GRDC GROWNOTES™

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

TRITICALE

SECTION 6

WEED CONTROL

WEED COMPETITIVENESS OF TRITICALE | INTEGRATED WEED MANAGEMENT | KEY WEEDS OF AUSTRALIA'S CROPPING SYSTEMS | HERBICIDES | PRE-EMERGENT HERBICIDES | POST-PLANTING PRE-EMERGENT HERBICIDES | IN-CROP HERBICIDES: KNOCKDOWNS AND RESIDUALS | CONDITIONS FOR SPRAYING | TESTING FOR HERBICIDE TOLERANCE | POTENTIAL HERBICIDE DAMAGE OF TRITICALE

Weed control

Key messages

- Weed control in triticale is similar to that for wheat.
- There are mixed reviews on triticale's ability to compete with weeds. Triticale can be a poor competitor against weeds due to reduced tillering capacity.
- In most cases, the herbicides that work on wheat and rye will work on triticale, however growers must check product labels for registration for use on triticale.
- Integrated weed management practices for becoming more common in Australian cropping systems, and show promising results that should also be employed with triticale.
- Good soil fertility along with vigorous germination and fast emergence may be one of the most efficient ways to reduce weeds through competition.

Weeds are estimated to cost Australian agriculture A$2.5–4.5 billion per annum. For winter cropping systems alone the cost is $1.3 billion, with annual rye grass being one of the biggest problems (Photo 1). [1] Consequently, any practice that can sustainably reduce the weed burden is likely to generate substantial economic benefits to growers and the grains industry.

Photo 1: *Annual ryegrass is one of the most problematic weeds in Australia and around the world (left). Here (right) it is heavily infesting a cereal paddock.*

Source: Southwest Farm Press

In most cases, the herbicides that work on wheat and rye will work on triticale, however growers must check product labels for registration for use on triticale. Some studies indicate that triticale may be less tolerant of some herbicide cocktails than wheat. Newer herbicides as well as pesticides are now being released with recommendations for use on triticale. [2]

6.1 Weed competitiveness of triticale

Good soil fertility along with vigorous germination and fast emergence may be one of the most efficient ways to reduce weeds through competition. A vigorously growing crop is usually weed-free, and this is as true of triticale as it is of other grains.

The actual competitiveness of different cereals depends on growing conditions, management practices, weed load and relative growth stage of the weed and crop.

1 R Smith (2014) Two-step program controls resistant ryegrass in wheat. 24 February. Southwest Farm Press, http://www.southwestfarmpress.com/wheat/two-step-program-controls-resistant-ryegrass-wheat

2 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/3/a-y5553e/y5553e00.pdf

Triticale's competition to weeds is provided by its leafiness and height, which impact light and moisture competition. [3]

Triticale may have some allelopathic effect which can inhibit the germination and growth of weeds but this effect is not as high as one of its parent crops, cereal rye. [4]

The grass weed annual ryegrass (*Lolium rigidum*) is one of the worst weeds of triticale (as well as other grains). Based on research in southern NSW the most competitive crops in the face of annual ryegrass (at 300 plants/m–2 are, in descending order, oats, cereal rye, triticale, oilseed rape, barley, wheat, field peas, and lupins. [5]

Suppression of annual ryegrass by wheat, triticale and rye was compared in field trials at Wagga Wagga in 1993. Triticale and cereal rye appeared to be more competitive than wheat: the biomass of mature ryegrass was 70 g/m^2 in triticale, compared to 170 g/m^2 in wheat. Triticale has large seeds which lead to rapid early growth and the capacity to suppress weeds because of a vigorous growth habit. Early seedling vigour, superior height and broad leaves appeared to influence the greater competitive ability of the triticale and cereal rye in this study. [6]

A general rule of thumb in cereals is that taller, leafier varieties are more competitive due to the ability to close the canopy quickly. Being somewhat weed competitive, triticale is sometimes used in a 'green' approach in crop rotations to reduce weed seedbanks. When seeded early and under good conditions, triticale will compete with many weed species. Although it is not as effective as rye, triticale can be very competitive with wild oats. [7]

To minimise weeds, prepare the seedbed so it is as clean as possible before planting, and be sure to practice crop rotation. Planting early will help with the quick establishment of a triticale stand and may stave off early weed pressure. Triticale can also be inter-seeded with another crop (including forage grasses or legumes) to aid in weed competition and nutrient management. [8]

6.1.1 Best management practices for weed control in triticale

Best management practices for weed control in triticale are similar to those for wheat. These include:

- Seed at higher rates and ensure proper crop nutrition, which can help control weeds in triticale.
- Plan ahead. Chemical weed control options in triticale are limited, making it more important to select relatively clean paddocks in which to seed triticale.
- In the case of perennial weed problems, apply pre-harvest glyphosate or use as a pre-seeding burn off when direct seeding. Use in-crop herbicides to control or suppress broadleaf weeds.
- Use certified or well-cleaned and graded seed as this ensures that only triticale, and not weeds, is seeded.
- Seed early within the recommended sowing window, as earlier sown triticale usually results in more competitive stand establishment, and provides a jump-start on the weeds.
- Seed shallow at between 13–38 mm (optimum 25 mm). Shallow seeding generally results in uniform seedling emergence with plants quickly covering

3 S Clarke, S Roques, R Weightman, D Kindred (2016) Understanding triticale. AHDB, https://cereals.ahdb.org.uk/media/897536/pr556-understanding-triticale.pdf

4 Albert Lea Seed (2010) Triticale, http://www.alseed.com/UserFiles/Documents/Product%20Info%20Sheets-PDF/Basics%20Triticale-2010.pdf

5 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 (6), 503–509.

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

7 Alberta Agriculture and Forestry (2016) Triticale Crop Protection. Alberta Agriculture and Forestry, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10572

8 UVM Extension Crops and Soils Team (2011) Triticale. University of Vermont, http://northerngraingrowers.org/wp-content/uploads/TRITICALE.pdf

the ground which may aid in competition against weeds. However, because of triticale's large seed size, it can be sown deeper under the right conditions.

- Use sanitary practices: clean machinery and seeding equipment before planting. [9]

6.2 Integrated weed management

MORE INFORMATION

GRDC, Integrated weed management manual

The Grains Research and Development Corporation (GRDC) supports the practice of integrated weed management (IWM). This is a system for managing weeds over the long term, and particularly incudes the management of weeds so as to minimise the development of herbicide resistance. There is a need to combine herbicide and non-herbicide methods into an integrated control program. Given that there are 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.

The GRDC manual, Integrated Weed Management in Australian Cropping Systems, looks at these issues and breaks them down into seven clear sections, to assist the reader to make the development of an IWM plan a simple process.

6.2.1 IWM for triticale

Although triticale has been shown to be more competitive against annual ryegrass than wheat, a sound weed-control program must still be implemented to avoid a blow-out in weed seed numbers and to optimise yields.

It is vital to control weeds early in the crop's growth to give the crop a chance to get ahead. Once the crop has grown it then becomes more competitive.

When sowing dual-purpose varieties early, choose a paddock with low weed numbers and control weeds prior to the first grazing. Strategic grazing can be used to help manage weeds. When planning to graze the crop, always check grazing withholding periods before you apply post-emergent herbicides. [10]

IN FOCUS

The effect of cultivation and row spacing on the competitiveness of triticale

Research in 2007 explored the effect of cultivation and row spacing on the competitiveness of triticale against weeds. The aim of this work was to identify agronomic practices that enable triticale to express its full genetic potential for competitive growth against the vigorous weedy competitor annual ryegrass (*Lolium rigidum*). Researchers assessed the effects on triticale of cultivation (disc ploughing), or lack thereof (zero tillage) before sowing, and row spacing (15 cm, 30 cm and 45 cm).

Most of the experiments evaluating the effect of row spacing and level of cultivation on cereals have been performed on wheat, so there is little data specifically on triticale. The researchers hoped to identify the optimal row spacing and level of cultivation that enhance the competitive ability of triticale, to help farmers secure more sustainable yields by increasing including triticale in their cropping rotations. They hoped the results would help farmers reduce the cost of weed control, reduce weed-induced losses of yield, and see greater fertiliser uptake and utilisation by the crop at the expense of weeds.

9 Alberta Agriculture and Forestry (2016) Triticale Crop Protection. Alberta Agriculture and Forestry, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10572

10 Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

Unfortunately, growing conditions were less than ideal. Episodic heavy rain early in the growing season caused waterlogging and poor establishment of the triticale and, late in the season, some lodging. In addition to above-average rainfall, temperatures were below average. This combination appeared to assist the growth of annual ryegrass at the expense of triticale. The data they collected was highly variable. Under these conditions, row spacing did not effect the biomass, grain yield or 1,000-grain weight of the triticale. Cultivation, however, while not showing an early impact, increased triticale biomass and grain yield at harvest. In this trial, the wet conditions appeared to affect the expression of competitive growth habits in both the crop and weed species present, although the weeds out-competed the triticale.

All was not lost. Several findings validated the value of the agro-ecological principles on which integrated weed management is based. They included:

- Weeds that emerge prior to or at the same time as the crop impose the greatest weed-–crop interference, particularly in those weed species (e.g. L. rigidum) that share similar morphology and phenology to cereal crops.
- Strong selection pressure from a given agronomic practice will cause a shift in the composition of the weed flora and may contribute to the development of single species becoming a problem, e.g. *Fallopia convolvulus* under high crop densities.
- Early suppression of weeds, in terms of preventing germination or limiting biomass accumulation, is the most important aspect of crop competitive ability, as even the most tolerant crops will have lower yields if early weed–crop competition results in reduced crop tillering during early crop growth.
- The expression of competitive growth in cereal crops with strong genetic potential for competitive ability (e.g. triticale) is highly influenced by optimal plant densities and competition between individual plants in the crop. [11]

6.2.2 General IWM principles and tactics

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

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

The following five-point plan will assist in developing a management plan 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, and consider using a rotational plan.

In an IWM plan, each target weed is attacked using tactics from several tactical groups (see links below). Each tactic provides an opportunity for weed control. It is

11 B Sindel (2008) UHS127: The effect of cultivation and row spacing on the competitive ability of triticale against weeds. GRDC, http://finalreports.grdc.com.au/UHS127

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 tactics:

- Reduce weed seed numbers in the soil.
- Controlling small weeds.
- Stop weed seed set.
- Reduce weed seed numbers in the soil.
- Hygiene: prevent weed seed introduction.
- Agronomic practices and crop competition.

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

There are several agronomic practices that improve crop environment and growth, along with the crop's inherent ability to out-compete weeds. These include crop choice and sequence, improving crop competition, planting herbicide-tolerant crops, improving pasture competition, using fallow phases, and using controlled traffic or tramlining. [12]

Review past actions

Knowing the historical level of selection pressure can be valuable information to give managers a 'heads up' as to which weed and herbicidal mode of action (MOA) groups are at greatest risk of developing resistance. Such knowledge can prompt more intensive monitoring for escapee weeds when a situation of higher risk exists. Noticing developing resistance while patches are still small and before they spread can make a big difference in the cost of management over time. If a population is suspected resistant, a herbicide resistance test should be conducted to confirm the resistance level and resistance group.

From all available paddock records, calculate or estimate the number of years in which different herbicide MOAs have been used. This is of far greater relevance than the number of applications in total. For most weeds, using 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 to you, state what is known and estimate the rest. Collate separate data on MOA use for summer and winter weed spectrums. Further subdivide these into broadleaved and grass weeds.

Account for past double-knock practices. Where survivors of one tactic would have been controlled in large part by the use of another tactic, reduce the number of MOA uses accordingly. An example might be: Trifluralin (Group D) has been used 20 times, but there have been six years when in-crop Group A selectives were used and several more years where in-crop group B products that targeted the same weed as the trifluralin were used. These 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 weed 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, using 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 in deciding which paddocks receive extra time for scouting for patches of escaped weeds.

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

12 DAFWA (2016) Crop weeds: Integrated weed management (IWM). DAFWA, https://www.agric.wa.gov.au/grains-research-development/crop-weeds-integrated-weed-management-iwm

Table 1: *Typical number of years of use to develop resistance MOA groups.*

Herbicide 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

Assess the current weed status

Record the key broadleaved 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 some other 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 of weeds in this paddock.

Add this information to paddock records.

Identify weed management opportunities

Identify what different herbicide and non-herbicide tactics could be cost effectively added to the system and where in the crop sequence these can be added.

Fine-tune your list of options

Which are your preferred options to add to your existing weed-management tactics, so that you to add diversity and help drive down the weed seedbank?

Combine and test ideas

Computer simulation tools can be useful to run a number of 'what if' 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 using a rotational planner, or test them in using decision-support software such as RIM (see below) and/or Weed Seed Wizard.

MORE INFORMATION

Section 4: Tactics for managing weed populations

MORE INFORMATION

Weed Seed Wizard

Weed Control Handbook for Declared Plants in South Australia

Declared plants of South Australia: Are they on your land?

SA weed risk management guide

Weed Seed Wizard

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

It is a computer simulation tool that uses paddock-management information to predict weed emergence and crop losses. Different weed management scenarios can be compared 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: users enter their own farm management records, their 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 oats, brome grass and silver grass in the southern states.

South Australian Weed Control App – SA Weed control

Biosecurity SA, in partnership with the eight natural resource management regions in South Australia, has developed a free weed-control app that provides essential information about the control of weeds declared in South Australia under the *Natural Resources Management Act 2004*. The app provides information from the Weed Control Handbook for Declared Plants in South Australia. The app includes:

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

In addition app users can:

- record the location of weeds
- keep a personal log of control activities
- phone or email regional natural resource officers
- send photos and text of high-risk weeds

It is intended that the app will be updated annually as chemical uses and plant declarations change. Download the app from Google Play (for Android devices) or the iTunes App Store.

6.2.3 IWM in the southern region

Grain growers in Victoria, South Australia and Tasmania have the ability to 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 there are high levels of herbicide resistance on their farms. Weed seedbanks can be eroded to near-zero levels by committing to a simple strategy, the five components of which are:

1. employing a double-knock of herbicides;
2. mixing and rotating chemicals;
3. planting competitive crops;
4. stopping seedset; and
5. harvest weed-seed control through crop topping or desiccation.

When you stack all these components together, you can drive down the weed seedbank.

Double-knock is not so much about the seedbank but preserving the usefulness of herbicides and glyphosate. If you double-knock every year glyphosate resistance shouldn't be an issue, but it's not a double-knock if you already have glyphosate resistance. If you have lot of glyphosate resistance and you start double-knocking, you are basically applying a single knock of paraquat, in which case paraquat resistance will develop. The best time to start using double-knock is before you have glyphosate resistance.

It's also important to mix herbicide use. By mixing two herbicides together at full rates, if a weed is resistant to one product the other will kill it before it sets seed. It is almost impossible for a weed to have two resistance mechanisms operating in the face of a mixed herbicide selection.

Crop competition involves four factors: seeding rate, row spacing, orientation and cultivars. Growers need to be employing at least one of these, and preferably two, to encourage crop competitiveness.

Another component is harvest weed-seed control (HWSC), which has been a focus of the research and development efforts of the Australian Herbicide Resistance Initiative (AHRI). 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, leaving chaff in the windrow to rot, is another option. Windrow burning is a popular option, with more people doing this than any other HWSC activity, but it does have its problems. With the other HWSC tools growers can do them in every crop every year, but that's not always the case with windrow burning.

Another tool is baling directly which 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 hold ryegrass and other weeds up so that growers can catch them in the header. HWSC works better on low-density ryegrass.

A lot of weeds are becoming more dormant: they are adapting to germinate later to avoid knock-down and pre-emergent herbicides. Ryegrass, barley and brome grasses are among these. This can be turned to the grower's advantage because they can sow a competitive crop early and it will compete well against 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. [13]

6.3 Key weeds of Australia's cropping systems

Section 8 of GRDC's *Profiles of common weeds* of cropping contains profiles of the common weeds of Australian crops: [14]

- 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*)

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

14 GRDC (2014) Section 8. Profiles of common weeds of cropping. GRDC, https://grdc.com.au/Resources/IWMhub/Section-8-Profiles-of-common-weeds-of-cropping

- feathertop Rhodes grass (*Chloris virgata*)
- fleabane (*Conyza* spp.)
- fumitory (*Fumaria* spp.)
- Indian hedge mustard (*Sysimbrium orientale*)
- liverseed grass (*Urochloa panicoides*)
- muskweed (*Myagrum perfoliatum*)
- paradoxa grass (*Phalaris paradoxa*)
- silver grass (*Vulpia* spp.)
- sweet summer grass (*Brachiaria ericuformis*)
- turnip weed (*Rapistrum rugosum*)
- wild oats (*Avena fatua* and *Avena ludoviciana*)
- wild radish (*Raphanus raphanistrum*)
- windmill grass (*Chloris truncata*)
- wireweed (*Polygonum aviculare* and *Polygonum arenastrum*)

IN FOCUS

RIM (Ryegrass Integrated Management)

RIM (Ryegrass Integrated Management) is software that provides insights into the long-term management of annual ryegrass in dryland broadacre crops where herbicide resistance is developing. RIM enables users to test different tactics for ryegrass management and observe their predicted impacts on ryegrass populations, crop yields and long-term economic outcomes. It can be used at paddock scale, and over short and long time scales. The underlying model of the software integrates biological, agronomic and economic considerations in a dynamic and user-friendly framework.

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.

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 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 occurs?
- If a pasture phase is included, how long should it be?

MORE INFORMATION

Ryegrass Integrated Management

VIDEOS

WATCH: Managing herbicide resistant ryegrass with IWM

6.3.1 Ryegrass management in the southern region

Herbicide resistance is increasing, with higher levels of chemical tolerance recorded in south-east South Australia. In 2013, a study found that 16% of paddocks in the south-east contained glyphosate-resistant ryegrass (Photo 2).

Photo 2: *Glyphosate-resistant ryegrass in crop paddock.*

Source: Weekly Times

Although herbicide resistance is widespread across Australia, in a three-year trial by the University of Adelaide at Roseworthy, in SA's mid-north, researchers found that the strategic use of oaten hay was the best tool for rapidly reducing the seedbank of annual ryegrass. However, having done this, another year of seedset control is needed to keep weed populations low.

In this four-year trial for improving weed management, researchers used three different weed-management for ryegrass control . Cutting oaten hay in the first year reduced the seedbank of ryegrass by 86%, from 4,819 seeds/m^2 to 692 seeds/m^2. Field peas were sown in the following year and three spray options used across three sections.

1. When trifluralin was used alone, seedbank levels increased from 692 seeds/m^2 to 8,319 seeds/m^2.
2. When Select® was applied after trifluralin, the ryegrass seedbank slightly increased, from 692 seeds/m^2 to 806 seeds/m^2.
3. When Select® was applied and the field peas crop-topped with Roundup® glyphosate, the seedbank declined to fewer than 500 seeds/m^2.

These results show that a second year of seedset control in managing annual ryegrass is important. Growers need to be cautious in using chemicals, as resistance to Select® is increasing in SA. This is a major concern as Select® is important for providing effective control of ryegrass. Crop-topping after Select® application, even if there are only a few weeds left in the paddock, decreased the risk of resistance emerging. Where two years of seedset control had been used, the annual ryegrass seedbank in the following crop continued to decline, even where Boxer Gold® was the only herbicide used. [15]

Another, long-term trial that began in 2012 at Southern Farming System's Lake Bolac site, in Victoria's high-rainfall zone (HRZ) has shown that adapting some farming practices can make a difference in the fight against weeds. The HRZ has a history of herbicide-resistant ryegrass. Researchers 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

15 D Lush (2013) Consistent weed control needed to combat ryegrass. Ground Cover. No. 106. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-106-Sept-Oct-2013/Consistent-seed-control-needed-to-combat-ryegrass

Victorian HRZ. The cultural practices include mouldboard ploughing, stubble burning, stubble incorporation with light cultivation, and retaining stubble and using direct sowing. These were followed up with low-cost (such as trifluralin mixtures), medium-cost and high-cost (such as Sakura® + Avadex® Xtra mixtures in wheat) pre-emergent herbicide treatments.

The following lessons have been gleaned from the work.

Mouldboard ploughing

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

Pre-emergent herbicides

The biggest lesson learned from using pre-emergent herbicides was not to incorporate stubble. Farmers with too much stubble are advised to burn it instead. Incorporating stubble moves the ryegrass away from the range of herbicides, limiting their effectiveness.

Farmers with ryegrass that is resistant to post-emergent herbicides cannot manage outbreaks by growing wheat and barley. Even with our best treatments, numbers of resistant plants are still going up.

Unsurprisingly, the cheapest pre-emergent herbicide strategies were the least effective. The mid-cost strategy is better, but the expensive strategy is the best. Growers in the HRZ have few options but to use expensive herbicides it they want to control resistant ryegrass. This is because it is the costly ones, particularly the Sakura® + Avadex® Xtra mix, that provide the length of persistence needed.

Narrow windrow burning

When attempting to burn windrows of barley in the trials, the burn got too fast and didn't burn the windrows all the way down to the ground, which meant that streaks of ryegrass were left across the site. The lesson is to gain windrow-burning skills using a crop such as canola, that is easy to control, before moving on to barley, which is probably the hardest crop to do it in. [16]

6.3.2 Brome grass and barley grass in the southern region

Control of brome grass is becoming increasingly difficult throughout south-eastern Australia's cropping zone due to high herbicide resistance, increasing seed dormancy, and the spread of the weed from its traditional low-rainfall area to new regions (Photo 3). [17]

The increasing incidence of brome and barley grass in cropping paddocks in southern Australia is likely to be associated with selection of more dormant biotypes as a response to growers' weed-management practices.

At present brome-grass management in cereals is heavily reliant on Group B herbicides, especially the ClearfieldTM technology. Delaying onset of resistance to these herbicides would require the identification of effective alternative herbicides.

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

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

Photo 3: *Brome grass growing in a cereal crop at a University of Adelaide trial in Balaklava.*

Source: GRDC

Barley grasses (Hordeum spp.) are annual species renowned for rapidly germinating in autumn to provide valuable stockfeed soon after breaking rain (Photo 4). [18] 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 is germinating later in the season.

Photo 4: *Emerging flower-head of barley-grass.*

Photo: AJ Brown

Barley grass is a problem for a number of reasons:

- They act as an alternate host for a number of cereal diseases.
- Seeds cause stock health problems where seed gets stuck in wool or eyes.
- Post-emergent herbicide control is limited in cereals.

18 Barley-grass. Victorian Resources Online. Department of Economic Development, Jobs, Transport and Resources, http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/sip_barley_grass

- Barley grasses generally mature earlier than the crop and seeds are readily dispersed.
- Populations of barley grasses can develop resistance to herbicides. [19]

Managing brome grass and barley grass

Field trials undertaken over four years have investigated various pre-emergence herbicides for brome-grass control in wheat. Even though Sakura® (pyroxasulfone) appears to be the most active pre-emergent herbicide against brome grass, it lacks the consistency required for long-term population management of brome grass.

Surveys by the University of Adelaide in a previous GRDC-funded project showed high levels of resistance to Group B herbicides, with 40–50% resistance to Atlantis® and CrusaderTM in the South Australian Mallee, and 40% resistance to Atlantis® in Victoria.

Field trials confirmed consistently high efficacy of Sakura® against barley grass, especially under situations with good soil moisture.

Barley-grass management is now being complicated by the evolution of Group A resistance in this weed species. However, there appear to be several effective alternatives (e.g. Sakura® and Raptor®) that could be used for barley-grass control in broadleaf crops. [20]

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 GRDC trials showed trifluralin may only provide about 50% control in wheat. The combination of Sakura® and Avadex® has been shown to be more effective, but the high cost means it is often uneconomical.

With herbicide control providing no easy solutions, an integrated weed management strategy is needed to control the problem weed.

Where there are severe brome-grass patches in cereals, in the range of >50 plants per square metre, 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 else the use of chaff carts can help reduce the seedbank. Note though that windrow burning for Brome grass is problematic as it tends to drop seeds before the header goes through.

However, the most effective control will be to use rotations. For a severe infestation, use a pulse or break crop with a grass-selective herbicide and crop-topping, followed by a ClearfieldTM variety using IMI chemistry. If there are still some weeds after two years, go with a crop of barley with pre-emergent trifluralin and metribuzin for a third-step control. High brome grass populations will require at least three years of very good grass control.

Full results from the trials are expected 2017. [21]

MORE INFORMATION

Brome and barley grass management in southern cropping systems

Long-term strategy needed for brome grass control

6.3.3 Emerging threat of flaxleaf fleabane

Flaxleaf fleabane (Photo 5) is a major weed in dryland crops in southern Queensland and northern New South Wales, and is emerging as a problem across the entire cereal-cropping belt of southern Australia. [22]

19 GRDC. Barley grass. In Integrated Weed Management Hub. Section 8. Profiles of common weeds of cropping. GRDC, https://grdc.com.au/Resources/IWMhub/Section-8-Profiles-of-common-weeds-of-cropping/Barley-grass

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

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

22 GRDC (2012) Multi-pronged attack needed in fight against fleabane weed. GRDC, https://grdc.com.au/Media-Centre/Media-News/Misc/2012/05/Multipronged-attack-needed-in-fight-against-fleabane-weed

Photo 5: *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 move 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 recent years have aided the weed's spread.

Costs of fallow weed control have increased markedly because of fleabane, with some zero-till growers having to reintroduce cultivation as a control tactic. Disturbingly, populations of fleabane have recently been confirmed as resistant to eight times the normal rate of glyphosate, earning it the title of Australia's first glyphosate-resistant broadleaf weed.

Control strategy

While 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 getting on top of fleabane is to attack all parts of the weed's life cycle to keep the seedbank low. Adopting an IWM strategy will result in substantially fewer fleabane problems and fewer resistant populations in subsequent seasons.

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

In southern and 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 growth. By the time there is a window for control, the fleabane plants are often mature, with a large root system, a reduced leaf area and a 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. Delaying herbicide application until the weed is mature and water-stressed can result in poor control.

The double-knock approach, using glyphosate followed by paraquat 7-10 days later, has proved to be a valuable component of a fleabane IWM program. This, coupled

MORE INFORMATION

Managing flaxleaf fleabane

Flaxleaf fleabane a weed best management guide

VIDEOS

WATCH: GCTV4: Flaxleaf fleabane

with the use of competitive crops and pastures and strategic cultivations to bury 'blowouts' of seed production, can reduce the weed's seedbank to manageable levels within a few seasons. A complete IWM approach to controlling fleabane includes targeting fence lines and roadsides. [23]

MORE INFORMATION

Managing Feathertop Rhodes grass.

Feathertop Rhodes grass integrated weed management manual

VIDEOS

WATCH: GCTV19: Feathertop Rhodes Grass: Important weed management recommendations

WATCH: Ecology and management of feathertop Rhodes grass

6.3.4 Feathertop Rhodes grass heads south

A shift to minimum tillage and increasing glyphosate use across southern Queensland and northern New South Wales has created the perfect environment for feathertop Rhodes grass (FTR) to flourish (Photo 6). Already a problem weed in central Queensland for many years, where it is mostly a roadside weed, FTR has only recently become an issue further south. GRDC-funded research has shown that no single management strategy will effectively control FTR. A variety of tactics across rotations is required to keep on top of this troublesome weed.

Photo 6: *Feathertop Rhodes grass.*

Source: GRDC

As with all problem weeds, the aim is to deplete the seedbank, control seedlings and small plants, stop seedset, and prevent new seeds entering from outside the area. [24]

Fallow control

Annual grasses such as FTR can rapidly develop resistance to the 'fop' chemistry of Group A herbicides. To reduce the rate at which this occurs in FTR, the Australian Pesticides and Veterinary Medicines Authority (APVMA) issued permit PER12941 to limit the use of Verdict® 520 to one application per season in fallow, and this must be followed by a double-knock application of a paraquat product at 250 g/L at a rate of at least 1.6 L/ha.

Researchers have found that once FTR is past early tillering, a Group M (glycine) herbicide used alone becomes ineffective, but if a Group L bipyridyl herbicide (paraquat) is applied sequentially, FTR control approaches 100%. This double-knock tactic has proved to be the most consistent and effective approach across a range of growth stages and plant-stress conditions. The same research shows that adding residual herbicides (particularly Group B) to the second knock enhances the effect of the Group L herbicide. The interval between knocks is important to overall efficacy. For many weeds, the interval required is short (three to four days), but FTR research by the GRDC-supported Northern Grower Alliance found that a minimum of seven days is necessary when using a Group M herbicide as the first knock. This is probably due to an antagonism that occurs inside the plant and is specific to FTR.

23 M Widderick (2013) Fleabane now a national challenge. In Emerging Issues with Diseases, Weeds and Pests: Ground Cover Supplement. January–February 2013. Ground Cover. No. 102. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS102

24 GRDC (2011) UQ00062: Improving IWM practice in the northern region. GRDC, http://projects.grdc.com.au/projects.php?action=view_project&project_id=2072

VIDEOS

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 tactic works best when applied to small, actively growing weeds, and rates for both knocks are robust. Applying the second knock as a spot spray, or using optical weed-detection technology (if available), can cut herbicide costs. Spot tilling is also an option and, in some instances, the second knock can be a spot-tillage operation instead of herbicide.

In-crop control

In-crop control of FTR will be limited by the herbicides that can be safely used within the crop. For post-emergence control, shielded sprayers might be required; control will be with Group L and M herbicides in most crops, and Group A herbicides in some grass and cereal crops. Research has shown that several of the grass-selective Group A herbicides control FTR well; however, butroxydim and clethodim are the only Group A herbicides registered for in-crop FTR control.

Researchers are examining other Group A herbicides, which may perform better. Grass-selective knockdown herbicides are widely used in broadleaf crops such as mungbeans, chickpeas, cotton and sunflowers. Growing these crops in the rotation will help manage FTR. In addition, certain Group A herbicides used in wheat and barley provide effective post-emergence control of FTR, so winter cereals are a good option in an FTR integrated weed management plan.

Weed control tactics rarely achieve 100% control, so monitoring for and controlling survivors is important. Target survivors as soon as possible by using spot tillage, spot spraying (including weed-sensor spray technology) or manual removal to avoid further seedset and minimise future problems. [25]

6.3.5 Wild radish resistance

Growers in the GRDC's southern cropping 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 (Photo 7). [26] This difficult weed is becoming a serious threat in the southern region, but western growers have considerable experience in keeping it in check.

Photo 7: *Herbicide-resistant wild radish plant in cereal paddock.*

25 M Widderick (2013) Feathertop heads south. In Emerging Issues with Diseases, Weeds and Pests: Ground Cover Supplement. January–February 2013. Ground Cover. No. 102. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS102

26 DAFWA (2016) Wild radish. DAFWA, https://www.agric.wa.gov.au/grains-research-development/wild-radish

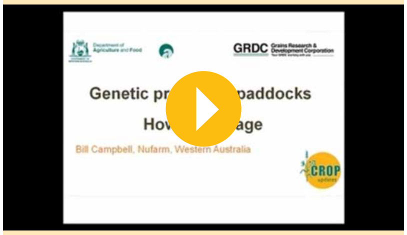
Source: DAFWA

MORE INFORMATION

Weedsmart, Herbicide resistant Wild radish: take back control

VIDEOS

WATCH: GRDC Grains Research Updates 6–7 February 2013, Southern Region, Ballarat Vic: Bill Campbell



WATCH: IWM: Weed seedbank destruction—wild radish seed

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

In contrast, Western Australia's intensive-cropping system has led to wild radish becoming the number-one weed issue, with 60% of wild radish populations having developed resistance to at least one herbicide. Some populations are now resistant to multiple herbicide groups.

While the level of resistant wild radish populations in the southern region is still significantly lower than in the west, with enterprise changes to more intensive cropping, characterised by fewer sheep and more herbicide use, southern farmers are beginning to replicate what has happened in WA.

According to University of Adelaide weed scientist Dr Christopher Preston, by 2013 there were more than 20 paddocks across Victoria and SA with wild radish that is resistant to herbicides. Of these, five wild radish populations were resistant to Group I herbicides (three in Victoria and two in SA) and one to Group B, Group I and Group F herbicides. Dr Peter Boutsalis, the director of Plant Science Consulting, reported that, between 2009 and 2013, half the 60 wild radish samples received from growers across south-eastern Australia have been verified as resistant to Group B and Group I herbicides. Plant Science Consulting carries out annual herbicide-resistance testing on wild radish from paddocks where herbicides have failed. [27]

When poor herbicide control of wild radish is identified, it is critical that the weed seed is tested for herbicide resistance. GRDC-funded research in the western and southern regions is quantifying the extent of the wild radish problem and developing management systems to lower the weed's on-farm seedbank.

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 burning, crushing (using 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, even worse still, to be transported to another paddock, where wild radish or herbicide-resistant wild radish may not be present. [28]

6.4 Herbicides

Chemical weed-control options in triticale varieties are in general similar to those for wheat, although some differences in tolerances are important. In all states, the agriculture departments produce a publication giving recommended herbicide usage. This should be consulted before using herbicides with triticale.

It is important that care is taken to ensure crop and weed tolerances based on the label recommendations are adhered to. Additionally, weather conditions, herbicide rates, water-dilution rates, and the status of adjoining crops need to be assessed and managed correctly. A range of chemicals is registered for use in both wheat and triticale, but some other herbicides are only legal for use in wheat. And for triticale, some herbicides are only legal to use at specific crop stages. [29]

27 J Paterson (2013) South faces wild radish resistance. In Emerging Issues with Diseases, Weeds and Pests: Ground Cover Supplement. January–February 2013. Ground Cover. No. 102. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS102

28 J Paterson (2013) South faces wild radish resistance. In Emerging Issues with Diseases, Weeds and Pests: Ground Cover Supplement. January–February 2013. Ground Cover. No. 102. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS102

29 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Rethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

6.4.1 Herbicides explained

When selecting a herbicide, it is important to know crop growth stage, weeds present and plant-back period. For best results, spray weeds 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.

Residual and non-residual herbicides

Residual herbicides remain active in the soil for months, and can act on successive germinations of weeds. Residual herbicides are absorbed through the roots or shoots, or both. Examples of residual herbicides are imazapyr, chlorsulfuron, atrazine and simazine. The persistence of residual herbicides is determined by several factors, such as application rate, soil texture, organic matter levels, soil pH, rainfall and irrigation, temperature, and the characteristics of the herbicide. Persistence of herbicides will affect the cropping sequence in the enterprise (e.g. a rotation of wheat–barley–chickpeas–canola–wheat).

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

Pre-emergent and post-emergent herbicides

Pre-emergent and post-emergent herbicides refer to chemicals utilised to fit in with the timing of plant growth. Pre-emergent refers to the application of the herbicide to the soil before the weeds have emerged, and post-emergent to foliar application of the herbicide after the target weeds have emerged from the soil. [30]

Herbicide groups

Herbicides have been classified into a number of groups that refer to the way a chemical works: their different chemical make-up and mode of action (Table 2). [31]

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

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

Table 2: *Herbicide groups and examples of chemical products in each group.*

Group	Common chemicals in the 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®

Notes. List of commonly used products only. List 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: Agriculture Victoria

VIDEOS

WATCH: GCTV17: Herbicide partnership

6.5 Pre-emergent herbicides

Triticale is competitive against weeds once it is established. If needed, a pre-emergent knockdown should be applied, as there are limited options available post-emergence. Ideally, a non-selective knockdown should be used when sowing main season varieties to reduce the reliance on post-emergent herbicides. [32] There are some herbicide options available against broadleaf weeds. [33]

For herbicides registered for use on triticale and for the recommended herbicide rate and time to apply, the Field Crop Herbicide Guide from the Kondinin Group is a good reference. Local agronomists and resellers are also a good source of advice on pesticide use.

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

6.5.1 Benefits and concerns

- 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 the 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.
- Both the positive and negative aspects of using pre-emergent herbicides should be considered in the planning phase. [34]

32 Waratah see Co. Ltd. (2010). Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

33 AGF Seeds. Triticale. https://agfseeds.com.au/triticale

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

The important factors in getting pre-emergent herbicides to work effectively while minimising crop damage are:

- to understand 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
- its ability to be bound by the soil.

6.5.2 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. There are typically more variables that can affect their efficacy than for post-emergent herbicides. Post-emergent herbicides are applied when weeds are present and usually the main considerations relate to application coverage, weed size and environmental conditions that impact on performance. Pre-emergent herbicides are applied before the weeds germinate and a number of other considerations come into play. The various pre-emergent herbicides behave differently in the soil, and may behave differently in different soil types. Therefore, it is essential to understand the behaviour of the herbicide, the soil type and the farming system in order to use pre-emergent herbicides in the most effective way.

Pre-emergent herbicides have to be absorbed from the soil by the germinating seedling. To do so, these herbicides need to be at least partly soluble in water and be in a position in the soil where the roots or emerging shoot can access them. The dinitroaniline herbicides, such as trifluralin, are an exception in that they are absorbed by the seedlings as a gas. These herbicides still require water in order to be activated as a gas. Therefore, weed control with pre-emergent herbicides will always be lower under dry conditions.

Behaviour of pre-emergent herbicides in the soil

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

- the solubility of the herbicide;
- how tightly the herbicide binds to soil components; and
- the rate of breakdown of the herbicide in the soil.

The characteristics of some common pre-emergent herbicides are given in Table 3. [35]

The 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 the herbicides move too far through the soil profile they risk 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.

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

Table 3: *Water solubility, binding characteristics, and degradation half-life for some common pre-emergent herbicides.*

Herbicide	Water solubility		Koc*		Degradation half-life (days)
	mg L^{-1} (at 20 C and neutral pH)	Rating	mL g^{-1} (in typical neutral soils)	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	3000	High	82
Prosulfocarb	13	Low	2000	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

*Koc, = the soil organic carbon-water partitioning coefficient. High Koc values mean that more herbicide will be bound to organic matter and less herbicide will be available to move in the soil solution. Koc values for pre-emergent herbicides in Table above range from very high for trifluralin and pendimethalin to low for triasulfuron and chlorsulfuron.

Source: GRDC.

- Soils with low organic matter, especially sandy soils, are particularly prone to crop damage from pre-emergent herbicides, and rates should be reduced where necessary to lower the risk of crop damage.
- The more water-soluble herbicides will move more readily through the soil profile, and are better suited to post sowing pre-emergent applications than the less water-soluble herbicides. They are also more likely to produce crop damage after heavy rain.
- Pre-emergent herbicides need to be at sufficient concentration at or below the location of 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.
- High crop-residue loads on the soil surface will impair the effectiveness of pre-emergent herbicides as they keep the herbicide from contact with the seed. More water-soluble herbicides cope better with crop residue, but the solution is to manage crop residue so that at least 50% of the soil surface is exposed at the time of application.
- 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.
- 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. [36]

6.5.3 Top tips for using pre-emergent herbicides

- Only use pre-emergent herbicides as part of an integrated weed control plan that includes both chemical and non-chemical practices.
- Preparation starts at harvest. Minimise compaction and maximise trash spreading from the header.

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

MORE INFORMATION

Understanding pre-emergent cereal herbicides

Using pre-emergent herbicides in conservation farming systems

Gearing up to use pre-emergent herbicides

GRDC, Pre-emergent herbicide use

How pre-emergent herbicides work

Kondinin Group, Field Crop Herbicide Guide

Weed control in winter crops 2016, Table 12. Herbicides for pre-emergent and post-sowing pre-emergent weed control

- Minimise soil disturbance so that weed seeds are more likely to remain on the soil surface.
- 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 mechanics of your machine and the its limitations compared to a knife point and press wheel.
- Pay attention to detail in your sowing operation and ensure soil throw on the inter-row while maintaining a seed furrow free of herbicide.
- Ensure the seed furrow is closed to prevent herbicide washing onto the crop seed.
- Ensure even seed placement, typically 3–5 cm of loose soil on top of seed in cereals, for best crop safety.
- Use incorporate by sowing (IBS) rather than post-sow per-emergent (PSPE) cropping for crop safety.
- Understand herbicide chemistry. Choose the right herbicide in the right paddock at the right rate. [37]

6.6 Post-planting pre-emergent herbicides

Post-sowing pre-emergent (PSPE) herbicides are, as the name implies, applied to the seedbed after sowing and before the crop emerges. Post-sown pre-emergent herbicides are absorbed primarily through the roots, but there may also be some foliar absorption (e.g. with Terbyne®). When applied to soil, best control is achieved when the soil is flat and relatively free of clods and trash. Sufficient rainfall (20–30 mm) to wet the soil through the weed root zone is necessary within two or three weeks of application. The best weed control is achieved from PSPE application because rainfall improves incorporation. Mechanical incorporation pre-sowing is less uniform, and so weed control may be less effective. If applied pre-sowing and sown with minimal disturbance, incorporation will essentially be by rainfall after application. Weed control in the sowing row may be less effective because a certain amount of herbicide will be removed from the crop row.

6.6.1 Incorporation by sowing

Incorporation by sowing (IBS) is when a herbicide is applied just before sowing (usually in conjunction with a knockdown herbicide such as glyphosate and soil throw from the sowing operation incorporates the herbicide into the seedbed.

This 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.

Applying pre-emergent herbicides before sowing and then incorporating them into the seedbed during the sowing process usually increases safety to the crops because the sowing operation moves a certain amount of herbicide away from the seed row. This can reduce weed control for the same reason. 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.

Two trials were conducted in 2013 to evaluate the crop safety and efficacy of registered residual herbicides for the control of annual ryegrass in wheat. This work was conducted due to concerns about commercial crop safety. The majority of treatments were managed by using IBS, which specifies the use of narrow-point tynes on the planting equipment. This approach helps to ensure sufficient soil is thrown across the inter-row space to effectively incorporate the herbicide, add it removes most of the herbicide-treated soil from the planting furrow, thus improving crop safety. The negative consequence is that IBS generally provides poor weed control in the

37 B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW DPI, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

zone immediately around the planting row. In many cases, post sowing pre-emergent application (PSPE) is also being evaluated as it provides more uniform weed efficacy but requires herbicides or rates with improved crop safety together with reduced incorporation characteristics. The main results of the study were that:

- 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). [38]
- The results reinforce the need to only use narrow-point tynes when using residual herbicides with IBS.

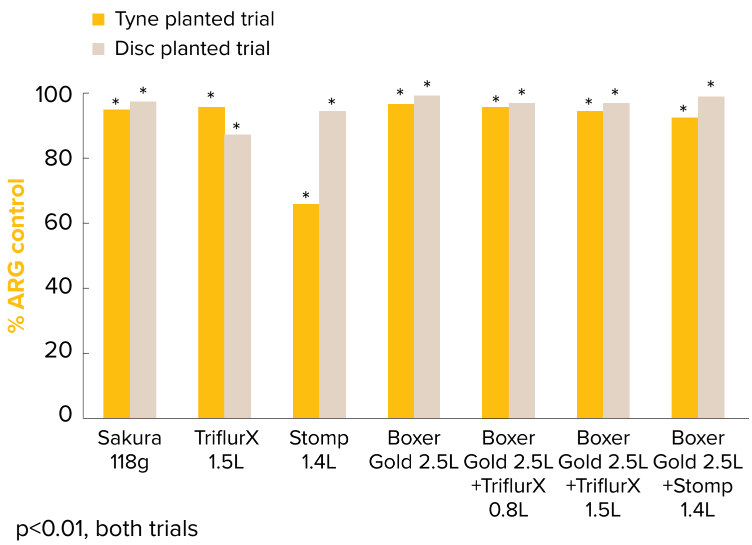


Figure 1: *Per cent annual ryegrass control based on counts taken on 22 September 2013, 94 days after planting. UTC = untreated control. All treatments applied in 70 L/ha total volume using AIXR110015 nozzles at 300 kPa * = significant annual ryegrass control compared to untreated within same trial.*

Source: GRDC

Note that Boxer Gold® is not registered for triticale, but Sakura® is.

During the trials, the researchers noted variations in efficacy, depending on treatment:

- High levels of annual ryegrass control were achieved by most IBS treatments.
- One of the most consistent products was Sakura®.

The trials highlighted problems with the use of disc planters:

- Crop safety was significantly reduced when a disc planter was used for incorporation.
- The disc set up appeared to have exacerbated crop safety concerns by planting seed in an area of greater herbicide concentration.
- In this scenario, observation suggested that small differences in planting depth may have made a difference to crop safety.

This work reinforces some of the difficulties 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 together with rainfall quantity and timing. As an industry we need to have a more thorough

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

understanding of the impacts from these (and perhaps other factors) to ensure we get the best from these important weed management tools. [39]

6.7 In-crop herbicides: knockdowns and residuals

Knockdown and residual herbicides control weeds that have emerged after crop or pasture establishment, and can be applied with little damage to the crop or pasture plants.

There are numerous herbicide options for early post-emergent and late post-emergent control of broadleaf weeds; however, there are only early-post emergent control options for grass weeds. [40]

The benefits are:

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

To avoid problems emerging from the use of these herbicides:

- Carefully consider the best post-emergent herbicide to use in any one situation.
- Choose the most suitable formulation of herbicide for each 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 when using selective post-emergent herbicides.
- The technique used for application must be suited for the situation in order to optimize 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.
- The effectiveness of post-emergent herbicides is influenced by a range of plant and environmental factors. [41]

MORE INFORMATION

Weed control in winter crops 2016, Table 12. Herbicides for pre-emergent and post-sowing pre-emergent weed control

6.7.1 Applying in-crop herbicides

When applying in-crop herbicides:

- 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.
- Correct rates of product application 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 the likelihood of drift.
- Appropriate conditions for spraying are always important. [42]

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

40 Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

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

42 GRDC (2014) In-crop herbicide use Factsheet. GRDC, https://grdc.com.au/GRDC-FS-InCropHerbicideUse

In-crop herbicides will normally require a different set of nozzles than those used in summer fallow spraying and the application of pre-emergent herbicides. Chemicals should be applied as an upper-end medium to lower-end coarse droplet spectrum depending on the particular herbicide being used.

Remember that this must be combined with the relevant application volume to get enough droplets per square centimetre on the target to achieve good coverage. You must also match the nozzles to your spray rig, pump and controller and desired travel speed.

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

How to get the most out of post-emergent herbicides

Consider the timing of the spray: 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 (and if unsure, send plants away for a 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 frosts with grass-weed chemicals.
- 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. [43]

MORE INFORMATION

GRDC, In-crop herbicide use

Plant Science Consulting – Quick tests

6.7.2 Agricultural Chemical Control Areas

Nine Agricultural Chemical Control Areas (ACCA) have been established in Victoria to protect high value herbicide sensitive crops. Within these areas restrictions apply to the types of herbicides, their method of application and the periods in which certain chemicals can be used.

To check if the location you intend to spray is within an ACCA, refer to the map below (Figure 2). Each ACCA is identified in the map by a purple or green shaded area. Click on the shaded area or follow the links for information about each ACCA, including detailed maps, area boundaries and chemical restrictions. Growers need to acquire a permit before using herbicides in these areas: Application for an Agricultural Chemical Control Area (ACCA) permit

43 WeedSmart. Post-emergents. WeedSmart, http://www.weedsmart.org.au/post-emergents/

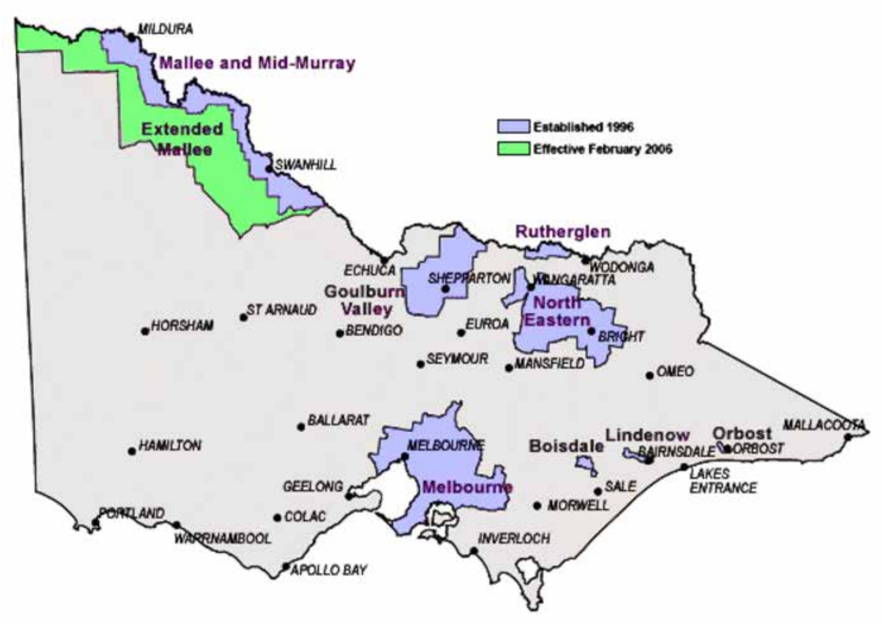


Figure 2: *Map showing areas where restrictions apply to herbicides use including; types, method of application and time of year used.*

Source: AgVic.

Tables 4, 5 and 6 specify the restrictions placed on herbicide use in the nine ACCA areas of Victoria.

Table 4: *Dates ACCA restrictions are operational*

ACCA	Start Date	Finish Date
Melbourne	All year	
Lindenow	All year	
Orbost	All year	
Boisdale	All year	
Mallee & Mid Murray	1st August	30th April the following year
Extended Mallee	1st August	30th April the following year
Goulburn Valley	1st September	30th April the following year
North Eastern	1st September	30th April the following year
Rutherglen	1st September	30th April the following year

Table 5: *Chemicals Prohibited by the Specified Method of Application*

ACCA	Chemical	Prohibited method
All ACCAs - except for Extended Mallee	Any formulation of Picloram Hexazinone applied as a liquid Products containing Sulfometuron Methyl Ester formulations of Triclopyr	Aerial spraying or mister application
All ACCAs - except for Extended Mallee	Ester formulations of 2,4-D, 2,4-DB or MCPA	All methods of application
Extended Mallee only	Ester formulations of Triclopyr	Aerial spraying or mister application
Extended Mallee only	Ester formulations of 2,4-D or MCPA	All methods of application

Table 6: *Chemicals Prohibited Unless an *ACCA Permit Has Been Granted*

ACCA	Chemical	Prohibited method
All ACCAs - except for Extended Mallee	Any formulation of chlorsulfuron, clopyralid, glyphosate or metsulfuron methyl Any amine formulation of MCPA, MCPB, 2,4-D, 2,4-DB, dicamba, mecoprop or triclopyr	Aerial spraying or mister application

MORE INFORMATION

Customer Service Centre 136 186

Agriculture Chemical Use

All users of agricultural and veterinary chemicals, including ACUP holders, are required to keep specified records for all chemical products used within 48 hours of using the chemical product, and to keep these records for a period of two years. [44]

6.8 Conditions for spraying

When applying herbicides, the aim is to maximise the amount of chemical that reaches 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 a range of agricultural enterprises coexist, conflicts can arise, particularly over the use of herbicides. All herbicides are capable of drifting. When spraying a herbicide, you have a moral and legal responsibility to prevent it from drifting into and contaminating or damaging neighbours' crops and other sensitive areas.

All grass herbicide labels emphasise the importance of spraying only when the weeds are actively growing and when conditions and mild and favourable (Photo 8). [45] Any of the following stress conditions can significantly impair both uptake and translocation of the herbicide within the plant, which is likely to result in an incomplete kill or only suppression of weeds:

- Moisture stress and drought.

44 Agriculture Victoria. (2015). Agricultural Chemical Control Areas. http://agriculture.vic.gov.au/agriculture/farm-management/chemical-use/agricultural-chemical-use/agricultural-chemical-control-areas

45 DAFWA (2016) Herbicide application. DAFWA, https://www.agric.wa.gov.au/grains/herbicide-application

- Waterlogging.
- High temperature, low humidity conditions.
- Extreme cold or frosts.
- Nutrient deficiency, especially of nitrogen.
- 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 retention on grass leaves.
- Ensure that grass weeds have fully recovered before applying grass herbicides.

Photo 8: *Using a boom spray on the crop when there is a slight amount of wind helps prevent spray drift.*

Source: DAFWA

6.8.1 Minimising spray drift

Before spraying:

- Always check for susceptible crops in the area, for example 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* growers must record the weather and relevant spray details when spraying.

During spraying:

- Always monitor weather conditions carefully and understand their effect on drift hazard.
- Don't 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 the crop, e.g. keeping a boom's width from the downwind edge of the paddock.
- 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 is the least damaging.

6.8.2 Types of drift

Sprayed herbicides can drift as droplets, as vapours or as particles (Photo 9).

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 fallows with glyphosate under the wrong conditions often leads to severe damage to establishing crops.

Particle drift occurs when water and other carriers of herbicides evaporate quickly from the droplet, leaving tiny particles of concentrated herbicide. This can occur with herbicide formulations other than esters. Instances of this form of drift have 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 as a result of the herbicide evaporating 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.

Photo 9: *Triticale plants showing spotting on leaves – a sign of spray-drift damage.*

Source: DelVal Crop Science

In 2006, the federal regulator of pesticide use, the APVMA, restricted the use of highly volatile for of 2,4-D ester. The changes are now seen with the substitution of lower volatile forms of 2,4-D and MCPA. Products with lower-risk ester formulations are commonly labelled LVE, short for low volatile ester. These formulations have a much lower tendency to volatilise (vaporise), but caution is still needed as 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. [46]

6.8.3 Factors in 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 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 3 m above the target and uses relatively low application volumes, while 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 does not have anything to 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

Many ester formulations are highly volatile when compared with the non-volatile amine, sodium salt and acid formulations. Table 7 [47] is a guide to the more common herbicide active ingredients that are marketed with more than one formulation.

46 A Storrie, T Cook (2015) Reducing herbicide spray drift. Revised. NSW DPI, http://www.dpi.nsw.gov.au/biosecurity/weeds/weed-control/herbicides/spray-drift

47 A Storrie, T Cook (2015) Reducing herbicide spray drift. Revised. NSW DPI, http://www.dpi.nsw.gov.au/biosecurity/weeds/weed-control/herbicides/spray-drift

Table 7: *Relative herbicide volatility.*

Form of active	Full name	Product example
Non-volatile		
Amine salts		
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®
Other salts		
MCPA Na salt	sodium salt	MCPA 250
MCPA Na/K salt	sodium & potassium salt	MCPA 250
2,4-DB Na/K salt	sodium & potassium salt	Buticide®
dicamba Na salt	sodium salt	Cadence®
SOME VOLATILITY		
Esters		
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: NSW DPI

6.8.4 Minimising drift

A significant part of minimising spray drift is the selection of equipment to reduce the number of small droplets produced. However, this in turn may affect coverage of the target, and therefore the possible effectiveness of the pesticide application.

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

In 2010, the APVMA announced new measures to ensure the number of spray-drift incidents are minimised (Table 8). [48] The changes are restrictions on the droplet size spectrum an applicator can use, the wind speed suitable for spraying, and the downwind buffer zone between spraying and a sensitive target. These changes

48 A Storrie, T Cook (2015) Reducing herbicide spray drift. Revised. NSW DPI, http://www.dpi.nsw.gov.au/biosecurity/weeds/weed-control/herbicides/spray-drift

VIDEOS

WATCH: IWM: Spray application of herbicides—nozzle selection

WATCH: IWM: Spray application of herbicides—travel speed

WATCH: IWM: Spray application of herbicides—spray deposition

should be evident on current herbicide labels. Hand-held spraying application is exempt from these regulations.

Table 8: *Nozzle selection guide for ground application.*

Distance downwind to susceptible crop	<1 km	1–30 km and more
Risk	High	Medium
Preferred droplet size (to minimise risk)	coarse to very coarse	medium to coarse
Volume median diameter (microns)	310	210
Pressure (bars)	2.5	2.5
Flat fan nozzle size #	11008	11004
Recommended nozzles (examples only)	Raindrop: Whirljet® Air induction: Yamaho Turbodrop® Hardi Injet® AI Teejet® LurmarkDrift-beta®	Drift reduction: DG TeeJet® Turbo TeeJet® Hardi® ISO LD 110 Lurmark® Lo-Drift
Caution	Can lead to poor coverage and control of grass weeds Requires higher spray volumes	Suitable for grass control at recommended pressures Some fine droplets

Source: DPI NSW

Volume median diameter: 50% of the droplets are less than the stated size and 50% greater.

Refer to manufacturer's selection charts, as range of droplet sizes will vary with recommended pressure. Always use the lowest pressure stated to minimise the small droplets.

6.8.5 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. The production of fine droplets that drift increases as the operating pressure is increased.

6.8.6 Size of area treated

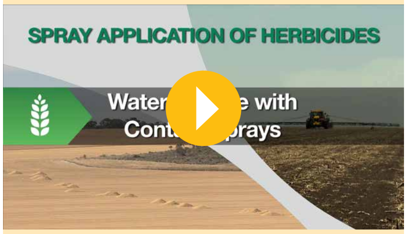
When large areas are treated relatively large amounts of active herbicide are applied and the risk of off-target effects increases due to the length of time taken to apply the herbicide. Conditions such as temperature, humidity and wind direction may change during spraying. Applying volatile formulations to large areas increases the chances of vapour drift damage to susceptible crops and pastures.

6.8.7 Capture surface

Targets vary in their ability to collect or capture spray droplets. 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.

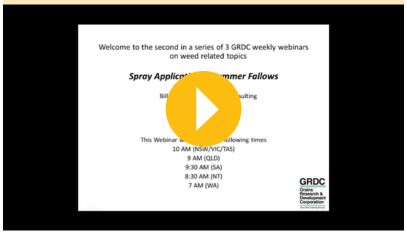
VIDEOS

WATCH: IWM: Spray application of herbicides—water volume with contact sprays



WATCH: IWM: Spray application of herbicides—application volume in stubble

WATCH: Advances in weed management: Webinar 2–Spray application in summer fallows



Well grown, leafy crops are efficient collectors of droplets. Turbulent airflow normally carries spray droplets down into the crop.

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

6.8.8 Weather conditions to avoid

Avoid using herbicidal sprays in the following conditions.

- Midday turbulence

Up-drafts during the heat of the day cause rapidly shifting wind directions, so avoid spraying in the middle of the day.

- High temperatures

Avoid spraying when temperatures exceed 28°C.

- Humidity

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

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

- Inversions

The most hazardous condition for herbicide spray drift is an atmospheric inversion, especially when combined with high humidity.

- Wind

Avoid spraying under still conditions.

11–14 km/h (a moderate breeze, when small branches move, dust is raised or loose paper moves) is suitable for spraying only if using low-drift nozzles or higher volume application, say 80–120 L/ha.

Agronomist's tip: There should always be at least a slight wind when spraying. No wind means there will be a high risk of inversion and too much wind means there is a high risk of spray drift.

The ideal wind speed at which to spray is 3–10 km/h, a light breeze, when leaves and twigs are in constant motion.

An inversion exists when temperature increases with altitude instead of decreasing. An inversion is like a cold blanket of air above the ground, and is usually less than 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. Inversions usually occur on clear, calm mornings and nights. Windy or turbulent conditions prevent the formation of inversion layers.

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. [49]

49 A Storrie, T Cook (2015) Reducing herbicide spray drift. Revised. NSW DPI, http://www.dpi.nsw.gov.au/biosecurity/weeds/weed-control/herbicides/spray-drift

6.9 Testing for herbicide tolerance

In most cases, the herbicides and pesticides that work on wheat and rye will work on triticale. However, some studies indicate that triticale may be less tolerant to some herbicide cocktails than wheat. Newer herbicides as well as pesticides are now being released with recommendations for use on triticale in many parts of the world. [50]

NVT herbicide-tolerance trails undertaken in NSW from 1996 to 2015 give an indication of triticale's response to a range of herbicides.

In 2004 and 2005, trials in the US tested the tolerance of three triticale varieties (AC Alta, AC Ultima, and Pronghorn) with four herbicides registered for wheat: florasulam + MCPA ester, clodinafop-propargyl, thifensulfuron-methyl/tribenuron-methyl, and sulfosulfuron-methyl + 2,4-D ester. Herbicides were applied at the label rate for wheat and at twice that rate. Crop injury, plant height, biomass, and seed yields were quantified. Neither florasulam + MCPA ester, clodinafop-propargyl, nor thifensulfuron-methyl/tribenuron-methyl used at the standard or double rates significantly injured triticale. Sulfosulfuron-methyl + 2,4-D ester reduced triticale height at the both rates, as well as reduced biomass and yield at the double rate.

The researchers concluded that florasulam + MCPA ester, clodinafop-propargyl, and thifensulfuron-methyl/tribenuron-methyl do not cause significant crop injury, and can be used for weed control in spring triticale, but sulfosulfuron-methyl + 2,4-D ester is not recommended for use in triticale. [51]

Cultivars of many broadacre crop species have been found to vary in sensitivity to commonly used herbicides and tank mixes. Using the wrong mixture for a cultivar may result in a loss of grain yield and in reduced farm profit. So the industry can fine-tune understanding of what chemicals can work in a complementary way with different cultivars, GRDC and state government agencies across Australia fund a series of 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.

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

The good news is that over 70% of all crop varieties tolerate most herbicides. The remaining varieties may show yield losses of 10–30%, and in some cases a 50% yield loss has been recorded. These results have occurred with the use of registered herbicides applied at label rates under good spraying conditions at the appropriate crop growth stage. [52]

MORE INFORMATION

Weed kill without crop damage

6.10 Potential herbicide damage of triticale

Excessive herbicide treatments may limit germination in triticale. The successive effect of five herbicide variants (isoxaben, chlorsulfuron, isoproturon, chlortoluron and control) on the germination and plant growth of triticale cultivars has been explored. Germinative energy and germinating power of winter triticale seeds, obtained from plants treated with herbicide, were generally lower, in particular for the isoproturon and chlorsulfuron variants. [53]

50 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/3/a-y5553e/y5553e00.pdf

51 L Raatz, M Hills, R McKenzie, RC Yang, K Topinka, L Hall (2011) Tolerance of spring triticale (× Triticosecale Wittmack) to four wheat herbicides. Weed Technology, 25 (1), 84–89.

52 E Leonard (2012) Weed kill without crop damage. Ground Cover Issue 101 – National Variety Trials Supplement. https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS101/Weed-kill-without-crop-damage

53 S Sławomir, M Robert (1996) Successive effect of herbicides on triticale seed germination and plant growth. In Triticale: Today and Tomorrow. Springer Netherlands, pp. 743–747.

6.10.1 Avoiding crop damage from residual herbicides

When researching the residual activity and cropping restrictions following herbicide application, the herbicide label is the primary source of information and it should be read thoroughly and followed precisely to minimise the development of resistance, and to maximise paddock health and crop yield.

What are the issues?

Some herbicides can remain active in the soil for weeks, months or even years. This can be an advantage, 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 (e.g. Glean®) is used in wheat and barley, but it can remain active in the soil for several years and damage legumes and oilseeds. A real difficulty for growers lies in identifying herbicide residues before they cause a problem.

Currently, 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, or 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 be confused with, and/or make the crop vulnerable to, other stresses, such as nutrient deficiency or disease. [54]

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

Which herbicides are residual?

The herbicides listed in Table 9 all have some residual activity or planting restrictions. Glean® is registered for use in triticale, cereal rye, wheat, and oats. Activity occurs through root and foliar uptake. There are no plant-back recommendations on alkaline soils for triticale and wheat. Ally® is registered for use in triticale, wheat, barley and cereal rye. Activity is by foliar translocation but also root absorption after rain. [55]

Product labels DO NOT use consistent terminology or put warnings in the same place so you need to read the entire label carefully.

54 Agriculture Victoria (2013) Avoiding crop damage from residual herbicides, Agriculture 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

55 L Lenaghan. Residual herbicides: Group B and C carry-over. http://www.croppro.com.au/resources/BCGGroupBResidual_herbicides(2)[1].pdf

Table 9: *A representative range of active constituents by herbicide group.*

Herbicide group	Active constituent
Group B: Sulfonylureas	azimsulfuron, bensulfuron, chlorsulfuron, halosulfuron, iodosulfuron, mesosulfuron, metsulfuron, sulfosulfuron, triasulfuron, tribenuron
Group B: Imidazolinones	imazamox, imazapic, imazapyr, imazethapyr
Group B: Triazolopyrimidines (sulfonamides)	flumetsulam, florasulam, metosulam, pyroxsulam
Group C: Triazines	atrazine, simazine
Group C: Triazinones	metribuzin
Group C: Ureas	diuron
Group D: Dinitroanilines	pendimethalin, trifluralin
Group H: Pyrazoles	pyrasulfotole
Group H: Isoxazoles	isoxaflutole
Group I: Phenoxycarboxylic acids	2,4-D
Group I: Benzoic acids	dicamba
Group I: Pyridine carboxylic acids	aminopyralid, clopyralid
Group K: Chloroacetamides	dimethenamid, metolachlor
Group K: Isoxazoline	pyroxasulfone

Source: AgVic.

How can I avoid damage from residual herbicides?

Select a herbicide appropriate for the weed population you have. Make sure you consider what the re-cropping limitations may apply 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 10). [56] In the case of unexpected damage, good records can be invaluable.

56 D Lush (2014) Water solubility key to effective pre-emergents. Ground Cover. No. 110. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/GC110/Water-solubility-key-to-effective-pre-emergents

Photo 10: *This trial plot is showing crop damage from pre-emergent herbicides due to poor separation of herbicide and crop seed.*

Photo: C Preston

MORE INFORMATION

Herbicide residues in soil and water

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. [57]

6.10.2 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 period. This is not the same as the half-life. Although the amount of chemical in the soil may break down rapidly to half the original amount, what remains can persist for long periods (e.g. sulfonylureas such as chlorsulfuron) (see Tables 10 [58] and 11 [59]). Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of the active ingredient, such as with the sulfonylureas. On product labels, this will be shown by plant-back periods, which are usually listed under a separate plant-back heading or under a heading such as 'Protection of crops' in the general instructions section.

Part of the management of herbicide resistance includes rotation of herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonyl urea, triazines) may be a problem in some paddocks. Remember that plant-back periods begin after rain. [60]

57 Agriculture Victoria (2013) Avoiding crop damage from residual herbicides, Agriculture 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

58 B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW DPI, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

59 W Hawthorne (2007) Residual herbicides and weed control. Southern Pulse Bulletin. Pulse Australia, http://www.pulseaus.com.au/storage/app/media/crops/2007_SPB-Pulses-residual-herbicides-weed-control.pdf

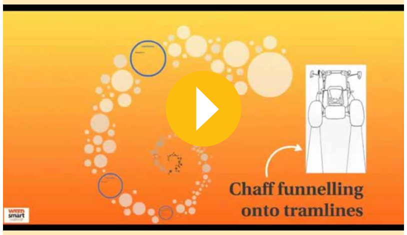
60 B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW DPI, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

VIDEOS

WATCH: Strategic narrow windrow burning.

WATCH: The art of narrow windrow burning

WATCH: Chaff funnelling onto tramlines



WATCH: Capture weed seeds at harvest: Bale Direct System

Table 10: *Known residual persistence of common pre-emergent herbicides.*

Herbicide	Half-life (days)	Residual persistence and prolonged weed control
Logran® (triasulfuron)	19	High. Persists longer in high pH soils. Weed control commonly drops off within 6 weeks.
Glean® (chlorsulfuron)	28–42	High. Persists longer in high pH soils. Weed control longer than Logran®.
Diuron	90 (range 1 month to 1 year, depending on rate)	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 (*Eragrostis* spp.) and to a lesser extent broadleaf weeds such as fleabane.
Atrazine	60–100, up to 1 year if dry	High. Has had observed long-lasting (>3 months) activity on broadleaf weeds such as fleabane.
Simazine	60 (range 28–149)	Medium–high, with 1 year residual in high pH soils. Has had observed long-lasting (>3 months) activity on broadleaf weeds such as fleabane.
Terbyne® (terbulthylazine)	6.5–139	High. Has had observed long-lasting (>6 months) activity on broadleaf weeds such as fleabane and sow thistle.
Triflur® X (trifluralin)	57–126	High. 6–8 months residual. Higher rates longer. Has had observed long-lasting activity on grass weeds such as black grass and stink grass (*Eragrostis* spp.).
Stomp® (pendimethalin)	40	Medium. 3–4 months residual.
Avadex® Xtra (triallate)	56–77	Medium. 3–4 months residual.
Balance® (isoxaflutole)	1.3 (metabolite 11.5)	High. Reactivates after each rainfall event. Has had observed long-lasting (> 6 months) activity on broadleaf weeds such as fleabane and sow thistle.
Boxer Gold® (prosulfocarb)	12–49	Medium. Typically quicker to break down than trifluralin, but tends to reactivate after each rainfall.
Sakura® (pyroxasulfone)	10–35	High. Typically quicker breakdown than trifluralin and Boxer Gold, however, weed control persists longer than Boxer Gold®.

Note residual persistence in broadacre trials and paddock experiences.

Source: NSW DPI

VIDEOS

WATCH: IWM: Weed seed destruction—beer can height

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

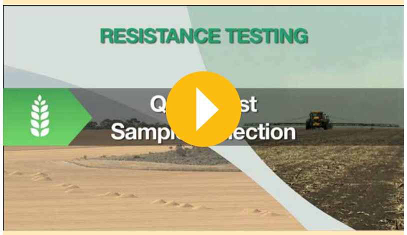


Table 11: *Minimum re-cropping intervals and guidelines.*

Group and type	Product	pH (H_2O) or product rate (mL/ha) as applicable	Minimum re-cropping interval (months after application), and conditions
B, sulfonyl urea (SU)	Chlorsulfurons 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
B, sulfonyl urea (SU)	triasulfuron, e.g. Logran®, Nugrain®	7.6–8.5	12 months, >250 mm for grain, 300 mm for hay
		>8.6	12 months, >250 mm grain, 300 mm hay
B, Sulphonamide	Flumetsulam e.g. Broadstrike®		0 months
B, sulfonyl urea (SU)	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) previous season before sowing larger area
B, sulfonyl urea (SU)	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) previous season before sowing larger area
B, sulfonyl urea (SU)	Sulfosulfuron e.g. Monza®	<6.5	0 months
		6.5–8.5	10 months

Note: always read labels to confirm product specifications and use details.

Source: Pulse Australia

Warm, moist soils are required to break down most herbicides through the processes of microbial activity. For the soil microbes to be most active they need good moisture and an optimum soil temperature range of 18–30°C. Temperatures above or below this range can adversely affect soil microbial activity and slow herbicide breakdown. Very dry soil also reduces breakdown. Once the soil profile gets very dry it requires a lot of rain to regain and then maintain sufficient topsoil moisture for the microbes to be active again.

For up-to-date plant-back periods, see Weed control in winter crops.

- Herbicide resistance
- Resistance is the inherited ability of an individual plant to survive and reproduce following a herbicide application that would kill a 'wild' individual of the same species.

- Thirty-six weed species in Australia currently have populations that are resistant to at least one herbicide mode of action (MOA).
- At June 2014, Australian weed populations have developed resistance to 13 distinct MOAs and at least 39 weed species in Australia have resistance to one or more MOAs.
- 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.
- 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 for 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.

Resistance: remains for many years, until all resistant weed seeds are gone from the soil seedbank. 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 mode of action group.
- Monitor your weed control regularly.
- Stop the seedset of survivors. [61]

Herbicide resistance has become far more widespread, reducing the effectiveness of a wide range of herbicide MOAs (Photo 11) [62]. Rapid expansion of herbicide resistance and the lack of new modes of action (MOA), require that non-herbicide tactics must be a significant component of any farming system and weed management strategy. Inclusion of non-herbicide tactics is critical to prolong the effective life of remaining herbicides, as well as for new products and modes of action 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.

61 DAF Qld (2015) Stopping herbicide resistance in Queensland. DAF Qld, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance

62 GRDC (n.d.) Section 1. Herbicide resistance. In Integrated Weed Management Hub. GRDC, https://grdc.com.au/Resources/IWMhub/Section-1-Herbicide-resistance

Photo 11: *2 4-D-resistant radish, Wongan Hills.*

Photo: A Storrie, Source: GRDC.

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 likelihood varying from 1 plant in 10,000 to 1 in a billion, depending on the weed and the herbicide used against it. 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 in from a contaminated paddock.

6.10.3 General principles to avoid resistance

Herbicides have a limited life before resistance develops, and that usable life is even shorter if they are used repeatedly and as the sole means of weed control, particularly in zero- and minimum-till systems. Resistance can develop within four to eight years for Group A and B herbicides, and after 15 years for Group L and M herbicides (see Table 12 and Figure 3). This can be avoided by:

- keeping weed numbers low
- changing herbicide groups
- using tillage
- rotating crops and agronomic practices [63]

The industry has gained further insight into the impact and efficacy of integrated weed management strategy components through a computer-simulated model. [64]

63 DAF Qld (2015) Stopping herbicide resistance in Queensland. DAF Qld, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance

64 DAF Qld (2015) Effectiveness of herbicide resistance management strategies. DAF Qld, 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

Table 12: *Rules of thumb for the number of years of herbicide application before resistance evolves*

Herbicide group	Years to resistance
A	6–8
B	4–6
C	10–15
D	10–15
L	15+
M	15+

Source: DAF Qld

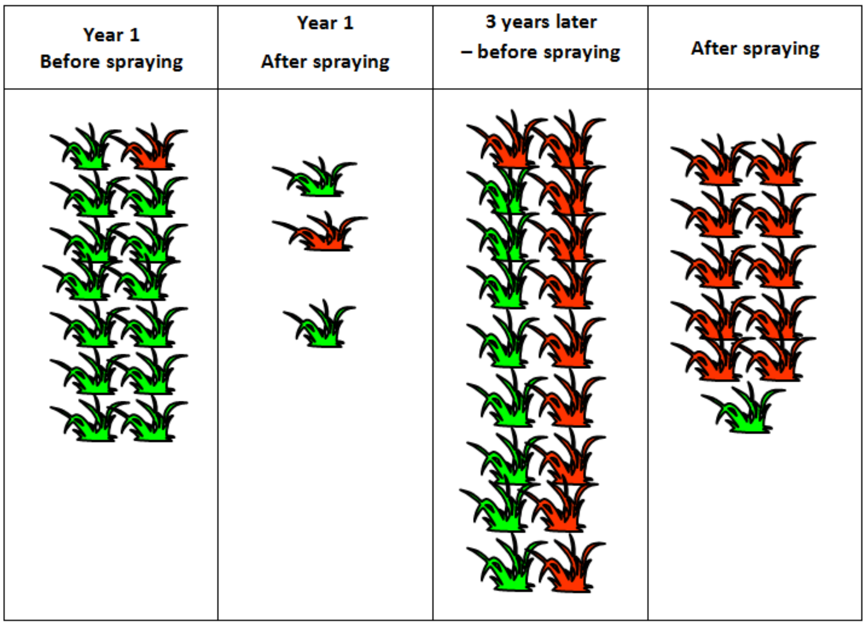


Figure 3: *How a weed population becomes resistant to herbicides.*

Source: GRDC

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

- Ensure 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 few 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, as buried weed seed generally persists longer than 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.

Specific guidelines for reducing the risk of glyphosate resistance are outlined in Table 13. Aim to include as many as possible of the risk-decreasing factors in your crop and weed management plans.

Table 13: *Balancing the risk of weeds developing glyphosate resistance, devised by the national Glyphosate Sustainability Working Group.*

Risk increasing	Risk decreasing
Continuous reliance on glyphosate pre-seeding	Double-knock technique with different MOA
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: DAF Qld

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 of these are winter-growing species and eight summer-growing species. The latter have been selected mainly in chemical fallows and on roadsides (Photo 12). [65]

Photo 12: *Winter fallow showing an early glyphosate-resistant sow thistle outbreak.*

Photo: A Storrie

65 Australian Glyphosate Sustainability Working Group (n.d.) Glyphosate-resistant weeds in Australia. Australian Glyphosate Sustainability Working Group , http://glyphosateresistance.org.au/register_summary.html

MORE INFORMATION

Australian glyphosate resistance register

Strategic risk management

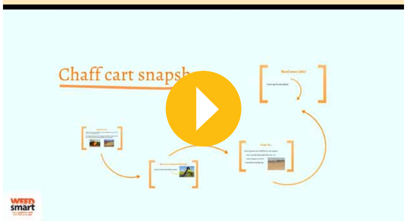
Farm business management: making effective business decisions

RIM

VIDEOS

WATCH: Act now: Plan your weed management program

WATCH: Chaff carts 101.



WATCH: Capture weed seeds at harvest: Harrington seed destructor.

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

- Intensive use of glyphosate over 15 years or more.
- Heavy reliance on glyphosate for weed control.
- No other weed controls targeted to stop seed set.

Chemical fallows are heavily 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. Grape growers are also heavily dependent on glyphosate for weed control. Therefore, it is highly likely that unconfirmed populations of glyphosate resistant annual ryegrass are present in this system. These populations are not recorded on the register of glyphosate resistant populations in Australia. [66]

The online glyphosate-resistance toolkit enables growers and advisers to assess their level of risk for developing glyphosate-resistant weeds on their farm.

6.10.4 Ten-point plan to weed out herbicide resistance

WeedSmart has developed a 10-point plan that farmers can use to protect the longevity of chemicals and slow down the development of resistance. [67]

1. Act now to stop weed seedset

Creating a plan of action is an important first step in 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 weed-smart 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 weed-smart 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 seedbank. There are several ways to do this:

- Tow a chaff cart behind the header.
- Use a Harrington Seed Destructor (Photo 13). [68]
- 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 is putting Australia's no-till farming system at risk.

66 C Preston. The Australian Glyphosate Sustainability Working Group. http://www.glyphosateresistance.org.au/

67 WeedSmart. Ten-point plan. WeedSmart, http://weedsmart.org.au/10-point-plan/

68 A Roginski (2012) Seed destructor shows its national potential. Ground Cover. No. 100. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-issue-100/Seed-destructor-shows-its-national-potential

Photo 13: *Harrington weed-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 modes of action

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 farmers a range of intervention opportunities. For example, we can crop-top lupins and other pulses, swath canola, and delay sowing some crops (e.g. 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 options, e.g. pastures and fallows.

Within the rotation it is also important to not 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, such as the control of harvest weed seed, in place of one or more herbicide applications.

4. Test for resistance to establish a clear picture of paddock-by-paddock status

- Before harvest, sample weed seeds and resistance test 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 the evolution of resistance to many of our common herbicides. However, a resistance test when something new is observed on the 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 to use them in a game-changing situation such as the discovery of a rare resistance gene (e.g. glyphosate resistance) or to determine if a patch of surviving weeds are any worse than what the grower has observed before. This bad patch of weeds gives insight into the future resistance profile of the farm if it is not contained and resistance testing in these situations can be very useful in building preventative strategies.

VIDEOS

WATCH: IWM: Seed test—what's involved

WATCH: Don't cut the rate

WATCH: Don't automatically reach for glyphosate

WATCH: Manage spray drift

5. Never cut the rate

Australian Herbicide Resistance Initiative (AHRI) researcher Dr Roberto Busi found that ryegrass being sprayed at below the advised rate of Sakura® evolved resistance not only to Sakura® but to Boxer Gold® and Avadex® too. To avoid this problem occurring:

- Use best management practice in spray application: apply according to the directions on the label.
- Consider selective weed sprayers such as WeedSeeker or WeedIt.

6. Don't automatically reach for glyphosate

Glyphosate has long been regarded as the world's most important herbicide, so it's natural to reach for it at the first sign of weeds. But what if it didn't work any more? Resistance to this herbicide is increasing rapidly, and in some areas it may fail completely. Why? Too much reliance on one herbicide group gives the weeds opportunities to evolve resistance.

Instead, introduce paraquat products when dealing with smaller weeds, and for a long-term solution farm with a very low seedbank. Also:

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

7. Carefully manage spray events

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

Spray technology has improved enormously in the last 10 years, making it far easier for growers to get herbicides precisely where they need to be. Also, many herbicide labels specify the droplet spectrum to be used when applying the herbicide.

As a general rule, medium to coarse droplet size combined with higher application volumes provides better coverage of the target. Using a pre-orifice nozzle slows droplet speed so that droplets 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.

- Stop resistant weeds from returning into 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.

8. Plant clean seed into clean paddocks with clean borders

With herbicide resistance on the rise, planting clean seed into clean paddocks with clean borders has become a top priority. Controlling weeds is easiest before the crop is planted, so once that is done 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's important to control these initial populations by keeping clean borders.

- It is easier to control weeds before the crop is planted.

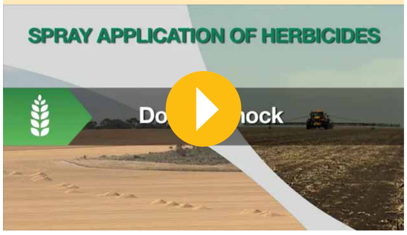
VIDEOS

WATCH: Plant clean seed into clean paddocks with clean borders

WATCH: Best results with double knock tactic

WATCH: Double knock application: a grower's experience

WATCH: Spray application of herbicides: double knock



- Plant weed-free crop seed to prevent the introduction of new weeds and the spread of resistant weeds.
- A recent 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.

9. Use the double-knock technique

The beauty of the double-knock technique is in combining two weed-control tactics with different modes of action, on a single flush of weeds. These two 'knocks' happen sequentially, with the second application being 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. When using this combination ensure the paraquat rate is high. The best time to initiate this double-knock is after rainfall. New weeds will quickly begin to germinate and should be tackled at this small stage.

10. Employ crop competitiveness to combat weeds

Help your crops win the war against weeds by increasing their competitiveness against weeds. There are numerous options to do this:

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

6.10.5 If you think you have resistant weeds

As soon as resistance is suspected, growers should contact their local agronomist. The following steps are then recommended.

First, consider the possibility of other common causes of herbicide failure by asking:

- Was the herbicide applied in conditions and at a rate that should kill the target weed?
- Did the suspect plants miss herbicide contact or emerge after the herbicide was applied?
- Does the pattern of surviving plants suggest a spray miss or other application problem?
- Has the same herbicide or herbicides with the same MOA been used in the same field or in the general area for several years?
- Has the uncontrolled species been successfully controlled in the past by the herbicide in question or by the current treatment?
- Has a decline in the control been noticed in recent years?
- Is the level of weed control generally good on the other susceptible species?

If resistance is still suspected:

- Contact crop and food-science researchers in your state agricultural department for advice on sampling suspect plants for testing of resistance status.
- Ensure all suspect plants do not set seed.

VIDEOS

WATCH: Double knock applications: target weed species and application strategy

WATCH: Learn to think outside the drum

WATCH: Crop competition: increasing wheat seeding rate

WATCH: Crop competition: row spacing

- If resistance is confirmed, develop a management plan for future years to reduce the impact of resistance and likelihood of further spread. [69]

Testing services

For testing of suspected resistant samples, contact:

- Plant Science Consulting
  22 Linley Avenue, Prospect
  SA 5082
  email: info@plantscienceconsulting.com.au
  Phone: 0400 664 460
- Charles Sturt University Herbicide Resistance Testing
  School of Agricultural and Wine Sciences Charles Sturt University
  Locked Bag 588
  Wagga Wagga, NSW 2678
  Phone (02) 6933 4001
- Charles Sturt University's Graham Centre weed research group

6.10.6 Monitoring weeds

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

- Keeping accurate records.
- Monitoring weed populations and recording results of the herbicide used.
- If herbicide resistance is suspected, preventing weed seedset.
- If a herbicide does not work, finding out why.
- Checking that weed survival is not due to spraying error.
- Conducting your own paddock tests to confirm herbicide failure and determine which herbicides remain effective.
- Obtaining a herbicide-resistance test on seed from suspected plants, testing for resistance to other herbicide MOA groups.
- Working hygienically so as not to 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, it is impossible to accurately assess the effectiveness of a management program or determine how it might be modified for better 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 localized 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.
- Weed density, height, and cover relative to crop height, cover, and stage of growth.

69 DAF Qld (2015) Stopping herbicide resistance in Queensland. DAF Qld, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance

- The impact of the weed 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 cultivation 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.

Tips for monitoring

To scout for weeds, walk slowly through the paddock, examining any vegetation that you have 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, noting whether they are 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.

MORE INFORMATION

CropLife Australia

Australian Glyphosate Sustainability Working Group

Australian Herbicide Resistance Initiative

Cotton Info, Weed pack