethink bare fallows. ^{53 54}

If you think you have resistant weeds

When resistance is first suspected, growers should contact their local agronomist.

The following steps are then recommended:

1. Consider the possibility of other common causes of herbicide failure by asking:
 - a. Was the herbicide applied in conditions and at a rate that should kill the target weed?
 - b. Did the suspect plants miss herbicide contact or emerge after the herbicide application?
 - c. Does the pattern of surviving plants suggest a spray miss or other application problem?
2. Has the same herbicide or herbicides with the same MoA been used in the same field or in the general area for several years?
3. Has the uncontrolled species been successfully controlled in the past by the herbicide in question or by the current treatment?
4. Has a decline in the control been noticed in recent years?
5. Is the level of weed control generally good on the other susceptible species?

53 AHRI. Harvest weed seed control. GRDC/Australian Herbicide resistance Initiative. <http://ahri.uwa.edu.au/~ahriuwae/wp-content/uploads/2014/10/1100-AHRI-Harvest-Weed-Seed-Control-Booklet-2013-version.pdf>

54 WeedSmart 10 point plan. WeedSmart, <http://weedsmart.org.au/10-point-plan/>

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WATCH: [Crop Competition – increasing wheat seeding rate.](#)



WATCH: [Crop competition—Row Spacing.](#)



MORE INFORMATION

[CropLife Australia](#)

[Australian Glyphosate Sustainability Working Group](#)

[Australian Herbicide Resistance Initiative](#)

[Cotton Catchment Communities CRC \(Weedpak\)](#)

If resistance is still suspected:

1. Contact a testing service (see below).
2. Ensure that all suspect plants do not set any seed.
3. If resistance is confirmed, develop a management plan for future years to reduce the impact of resistance and likelihood of further spread.⁵⁵

Testing services

For testing of suspected resistant samples, contact:

- Charles Sturt University Herbicide Resistance Testing
School of Agricultural and Wine Sciences Charles Sturt University
Locked Bag 588
Wagga Wagga, NSW 2678
02 6933 4001
<https://www.csu.edu.au/weedresearchgroup/herbicide-resistance>
[CSU plant testing application form](#)
- Plant Science Consulting P/L
22 Linley Avenue, Prospect
SA 5082, Australia
info@plantscienceconsulting.com.au
Phone: 0400 66 44 60

6.11 Monitoring weeds

Monitoring of weed populations before and after any spraying is an important part of management:

- Keep accurate records.
- Monitor weed populations and record results of herbicides used.
- If herbicide resistance is suspected, prevent weed seedset.
- If a herbicide does not work, find out why.
- Check that weed survival is not due to spraying error.
- Conduct your own paddock tests to confirm herbicide failure and determine which herbicides remain effective.
- Obtain a herbicide-resistance test on seed from suspected plants, testing for resistance to other herbicide MoA groups.
- Do not introduce or spread resistant weeds in contaminated grain or hay.

Regular monitoring is required to assess the effectiveness of weed management and the expected situation following weed removal or suppression. Without monitoring, we cannot assess the effectiveness of a management program or determine how it might be modified for improved results. Effective weed management begins with monitoring weeds to assess current or potential threats to crop production, and to determine best methods and timing for control measures.

Regular monitoring and recording details of each paddock allows the grower to:

- spot critical stages of crop and weed development for timely cultivation or other intervention;
- identify the weed flora (species composition), which helps to determine best short- and long-term management strategies; and
- detect new invasive or aggressive weed species while the infestation is still localised and able to be eradicated.

Watch for critical aspects of the weed–crop interaction, such as:

- weed-seed germination and seedling emergence
- weed growth sufficient to affect crops if left unchecked

⁵⁵ QDAF (2015) Stopping herbicide resistance in Queensland. Queensland Department of Agriculture and Fisheries, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance>

- weed density, height, and cover relative to crop height, cover, and stage of growth
- weed effects on crops, including harbouring pests, pathogens or beneficial organisms; or modifying microclimate, air circulation or soil conditions; as well as direct competition for light, nutrients, and moisture
- flowering, seedset, or vegetative reproduction in weeds
- efficacy of cultivations and other weed-management practices.

Information gathered through regular and timely field monitoring helps growers to select the best tools and timing for weed-control tactics. Missing vital cues in weed and crop development can lead to costly efforts to rescue a crop, efforts that may not be fully effective. Good paddock scouting can help the grower to obtain the most effective weed control for the least fuel use, labour cost, chemical application, crop damage and soil disturbance.⁵⁶

6.11.1 Tips for monitoring

To scout weeds, walk slowly through the paddock, examining any vegetation that was not planted. In larger paddocks, walk back and forth in a zigzag pattern to view all parts of the paddock, noting areas of particularly high or low weed infestation. Identify weeds with the help of a good weed guide or identification key for your region, and note the weed species that are most prominent or abundant. Observe how each major weed is distributed through the paddock. Are the weeds randomly scattered, clumped or concentrated in one part of the paddock?

Keep records in a field notebook. Prepare a page for each paddock or crop sown, and take simple notes of weed observations each time the paddock is monitored. Over time, your notes become a timeline of changes in the weed flora over the seasons and in response to crop rotations, cover crops, cultivations and other weed control practices. Many growers already maintain separate records for each paddock; weed observations (species, numbers, distribution, size) can be included with these.

56 M Schonbeck (2011) Weed monitoring. Cooperative Extension System, <http://articles.extension.org/pages/32636/weed-monitoring>