SOUTHERN
AUGUST 2017

GRDC™
GROWNOTES™

GRDC™
GRAINS RESEARCH & DEVELOPMENT CORPORATION

DURUM

SECTION 6

WEED CONTROL

INTEGRATED WEED MANAGEMENT | USING CROP COMPETITION FOR WEED CONTROL IN DURUM | PRE-EMERGENT HERBICIDES | POST-PLANT PRE-EMERGENT HERBICIDES | IN-CROP HERBICIDES: KNOCK DOWNS AND RESIDUALS | CONDITIONS FOR SPRAYING | HERBICIDE TOLERANCE RATINGS, NVT | POTENTIAL HERBICIDE DAMAGE EFFECT | HERBICIDE RESISTANCE

FAQ

Weed control

Key messages

- Good weed control is essential, as weeds compete with crops for available moisture and nutrients, causing yield reduction (Photo 1).
- Varieties differ in their ability to compete with weeds.
- Durum has typically been a poor competitor with weeds, but the durum varieties DBA Aurora⊕ and Saintly⊕ show similar weed competitiveness to the wheat variety Mace. Weed-competitive varieties are a useful weed management tool.
- Knowing which weeds are in the paddock and where the weed seeds are located (shallow or deep) is important in selecting a herbicide program.
- Durum wheats can be more sensitive to some herbicides that are commonly and safely used in bread wheat.
- Knowledge of a product's ability to be translocated within the weed and formulation type is important for selecting nozzles and application volumes.
- Consider application timing—the younger the weeds the better. Frequent crop monitoring is critical. Also consider the growth stage of the crop, the crop variety being grown and its herbicide tolerances.
- Do not spray a crop stressed by waterlogging, frost, high or low temperatures, drought. This is especially pertinent for frosts with grass weed chemicals.

Weeds cost Australian agriculture an estimated AU$2.5–4.5 billion per annum. For winter cropping systems alone, the cost is $1.3 billion. Consequently, any practice that can reduce the weed burden is likely to generate substantial economic benefits to growers and the grains industry. [1]

Photo 1: *A ryegrass head in a wheat crop.*

Photo: Nicole Baxter, Source: GRDC.

6.1 Integrated weed management

The Grains Research and Development Corporation (GRDC) supports integrated weed management.

Download the Integrated Weed Management Manual.

1 GRDC (2014) Integrated weed management hub. GRDC, https://grdc.com.au/weedlinks

Integrated weed management (IWM) is a system for managing weeds over the long term, particularly the management and minimisation of herbicide resistance. There is a need to combine herbicide and non-herbicide methods into an integrated control program. Given 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 IWM manual looks at these issues and breaks it down into seven clear sections, assisting the reader to make the development of an IWM plan a simple process.

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 IWM to reduce the damage caused by herbicide-resistant weeds.

The following 5-point plan will assist in developing a management plan in each and every paddock:

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

IWM is a system for long-term weed management and is particularly useful for managing and minimising herbicide resistance.

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

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

6.1.1 IWM tactics

- 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 of the crop system are the important steps towards weed management.

There are several agronomic practices that improve crop environment and growth, along with the crop's ability to reduce weed competition. These include crop choice and sequence, improving crop competition, planting herbicide tolerant crops, improving pasture competition, using fallow phases and controlled traffic or tramlining. [2]

Review past actions

Knowing the historical level of selection pressure can be valuable information to give managers a 'heads up' as to which weed/ MOA groups are at greatest risk of breaking. Such knowledge can prompt more intensive monitoring for weed escapes when a situation of higher risk exists. Picking up newly developing resistance issues

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

while patches are still small and before they spread can mean a big difference in the cost of management over time.

From all available paddock records, calculate or estimate the number of years in which different herbicide MOA's have been used. The number of years in which a herbicide MOA has been used 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 sub divide these into broadleaved and grass weeds.

Account for double knocks. 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 has been used 20 times, but there have been 6 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 in-crop herbicides effectively double knocked the trifluralin, thus reducing the effective selection pressure for resistance to trifluralin somewhat.

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

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

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

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 (SU's, IMI's)	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

Source: DAFWA

Assess the current weed status

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

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

Add this information to paddock records.

Identify weed management opportunities within the cropping system

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. For information on the different integrated weed management tactics, see IWM: Section 4: Tactics for managing weed populations.

Fine-tune your list of options

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

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 &/ or Weed Seed Wizard.

IN FOCUS

Weed Seed Wizard

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

It is a computer simulation tool 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 and 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 oat, brome grass and silver grass in the southern states.

MORE INFORMATION

Weed seed wizard

South Australian Weed Control App

The free Weed Control app provides essential information about the control of weeds declared in South Australia under the Natural Resources Management Act 2004.

The weed control 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

The Weed control app provides information from the Weed Control Handbook for Declared Plants in South Australia.

In addition app users can:

- record the location of weeds

MORE INFORMATION

Weed control handbook for declared plants in South Australia.

Declared plants in SA – are they on your land?

SA weed risk management guide.

- keep a personal log of control activities
- phone or email regional Natural Resource officers
- send photos and text of high risk weeds

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

The SA Weed Control app is produced by Biosecurity SA in partnership with the eight Natural Resource Management regions.

Download app from Google Play (for Android devices) or iTunes App Store.

6.1.2 Improved grass weed control in durum

Durum wheat is an inherently poor competitor with grass weeds and requires an increased reliance on herbicide use coupled with good agronomic practices (i.e. paddock selection). There are limited safe and effective herbicide options for grass weed control in durum. The introduction of new pre-emergent chemistry for managing resistant ryegrass populations has been welcomed by industry. However, BoxerGold® and Avadex® are the only registered pre-emergent options for durum, and both these herbicides still present some issues in durum as they have potential to cause significant crop damage resulting in reductions in plant establishment, early vigour and yield. Furthermore, ryegrass can still set large amounts of seed even if it has been treated with a pre-emergent herbicide. It is therefore prudent for growers to integrate other strategies to help improve a crop's competitive ability with weeds. A project aiming to improve grass weed control in durum wheat was led by the SA Durum Growers Association. Trials in 2012 demonstrated that the management combination of variety, seeding rate, and herbicide all play a significant role in the success of the system (Figure 1). [3]

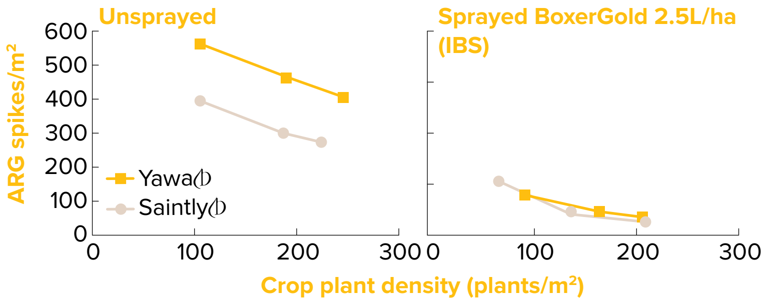


Figure 1: *The effect of management combination of variety, herbicide and plant density on the density of annual ryegrass spike at Tarlee, 2012 (LSD 5% = 55 spikes/m²).*

Source: SA Research and Development Institute

Key messages from research in durum wheat in South Australia:

- In Mace⒫ wheat and DBA Aurora⒫ durum, increasing crop seeding rate reduced ryegrass head set and decreased screening percentage.
- Durum varieties Saintly⒫ and DBA Aurora⒫ showed they had a similar ability to reduce ryegrass seed set through competition when compared to Mace⒫ wheat.
- DBA Aurora⒫ and Saintly⒫ were the best choices of durum variety for weed competitiveness.
- Varying seeding rates can change the amount of crop yield loss under high weed pressure.

3 K Porker, R Wheeler (2012) Improving grass weed control in durum. SA Research and Development Institute, http://midnorthhighrainfall.org.au/wp-content/uploads/2014/08/0012IWM-durum-article.pdf

MORE INFORMATION

A new approach to grass weed control for durum wheat.

- Sakura® is unlikely to be registered for use in durum as it shows high levels of crop damage.
- Although some initial damage can occur, a package combining higher seeding rates, large seed size and Boxer Gold® were the best available chemical and agronomic practices for pre-emergent weed control. [4]

6.1.3 IWM in Southern Region

Grain growers in Victoria, South Australia and Tasmania have the ability to beat costly weeds by driving down the weed seed bank through an aggressive 'stacked' approach.

By combining five essential measures and repeating the exercise year after year, growers can run down seed banks even when experiencing high levels of herbicide resistance on their farms.

Very high weed seed banks can be eroded to low, near-zero levels by committing to a simple strategy.

The five components of a successful strategy are:

1. a double knock of herbicides;
2. mixing and rotating chemicals;
3. competitive crops;
4. stopping seed set; and
5. harvest weed seed control.

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

Double knock is not so much about the seed bank but preserving 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, and paraquat resistance will happen. The best time to start using double knock is before you have glyphosate resistance.

It's also important to have mixed 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, as it is almost impossible for a weed to have two resistance mechanisms before herbicide selection.

Crop competition involves four aspects—seeding rate, row spacing, orientation and cultivars. Growers need to be doing at least one of these things, preferably two, in terms of encouraging crop competition.

The fifth component is harvest weed seed control (HWSC), which has been a focus of AHRI's research and development efforts. In mixed farming systems with sheep, using a chaff cart for HWSC is recommended. For continuous croppers in high production areas, the Harrington Seed Destructor is recommended. Putting chaff on tramlines is cheap and there is nothing to do after harvest. Chaff lining is another option, leaving it in the window to rot. Window burning is a popular option, with more people window burning 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 window burning.

The sixth tool is bale direct, 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 the ryegrass and other weeds up so that growers can catch them in the header. HWSC works better on low-density ryegrass.

4 SAGIT (2015). SAGIT research snapshot. DG1202: A new approach to grass weed control for durum wheat. http://www.sagit.com.au/wp-content/uploads/2014/07/ResearchSummary_DG1202_A-new-approach-to-durum-weed-control.pdf

VIDEOS

WATCH: Over the Fence: IPM delivers 'unexpected' pest control benefits.

A lot of weeds are becoming more dormant. They are adapted to germinate later to avoid knock-down and pre-emergent herbicides. Ryegrass, barley and brome grasses are germinating later. But it is an advantage because it means growers can sow a competitive crop early and compete with the weeds.

When all components of weed seed management are stacked together and growers commit to the regime for at least six years, the outcome can be dramatic. [5]

6.1.4 Ryegrass management in the Southern Region

Herbicide resistance is on the increase, 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

While herbicide resistance is widespread across Australia, a three-year trial by the University of Adelaide at Roseworthy in SA's mid-north found strategic use of oaten hay was the best tool for rapidly reducing the seedbank of annual ryegrass. However, another year of seed-set control is vital for keeping populations low.

Three different weed management strategies were used for ryegrass control in a four-year trial for improving weed management.

Cutting oaten hay in the first year reduced the seedbank of ryegrass by 86 %, from 4819 seeds/m^2 to 692 seeds/m^2 in one year.

Field peas were sown in the following year and three spray options used across three sections.

- When trifluralin was used alone, seedbank levels increased from 692 seeds/m^2 to 8319 seeds/m^2.
- When Select® was applied after trifluralin, the ryegrass seedbank slightly increased from 692 seeds/m^2 to 806 seeds/m^2.
- When Select® was applied and the field peas crop-topped with Roundup® glyphosate, the seedbank declined to less than 500 seeds/m^2.

This shows the importance of that second year of seed-set control in managing annual ryegrass.

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

Growers need to be cautious in chemical use because resistance to Select® is on the increase in SA, which is a major concern given the herbicide's importance for providing effective control of ryegrass in pulse and canola break crops.

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

Where two years of seed-set control had been used, the annual ryegrass seedbank in the following wheat crop continued to decline, even where Boxer Gold® was the only herbicide used. [6]

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

The cultural control practices include mouldboard ploughing, stubble burning, stubble incorporation with light cultivation and retained stubble with 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 options.

Lessons learnt from the trial so far include:

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 is germinating late after treatments have been applied will produce a lot of seed. In the HRZ it is a problem. If growers are not stopping the seed set of ryegrass it will reset the seedbank pretty quickly.

Pre-emergent herbicides

The biggest lesson learned from using pre-emergent herbicides was to not incorporate stubble.

If you have too much stubble and you want to get rid of it, burn it. Incorporating stubble moves the ryegrass away from where the herbicides are applied, limiting their effectiveness.

If you have post-emergent resistant ryegrass and you think you are going to manage your way out of that by growing wheat and barley, it's not going to happen. Even with best treatments, numbers 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 best.

In the cereal side of your rotation, if you really want to keep a lid on the ryegrass you're going to have to go for some pretty expensive herbicide options to do that in the HRZ. A lot of that is about needing the length of persistence we get out of that product, particularly the Sakura® + Avadex® Xtra mix.

Narrow windrow burning

When attempting to windrow burn barley in these trials the burn got too fast and didn't burn the windrows all the way down to the ground, leaving streaks of ryegrass across the site.

The lesson there is that if you're going to windrow burn, don't start practising with barley because it's probably the hardest crop to do it in. Start with something easy like canola. Learn how to do it and do it well. [7]

MORE INFORMATION

Ryegrass Integrated Management

VIDEOS

WATCH: Managing herbicide resistant ryegrass with IWM.

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

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

6.1.5 Brome 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 spread of the weed from its traditional low rainfall area to new regions (Photo 3).

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

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

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

Source: GRDC

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-emergence herbicide against brome grass, it lacks 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 Crusader™ in the South Australian Mallee, and 40% resistance to Atlantis® in Victoria.

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

Barley grass management is now being complicated by 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. [8]

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

MORE INFORMATION

[Brome and Barley grass management in Southern cropping systems.](#)

[Long-term strategy needed for brome grass control.](#)

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 trials have shown 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 patches in cereals, in the range of >50 plants/m^2, 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 options such as chaff carts can help reduce the seedbank.

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 Clearfield variety using Imidazolinone (imi) chemistry. If there are still some weeds after two years, go to barley with trifluralin and metribuzin for a third-step control.

Full results from the trials are expected in 2017. [9]

Barley grasses (*Hordeum* spp) are annual species renowned for rapidly germinating in autumn to provide valuable stock feed soon after season-opening rains (Photo 4). 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: *Seedling of barley grass (Hordeum leporinum).*

Photo D. Holding. Source: GRDC

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

Barley grass is a problem for a number of reasons:

- Barley grasses act as an alternate host for a number of cereal diseases.
- Seeds of barley grasses cause stock health problems.
- Post-emergent herbicide control is limited in cereals.
- Barley grasses are readily dispersed.
- Populations of barley grasses can develop resistance to herbicides. [10]

6.1.6 Emerging flaxleaf fleabane threat

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 weed across the entire cereal-cropping belt of southern Australia.

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 the past two years have aided the weed's spread.

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

Control strategy

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

10 GRDC. Integrated weed management hub: Barley grass, https://grdc.com.au/Resources/IWMhub/Section-8-Profiles-of-common-weeds-of-cropping/Barley-grass

MORE INFORMATION

Managing Flaxleaf fleabane factsheet.

Flaxleaf fleabane – a weed best management guide.

VIDEOS

WATCH: GCTV4: Flaxleaf fleabane.

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, which includes chemical and non-chemical tactics, will result in substantially fewer fleabane problems and resistant populations in subsequent seasons.

With the capacity to produce two or three generations each year and 110,000 seeds per plant, controlling fleabane before it sets seed is critical.

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 weed 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. Conversely, delaying herbicide application until the weed is mature and water-stressed can result in poor control.

The "double-knock' approach, with glyphosate followed by paraquat, has proved a critical component of a fleabane IWM program.

This approach, coupled with the use of competitive crops and pastures and strategic cultivations to bury "blowouts" of seed production, can reduce the weed's seedbank to manageable levels within a few seasons. It is also important to target fencelines and roadsides. [11]

6.1.7 Feathertop Rhodes Grass management

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). A problem weed in Central Queensland for many years, FTR has only become an issue further south recently. Previously it was only a roadside weed in these areas. 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 the 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 seed set and prevent new seeds entering from outside the system.

Research has been determining the most effective herbicide and cultural controls for managing FTR in fallow and cropping systems. A newly funded GRDC project

11 M Widderick (2013) Fleabane now a national challenge, GRDC Ground cover supplement.

"Improving IWM practices in the Northern Region" is investigating FTR ecology and other control options.

Fallow control

Annual grasses can rapidly develop resistance to "fop" chemistry. To reduce the rate at which this occurs in FTR, the PER12941 permit limits Verdict® 520 use to one application per season in fallow, and this must be followed by a double knock application of at least 1.6 litres per hectare of a 250 g/L paraquat product.

Research has found that once FTR is past early tillering, a Group M (glycine) herbicide used alone becomes ineffective, but if a Group L bipyridyl herbicide is applied sequentially FTR control approaches 100%. This double-knock tactic has proved the most consistent and effective approach across a range of growth stages and plant stress conditions. The same research shows that adding residuals (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 as the first knock. This is probably due to an antagonism that occurs inside the plant and is specific to FTR.

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 weed-detection technology (if available), can cut herbicide costs. Spot tillage 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 specific crops. For post-emergence control, shielded sprayers might be required (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.

Research is 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.

Most weed control tactics rarely achieve 100% control, so monitoring for and controlling survivors is important. Controlling survivors as soon as possible by spot tillage, spot spraying (including weed sensor spray technology) or manual removal will avoid further seed set and minimise future problems. [12]

VIDEOS

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

WATCH: Ecology and management of feathertop Rhodes grass

6.2 Using crop competition for weed control in durum

Durum wheat has typically been a poor performer in terms of competitiveness with weeds. This characteristic, as well as other issues, has turned many farmers away from durum cropping. There is considerable need to improve weed control in durum; an integrated approach to weed control will need to be adopted to maintain durum in rotations. [13]

Research conducted over the past three years by the Southern Australian Durum Growers Association has investigated the best management system for tackling weed issues in durum crops. A trial conducted at Hart, South Australia (SA), in 2014 compared the new durum variety DBA Aurora⍱ to the wheat variety Mace

12 M Widderick (2013) Feathertop heads south, GRDC Ground cover supplement.

13 GRDC (2015) Durum expansion in SA through improved agronomy – DGA00001. Grains Research and Development Corporation, March 2015, http://finalreports.grdc.com.au/DGA00001

to determine what management packages worked best and how the two crop types compared. The major finding was that both crops showed similar weed competitiveness. As detailed in Table 2, key findings included:

- In both crops, increasing the seeding rate reduced ryegrass head set.
- Both crops were similar in their ability to reduce ryegrass seed set.
- Mace had less yield loss than DBA Aurora⫶ when under high weed pressure.
- Varying seeding rates can change the amount of crop yield loss under high weed pressure.
- No significant difference in ryegrass control was found between normal and spreader seeder boots.

Competitive varieties are an important part of integrated weed management systems and should be considered when planning for weed control. Increasing seeding rates improves yield by out-competing weeds and reducing the amount of weeds that set seed. [14]

Table 2: *The effect of seed rate and normal and spreader seeding boots on grain yield (t/ha), and grass seed set (heads/m²), when sown to DBA-Aurora⫶ durum wheat and Mace⫶ wheat at Hart, SA, in 2014. Yield loss percentage is the difference between plots with high weed pressure compared to no weed pressure.*

Variety	Seeding boot	Seeding rate (kg/ha)	Yield loss %	Rye grass heads/m²	Yield t/ha
DBA Aurora⫶	Normal boots	100	9.26	138	2.29
DBA Aurora⫶	Normal boots	200	12.16	90	2.44
DBA Aurora⫶	Normal boots	300	8.17	29	2.95
Mace⫶	Normal boots	100	9.61	100	3.02
Mace⫶	Normal boots	200	11.52	79	3.52
Mace⫶	Normal boots	300	3.94	52	3.75
DBA Aurora⫶	Spreader boots	100	18.34	104	2.41
DBA Aurora⫶	Spreader boots	200	10.80	67	2.75
DBA Aurora⫶	Spreader boots	300	9.16	54	3.02
Mace⫶	Spreader boots	100	8.26	138	3.19
Mace⫶	Spreader boots	200	8.72	90	3.75
Mace⫶	Spreader boots	300	7.27	29	3.83
	LSD		2.59	30	0.27

Source: Grains Research and Development Corporation

14 S Goss, R Wheeler (2015) Using crop competition for weed control in barley and wheat. Grains Research and Development Corporation, February 2015, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Using-crop-competition-for-weed-control-in-barley-and-wheat

6.2.1 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

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

The persistence of residual herbicides is determined by a range of factors including application rate, soil texture, organic matter levels, soil pH, rainfall/irrigation, temperature and the herbicide's characteristics. Persistence of herbicides will affect the enterprise's sequence (a rotation of crops, e.g. wheat > barley > chickpeas > canola > wheat). Non-residual herbicides, such as the non-selective paraquat and glyphosate, have little or no soil activity and they are quickly deactivated in the soil. They are either broken down or bound to soil particles, becoming less available to growing plants. They also may have little or no ability to be absorbed by roots.

Post-emergent and pre-emergent

These terms refer to the target and timing of herbicide application. Post-emergent refers to foliar application of the herbicide after the target weeds have emerged from the soil, while pre-emergent refers to application of the herbicide to the soil before the weeds have emerged. [15]

Herbicides have been classified into a number of "groups". The group refers to the way a chemical works—their different chemical make-up and mode of action (Table 3). [16]

Table 3: *Herbicide groups and examples of chemical products in each group.*

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

List of commonly used products only.
List of products does not necessarily imply state registration.

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

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

Check that product is registered in your state before use. Groups G and J not included.

Source: DPI NSW

6.3 Pre-emergent herbicides

Good weed control is essential to make full use of stored summer rainfall, minimise yield losses and prevent weed seed contamination at harvest. Effective weed control can be achieved by growing competitive durum crops, controlling weeds in preceding crops and fallow, rotating crops and the judicious use of herbicides. There are limited safe and effective herbicide options in durum to control annual ryegrass and the older varieties have been typically shown to be less competitive than bread wheat and barley. [17]

With the continued evolution of herbicide resistance, growers are being forced to implement a range of different weed control tactics. A tactic that has rapidly increased in recent seasons is the use of pre-emergent herbicides, especially in the summer crop and fallow. To predict field performance of these herbicides, an understanding is needed of their chemical properties and how they interact with the environment. When devising a weed control strategy, consider the use of pre-emergent herbicides as an additional tactic available to help drive weed numbers down. Used alone they usually will not achieve the objective of reducing weed seedbank numbers, but when used amongst a suite of tactics they can be particularly effective.

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

Key points for using pre-emergent herbicides

- Knowing which weeds are in the paddock and where the weed seeds are located (shallow or deep) is important in selecting a herbicide to be applied.
- Be aware of whether a herbicide is subject to volatilisation or photo-degradation in order to determine an incorporation strategy that minimises losses to the environment.
- Solubility influences how much rain is required for herbicide incorporation, how easily a herbicide will be taken up by a germinating weed and crop and whether a herbicide will be likely to move down the soil profile—potentially causing crop injury or loss to leaching.
- Sandy or low organic matter soils will have less binding and allow greater herbicide availability for crop and weed uptake.
- Herbicides that bind tightly to soil and organic matter generally require higher application rates, stay close to where they are applied (unless the soil moves) and persist for longer.
- Soil pH affects how long some herbicides persist for and how available they are for plant uptake and soil binding.
- The persistence of a herbicide and the way in which it breaks down will dictate the length of residual control and plant-back constraints to sensitive crops.
- Rainfall after application is important for incorporation and availability to the weeds and crop for a number of pre-emergent herbicides. Rainfall and temperature also affect degradation.
- Application rate will affect length of residual, and possibly crop selectivity.
- If using your sowing system for mechanical incorporation of pre-emergent herbicides, understand how speed, row spacing and row configuration impacts soil throw and subsequent chemical incorporation. [18]

VIDEOS

WATCH: GCTV17: Herbicide partnership.

WATCH: GRDC – Managing herbicide-resistant ryegrass with integrated weed management.

17 GRDC (2015) Durum expansion in SA through improved agronomy – DGA00001. Grains Research and Development Corporation, March 2015, http://finalreports.grdc.com.au/DGA00001

18 GRDC (2015) Pre-emergent herbicides fact sheet. Grains Research and Development Corporation, December 2015, https://grdc.com.au/GRDC-FS-PreEmergentHerbicide

Photo 7: *Annual ryegrass is widespread across Australia and prone to herbicide resistance. It accounts for the highest overall cost to Australian grain production but several other weeds are becoming increasingly costly to growers.*

Source: Weedsmart

Choosing herbicides for weed control in wheat will depend on the specific weed species present in the paddock and the variety being grown. Consult your agronomist to discuss specific strategies. Pre-emergent herbicides control weeds at the early stages of the life cycle, between radicle (root shoot) emergence from the seed and seedling leaf emergence through the soil.

The important factors in getting pre-emergent herbicide to work effectively while minimising crop damage are to understand: the position of the weed seeds in the soil; the soil type (particularly the amount of organic matter and crop residue on the surface); the solubility of the herbicide; and its ability to be bound by the soil. [19]

Benefits of pre-emergent herbicides

The residual activity of a pre-emergent herbicide controls the first few flushes of germinating weeds (cohorts) when the crop is too small to compete. The earliest emerged weeds are the most competitive. Therefore, pre-emergent herbicides are ideal tools to prevent yield losses from these 'early season' weeds. The residual activity gives control of a number of cohorts, not just those germinating around the time of application. Ideally, pre-emergent herbicides should be applied just prior to, or just after, sowing the crop or pasture. This maximises the length of time that the crop will be protected by the herbicide during establishment. [20]

Benefits and issues

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

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

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

- Both the positive and negative aspects of using pre-emergent herbicides should be considered in the planning phase. [21]

The important factors in getting pre-emergent herbicide 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.

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. Pre-emergent herbicides typically have more variables that can affect efficacy than 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 and crop growth stage. 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 by the germinating seedling from the soil. To do so, these herbicides need to have some solubility in water and be in a position in the soil to be absorbed by the roots or emerging shoot. 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 released from the soil 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

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

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

Characteristics of some common pre-emergent herbicides are given in Table 4.

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.

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

Table 4: *Water solubility, binding characteristics to soil organic matter 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	3,000	High	82
Prosulfocarb	13	Low	2,000	High	12
Atrazine	35	Medium	100	Medium	75
Diuron	36	Medium	813	High	75.5
S-metolachlor	480	High	200	Medium	15
Triasulfuron	815	High	60	Low	23
Chlorsulfuron	12,500	Very High	40	Low	160

Source: C. Preston, University of Adelaide

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. Managing all these factors is complex, but some rules of thumb are:

1. Soils with low organic matter are particularly prone to crop damage from pre-emergent herbicides (especially sandy soils) and rates should be reduced where necessary to lower the risk of crop damage.
2. The more water-soluble herbicides will move more readily through the soil profile and are better suited to post sowing pre-emergent applications than the less water-soluble herbicides. They are also more likely to produce crop damage after heavy rain.
3. Pre-emergent herbicides need to be at sufficient concentration at or below the weed seed (except for triallate which needs to be above the weed seed) to provide effective control. Keeping weed seeds on the soil surface will improve control by pre-emergent herbicides.
4. High crop residue loads on the soil surface are not conducive to pre-emergent herbicides working well 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.
5. If the soil is dry on the surface but moist underneath, there may be sufficient moisture to germinate the weed seeds, but not enough to activate the herbicide. Poor weed control is likely under these circumstances. The more water-soluble herbicides are less adversely affected under these conditions.
6. Many pre-emergent herbicides can cause crop damage. Separation of the product from the crop seed is essential. In particular care needs to be taken with disc seeding equipment in choice of product and maintaining an adequate seeding depth. [22]

22 C Preston (2014) Understanding pre emergent cereal herbicides, 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 herbicides Factsheet.](#)

[How pre-emergent herbicides work.](#)

Top tips for using pre-emergent herbicides:

- Only use pre-emergent herbicides as part of an integrated weed control plan including both chemical and non-chemical weed control practices.
- Preparation starts at harvest. Minimise compaction and maximise trash spreading from the header.
- Minimise soil disturbance allowing weed seeds to remain on the soil surface.
- 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 limitations it may carry compared to a knife point and press wheel.
- Pay attention to detail in your sowing operation and ensure soil throw on the inter row whilst maintaining a seed furrow free from herbicide.
- Ensure the seed furrow is closed to prevent herbicide washing onto the seed.
- Ensure even seed placement, typically 3–5 cm of loose soil on top of seed in cereals for best crop safety.
- Use incorporation by sowing (IBS) practices rather than post sowing, pre-emergence (PSPE) for crop safety.
- Understand herbicide chemistry. Choose the right herbicide in the right paddock at the right rate. [23]

6.4 Post-plant pre-emergent herbicides

When selecting a herbicide it is important to know the weeds present, the crop growth stage, the recommended growth stage for herbicide application, and the herbicide history of the paddock. Weeds should be sprayed while they are small and actively growing. It is important to rotate between herbicide groups to prevent weeds developing herbicide resistance. Herbicide labels should be read carefully before use as their use patterns vary. Research has found that durum cultivars differ in their tolerance to herbicides registered for use in durum wheats. [24]

VIDEOS

WATCH: [GRDC Manual on pre-emergent herbicides – Incorporation by sowing](#)

6.5 In-crop herbicides: knock downs and residuals

These products control weeds that have emerged since crop or pasture establishment.

Benefits:

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

Issues:

- Use careful consideration when selecting the best post-emergent herbicide to use in any one situation.
- Application of post-emergent herbicides to stressed crops and weeds can result in reduced levels of weed control and increased crop damage.
- Crop competition is important for effective weed control when using selective post-emergent herbicides.

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

24 DAFQ (2012) Durum wheat in Queensland. Department of Agriculture and Fisheries Queensland, June 2012, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/durum-wheat

- 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.
- Choose the most suitable formulation of herbicide for each situation.
- The effectiveness of post-emergent herbicides is influenced by a range of plant and environmental factors. [25]

Key points for using in-crop herbicides:

- Knowledge of a product's ability to be translocated within the weed and formulation type is important for selecting nozzles and application volumes.
- Evenness of deposit is important for poorly or slowly translocated products.
- Crop growth stage, canopy size and stubble load should influence decisions about nozzle selection, application volume and sprayer operating parameters.
- Robust rates of products and appropriate water rates are often more important for achieving control than the nozzle type, but correct nozzle type can widen the spray window, improve deposition and reduce drift risk.
- Travel speed and boom height can affect control and drift potential.
- Application of herbicides in appropriate conditions for spraying is always important.
- Knowledge of potential herbicide resistance of targeted weeds. [26]

Effective post-emergent herbicide application is dependent upon adequate contact with above-ground plant shoots and leaves. Therefore, it is important that spray pressure and volume be adjusted for adequate plant coverage. Also, it is very important that the proper nozzles be used. Read the herbicide label for details.

For post-emergence herbicides, the chemical and physical relationships between the leaf surface and the herbicide often determine the rate and amount of uptake. Factors such as plant size and age, water stress, air temperature, relative humidity and herbicide additives can influence the rate and amount of herbicide uptake. Additives such as crop oil concentrates, surfactants or liquid fertiliser solutions can increase herbicide uptake by a plant. Application of herbicides under hot and dry conditions, or to older and larger weeds or weeds under water stress can decrease the amount of herbicide uptake. Differences in the rate and amount of herbicide uptake influence the potential for crop injury and weed control and often explain the year-to-year variation in the effectiveness of the herbicide.

Also, the faster a herbicide is absorbed by a plant, the less likely that rain will wash the herbicide off the plants. Like soil-applied herbicides, post-emergent herbicides differ in their ability to move within a plant. For adequate weed control, non-mobile post-emergent herbicides must thoroughly cover the plant. Other herbicides are mobile within the plant and can move from the site of application to their site of herbicidal activity. In general, injury symptoms will be most prominent at the sites at which the mobile herbicides concentrate. [27]

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

- Consider application timing—the younger the weeds the better the weed kill. Frequent crop monitoring is critical.
- Consider the growth stage of the crop.
- Consider the crop variety being grown and applicable herbicide tolerances.
- Know which species were historically in the paddock and the resistance status of the paddock (if unsure, send plants away to 'Plant science consulting's Weed Resistance Quick test'.

VIDEOS

WATCH: GRDC Grains Research Updates 2015 – In-crop herbicide developments.

WATCH: GRDC Grains Research Updates 2015 – New technology for improved herbicide use efficiency

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

26 GRDC (2014) In-crop herbicide use. Grains Research and Development Corporation, July 2014, http://grdc.com.au/GRDC-FS-InCropHerbicideUse

27 JL Gunsolus, WS Curran (1999) Herbicide mode of action and injury symptoms. University of Minnesota Extension Service – North Central Regional Extension Publication No. 377, http://www.cof.orst.edu/cof/fs/kpuettmann/FS%20533/Vegetation%20Management/Herbicide%20Mode%20of%20Action%20and%20Injury%20Symptoms.htm

MORE INFORMATION

GRDC In-crop herbicide use Fact sheet

- Do not spray a crop stressed by waterlogging, frost, high or low temperatures or, drought. 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.

6.6 Conditions for spraying

The problem

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

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

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

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

All grass herbicides labels emphasise the importance of spraying only when the weeds are actively growing under mild, favourable conditions (Photo 8). Any of the following stress conditions can significantly impair both uptake and translocation of the herbicide within the plant, likely resulting in incomplete kill or only suppression of weeds:

- moisture stress (and drought)
- waterlogging
- high temperature–low humidity conditions
- extreme cold or frosts
- nutrient deficiency, especially effects of low 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 retentions on grass leaves

Photo 8: *Boom spray on crop.*

Source: DAFWA

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

6.6.1 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, when spraying you must record the weather and relevant spray details.

During spraying

- Always monitor weather conditions carefully and understand their effect on “drift hazard”.
- Do not spray if conditions are not suitable, and stop spraying if conditions change and become unsuitable.
- Record weather conditions (especially temperature and relative humidity), wind speed and direction, herbicide and water rates, and operating details for each paddock.
- Supervise all spraying, even when a contractor is employed. Provide a map marking the areas to be sprayed, buffers to be observed and sensitive crops and areas.
- Spray when temperatures are less than 28°C.
- Maintain a downwind buffer. This may be incrop, for example keeping a boom's width from the downwind edge of the field.
- Minimise spray release height.
- Use the largest droplets that will give adequate spray coverage.
- Always use the least-volatile formulation of herbicide available.

- If there are sensitive crops in the area, use the herbicide that will cause no off-target impacts.

Delta T

Delta T values indicate evaporative potential. High values can reduce droplet survival in the air and at the target. Airborne droplets will rapidly decrease in size when the delta T value of the air exceeds 8 to 10 (Figure 2). When using a coarse spray quality or larger, also check the Delta T value at the target and avoid values above 10 to 12. Low Delta T values (below 2) encourage droplet survival, which can increase the risk of spray drift. Using the coarsest droplets that will provide efficacy will reduce the airborne fraction and increase droplet survival times.

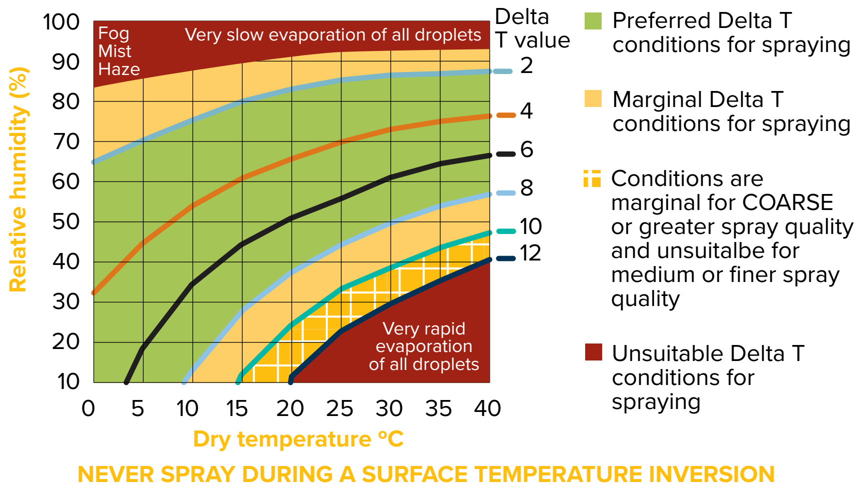


Figure 2: *The relationship of Delta T to relative humidity and temperature. A Common spray guideline is to spray when Delta T is between 2 and 8; with caution below 2 or above 10.*

Source: GRDC, Adapted by Graeme Tepper (2012), originally sourced from Nufarm's Spraywise Decisions Chart (2012).

6.6.2 Types of Drift

Sprayed herbicides can drift as droplets, as vapours or as particles.

Droplet drift is the easiest to control because under good spraying conditions, droplets are carried down by air turbulence and gravity, to collect on plant or soil surfaces. Droplet drift is the most common cause of off-target damage caused by herbicide application. For example, spraying fallows with glyphosate under the wrong conditions often leads to severe damage to establishing crops.

Particle drift occurs when water and other herbicide carriers evaporate quickly from the droplet leaving tiny particles of concentrated herbicide. This can occur with herbicide formulations other than esters. 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 evaporation of herbicide from sprayed surfaces. Use of 2,4-D ester in summer can lead to vapour drift damage of highly susceptible crops such as tomatoes, cotton, sunflowers, soybeans and grapes. This may occur hours after the herbicide has been applied.

In 2006 the federal regulators of pesticide use, the APVMA, restricted the use of highly volatile forms 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

MORE INFORMATION

Practical tips for spraying Fact sheet.

are commonly labelled with LVE—short for low volatile ester. These formulations of esters have a much lower tendency to volatilise, but caution still remains, 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.

6.6.3 Factors affecting the risk of spray drift

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

- Volatility of the formulation applied. Volatility refers to the likelihood that the herbicide will evaporate and become a gas. Esters volatilise (evaporate) whereas amines do not.
- Proximity of crops susceptible to the particular herbicide being applied, and their growth stage. For example cotton is most sensitive to Group I herbicides in the seedling stage.
- Method of application and equipment used. Aerial application releases spray at 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 5 is a guide to the more common herbicide active ingredients that are marketed with more than one formulation.

Table 5: *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		
Ester		
MCPA ehe	ethylhexyl ester	LVE MCPA
MCPA ioe	isooctyl ester	LVE MCPA
triclopyr butoxyl	butoxyethyl ester	Garlon® 600
picloram ioe	isooctyl ester	Access®
2,4-D ehe	ethylhexyl ester	2,4-D LVE 680
fluroxypyr M ester	meptyl ester	Starane® Advanced

Source: Mark Scott, former Agricultural Chemicals Officer, NSW Agriculture

6.6.4 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.

This aspect of spraying needs to be carefully considered when planning to spray.

As the number of smaller droplets decreases, so does the coverage of the spray.

A good example of this is the use of air-induction nozzles that produce large droplets that splatter. These nozzles produce a droplet pattern and number that are unsuitable for targets such as seedling grasses that present a small vertical target.

In 2010, the APVMA announced new measures to ensure the number of spray drift incidents is minimized (Table 6). The changes are restrictions on the droplet size spectrum an applicator could use, wind speed suitable for spraying and the downwind buffer zone between spraying and a sensitive target. These changes

VIDEOS

WATCH: Nozzle Selection.

WATCH: Travel Speed.

WATCH: Spray deposition.

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

Table 6: *Nozzle selection guide for ground application.*

Distance downwind to susceptible crop	< 1 km	1 to 30 km >
Risk	High	Medium
Preferred droplet size (British Crop Protection Council) (to minimise risk)	coarse to very coarse	medium to coarse
Volume median diameter (microns)	310	210
Pressure (bars)	2.5	2.5
Flat fan nozzle size #	11,008	11,004
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. Require higher spray volumes.	Suitable for grass control at recommended pressures. Some fine droplets.

Volume Median Diameter (VMD): 50% of the droplets are less than the stated size and 50% greater.
Refer to manufacturers' selection charts, as droplet size range will vary with recommended pressure. Always use the lowest pressure stated to minimise the small droplets. (Adapted from P. Hughes, DPI, Queensland.)

Source: DPI NSW

6.6.5 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. Production of driftable fine droplets increases as the operating pressure is increased.

6.6.6 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.

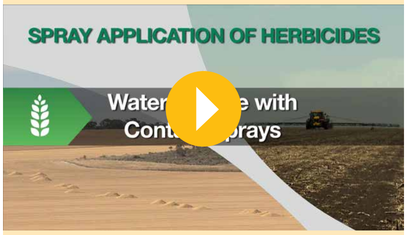
6.6.7 Capture surface

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

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

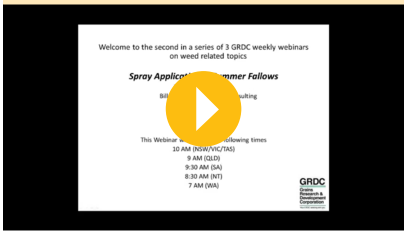
VIDEOS

WATCH: Water Volume with contact sprays.



WATCH: Application Volume in stubble.

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



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

6.6.8 Weather conditions to avoid

Midday turbulence

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

High temperatures

- Avoid spraying when temperatures exceed 28°C.

Humidity

- Avoid spraying under low relative humidity conditions, 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.

Wind

- Avoid spraying under still conditions.
- Ideal safe wind speed is 3–10 km/h, a light breeze (leaves and twigs are in constant motion).
- 11–14 km/h (a moderate breeze) is suitable for spraying if using low drift nozzles or higher volume application, 80-120 L/ha (small branches move, dust is raised and loose paper is moving).

Inversions

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

Do not spray under inversion conditions.

An inversion exists when temperature increases with altitude instead of decreasing. An inversion is like a cold blanket of air above the ground, 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 inversion formation. Blankets of fog, dust or smoke and the tendency for sounds and smells to carry long distances indicate inversion conditions.

Smoke generators or smoky fires can be used to detect inversion conditions. Smoke will not continue to rise but will drift along at a constant height under the inversion "blanket". [28]

6.7 Herbicide tolerance ratings, NVT

Durum wheats can be more sensitive to some herbicides that are commonly and safely used in bread wheat. Within many broadacre crop species, cultivars have been found to vary in sensitivity to commonly used herbicides and tank mixes, thereby Knowing a durum variety's herbicide tolerance rating would enable a grower to select the appropriate non damaging herbicide for that variety or alternatively select the appropriate variety to use with the herbicides wanting to be used thus avoiding an potential yield loss. resulting in potential grain yield loss and reduced farm profit.

28 A Storrie (2015) Reducing herbicide spray drift. DPI NSW, http://www.dpi.nsw.gov.au/content/agriculture/pests-weeds/weeds/images/wid-documents/herbicides/spray-drift

With funding from GRDC and state government agencies across Australia, 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. 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. The good news is that >70% of all crop varieties are tolerant to most herbicides. The remaining varieties can experience yield losses of 10–30%, and in some cases, 50% yield loss has been recorded. [29]

Diagnosing Group B herbicide damage in cereals

Herbicide sensitivity trials suggest durum varieties are sensitive to various Group B herbicides. Growers are advised to read product labels and refer to the Weed control in winter crops guide for the latest information on variety tolerances. [30]

The three major Group B herbicides are sulfonlyureas (SUs), sulfonamides (SAs) and imidazolinones (Imis). SUs and SAs are systemic herbicides that are used for pre- and/or post-emergent grass and/or broadleaf weed control in cereals. Imis are toxic to most cereals and especially durums.

Paddock-scale symptoms:

- Normal crop emergence followed by paleness and stunting, particularly in alkaline (SUs only) and wetter areas (SAs persistence is increased in acidic soils).

Plant symptoms:

- Symptoms often appear five to eight days after germination or spray application.
- Emerging or young plants can be stunted with curled or spiky new leaves.
- Pale to yellow-red or purplish colouration of new leaves, that may show as inter-veinal chlorosis, streaks, mottles or blotches.
- Growth of lateral roots may be reduced.
- Imis may cause head damage.
- Tillering may be reduced, but SU- or SA-affected plants generally recover.
- Group B herbicide damaged plants are more susceptible to root disease, nematodes and trace element deficiencies. [31]

MORE INFORMATION

NVT Herbicide tolerance

6.8 Potential herbicide damage effect

Herbicides can cause damage to non-target plants in some circumstances. Injury can range from slight to serious and can result in economic damage. Herbicide chemistry and physical properties usually determine how herbicides interact with the biological and physical systems of the plant. Factors determining herbicide efficacy and crop safety are complex and include plant species, plant size, stage of growth, soil chemical and physical properties, soil moisture, temperature and relative humidity. Post-emergent herbicide uptake and efficacy can be affected by spray additives that enhance the performance of the herbicide but may also increase the risk of crop injury. Herbicides can injure foliage, shoots and flowers (Photo 9). Herbicide injury symptoms include general and interveinal chlorosis, mottled chlorosis, yellow spotting, purpling of the leaves, necrosis and stem dieback. [32]

29 GRDC (2017) South Australia Sowing Guide http://www.pir.sa.gov.au/__data/assets/pdf_file/0005/268862/SA_Sowing_Guide_2017.pdf

30 P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. New South Wales Department of Primary Industries, ISSN-2206-3056, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2016.pdf

31 DAFWA (2015) Diagnosing group B herbicide damage in cereals. Department of Agriculture and Food Western Australia, June 2015, https://agric.wa.gov.au/n/1977

32 K Al-Khatib. Herbicide damage. University of California Division of Agriculture and Natural Resources, http://herbicidesymptoms.ipm.ucanr.edu/HerbicideDamage/

Photo 9: *Cereal plants showing herbicide damage caused by the presence of residues from the application of a triazine (such as atrazine) to the previous crop; symptoms are bleaching of the leaves followed by necrosis.*

Source: International Maize and Wheat Improvement Center

Good agronomic practice that promotes early crop health and vigour can assist in overcoming some low-level marginal damage. While any level of herbicide damage or setback to a young crop may potentially lead to a yield loss or change in phenology, and should thus be avoided, it is not uncommon for crops suffering from low-level herbicide damage in the early vegetative phases of growth to compensate and yield well despite their early setback. Growers relying on the crop's ability to compensate and grow out of early damage are, however, taking a significant risk. [33]

Timely and correct application of herbicides is essential. Seek local advice from advisers or agronomists and follow label directions. All chemical labels should be read carefully before the product is used, as the law requires that growers follow the label when using a product. New products and product formulations may have changed safety margins. Where herbicide residue may remain in the soil, avoid the use of herbicides from the same mode of action group in following crops. It is not uncommon to see a herbicide stress acting on top of an existing herbicide stress to make a potentially damaging residual situation worse.

6.8.1 Residual herbicides

Some herbicides can remain active in the soil for weeks, months or 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.

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 often be confused with, and/or make the crop vulnerable to, other stresses such as nutrient deficiency or disease. [34]

33 J Cameron, M Congreve (2016) Recropping issues with pre-emergent herbicides. Grains Research and Development Corporation, February 2016, https://grdc.com.au/RecroppingIssuesWithPreEmergentHerbicides

34 DEPI (2013) Avoiding crop damage from residual herbicides, Department of Economic Development, Jobs, Transport and Resource, August 2013, http://www.depi.vic.gov.au/agriculture-and-food/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

Which herbicides are residual?

The herbicides listed in Table 7 all have some residual activity or planting restrictions.

Table 7: *Active constituent by herbicide group (may not include all current herbicides).*

Herbicide Group	Active Constituent
Group B: Sulfonylureas	Chlorosulfuron (Glean®), iodosulfuron (Hussar®), mesosulfuron (Atlantis®), metsulfuron (Ally®), triasulfuron (Logran®)
Group B: Imidazolinones	Imazamox (Raptor®), imazapic (Flame®), imazapyr (Arsenal®)
Group B: Triazolopyrimidines (sulfonamides)	Florasulam (Conclude®)
Group C: Triazines	Atrazine, simazine
Group C: Triazinones	Metribuzin (Sencor®)
Group C: Ureas	Diuron
Group D: Dinitroanilines	Pendimethalin (Stomp®), trifluralin
Group H: Pyrazoles	Pyrasulfotole (Precept®)
Group H: Isoxazoles	Isoxaflutole (Balance®)
Group I: Phenoxycarboxylic acids	2,4-Ds
Group I: Benzoic acids	Dicamba
Group I: Pyridine carboxylic acids	Clopyralid (Lontrel®)
Group K: Chloroacetamides	Metolachlor
Group K: Isoxazoline	Pyroxasulfone (Sakura®)

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 do 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). In the case of unexpected damage, good records can be invaluable.

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

Photo: Dr Christopher Preston. Source: GRDC

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. [35]

6.8.2 Plant-back intervals

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

Some herbicides have a long residual. The residual is not the same as the half-life. Although the amount of chemical in the soil may break down rapidly to half the original amount, what remains can persist for long periods (e.g. sulfonylureas (chlorsulfuron)). This is shown in the Table 8 and 9 where known. Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the sulfonylureas. On labels, this will be shown by plant-back periods, which are usually listed under a separate plant-back heading or under the "Protection of crops etc." heading in the "General Instructions" section of the label.

Part of the management of herbicide resistance includes rotation of herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonyl urea, triazines etc.) may be an issue in some paddocks. Remember that plant-back periods begin after rainfall occurs. [36]

35 DEPI (2013) Avoiding crop damage from residual herbicides, Department of Economic Development, Jobs, Transport and Resource, August 2013, http://www.depi.vic.gov.au/agriculture-and-food/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

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

Table 8: *Residual persistence of common pre-emergent herbicides, and note residual persistence in broad-acre trials and paddock experiences.* [37]

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 longlasting 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)	Med./high. 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/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 event.
Sakura® (pyroxasulfone)	10–35	High. Typically quicker breakdown than Trifluralin and Boxer Gold, however, weed control persists longer than Boxer Gold.

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

Table 9: *Minimum re-cropping intervals and guidelines (NOTE: always read labels to confirm).*

Group and type	Product	pH (H2O) or product rate (ml/ha) as applicable	Minimum re-cropping interval (months after application), and conditions
B, sulfonyl urea (SU)	Chlorsulfurons eg 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, eg Logran®, Nugrain®	7.6–8.5	12 months, >250 mm grain, 300 mm hay
		>8.6	12 months, >250 mm grain, 300 mm hay
B, Sulphonamide	Flumetsulam eg Broadstrike®		0 months
B, sulfonyl urea (SU)	metsulfuron eg 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 Eg 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 eg Monza®	<6.5	0 months
		6.5–8.5	10 months

Source: Pulse Australia

Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the sulfonylureas. On labels, this will be shown by plant-back periods, which are usually listed under a separate plant-back heading or under the "Protection of crops etc." heading in the "General Instructions" section of the label. [38]

Conditions required for breakdown

Warm, moist soils are required to breakdown 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°C to 30°C. Extreme temperatures above or below this range can adversely affect soil microbial activity and slow herbicide

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

MORE INFORMATION

[Avoiding crop damage from residual herbicides]

breakdown. Very dry soil also reduces breakdown. To make matters worse, where the soil profile is very dry it requires a lot of rain to maintain topsoil moisture for the microbes to be active for any length of time.

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

6.9 Herbicide resistance

Herbicide resistance facts:

- Resistance is the inherited ability of an individual plant to survive and reproduce following a herbicide application that would kill a “wild type” individual of the same species.
- Thirty-six weed species in Australia currently have populations that are resistant to at least one herbicide mode-of-action (MOA).
- As at June 2014, Australian weed populations had developed resistance to 13 distinct MOAs (click here for up-to-date statistics).
- 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 as long as seed remains viable in the soil. Only weed density can be reduced, not the ratio of resistant-to-susceptible individuals. The exception is when the resistance gene(s) carry a fitness penalty so that resistant plants produce less seed than susceptible ones—but this is rare.

Key messages

Resistance:

- Remains for many years, until all resistant weed seeds are gone from the soil seed bank.
- 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 seed set of survivors. [39]

Herbicide resistance has become far more widespread, reducing the effectiveness of a wide range of herbicide modes-of-action (MOAs) (Photo 11). 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

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

key components of profitable cropping systems. Protecting their efficacy directly contributes to the future sustainability and profitability of cropping systems.

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

Photo: A Storrie in 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 plants, depending on the weed and herbicide. A grower may also import weed seed with the herbicide-resistant gene in contaminated feed, seed or machinery.

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

6.9.1 General principles to avoid resistance

Herbicides have a limited life before resistance develops, if they are used repeatedly and exclusively as the sole means of weed control—particularly in zero and minimum tilled 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 10 and Figure 3). This can be avoided by:

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

We have gained further insight into the impact and efficacy of integrated weed management strategy components through a computer-simulated model.

Table 10: *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: Chris Preston, University of Adelaide, in DAFF

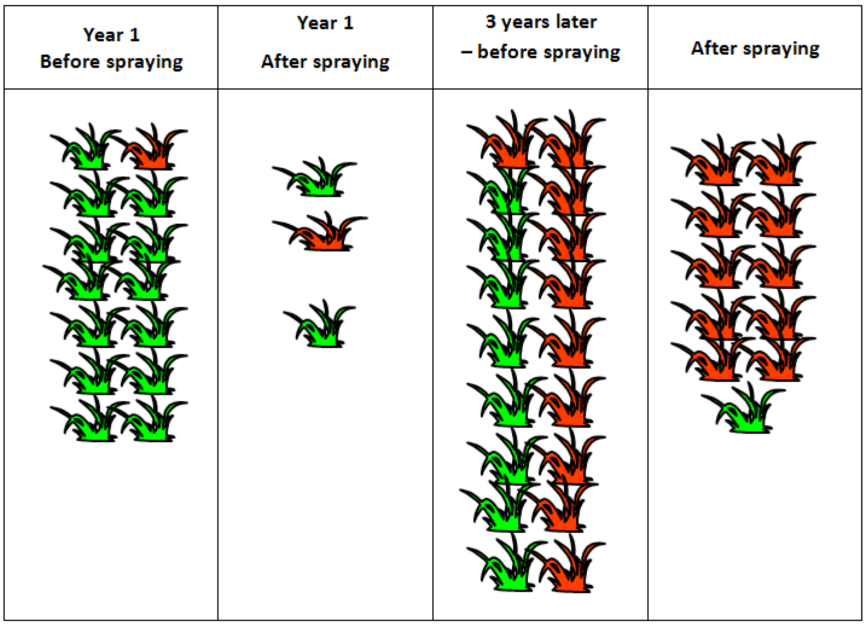


Figure 3: *How a weed population becomes resistant to herbicides.*

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 seed bank.
- 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 mode of action group. It is important to use effective "stand-alone" rates for both herbicides in the mix.
- Aim for maximum effectiveness to keep weed numbers low. The primary aim of weed control is to minimise their impact on productivity, and resistance is much less likely to develop in paddocks with fewer weeds than in heavily infested paddocks.
- Use a wide range of cultural weed control tools in your weed management plan. Sowing different crops and cultivars provides opportunities to use different weed management options on key weeds. Tillage is useful when it targets a major weed flush and minimises soil inversion, 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 11. Aim to include as many as possible risk-decreasing factors in your crop and weed management plans.

Table 11: *Balancing the risk for weeds developing glyphosate resistance, devised by the national Glyphosate Sustainability Working Group with minor modifications for the Queensland cropping region.*

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

(Source: DAFF

Glyphosate resistant weeds in Australia

Glyphosate resistance was first documented for annual ryegrass (*Lolium rigidum*) in 1996 in Victoria. Since then glyphosate resistance has been confirmed in 11 other weed species. Resistance is known in 8 grass species and 4 broadleaf species. There are 4 winter-growing weed species and 8 summer-growing weed species. The latter have been selected mainly in chemical fallows and on roadsides (Photo 12).

Photo 12: *Winter fallow showing an early glyphosate resistant sowthistle infestation.*

Photo: A Storrie. Source: GSWG

MORE INFORMATION

Australian glyphosate resistance register

VIDEOS

WATCH: Act now: Plan your weed management program.

WATCH: Chaff carts 101.

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

WATCH: Strategic narrow windrow burning.

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, few or no other effective herbicides used and few other weed control practices are used. This suggests that the following are the main risk factors for the evolution of glyphosate resistance:

- Intensive use of glyphosate—every year or multiple times a year for 15 years or more.
- Heavy reliance on glyphosate for weed control.
- No other weed controls targeted to stop seed set.

Farming practices in 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.

Farming practices under the vines in vineyards across Australia are 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 unconfirmed glyphosate-resistant populations are not recorded on the register of glyphosate resistant populations in Australia. [40]

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

6.9.2 10-point plan to weed out herbicide resistance

1. Act now to stop weed seed set.

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

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

2. Capture weed seeds at harvest.

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

- Tow a chaff cart behind the header.
- Check out the Harrington Seed Destructor. (Photo 13)
- Create and burn narrow windrows.
- Produce hay where suitable.
- Funnel seed onto tramlines in controlled traffic farming (CTF) systems.
- Use a green or brown manure crop to achieve 100% weed control and build soil nitrogen levels.

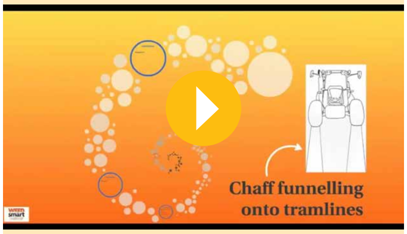
Controlling weed seeds at harvest is emerging as the key to managing the increasing levels of herbicide resistance, which are putting Australia's no-till farming system at risk.

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

VIDEOS

WATCH: The art of narrow windrow burning.

WATCH: Chaff funneling onto tramlines.



WATCH: Capture weed seeds at harvest: Bale Direct System.

WATCH: IWM: Weed seed destruction – Beer can height.

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 us a range of intervention opportunities. For example, we can crop top lupins/pulses, swath canola, and delay sowing some crops (like field peas).

Rotations that include both broadleaf crops, like pulses and oilseeds, and cereals allow the use of a wider range of tactics and chemistry.

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

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

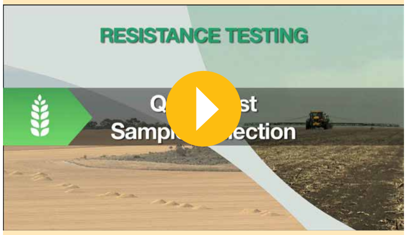
Repeated use of herbicides with the same MOA is the single greatest risk factor for herbicide resistance evolution.

VIDEOS

WATCH: Crop rotation with Colin McAlpine.

WATCH: Test for resistance to establish a clear picture of paddock-by-paddock farm status.

WATCH: IWM: Resistance Testing – Quick test sample collection.



WATCH: IWM: Seed test – What's involved.

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

- Sample weed seeds prior to harvest for resistance testing to determine effective herbicide options.
- Use the "Quick Test" option to test emerged ryegrass plants after sowing to determine effective herbicide options before applying in-crop selective herbicides.
- Collaborate with researchers by collecting weeds for surveys during the double-knock program.
- Visit WeedSmart for more information on herbicide-resistance survey results.

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

Perhaps the best use for herbicide resistance tests is 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.

5. Never cut the rate.

AHRI researcher Dr. Roberto Busi found that ryegrass receiving below the label recommended rate of Sakura® evolved resistance not only to Sakura® but also to Boxer Gold® and Avadex®.

Imagine developing these multiple resistant, monster weeds just because you cut the rate!

- Use best management practice in spray application.
- 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 anymore?

Resistance to this herbicide is shooting through the roof in some areas and this could be the first year we see it fail for growers all across Australia. Why? Too much reliance on one herbicide group gives the weeds opportunity to evolve resistance.

To preserve glyphosate as the wonder weed-killer we know and love we need to break the habit and stop automatically reaching for glyphosate. Introduce paraquat products when dealing with smaller weeds and for a long-term solution, farm with a very low seed bank.

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

VIDEOS

WATCH: Don't cut the rate.

WATCH: Don't automatically reach for glyphosate.

WATCH: Manage spray drift.

WATCH: Plant clean seed into clean paddocks with clean borders.

WATCH: Best results with double knock tactic.

7. Carefully manage spray events.

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

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

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 they 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.

Keep it clean! 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 be sure to plant weed-free crop seed to prevent the introduction of new weeds and the spread of resistant ones.

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

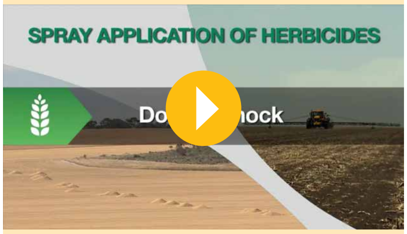
Lastly, roadsides and fence lines are often a source of weed infestations. Weeds here set enormous amounts of seed because they have little competition, so it's important to control these initial populations by keeping clean borders.

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

VIDEOS

WATCH: Double knock application – a Grower's Experience.

WATCH: Spray application of herbicides – Double Knock.



WATCH: Double knock applications - target weed species & application strategy

MORE INFORMATION

CropLife Australia

Australian Glyphosate Sustainability Working Group

Australian Herbicide Resistance Initiative

Cotton Info Weedpak

9. Use the double-knock technique.

What's better than an attack on weeds? A second one. Come at them with a different strategy and any survivors left over don't stand a chance, that's the beauty of the double-knock.

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

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

The best time to initiate a glyphosate/paraquat double-knock is after rainfall. New weeds will quickly begin to germinate and 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 them:

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

If you think you have resistant weeds

When resistance is first suspected, it is recommended that growers contact their local agronomist.

The following steps are then recommended.

Consider the possibility of other common causes of herbicide failure by asking:

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

If resistance is still suspected:

1. Contact your local agronomist for advice on sampling suspect plants for testing of resistance status.
2. Ensure all suspect plants do not set any seed.
3. If resistance is confirmed, develop a management plan for future years to reduce the impact of resistance and likelihood of further spread. [41]

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

VIDEOS

WATCH: Learn to think outside the drum.

WATCH: Crop Competition – increasing wheat seeding rate.

WATCH: Crop competition—Row Spacing.

Testing services

For testing of suspected resistant samples, contact:

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