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GRDC GROWNOTES™

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

TRITICALE

SECTION 6

WEED CONTROL

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

Weed control

Key messages

- Weed control in triticale is similar to that for wheat.
- There are mixed reviews on triticale's ability to compete with weeds. Triticale is a more vigorous crop than wheat, and so offers greater competition against weeds; however, it grows a bit more slowly than spring wheat, so annual grasses and other weeds can be problematic.
- Triticale may have some allelopathic effect which can inhibit the germination and growth of weeds but this effect is not as high as cereal rye.
- Triticale is a minor crop, and as such herbicide options are not as extensive as those for wheat.
- Integrated weed management is becoming more common in Australian cropping, and shows promising results that should also be employed when growing triticale.
- Good soil fertility along with vigorous germination and fast emergence may be one of the most efficient ways to reduce weeds through competition.

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

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

Source: Southwest Farm Press

6.1 Weed competitiveness of triticale

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

The actual competitiveness of different cereals depends on growing conditions, management practices, weed load and relative growth stage of the weed and crop. Triticale's competition to weeds is provided by its leafiness and height, which impact light and moisture competition. [2] Even so, there is still a large number of weeds that can be a problem for triticale.

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

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

Triticale may have some allelopathic effect which can inhibit the germination and growth of weeds but this effect is not as high as one of its parent crops, cereal rye. [3]

For example, trials from 2012–2014 in Wagga Wagga, explored differences in weed infestation in crop and also in postharvest crop fallows associated with grain crop cultivar and species. The results suggested that some crops were clearly more suppressive of in-crop weeds than others. Crop residues of all types resulted in greater in-fallow weed suppression, with 50–100% increases in weed management in comparison to uncropped borders with no residue following crop harvest. Witchgrass was the major weed infesting plots by May 2013 and 2014. In 2014, grazing wheat and canola plus triticale suppressed witchgrass establishment more effectively than any of the other crop sequences (Figure 1). [4]

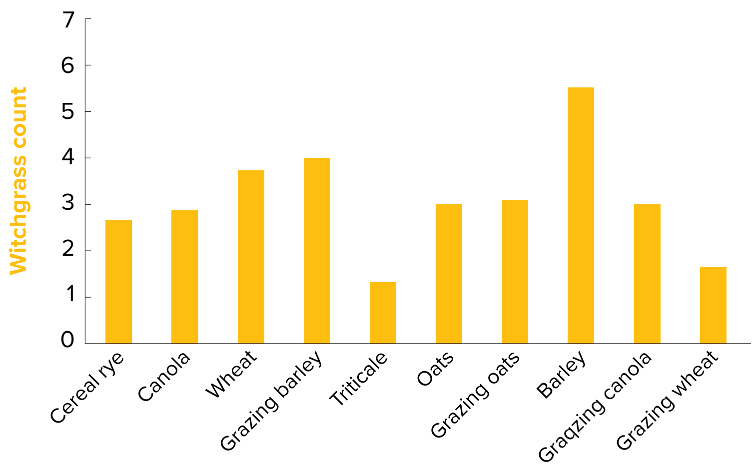


Figure 1: *Witchgrass counts in plots in March 2014. The triticale plots showed the lowest count of witchgrass plants. Areas with no residues averaged 20 plants m^{-2}.*

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

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

Triticale's potential as a substitute for herbicides is of particular interest to organic growers, who could use this crop for partial control of weeds in their rotations. Although triticale's competitiveness is known, there is not a large scientific database about its effectiveness as a weed control when used in this manner. [7]

MORE INFORMATION

Impact of crop residues on summer fallow weeds

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

4 L Weston, R Stanton, H Wu, J Mwendwa, P Weston, J Weidenhamer, W Brown (2015) GRDC Update Papers: Impact of crop residues on summer fallow weeds. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Impact-of-crop-residues-on-summer-fallow-weeds

5 D Lemerle, B Verbeek, N Coombes (1995) Losses in grain yield of winter crops from *Lolium rigidum* competition depend on crop species, cultivar and season. Weed Research, 35 (6), 503–509.

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

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

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

6.1.1 Best management practices for weed control in triticale

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

- Sow at higher rates (e.g. ~150 - 200 plants/m^2) and ensure proper fertility
- Plan ahead. Chemical weed control options in triticale are limited, making it more important to select relatively clean paddocks in which to sow triticale.
- Apply a knockdown spray prior to sowing. Ensure that the majority of weeds have emerged prior to this spray.
- Seed early, as earlier sown triticale usually results in more competitive stand establishment, and provides a jump-start on the weeds.
- Seed at shallow depths, between 13–38 mm (optimum 25 mm). Shallow seeding generally results in uniform seedling emergence, and plants that quickly cover the ground and compete well against emerging weeds.
- Use sanitary practices: clean machinery and seeding equipment before planting. [9]

6.2 Integrated weed management

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

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

MORE INFORMATION

Weed management as a key driver of crop agronomy

6.2.1 IWM for triticale

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

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

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

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

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

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

IN FOCUS

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

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

Most of the previous experiments evaluating the effect of row spacing and level of cultivation on cereals were performed on wheat, so in 2007 there was little data specifically on triticale. The researchers hoped to identify the optimal row spacing and level of cultivation that enhance the competitive ability of triticale, to help farmers secure more sustainable yields by increasing including triticale in their cropping rotations. They hoped the results would help farmers reduce the cost of weed control, reduce weed-induced losses of yield, and see greater fertiliser uptake and utilisation by the crop at the expense of weeds.

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

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

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

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

6.2.2 IWM principles and tactics

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

An integrated weed management plan should be developed for each paddock or management zone. Each target weed is attacked using tactics from several tactical groups. Each tactic provides an opportunity for weed control. It is dependent on the management objectives, and the stage of growth of the target weed. Integrating tactic groups reduces weed numbers, stops replenishment of the seedbank and minimises the risk of developing herbicide-resistant weeds. The IWM groups are:

- Reduce weed seed numbers in the soil.
- Controlling small weeds.
- Stop weed seed set.
- Hygiene: prevent weed seed introduction.
- Agronomic practices and crop competition.
- Conduct a pre-harvest audit of the paddock determining species present and species density and where in the paddock they occur.
- Use HWSM (harvest weed seed management) strategies e.g. windrow burning, to reduce numbers.
- Consider bailing hay, and green and brown manuring.

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

MORE INFORMATION

Agronomy to enhance the implementation and benefits of weed management tactics

Review past actions

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

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

Account for 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 (Group D) has been used 20 times, but there have been six years when in-crop Group A selectives were used and several more years where in-crop group B products that targeted the same weed as the trifluralin were used. These herbicides effectively double-knocked the trifluralin, thus somewhat reducing the effective selection pressure for resistance to trifluralin.

Review the data have collected and identify which weed and MOA groups have been selected for at a frequency likely to lead to resistance in the absence of a double-

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

knock. Trifluralin typically takes about 10–15 years of selection for resistance to occur (Table 1). Thus, using the above example, a watching brief would be in place for trifluralin and other Group D MOA herbicides.

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

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

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

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

Assess the current weed status

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

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

Add this information to paddock records.

Identify weed management opportunities

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

Fine-tune the list of options

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

Combine and test ideas

Computer simulation tools can be useful to run a number of 'what if' scenarios to investigate potential changes in management and the likely effect of weed numbers and crop yield. Two simulation tools being used are the Weed Seed Wizard and RIM (Ryegrass Integrated Management). [13]

MORE INFORMATION

Section 4: Tactics for managing weed populations

6.2.3 IWM in the Northern Region

Key points:

- The major weeds of the Northern Region are feathertop Rhodes grass, windmill grass, flaxleaf fleabane, awnless barnyard grass, liverseed grasses, common sowthistle, wild oats, annual ryegrass, skeleton weed and spiny emex.
- Weeds cause economic losses in various ways, usually by reducing crop yields or contaminating harvested grain.

13 GRDC (2014) Integrated weed management hub. https://grdc.com.au/Resources/IWMhub

- Weeds use soil moisture during both fallow and cropping periods, so that less moisture is available for the following crop.
- Weed competition for moisture may result in poor crop establishment and growth, therefore reducing crop yield potential.
- Weed-seed contamination of harvested grain can result in seed grading being required or discounts on contaminated grain.

Broadscale herbicide resistance is continuing to spread through the Northern region. Using more herbicide is not the answer to overcoming the situation; Growers can choose from a range of chemical and non-chemical integrated weed management tactics that delay or prevent resistance developing and control herbicide-resistant weeds.

Other non-herbicidal tactics are needed to aid in weed control and to kill survivors of herbicide applications.

Crop competition is a proven tactic to reduce weed germination in the crop. In early sown crops planted using narrow spacing, the canopy can close over quickly and shade the soil surface to effectively suppress weed germination. Research conducted at Trangie Agricultural Research Centre has shown the beneficial impact of both narrow row spacing and increased crop density in wheat crops, which successfully suppressed fleabane. Increasing the seeding rate alone had a small impact on fleabane density, but narrow row spacing, decreasing from around 50 cm to 25 cm, reduced fleabane populations by about 50%. When the seeding rate was increased and the row spacing narrowed, the combination brought about a 90% reduction in the number of seed heads produced.

When looking to use crop competition as a weed-control tactic it is necessary to look for the best crop species and variety for the location. Some winter cereals, summer crops and winter pulses can achieve the desired effect of shading about 90% of the soil surface soon after being sown.

Strategic cultivation may also be a valuable tactic, particularly to kill small patches of resistant weeds or to kill large weeds that are not susceptible to herbicide.

For isolated plants, hand chipping may be a viable option.

Harvest weed-seed control is another method of reducing the amount of weed seed reaching the soil. Narrow windrow burning, brown manuring, crop topping, weed seed grinding, chaff carts and baling have all been shown to be effective against weed species that do not shed their seed before harvest and do not produce air-borne seed.

For more information, see Section 6.12.3 Capture weed seeds at harvest, below.

Row direction

Deliberately orienting crop rows at 90 degrees to the direction of sunlight, i.e. east–west, works on the principle that the crop will intercept more sunlight (i.e. photosynthetically available radiation) than crops sown north–south, giving weeds less chance to develop between the rows. In winter, when the sun is at a lower angle (solar plane) shading of the inter-row can be advantagous, particularly in southern latitudes.

In summer crops and at higher latitudes, row direction has no advantage in terms of yield or weed control. This is most likely because the sun is at a higher angle and also because of the relatively lower plant populations involved and the wider rows (75 cm). Importantly east–west sowing did not yield any less than north–south sowing, meaning it would be compatible with winter crop programs that could benefit from rows oriented east–west for weed control.

Many paddocks in the northern region were set up for controlled-traffic tramlines 15 years ago. The orientation of the tramlines was based on practicalities such as reducing headland area by choosing row direction according to the longest run of the

MORE INFORMATION

Costs of key integrated weed management tactics in the Northern Region

paddock, and in irrigated paddocks by the fall of the land. These practicalities may override the potential weed-control benefits.

Competitive choices

Triticale, barley and rye are more competitive than wheat, and some wheat varieties are more competitive than others. Pulses are less competitive than cereals, and the competitiveness of brassicas is very dependent on sowing time. Choose varieties that have rapid early growth and early canopy closure.

If weed pressure is a concern, choose a seeding rate at the higher end of the recommended range for your crop. Calibrate your equipment and use only clean, fresh, viable seed. Even though wider row spacing may be beneficial in conservation cropping systems for ease of planting and where stubble can reduce weed emergence, crops planted in wider rows are less competitive. [14]

6.3 Weeds in northern cropping systems

Weed management, particularly in reduced-tillage fallows, has become an increasingly complex and expensive part of cropping in the Northern Region. Heavy reliance on glyphosate has selected for species that were naturally more glyphosate-tolerant or has selected for glyphosate-resistant populations. The four key weeds that cause major problems during fallow are:

- awnless barnyard grass (ABYG) (*Echinochloa colona*)
- flaxleaf fleabane (*Conyza bonariensis*)
- feathertop Rhodes grass (*Chloris virgata*)
- windmill grass (*Chloris truncata*)

6.3.1 Awnless barnyard grass

Key points:

- Glyphosate resistance is widespread in awnless barnyard grass. Tactics against this weed must change from glyphosate alone.
- Utilise residual chemistry wherever possible and aim to control escapees with camera-spray technology.
- Try to ensure that a double-knock of glyphosate followed by paraquat is used on one of the larger early summer flushes of ABYG.
- Restrict Group A herbicides to manage the grass in the crop, and aim for strong competition from the crop if a summer crop is being sown.

Awnless barnyard grass (ABYG) has been a key summer grass problem for many years (Photo 2). It is a difficult weed to manage for at least three main reasons:

- There are multiple emergence flushes (cohorts) each season.
- It is easily moisture-stressed, leading to inconsistent knockdown control.
- Glyphosate-resistant populations are being found more often.

14 GRDC (2014) Integrated weed management. GRDC, https://grdc.com.au/Media-Centre/Hot-Topics/Integrated-weed-management

Photo 2: *Large specimen of glyphosate-resistant awnless barnyard grass.*

Source: Agronomo

Resistance levels

Before the summer 2011–12, there were 21 cases of glyphosate-resistant ABYG. But that summer, collaborative surveys were conducted by NSW DPI, DAF Queensland and the Northern Grower Alliance, and followed up in 2012–13. Agronomists from the Liverpool Plains to the Darling Downs and west to areas including Mungindi collected ABYG samples, which were tested at the Tamworth Agricultural Institute with glyphosate CT at 1.6 L/ha (a.i. 450 g/L) at a mid-tillering growth stage. The total volume applied was 100 L/ha.

The main finding was that the number of confirmed glyphosate-resistant ABYG populations had nearly trebled. Selected populations were also evaluated in a separate glyphosate rate–response trial. The experiment showed that some of these populations were suppressed only when sprayed with 12.8 L/ha.

Therefore, growers can no longer rely on glyphosate alone to control ABYG.

Residual herbicides in fallow and in the crop

Several active ingredients are registered for use in summer crops (e.g. metolachlor, such as in Dual Gold®) and atrazine) or in fallow (e.g. imazapic, used in Flame®) that are useful in managing ABYG. The new fallow registration of isoxaflutole (Balance®) can suppress ABYG, but is more active against other problem weeds. Few (if any) residuals give consistent, complete control. However, they are important tools that need to be considered to reduce the weed population exposed to knockdown herbicides, as well as to alternate the herbicide chemistries being employed. Use of residuals together with camera-spray technology (for escapees) can be a very effective strategy in fallow.

Double-knock control

The double-knockdown approach uses two tactics in sequence. In reduced tillage situations, the frequent combination is glyphosate first followed by a paraquat-based spray as the second application or knock. This is supported by trials, which have shown that glyphosate followed by paraquat has given effective control even on glyphosate-resistant ABYG. Note that most effective results will be achieved from paraquat-based sprays by using higher total application volumes (100 L/ha) and by targeting seedling weeds.

Several Group A herbicides, e.g. Verdict® and Select®, are effective on ABYG but should be used in registered summer crops, e.g. mungbeans. In the same situations there has been little benefit from a Group A followed by paraquat. Note that Group A herbicides appear to be more sensitive to ABYG moisture stress. Application on mature weeds can result in very poor efficacy.

The timing of the paraquat application for ABYG control has been shown to be generally flexible. The most consistent control is obtained from a delay of ~3–5 days after glyphosate, when lower rates of paraquat can also be used. Longer delays may be warranted when ABYG is still emerging at time the first herbicide is applied; shorter intervals are generally required when weed size is larger or moisture stress is expected. High levels of control can still be obtained with larger weeds but paraquat rates will need to be increased to 2.0 or 2.4 L/ha. [15]

6.3.2 Flaxleaf fleabane

Key points:

- Utilise residual chemistry wherever possible and aim to control escapees with camera-spray technology.
- This weed thrives in situations of low competition; avoid planting crops in wide rows unless effective residual herbicides are included.
- 2,4-D is a crucial tool for consistent double-knock control, though be wary of spray drift onto susceptible crops e.g. cotton.
- Successful growers have increased their focus on fleabane management in winter (crop or fallow) to avoid expensive and variable salvage control in the summer. This is best done with a spring application in a cereal crop with a Group I chemical.

For more than a decade, flaxleaf fleabane (*Conyza bonariensis*) has been the major weed management problem in the Northern Region, particularly in reduced-tillage systems (Photo 3).

Photo 3: *Flaxleaf fleabane is common through southern Queensland and northern NSW.*

Source: Brisbane City Council

15 R Daniel (2013) Weeds and resistance: considerations for awnless barnyard grass, *Chloris* spp. and fleabane management. Northern Grower Alliance, http://www.nga.org.au/module/documents/download/225

Fleabane has a wind-borne, surface-germinating seed that sprouts readily. Germination flushes typically occur in autumn and spring, when surface soil moisture levels stay high for a few days. However, emergence can occur at nearly all times of the year. An important issue with fleabane is that knock-down control of large plants in the summer fallow is variable, and can be expensive due to reduced control rates.

Resistance levels

Glyphosate resistance has been confirmed in fleabane. There is great variability in the response of fleabane to this chemical: many samples from non-cropping areas still well controlled by glyphosate, but fleabane from reduced-tillage cropping shows increased levels of resistance. The most recent survey focused on non-cropping situations, with a large number of resistant populations found on roadsides and railway lines where glyphosate alone has been the principal weed management tool employed.

Residual herbicides in fallow and in the crop

One of the most effective strategies to manage fleabane is the use of residual herbicides during summer fallow or in the crop. Trials have consistently shown good efficacy from a range of residual herbicides commonly used in sorghum, cotton, chickpeas and winter cereals. There are now two registrations for residual fleabane management in fallow. Additional product registrations for in-crop knockdown and residual herbicide use, particularly in winter cereals, are still being sought. A range of commonly used winter-cereal herbicides exists with useful knockdown and residual fleabane activity. Trials to date have indicated that increasing water volumes from 50 L/h to 100 L/ha may help the consistency of residual control, with the timing of application to ensure good herbicide–soil contact also being important.

Knockdown herbicides in fallow and in the crop

Group I herbicides have been the major products for fallow management of fleabane, with 2,4-D amine the most consistent one evaluated. Although glyphosate alone generally gives poor control of fleabane, trials have consistently shown a benefit from tank-mixing 2,4-D amine and glyphosate in the first application. Amicide® Advance at 0.65–1.1 L/ha mixed with Roundup® Attack at a minimum of 1.15 L/ha and followed by Nuquat® at 1.6–2.0 L/ha is a registered option for fleabane knockdown in fallow. Sharpen is a product with Group G mode of action. It is registered for fallow control when mixed with Roundup® Attack at a minimum of 1.15 L/ha but only on fleabane up to a maximum size of six leaves.

Be wary of spray drift that could lead to damage to surrounding susceptible crops like cotton. For more information about the risks and management of spray drift, see Section 6.9 Conditions for spraying, below.

Double-knock control

The most consistent and effective double-knock control of fleabane has included 2,4-D in the first application followed by paraquat as the second. Glyphosate alone followed by paraquat will result in high levels of leaf desiccation but plants will nearly always recover.

The timing of the second application in fleabane is generally aimed at ~7–14 days after the first. However, the interval to the second knock appears to be quite flexible. Increased efficacy is obtained when fleabane is actively growing, or when the rosette stages can be targeted. Although complete control can be obtained in some situations, control levels will frequently reach only ~70–80%, particularly when targeting large, flowering fleabane that is moisture-stressed. The high cost of fallow double-knock approaches and inconsistent degrees of control of large, mature plants are good reasons to focus on proactive fleabane management when the plant is young. [16]

VIDEOS

WATCH: GCTV4: Flaxleaf fleabane

16 R Daniel (2013) Weeds and resistance: considerations for awnless barnyard grass, *Chloris* spp. and fleabane management. Northern Grower Alliance, http://www.nga.org.au/module/documents/download/225

6.3.3 Feathertop Rhodes grass

Key points:

- Glyphosate alone or glyphosate followed by paraquat have generally poor efficacy.
- Utilise residual chemistry wherever possible and aim to control escapees with camera-spray technology.
- Where large spring flushes of the grass occur, a double-knock of Verdict followed by paraquat can be used in Queensland .
- Treat patches aggressively, even with cultivation, to avoid paddock blow-outs.

Feathertop Rhodes grass (*Chloris virgata*) emerged as an important weed management concern in southern Queensland and northern NSW in about 2008 (Photo 4). This grass is another small-seeded weed species that germinates on, or close to, the soil surface. It has rapid early growth and can become moisture stressed quickly. Although feathertop Rhodes grass (FTR) is well established in central Queensland, it remains largely an emerging threat further south. Patches should be aggressively treated to avoid whole-of-paddock blow-outs.

Photo 4: *The seed heads of feathertop Rhodes grass.*

Source: Brisbane City Council

Residual herbicides in fallow and in the crop

This weed is generally poorly controlled by glyphosate alone, even when sprayed under favourable conditions at the seedling stage. Trials have shown that residual herbicides generally provide the most effective control, a similar pattern to that seen with fleabane. Currently registered residual herbicides are being screened and offer promise in both fallow and crop situations. The only product currently registered for FTR control is Balance (isoxaflutole) at 100 g/ha for use fallow.

Double-knock control

A glyphosate followed by paraquat double-knock is variable and generally disappointing for FTR management. By contrast, a small number of Group A herbicides (all members of the fop class) can be effective against FTR, but need to be managed within a number of constraints:

- Although they can provide high levels of efficacy on fresh and seedling FTR, they need to be followed by a paraquat double-knock to get consistent high levels of final control.

- Group A herbicides give a high risk of resistance selection, and require follow-up treatment with paraquat.
- Many Group A herbicides have plant-back restrictions for cereal crops.
- With Group A herbicides, there is generally a narrow range of growth stages when weeds can be sprayed successfully, so they will generally give unsatisfactory results on flowering and/or moisture-stressed FTR.
- Not all Group A herbicides are effective on FTR.

For information on a permit (PER12941) issued for Queensland only for the control of FTR in summer fallow situations prior to planting mungbeans, see the website of the Australian Pesticides and Veterinary Medicines Authority (APVMA).

Timing of the second application for FTR is still being refined, but application at ~7–14 days generally provides the most consistent control. Application of paraquat at shorter intervals can be successful, when the Group A herbicide is translocated rapidly through the plant, but has resulted in more variable control in field trials. Good control can often be obtained up to 21 days after the initial application.

6.3.4 Windmill grass

Key points:

- Glyphosate alone or glyphosate followed by paraquat generally have poor efficacy.
- Preliminary data suggest that residual chemistry may provide some benefit.
- A double-knock of quizalofop-p-ethyl (e.g. Targa) followed by paraquat can be used in NSW.

While FTR has been a grass weed threat that originated in Queensland and is heading south, windmill grass is more of an problem in central NSW that is spreading north. Windmill grass is a perennial, native species found throughout northern NSW and southern Queensland (Photo 5). The main cropping threat appears to be from the selection of glyphosate-resistant populations, with control at the tussock stage providing most management challenges.

Photo 5: *Windmill grass plant and seed head.*

Source: Native Seeds

Resistance levels

Glyphosate resistance has been confirmed in windmill grass with three documented cases in NSW, all west of Dubbo. Glyphosate-resistant populations of windmill grass in other states have all been collected from roadsides, but in central-western NSW, two were from fallow paddocks.

Residual herbicides in fallow and in the crop

Preliminary trials have shown that some residual herbicides have useful levels of efficacy against windmill grass. These have potential for both fallow and crop situations, but currently there are no products registered for residual control of windmill grass.

Double-knock control

A double-knock of a Group A herbicide followed by paraquat has provided clear benefits compared with the disappointing results usually achieved by glyphosate followed by paraquat. Constraints apply to double-knock for windmill grass control similar to those for FTR.

The timing of the second application for windmill grass is still being refined, but for now application at ~7–14 days generally provides the most consistent control. Application of paraquat at shorter intervals can be successful when the Group A herbicide is translocated rapidly through the plant, but has resulted in more variable control in field trials and has been clearly antagonistic when the interval is one day or less. Good control can often be obtained up to 21 days after the application of the first herbicide. [17] The APVMA site will also give you information on label rates.

6.3.5 Non-herbicide weed control in the Northern Region

Diversity in cropping systems and diversity in weeds in the GRDC Northern Region calls for diversity in weed management solutions, which includes the utilisation of non-herbicide tactics.

Survey work in the region has identified over 70 weed species that have an impact on grain production, and over 10% of these have confirmed populations in Australia that are resistant to glyphosate and several other chemical modes of action (Table 2). [18]

Table 2: *Confirmed herbicide resistance in weeds found in NSW and Queensland.*

Mode of action	Resistant weeds
A (fops, dims, dens)	Wild oats, paradoxa grass, annual ryegrass
B (SUs, imis, etc.)	Annual ryegrass, wild oats, paradoxa grass, Indian hedge mustard, charlock, wild radish, turnip weed, African turnip weed, common sowthistle, black bindweed
C (triazines, ureas, amides, etc.)	Awnless barnyard grass, liverseed grass
D (DNAs, benzamides, etc.)	Annual ryegrass
I (phenoxys, pyridines, etc.)	Wild radish
L (bipyridyls, i.e. diquat, paraquat)	Flaxleaf fleabane
M (glycines, i.e. glyphosate)	Annual ryegrass, awnless barnyard grass, liverseed grass, windmill grass, feathertop Rhodes grass, sweet summer grass, flaxleaf fleabane, common sowthistle
Z (dicarboxylic acids, etc)	Wild oats

Source: WeedSmart

17 Daniel R. (2013) Weeds and resistance—considerations for awnless barnyard grass, Chloris spp. and fleabane management. Northern Grower Alliance, http://www.nga.org.au/module/documents/download/22

18 WeedSmart (2017) Non-herbicide weed control in the Northern Region. WeedSmart, http://weedsmart.org.au/non-herbicide-weed-control-in-the-northern-region/

A recent survey of common sowthistle determined populations as glyphosate-resistant if treated seedlings were surviving and reshooting 21 days after the application of glyphosate. In this testing, glyphosate had been applied at the upper label rate for small plants (up to five leaves). While most of the common sowthistle samples collected in an area from central Queensland to central NSW were still susceptible to label rates of glyphosate when applied to small seedlings, resistant populations were found throughout the study area, showing that this is not a localised problem but rather the inevitable result of over-reliance on a particular herbicide.

Most Northern Region weeds are self-pollinated, so resistant plants will produce resistant seed. To reduce the likelihood of resistance, a key approach is to use multiple tactics to maintain low weed numbers. While weed numbers are low so too is the risk of resistant genes being present in the population.

Keeping these 'difficult to control' weeds in check will clearly require non-herbicide tactics to reduce germination and weed seedset. Queensland Department of Agriculture and Fisheries (DAF Queensland) researchers have been studying common weeds, particularly feathertop Rhodes grass, barnyard grass and common sowthistle, to find weaknesses in each weed's ecology to help identify non-chemical controls that could become part of an effective management system. The DAF Queensland weed research team is concentrating on non-chemical options, including cover crops, crop competition, strategic tillage, strategic burning, and harvest weed-seed controls.

Weeds researchers recognise that although growers are making good use of chemical strategies such as double-knock, residual herbicides, spot spraying and weed-sensing technology to preserve the efficacy of herbicides for as long as possible, there remains an urgent need to investigate non-chemical options that can be added to a weed management program to target resistant weeds, as outlined in the WeedSmart 10 Point Plan.

Strategic tillage

Most growers are keen to preserve their zero- or minimum-till farming systems because they have delivered significant benefits, and are understandably reluctant to re-introduce cultivation to control weeds. Research is under way to investigate ways to use cultivation that will have maximum effect on driving down weed numbers while having least impact on minimum-till farming. The aim of this research is to investigate the impact of different types of tilling where the weed population has blown out and intensive patch or paddock management is required.

The key is to understand weed ecology, particularly how seed in the soil seedbank responds to different types of cultivation. Researchers used small plots to determine the effect of burying weed seeds on their persistence (long-term viability after burial in soil) and emergence. They also experimented to determine the displacement of seed throughout the cultivated zone using four different types of machine—harrows, Gyral, off-set discs and one-way discs—compared to a zero-till control.

Sowthistle emergence occurs primarily from seeds close to the soil surface, with up to 30% of viable seeds emerging over five months.

Seed persistence in fleabane was most reduced when seed was buried to 2 cm and let undisturbed for at least two years. Seed buried to a depth of 10 cm remained viable for over three years.

Feathertop Rhodes grass seed persisted for only 12 months regardless of being left on the surface or buried to 10 cm.

Barnyard grass however, persisted on the soil surface for up to two years, and when buried to 10 cm depth remained viable for over three years.

The Gyral machine placed the majority of weed seed in the 0–2 cm and 2–5 cm zones while the offset discs and one-way discs achieving burial of about half the seed below 5 cm depth.

All species responded to increased tilling intensity with reduced germinations. The message from this research is that infrequent but intense cultivation can be a useful weed-management tool within an otherwise zero-till system. Generally, once a paddock has been deeply cultivated there should be no cultivation of that area or paddock for at least four years so as to avoid the risk of bringing seed back to the soil surface.

Strategic burning

Feathertop Rhodes grass is known to colonise around mature plants, and may spread from here to form distinct weedy patches. Once it gets this big, killing the large plant at the centre of the colony is usually not possible using chemical treatments.

In this situation, the strategic burning of early infestations can effectively reduce the biomass of the part of the colony that survives and reduce the amount of viable seed present on the soil surface from 7,500 seeds/m^2 to less than 500 seeds/m^2. Growers have made effective use of a flame-thrower to burn large feathertop Rhodes grass plants during the fallow (Photo 6).

Photo 6: *Strategic burning of feathertop Rhodes grass in a fallow can be an effective way of reducing the biomass of the survivor plant and of reducing the amount of viable seed on the soil surface.*

Source: WeedSmart

Crop competition

Using crop competition by planting with a narrower row spacing and or greater planting density provides an effective offensive against common sowthistle and flaxleaf fleabane.

In recent tests, researchers looked at the effect of crop competition on its own, but realized that in commercial situations crop competition would have to be used in conjunction with herbicide. Narrowing wheat rows from a spacing of 50 cm to 25 cm had the most marked effect on fleabane seed-head production, with an added advantage that the crop density also increased from 50 plants/m^2 to 100 plants/m^2 (Figure 2 and Photo 7).

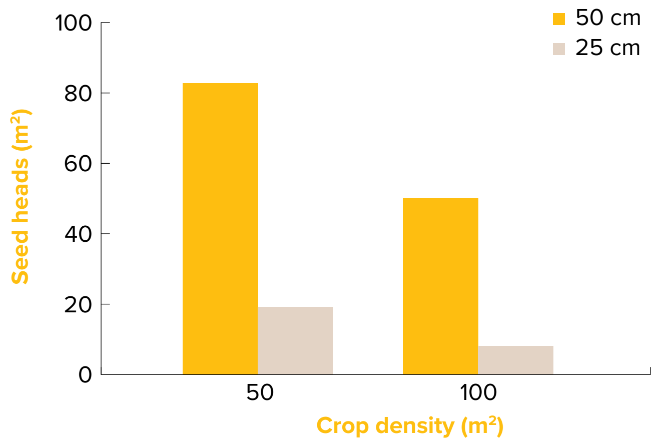


Figure 2: *Fleabane seed-head production is dramatically curtailed when the crop is planted more densely.*

Source: WeedSmart

Photo 7: *Crop competition through narrower row spacing and or increased planting density provides an effective offensive against common sowthistle and flaxleaf fleabane.*

Source: WeedSmart

Cover crops

Growers using summer for fallowing paddocks rely heavily on glyphosate as a chemical fallow to control summer grasses. Cover crops are primarily grown to provide soil cover and help increase water infiltration and decrease evaporation. In preliminary research, the use of cover crops to replace the chemical fallow has been explored. Crops such as cowpeas, lablab and French millet have the potential to smother summer-growing weeds, particularly barnyard grass and feathertop Rhodes grass, and return large amounts of organic biomass to the soil. [19]

MORE INFORMATION

Non-herbicide weed control in the Northern region

19 WeedSmart (2017) Non-herbicide weed control in the Northern Region. WeedSmart, http://www.weedsmart.org.au/bulletin-board/non-herbicide-weed-control-in-the-northern-region/

6.4 Key weeds of Australia's cropping systems

Section 8 of GRDC's contains profiles of the common weeds of Australian crops: [20]

- annual ryegrass (*Lolium rigidum*)
- barley grass (*Hordeum* spp.)
- barnyard grasses (*Echinochloa* spp.)
- black bindweed (*Fallopia convolvulus*)
- bladder ketmia (*Hibiscus trionum*)
- brome grass (*Bromus* spp.)
- capeweed (*Arctotheca calendula*)
- doublegee (*Emex australis*)
- feathertop Rhodes grass (*Chloris virgata*)
- fleabane (*Conyza* spp.)
- fumitory (*Fumaria* spp.)
- Indian hedge mustard (*Sysimbrium orientale*)
- liverseed grass (*Urochloa panicoides*)
- muskweed (*Myagrum perfoliatum*)
- paradoxa grass (*Phalaris paradoxa*)
- silver grass (*Vulpia* spp.)
- sweet summer grass (*Brachiaria ericuformis*)
- turnip weed (*Rapistrum rugosum*)
- wild oats (*Avena fatua* and *Avena ludoviciana*)
- wild radish (*Raphanus raphanistrum*)
- windmill grass (*Chloris truncata*)
- wireweed (*Polygonum aviculare* and *Polygonum arenastrum*)

IN FOCUS

RIM (Ryegrass Integrated Management)

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

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

A wide variety of chemical and non-chemical weed treatment options are included, so that as chemicals are lost to herbicide resistance, the next-best substitute can be identified.

To do this by trial and error in the real world, rather than in a computer simulation, would take many years and may leave farmers with a major weed problem they could have avoided. With RIM, farmers and others can

20 GRDC (2014) Section 8. Profiles of common weeds of cropping. GRDC, https://grdc.com.au/resources-and-publications/iwmhub/common-weeds-of-cropping

MORE INFORMATION

Ryegrass Integrated Management

VIDEOS

WATCH: Managing herbicide resistant ryegrass with IWM

conduct virtual experiments with a range of treatment options before they put real dollars at risk.

RIM can help farmers to tackle questions such as:

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

6.5 Herbicides

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

It is important that care is taken to ensure crop and weed tolerances based on the label recommendations are adhered to. Additionally, weather conditions, herbicide rates, water-dilution rates, and the status of adjoining crops need to be assessed and managed correctly. A range of chemicals is registered for use in both wheat and triticale, but some other herbicides are only legal for use in wheat. And for triticale, some herbicides are only legal to use at specific crop stages. [21]

6.5.1 Herbicides explained

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

Residual and non-residual herbicides

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

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

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

Pre-emergent and post-emergent herbicides

Pre-emergent and post-emergent herbicides are chemicals that are utilised to fit in with the timing of plant growth. Pre-emergent refers to the application of the herbicide to the soil before the weeds have emerged, and post-emergent to foliar application of the herbicide after the target weeds have emerged from the soil. [22]

Herbicide groups

Herbicides have been classified into a number of groups that refer to the way a chemical works: their different chemical make-up and mode of action (Table 3). [23]

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

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

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

Source: Agriculture Victoria

VIDEOS

WATCH: Over the Fence North: Weed and nutrient research delivers at Silverton

WATCH: GCTV17: Herbicide partnership

6.6 Pre-emergent herbicides

Triticale is competitive against weeds once it is established. If needed, a pre-emergent knockdown should be applied, as there are limited options available post-emergence. Ideally, a non-selective knockdown should be used when sowing main season varieties to reduce the reliance on post-emergent herbicides. [24] There are some herbicide options available against both grass and broadleaf weeds. [25]

> *A non-selective knockdown should be used in early AND main sown crops—it is a cheap way to control early weeds that does not cause crop damage.*
>
> Agronomist's view

22 GRDC Integrated weed management, Section 4: Tactics for managing weed populations. GRDC, https://grdc.com.au/resources-and-publications/iwmhub

23 Agriculture Victoria. Herbicide resistance and integrated weed management (IWM) in crops and pasture monitoring tools. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/farm-management/business-management/ems-in-victorian-agriculture/environmental-monitoring-tools/herbicide-resistance

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

25 AGF Seeds. Triticale. AGF Seeds, https://agfseeds.com.au/triticale

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

6.6.1 Benefits and concerns

- The residual activity of pre-emergent herbicides controls the first few flushes of germinating weeds while the crop or pasture is too small to compete.
- Good planning is needed to use pre-emergent herbicides as an effective tactic. It is necessary to consider weed species and density, crop or pasture type, soil condition, and the rotation of crop or pasture species.
- Soil activity and environmental conditions at the time of application play an important role in the availability, activity and persistence of pre-emergent herbicides.
- Both the positive and negative aspects of using pre-emergent herbicides should be considered in the planning phase. [26]

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

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

6.6.2 Understanding pre-emergent herbicides

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

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

Behaviour of pre-emergent herbicides in the soil

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

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

The characteristics of some common pre-emergent herbicides are given in Table 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

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

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.

Table 4: *Water solubility, binding characteristics, and degradation half-life of some common pre-emergent herbicides.*

Herbicide	Water solubility		Koc		Degradation half-life (days)
	mg/L-1 (at 20°C and neutral pH)	Rating	mL/g-1 (in typical neutral soils)	Rating	
Trifluralin	0.22	Very low	15,800	Very high	181
Pendimethalin	0.33	Very low	17,800	Very high	90
Pyroxasulfone	3.9	Low	223	Medium	22
Triallate	4.1	Low	3000	High	82
Prosulfocarb	13	Low	2000	High	12
Atrazine	35	Medium	100	Medium	75
Diuron	36	Medium	813	High	75.5
S-metolachlor	480	High	200	Medium	15
Triasulfuron	815	High	60	Low	23
Chlorsulfuron	12,500	Very high	40	Low	160

The values are for the Koc, the soil organic carbon-water partitioning coefficient. High Koc values mean that more herbicide will be bound to organic matter and less herbicide will be available to move in the soil solution.

Source: GRDC

It is complex managing all the factors that result in the herbicide working effectively, without damage to the crop, but some rules of thumb are:

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

MORE INFORMATION

Understanding pre emergent cereal herbicides

Using pre-emergent herbicides in conservation farming systems

Gearing up to use pre-emergent herbicides

GRDC factsheet, Pre-emergent herbicides

How pre-emergent herbicides work

Seeding systems and pre emergence herbicides

with disc seeding equipment in choice of product and maintaining an adequate seeding depth. [27]

6.6.3 Top tips for using pre-emergent herbicides

- Only use pre-emergent herbicides as part of an integrated weed control plan that includes both chemical and non-chemical practices.
- Preparation starts at harvest. Minimise compaction and maximise trash spreading from the header.
- Minimise soil disturbance so that weed seeds are more likely to remain on the soil surface.
- Leave stubble standing rather than laying it over.
- Knife points and press wheels allow greatest crop safety. Avoid harrows.
- If using a disc seeder understand the mechanics of your machine and its limitations compared to a knife point and press wheel. Note that not all pre-emergent herbicides are registered with disc machines so make sure to check the label prior to application.
- Pay attention to detail in your sowing operation and ensure soil throw on the inter-row while maintaining a seed furrow free of herbicide.
- Ensure the seed furrow is closed to prevent herbicide washing onto the crop seed.
- Ensure even seed placement, typically 3–5 cm of loose soil on top of seed in cereals, for best crop safety.
- Use incorporate by sowing (IBS) rather than post-sowing pre-emergent (PSPE) cropping for crop safety.
- Understand herbicide chemistry. Choose the right herbicide in the right paddock at the right rate. [28]

6.6.4 Incorporation by sowing

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

This is the preferred method of applying pre-emergent herbicides in conservation farming systems, as crop safety is maximised, stubble remains standing to protect the seedbed, and soil disturbance is minimised.

Applying pre-emergent herbicides before sowing and then incorporating them into the seedbed during planting usually increases the safety of the crop because the sowing operation moves a certain amount of herbicide away from the seed row. Sowing can reduce weed control for the same reason. In this case, it is wise to include a water-soluble herbicide into the mix aiming to have some herbicide wash into the seed furrow.

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

27 C Preston (2014) Understanding pre-emergent cereal herbicides. GRDC Update Paper. GRDC, https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2014/03/understanding-pre-emergent-cereal-herbicides

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

rates with improved crop safety together with reduced incorporation characteristics. The main results of the study were that:

- The use of a disc planter for IBS of residual herbicides resulted in significantly reduced wheat emergence for all four herbicides evaluated.
- The disc planter set up actually increased the risk of crop damage (Figure 3). [29]
- The results reinforce the need to only use narrow-point tynes when using residual herbicides with IBS.

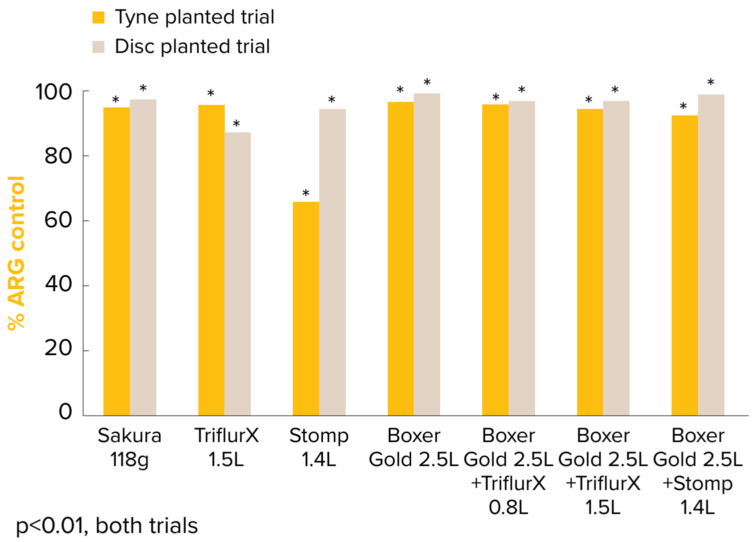


Figure 3: *Per cent annual ryegrass control based on counts taken 94 days after planting, on 22 September 2013.*

UTC = untreated control. All treatments applied in 70 L/ha total volume using AIXR110015 nozzles at 300 kPa * = significant annual ryegrass control compared to untreated within same trial.

Source: GRDC

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

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

The trials highlighted problems with the use of disc planters:

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

This work reinforces some of the difficulties growers (and agronomists) face with the use of residual herbicides. Crop safety and efficacy are influenced by a range of factors including planting equipment, planting depth, soil type and stubble load, together with how much rain falls and when. More research is needed to give everyone in the industry a more thorough understanding of the impact of these

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

factors (and perhaps others) to ensure not only that weed management tools are effective, but that they remain effective for decades to come. [30]

6.7 Post-sowing pre-emergent herbicides

MORE INFORMATION

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

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

6.8 In-crop herbicides: knockdowns and residuals

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

There are numerous herbicide options for early post-emergent and late post-emergent control of broadleaf weeds; however, there are only early-post emergent control options for grass weeds. [31]

The benefits are:

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

To avoid problems emerging from the use of these herbicides:

- Carefully consider the best post-emergent herbicide to use in any one situation.
- Choose the most suitable formulation of herbicide for each situation.
- Application of post-emergent herbicides to stressed crops and weeds can result in reduced levels of weed control and increased crop damage.
- Crop competition is important for effective weed control when using selective post-emergent herbicides.
- The technique used for application must be suited for the situation in order to optimize control.
- Always use the correct adjuvant to ensure effective weed control.
- The effectiveness of post-emergent herbicides is influenced by a range of plant and environmental factors. [32]

6.8.1 Applying in-crop herbicides

When applying in-crop herbicides:

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

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

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

- Knowledge of a product's translocation and formulation type is important for selecting nozzles and application volumes.
- Evenness of deposit is important for poorly or slowly translocated products.
- Crop growth stage, canopy size and stubble load should influence decisions about nozzle selection, application volume and sprayer operating parameters.
- Travel speed and boom height can affect control and the likelihood of drift.
- Appropriate conditions for spraying are always important.

Uptake, translocation and application volume

Products that have a slow uptake or slow or limited translocation (such as Group A herbicides) should be applied at higher water rates (typically 70–100 L/ha in cereals and higher in many pulses).

Products that are phloem and xylem transported (such as Groups B, i and M herbicides) can often be applied at lower application volumes–50–70 L/ha in low stubble situations and small crop canopy–but normally need to be applied at 70 L/ha or more where high stubble loads exist or the crop canopy is dense. Always check product labels and the manufacturer's technical information for specific advice about appropriate application volumes and timing in relation to a crop's growth stage.

Water volume and spray quality

Depositing droplets onto foliar targets is a numbers game. increasing application volumes produces more droplets, which usually increases the evenness of the application, provided droplets reach where they are required. Anything that is situated between the nozzle and the desired target weed, such as stubble or a large crop canopy, has the potential to intercept spray droplets. Where crop canopies are large or stubble load is heavy, it is always advisable to use robust or higher water rates. More droplets can be produced by decreasing the droplet size. However, fine spray qualities do not penetrate dense canopies as well as medium spray qualities from non-air induction nozzles or air inducted coarse droplets (unless they are used with an air-assisted spray system). finer spray qualities also increase spray drift risk and are likely to be intercepted by stubble when the load is high.

Adjuvant choice

Choosing the most appropriate adjuvant can improve control, whereas the wrong adjuvant choice may reduce it. non-ionic surfactants will generally improve droplet spread on the leaf surface and normally will not adversely interact with products. However, a non-ionic may not improve product performance in situations where an oil-based adjuvant is recommended due to the way oil-based products are absorbed into the plant. Oil-based adjuvants are usually mixed with oil-based formulations, some emulsifiable concentrates and some low volatile ester-based formulations. The addition of oil-based surfactants to water-soluble products such as glyphosate is not recommended by most manufacturers. Always check the label recommendations and the manufacturer's recommendations about the most suitable adjuvant for mixing with a particular product.

Interactions between nozzle type and formulation or adjuvants

When it comes to choosing a nozzle, select the nozzle size to deliver the desired volume, but choose the nozzle type to produce the desired pattern and spray quality. Most product labels will suggest either a medium or larger spray quality, or a coarse or larger spray quality. When a medium spray quality is required, it is often best to do this with a standard pre-orifice (low drift) nozzle or a larger orifice flat fan (capable of producing a medium spray quality). This is particularly important where labels specify that only a medium spray quality can be used, or when oil-based formulations or adjuvants are to be used.

In some instances, oil-based formulations and adjuvants have the ability to collapse the air within the droplets produced by air induction nozzles, especially when they are operated at the lower end of their pressure range and the spray quality approaches the larger end of the coarse spectrum (towards very coarse). This becomes an issue when speeds are reduced at the ends of paddocks, around trees and over contours, when the automatic rate controller reduces the pressure to maintain the application rate. using the minimum hold (or lower limit function) in the controller can reduce this, but can also encourage overdosing leading to crop damage.

In some instances, using larger headlands can help to reduce overdosing. in other situations where larger headlands cannot be achieved, a small increase in application volume can reduce the speed at which the minimum hold engages, which reduces the amount of overdosing.

When operated at the high end of their pressure range some air induction nozzles produce medium droplets. When a nonionic surfactant is used with an air induction nozzle, it is possible to produce less-dense droplets that have the potential to drift due to the air inclusion within the droplet. In some instances, air induction nozzles producing air-filled medium droplets may actually drift more than other nozzle types that don't include air, such as standard orifice or low-drift nozzles.

Travel speed and nozzle design

Travel speed and nozzle design can affect coverage and the evenness of application. With standard nozzle patterns that face straight down, as travel speed increases the net droplet movement is often in a forward direction, which can result in more droplets depositing on one side of the weed, or increasing retention on stubble. The use of offset (angled) nozzles or twin designs can improve the evenness of deposition, provided the travel speed is not excessive. Control-based trials in fallow have shown that a number of angled and twin designs perform well at speeds up to 21 km/h. Overseas control-based trials have also shown more even deposition from angled or twin nozzles compared with standard patterns that face directly downwards. [33]

How to get the most out of post-emergent herbicides

Consider the timing of the spray: the younger the weeds, the better. Frequent crop monitoring is critical.

Also consider the growth stage of the crop:

- Consider the crop variety being grown and applicable herbicide tolerances.
- Know which species were historically in the paddock and the resistance status of the paddock (and if unsure, send plants away for a Quick-Test).
- Do not spray a crop stressed by waterlogging, frost, high or low temperatures, drought or, for some chemicals, cloudy or sunny days. This is especially pertinent for frosts with grass-weed chemicals.
- Use the correct spray application:
- Consider droplet size with grass-weed herbicides, water volumes with contact chemicals and time of day.
- Observe the plant-back periods and withholding periods.
- Consider compatibility if using a mixing partner.
- Add correct adjuvant. [34]

MORE INFORMATION

GRDC factsheet, In-crop herbicide use

GRDC factsheet, Pre-harvest herbicide use factsheet

6.9 Conditions for spraying

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

- improved herbicide effectiveness

33 GRDC (2014) In-crop herbicide use Factsheet. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/08/grdc-fs-incropherbicideuse

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

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

In areas where a range of agricultural enterprises coexist, conflicts can arise, particularly from the use of herbicides. All herbicides are capable of drifting. When spraying an herbicide, you have a moral and legal responsibility to prevent it from drifting into and contaminating or damaging neighbours' crops and other sensitive areas. Record weather conditions, herbicide and water rates, and operating details for each paddock.

Any of the following stress conditions can significantly impair both uptake and translocation of the herbicide within the plant, which is likely to result in an incomplete kill or only suppression of weeds:

- Moisture stress and drought.
- Waterlogging.
- High temperature, low humidity conditions.
- Extreme cold or frosts.
- Nutrient deficiency, especially of nitrogen.
- Use of pre-emergent herbicides that affect growth and root development; i.e. simazine, Balance®, trifluralin, and Stomp®.
- Excessively heavy dews resulting in poor spray retention on grass leaves.

6.9.1 Minimising spray drift

Before spraying:

- Always check for susceptible crops in the area (see Photo 8), for example broadleaf crops such as grape vines, cotton, vegetables and pulses, if you are using a broadleaf herbicide. The Cotton Map is a resource to help growers minimise off-target damage from downwind herbicide and pesticide application.
- Check sensitive areas such as houses, schools, waterways and riverbanks.
- Notify neighbours of your spraying intentions.

During spraying:

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

Photo 8: *Triticale plants showing classic signs of damage from spray drift.*

Source: Delaware Valley University

6.9.2 Types of drift

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

Photo 9: *Using a boom spray on the crop when there is only a very light breeze helps prevent spray drift.*

Source: DAFWA

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

Particle drift occurs when water and other carriers of herbicides evaporate quickly from the droplet, leaving tiny particles of concentrated herbicide. This can occur with herbicide formulations other than esters. Instances of this form of drift have damaged susceptible crops up to 30 km from the source.

Vapour drift is confined to volatile herbicides such as 2,4-D ester. Vapours may arise directly from the spray or as a result of the herbicide evaporating from sprayed surfaces. Use of 2,4-D ester in summer can lead to vapour-drift damage of highly susceptible crops such as tomatoes, cotton, sunflowers, soybeans and grapes. This may occur hours after the herbicide has been applied.

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

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

Surrounding crops may be far more sensitive to herbicides than the crops targeted for spraying. Even small quantities of drifting herbicide can cause severe damage to highly sensitive plants.

6.9.3 Factors influencing the risk of spray drift

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

- Volatility of the formulation applied—volatility refers to the likelihood that the herbicide will evaporate and become a gas. Esters volatilise whereas amines do not.
- Proximity of crops susceptible to the particular herbicide being applied, and their growth stage. For example, cotton is most sensitive to Group I herbicides in the seedling stage.
- Method of application and equipment used. Aerial application releases spray 3 m above the target and uses relatively low application volumes, while ground rigs have lower release heights and generally higher application volumes, and a range of nozzle types. Misters produce large numbers of very fine droplets that use wind to carry them to their target.
- Size of the area treated—the greater the area treated the longer it takes to apply the herbicide. If local meteorological conditions change, particularly in the case of 2,4-D ester, then more herbicide is able to volatilise.
- Amount of active ingredient (herbicide) applied—the more herbicide applied per hectare the greater the amount available to drift or volatilise.
- Efficiency of droplet capture—bare soil does not have anything to catch drifting droplets, unlike crops, erect pasture species and standing stubbles.
- Weather conditions during and shortly after application.

Changing weather conditions can increase the risk of spray drift.

Volatility

Many ester formulations are highly volatile when compared with the non-volatile amine, sodium salt and acid formulations. Table 5 [35] is a guide to the more common active ingredients of herbicides that are marketed in more than one formulation.

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

Table 5: *Relative herbicide volatility.*

Form of active ingredient	Full name	Product example
Non-volatile		
Amine salts		
MCPA DMA	dimethyl amine salt	MCPA 500
2,4-D DMA	dimethyl amine salt	2,4-D Amine 500
2,4-D DEA	diethanolamine salt	2,4-D Amine 500 Low Odour®
2,4-D IPA	isopropylamine salt	Surpass® 300
2,4-D TIPA	triisopropanolamine	Tordon® 75-D
2,4-DB DMA	dimethyl amine salt	Buttress®
dicamba DMA	dimethyl amine salt	Banvel® 200
triclopyr TEA	triethylamine salt	Tordon® Timber Control
picloram TIPA	triisopropanolamine	Tordon® 75-D
clopyralid DMA	dimethylamine	Lontrel® Advanced
clopyralid TIPA	triisopropanolamine	Archer®
aminopyralid K salt	potassium salt	Stinger®
aminopyralid TIPA	triisopropanolamine	Hotshot®
Other salts		
MCPA Na salt	sodium salt	MCPA 250
MCPA Na/K salt	sodium & potassium salt	MCPA 250
2,4-DB Na/K salt	sodium & potassium salt	Buticide®
dicamba Na salt	sodium salt	Cadence®
Some volatility		
Esters		
MCPA EHE	ethylhexyl ester	LVE MCPA
MCPA IOE	isooctyl ester	LVE MCPA
triclopyr butoxyl	butoxyethyl ester	Garlon® 600
Picloram IOE	isooctyl ester	Access®
2,4-D ehe	ethylhexyl ester	2,4-D LVE 680
fluroxypyr M ester	meptyl ester	Starane® Advanced

Source: NSW DPI

6.9.4 Minimising drift

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

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

In 2010, the APVMA announced new measures to ensure the number of spray-drift incidents are minimised (Table 6). [36] The changes are restrictions on the droplet

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

VIDEOS

WATCH: IWM: Spray application of herbicides—nozzle selection

WATCH: IWM: Spray application of herbicides—travel speed

WATCH: IWM: Spray application of herbicides—spray deposition

MORE INFORMATION

Review speed and boom height to improve spray deposition

size spectrum an applicator can use, the wind speed suitable for spraying, and the downwind buffer zone between spraying and a sensitive target. These changes should be evident on current herbicide labels. Hand-held spraying application is exempt from these regulations.

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

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

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

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

Source: DPI NSW

6.9.5 Spray release height

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

6.9.6 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.

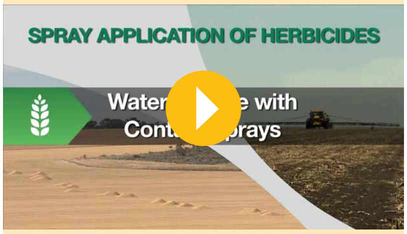
6.9.7 Capture surface

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.

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

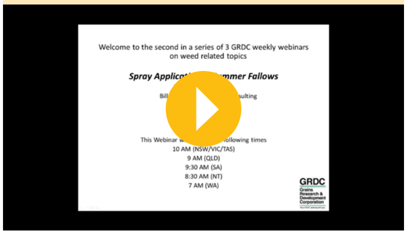
VIDEOS

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



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

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



MORE INFORMATION

Surface temperature inversions and spraying factsheet

6.9.8 Weather conditions to avoid

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

Avoid using herbicidal sprays in the following conditions.

- Midday turbulence
- Up-drafts during the heat of the day cause rapidly shifting wind directions, so avoid spraying in the middle of the day.
- High temperatures
- Avoid spraying when temperatures exceed 28°C.
- Humidity
- Avoid spraying under low relative humidity, i.e. when the difference between wet and dry bulbs (Delta T, ΔT) exceeds 10°C.
- High humidity extends droplet life and can greatly increase the drift hazard under inversion conditions. This results from the increased life of droplets smaller than 100 microns.
- Inversions
- The most hazardous condition for herbicide spray drift is an atmospheric inversion, especially when combined with high humidity.
- Wind
- Avoid spraying under still conditions.
- 11–14 km/h (a moderate breeze, when small branches move, dust is raised or loose paper moves) is suitable for spraying only if using low-drift nozzles or higher volume application, say 80–120 L/ha.

An inversion exists when temperature increases with altitude instead of decreasing. An inversion is like a cold blanket of air above the ground, and is usually less than 50 m thick. Air will not rise above this blanket; and smoke or fine spray droplets and particles of spray deposited within an inversion will float until the inversion breaks down. Inversions usually occur on clear, calm mornings and nights. Windy or turbulent conditions prevent the formation of inversion layers.

Blankets of fog, dust or smoke and the tendency for sounds and smells to carry long distances indicate inversion conditions. Smoke generators or smoky fires can be used to detect inversion conditions. Smoke will not continue to rise but will drift along at a constant height under the inversion blanket. [37]

6.10 Testing for herbicide tolerance

In most cases, the herbicides and pesticides that work on wheat and rye will work on triticale. However, some studies indicate that triticale may be less tolerant to some herbicide cocktails than wheat. Newer herbicides as well as pesticides are being released with recommendations for use on triticale in many parts of the world. [38]

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

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

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

38 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/docrep/009/y5553e/y5553e00.htm

MORE INFORMATION

Cultivar herbicide tolerance trial protocols

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

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

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

6.11 Potential herbicide damage of triticale

Excessive herbicide treatments may limit germination in triticale. The successive effect of five herbicide variants (isoxaben, chlorsulfuron, isoproturon, chlortoluron and control) on the germination and plant growth of triticale cultivars has been explored. Germination of winter triticale seeds, obtained from plants treated with herbicide, was generally lower, in particular for the isoproturon and chlorsulfuron variants. [39]

6.11.1 Avoiding crop damage from residual herbicides

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

What are the issues?

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

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

Currently, growers rely on information provided on the labels about soil type and climate. Herbicide residues are often too small to be detected by chemical analysis, or if testing is possible it is too expensive to be part of routine farming practice. Once the crop has emerged, diagnosis is difficult because the symptoms of residual herbicide damage can be confused with, and/or make the crop vulnerable to, other stresses, such as nutrient deficiency or disease. [40]

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

Which herbicides are residual?

The herbicides listed in Table 7 all have some residual activity or planting restrictions. Glean® is registered for use in triticale, cereal rye, wheat, and oats. Activity occurs through root and foliar uptake. There are no plant-back recommendations on alkaline

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

40 Agriculture Victoria (2013) Avoiding crop damage from residual herbicides. Updated. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

soils for triticale and wheat. Ally® is registered for use in triticale, wheat, barley and cereal rye. Activity is by foliar translocation but also root absorption after rain. [41]

Table 7: *A representative range of active constituents by herbicide group.*

Herbicide group	Active constituent
Group B: Sulfonylureas	Chlorsulfuron (Glean®), iodosulfuron (Hussar®), mesosulfuron (Atlantis®), metsulfuron (Ally®), triasulfuron (Logran®)
Group B: Imidazolinones	Imazamox (Raptor®), imazapic (Flame®), imazapyr (Arsenal®)
Group B: Triazolopyrimidines (sulfonamides)	Florasulam (Conclude®)
Group C: Triazines	Atrazine, simazine
Group C: Triazinones	Metribuzin (Sencor®)
Group C: Ureas	Diuron
Group D: Dinitroanilines	Pendimethalin (Stomp®), trifluralin
Group H: Pyrazoles	Pyrasulfotole (Precept®)
Group H: Isoxazoles	Isoxaflutole (Balance®)
Group I: 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 apply to future rotation options.

Consider your soil types; sandy soils can leach herbicides, whereas heavier soils will have longer residuals

Look at the weather forecast prior to applying. If heavy rainfall expected post sow, pre-emergent, do not apply the herbicide as this may be washed into the furrow and cause damage to the emerging seedling.

Soil surface condition; cloddy soil surfaces can result in more damage.

Agronomist's view

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). [42] In the case of unexpected damage, good records can be invaluable.

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

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

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

Photo: C Preston

MORE INFORMATION

Herbicide residues in soil and water

If residues could be present, choose the least susceptible crops; refer to product labels. Optimise growing conditions to reduce the risk of compounding the problem with other stresses such as herbicide spray damage, disease and nutrient deficiency. These stresses make a crop more susceptible to herbicide residues. [43]

6.11.2 Plant-back intervals

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

Some herbicides have a long residual period. This is not the same as the half-life. Although the amount of chemical in the soil may break down rapidly to half the original amount (the half-life), what remains can persist for long periods (the residual period), as sulfonylureas such as chlorsulfuron do (Table 8 [44]). Herbicides with long residuals can affect later crops, especially if they are effective at low levels of the active ingredient, such as with the sulfonylureas. On product labels, this will be shown by plant-back periods (Table 9 [45]), which are usually listed under a separate plant-back heading or under a heading such as 'Protection of crops' in the general instructions section.

Part of the management of herbicide resistance includes rotation of herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonyl urea, triazines) may be a problem in some paddocks. Remember that plant-back periods begin after rain. [46]

43 Agriculture Victoria (2013) Avoiding crop damage from residual herbicides, Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

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

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

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

Table 8: *Known residual persistence of common pre-emergent herbicides.*

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

Note residual persistence in broadacre trials and paddock experiences.

Source: NSW DPI

Table 9: *Minimum re-cropping intervals and guidelines.*

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 e.g. Glean®, Seige®, Tackle®	<6.5		3 months
		6.6–7.5	3 months, minimum 700 mm	
		7.6–8.5	18 months, minimum 700 mm	
B, sulfonyl urea (SU)	triasulfuron, e.g. Logran®, Nugrain®	7.6–8.5		12 months, >250 mm for grain, 300 mm for hay
		>8.6	12 months, >250 mm grain, 300 mm hay	
B, Sulphonamide	Flumetsulam e.g. Broadstrike®			0 months
B, sulfonyl urea (SU)	metsulfuron e.g. Ally®, Associate®	5.6–8.5		1.5 months
		>8.5	Tolerance of crops grown through to maturity should be determined (small scale) previous season before sowing larger area	
B, sulfonyl urea (SU)	Metsulfuron + thifensulfuron, e.g. Harmony® M	7.8–8.5 organic matter >1.7%	3 months	
	>8.6 or organic matter <1.7%	Tolerance of crops grown through to maturity should be determined (small scale) previous season before sowing larger area		
B, sulfonyl urea (SU)	Sulfosulfuron e.g. Monza®	<6.5	0 months	
		6.5–8.5	10 months	

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

MORE INFORMATION

Avoiding crop damage from residual herbicides

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

Conditions required for breakdown

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

6.12 Herbicide resistance

Key points:

- Resistance is the inherited ability of an individual plant to survive and reproduce following a herbicide application that would kill a 'wild' individual of the same species.
- Thirty-six weed species in Australia currently have populations that are resistant to at least one herbicide mode of action (MOA).
- As of August 2016, Australian weed populations had developed resistance to 25 at least one MOA group. (Information is kept up to date by the International Survey of Herbicide Resistant Weeds.)

- 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.

Resistance remains for many years, until all resistant weed seeds are gone from the soil seedbank. It evolves more rapidly in paddocks where chemicals from the same herbicide group are used frequently, especially if no other types of control are used.

Action points:

- Assess your level of risk with the online glyphosate resistance toolkit.
- Aim for maximum effectiveness in control tactics, because resistance is unlikely to develop in paddocks with low weed numbers.
- Do not rely on the same mode of action group.
- Monitor your weed control regularly.
- Stop the seedset of survivors. [47]

As herbicide resistance becomes more widespread, it reduces the effectiveness of a wide range of herbicide MOAs (see Photo 11) [48]. Rapid expansion of herbicide resistance and the lack of new MOA require that non-herbicide tactics must be a significant component of any farming system and weed management strategy. Inclusion of non-herbicide tactics is critical to prolong the effective life of remaining herbicides, as well as for new products and modes of action that have not yet been released or indeed invented. Effective herbicides are key components of profitable cropping systems. Protecting their efficacy directly contributes to the future sustainability and profitability of cropping systems.

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

Photo: A Storrie

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

48 GRDC (n.d.) Section 1. Herbicide resistance. In Integrated Weed Management Hub. GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-3-herbicide-resistance

Herbicide resistance is an increasing threat across Australia's northern grain region for both growers and agronomists. Many weeds are confirmed as being resistant to herbicides of Groups A, B, C, I, M or Z (Table 10). [49] As well, barnyard grass, liverseed grass, common sowthistle and wild oat are at risk of developing resistance to Group M (glyphosate) herbicides (Table 11). [50]

Table 10: *Weeds confirmed as resistant in northern NSW.*

Weed	Herbicide group and product/chemical (examples only)	Areas with resistance in NSW	Future risk	Detrimental impact
Wild oats	A. Topik®, Wildcat® B. Atlantis® Z. Mataven®	Spread across the main wheat-growing areas More common in western-cropping areas	Areas growing predominantly winter crops	High
Paradoxa grass	A. Wildcat®	North and west of Moree	Areas growing predominantly winter crops	High
Awnless barnyard grass	C. Triazines M. Glyphosate	Mainly between Goondiwindi and Narrabri	No-till or minimum-till farms with summer fallows	High Very high
Charlock, black bindweed, common sowthistle, Indian hedge mustard, turnip weed	B. Glean®, Ally®	Spread across the main wheat-growing areas	Areas growing predominantly winter crops	Moderate
Annual ryegrass	M. Glyphosate B. Glean® A. Verdict®	Group M resistance widespread in Liverpool Plains Group A and B resistance in central west NSW	Areas with predominantly summer fallows Winter cropping areas	High
Fleabane	M. Glyphosate	Spread uniformly across the region	Cotton crops and no-till or minimum-till systems	Moderate
Wild radish	I. 2,4-D amine	Central-west NSW	Continuous winter cereal cropping	High
Windmill grass	M. Glyphosate	Central-west NSW	Continuous winter cropping and summer fallows	High
Liverseed grass	M. Glyphosate	A few isolated cases	No-till or minimum-till systems	Moderate
Sowthistle[A]	M. Glyphosate	Liverpool Plains	Winter cereal contaminated areas with minimum tillage	High

Source: NSW DPI

49 A Storrie, T Cook, P Moylan, A Maguire, S Walker, M Widderick (n.d.) Managing herbicide resistance in northern NSW. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/155148/herbicide-resistance-brochure.pdf

50 A Storrie, T Cook, P Moylan, A Maguire, S Walker, M Widderick (n.d.) Managing herbicide resistance in northern NSW. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/155148/herbicide-resistance-brochure.pdf

Table 11: *Weeds that may become resistant in northern NSW.*

Weed	Herbicide group and product/chemical (examples only)	Future risk	Detrimental impact
Barnyard, liverseed and windmill grasses	A. Verdict® L. Paraquat	No-till and minimum-till systems	Very high
Common sowthistle	I. 2,4-D amine	Winter cereals	High
Paradoxa grass	B. Glean®, Atlantis®	Western wheat growing areas	High
Other brassica weeds, including wild radish	B. Glean®, Ally®	Areas growing predominantly winter crops	Moderate
Annual ryegrass	L. Paraquat	Areas with predominantly summer fallows	Very high
Wireweed, black bindweed, melons and cape weed	I. 2,4-D amine, Lontrel®, Starane®	Areas growing predominantly winter crops	High
Fleabane	I. 2,4-D amine L. Paraquat	Cotton crops and no-till or minimum-till systems	Very high
Other fallow grass weeds	M. Glyphosate	No-till or minimum-till systems	High

Source: NSW DPI

In southern Queensland, seven weeds are confirmed to be resistant to Groups A, B or C herbicides (see Table 11). [51] A further four weeds are confirmed resistant to glyphosate (e.g. Roundup®).

Table 12: *Weeds confirmed as resistant in southern Queensland.*

Weed	Herbicide group	Extent of resistance in SQ	Future risk	Detrimental impact
Wild oats	A, e.g. Topik®, Wildcat®	Spread across the main wheat growing areas	Areas growing predominantly winter crops	High
African turnip weed, black bindweed, common sowthistle, Indian hedge mustard, turnip weed	B, e.g. Glean®, Ally®	Spread across the main wheat growing area	Areas growing predominantly winter crops	Moderate
Liverseed grass	C, e.g. atrazine	A few paddocks in eastern Darling Downs	Areas growing predominantly sorghum	High
Barnyard grass	M, e.g. glyphosate	Western Darling Downs	Summer fallows	Very high
Flaxleaf fleabane Common sowthistle	M, e.g. glyphosate	Eastern and western Darling Downs	Fallows	Very high

Source: DAF Qld

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

In Central Queensland (CQ), the first case of herbicide resistance was confirmed in 2014 with a sweet summer grass population found to be resistant to glyphosate.

The first glyphosate-resistant liverseed grass was found on the Liverpool plains area of northern NSW, and has recently become more widespread (Table 13).

Table 13: *Weeds that may become resistant in central and southern Queensland.)*

Weed	Herbicide group	Future risk	Detrimental impact
Wild oats	**M,** e.g. glyphosate	No-till and minimum-till systems (southern Queensland only)	High
Barnyard grass	**C,** e.g. atrazine	Areas growing predominantly sorghum	High
Parthenium	**B,** e.g. Ally®	Areas growing predominantly winter crops	High
Other brassica weeds	**B,** e.g. Glean®, Ally®	Areas growing predominantly winter crops	Moderate

Source: DAF Qld

Other broadleaf and grass weeds are also at risk of developing resistance, depending on weed numbers and management practices used.

6.12.1 How does resistance start?

Resistance starts in a paddock in several ways. Some rare mutations can occur naturally in weeds already in the paddock, with the likelihood varying from 1 plant in 10,000 to 1 in a billion, depending on the weed and the herbicide used against it. A grower may also import weed seed with the herbicide-resistant gene in contaminated feed, seed or machinery. Resistance may also be introduced by natural seed spread by wind and water or by pollen, which may blow in from a contaminated paddock.

6.12.2 General principles to avoid resistance

Herbicides have a limited life before resistance develops, and that usable life is even shorter if they are used repeatedly and as the sole means of weed control, particularly in zero- and minimum-till systems. Resistance can develop within four to eight years for Group A and B herbicides, and after 15 years for Group L and M herbicides (see Table 14 and Figure 4). This can be avoided by:

- keeping weed numbers low
- changing herbicide groups
- using tillage
- rotating crops and agronomic practices [52]

Table 14: *Rules of thumb for the number of years of herbicide application before resistance evolves.*

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

Source: DAF Qld

MORE INFORMATION

Preventing herbicide resistance in specific weeds.

GRDC IWM Hub, Herbicide resistance

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

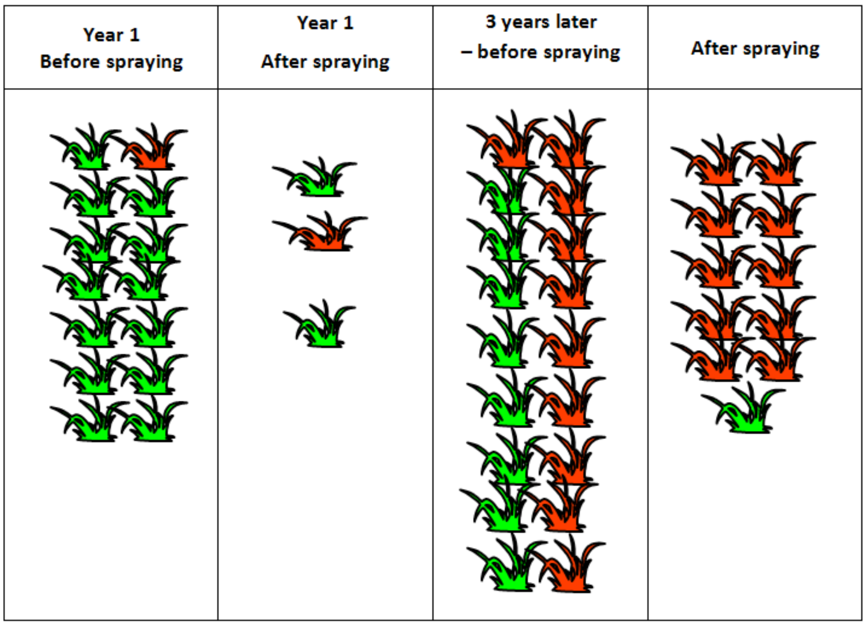


Figure 4: *How a weed population becomes resistant to herbicides.*

Source: GRDC

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

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

Specific guidelines for reducing the risk of glyphosate resistance are outlined in Table 15. Aim to include as many as possible of the risk-decreasing factors in your crop and weed management plans.

Table 15: *Balancing the risk of 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: DAF Qld

Glyphosate-resistant weeds in Australia

Glyphosate resistance was first documented for annual ryegrass in 1996 in Victoria. Since then glyphosate resistance has been confirmed in another 13 weed species. Resistance is known in eight grass species and six broadleaf species of which four are winter-growing weed species and 10 are non-seasonal or summer-growing weed species (Photo 12). [53]

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

Photo A. Storrie

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

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

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

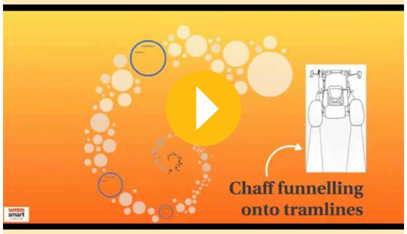
MORE INFORMATION

VIDEOS

WATCH: Strategic narrow windrow burning

WATCH: The art of narrow windrow burning

WATCH: Chaff funnelling onto tramlines



WATCH: Capture weed seeds at harvest: Bale Direct System

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

6.12.3 Ten-point plan to weed out herbicide resistance

WeedSmart has developed a 10-point plan that farmers can use to protect the longevity of chemicals and slow down the development of resistance. [54]

1. Act now to stop weed seedset

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

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

2. Capture weed seeds at harvest

Destroying or capturing weed seeds at harvest is the number one strategy for combating herbicide resistance and driving down the weed seedbank. There are several ways to do this:

- Tow a chaff cart behind the header.
- Use a Harrington Seed Destructor (Photo 13). [55]
- Create and burn narrow windrows.
- Produce hay where suitable.
- Funnel seed onto tramlines in controlled-traffic farming (CTF) systems.
- Use a green or brown manure crop to achieve 100% weed control and build soil nitrogen levels.

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

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.

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

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

3. Rotate crops and herbicide modes of action

Crop rotation is great for farming systems! Make sure weed management is part of the decision when planning crop rotation. Crop rotation offers many opportunities to use different weed control tactics, both herbicide and non-herbicide, against different weeds at different times. Rotating crops also gives farmers a range of intervention opportunities. For example, we can crop-top lupins and other pulses, swath canola, and delay sowing some crops (e.g. field peas).

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

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

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

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

- Before harvest, sample weed seeds and resistance test to determine effective herbicide options. One such service is provided by Plant Science Consulting.
- 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
- Visit WeedSmart for more information on herbicide-resistance survey results.

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

Perhaps the best use for herbicide-resistance tests is to use them to determine if a patch of surviving weeds are worse than what the grower has observed before. Take a GPS recording of the site location of potentially resistant weeds. These weeds may give 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

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

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

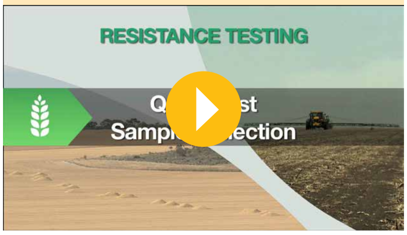
VIDEOS

WATCH: IWM: Weed seed destruction—beer can height

WATCH: Crop rotation with Colin McAlpine

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

WATCH: IWM: Resistance testing—Quick Test sample collection



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. Resistance to this herbicide is increasing rapidly, and in some areas it may fail completely. This can be due to too much reliance on one herbicide group, giving the weed opportunity to evolve resistance.

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

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

7. Carefully manage spray events

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

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

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

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

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

8. Plant clean seed into clean paddocks with clean borders

With herbicide resistance on the rise, planting clean seed into clean paddocks with clean borders has become a top priority. Controlling weeds is easiest before the crop is planted, so once that is done plant weed-free crop seed to prevent the introduction of new weeds and the spread of resistant ones.

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

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

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

VIDEOS

WATCH: IWM: Seed test—what's involved

WATCH: Don't cut the rate

WATCH: Don't automatically reach for glyphosate

WATCH: Manage spray drift

WATCH: Plant clean seed into clean paddocks with clean borders

9. Use the double-knock technique

The beauty of the double-knock technique is in combining two weed-control tactics with different modes of action, on a single flush of weeds. These two 'knocks' happen sequentially, with the second application being designed to control any survivors from the first.

One such strategy is the glyphosate–paraquat double-knock. These two herbicides use different MOAs to eliminate weeds and so make an effective team when paired. When using this combination ensure the paraquat rate is high. The best time to initiate this double-knock is after rainfall. New weeds will quickly begin to germinate and should be tackled at this small stage.

10. Employ crop competitiveness to combat weeds

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

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

6.12.4 If you think you have resistant weeds

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

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

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

If resistance is still suspected:

- Contact crop and food-science researchers in your state agricultural department for advice on sampling suspect plants for testing of resistance status..
- Ensure all suspect plants do not set seed.
- If resistance is confirmed, develop a management plan for future years to reduce the impact of resistance and likelihood of further spread. [56]

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

VIDEOS

WATCH: Best results with double knock tactic

WATCH: Double knock application: a grower's experience

WATCH: Spray application of herbicides: double knock

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

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 Phone (02) 6933 4001
- Charles Sturt University's Graham Centre weed research group
- Plant Science Consulting 22 Linley Avenue, Prospect SA 5082 email: info@plantscienceconsulting.com.au Phone: 0400 664 460

6.12.5 Monitoring weeds

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

- Keeping accurate records.
- Monitoring weed populations and recording results of the herbicide used.
- If herbicide resistance is suspected, preventing weed seedset.
- If a herbicide does not work, finding out why.
- Checking that weed survival is not due to spraying error.
- Conducting your own paddock tests to confirm herbicide failure and determine which herbicides remain effective.
- Obtaining a herbicide-resistance test on seed from suspected plants, testing for resistance to other herbicide MOA groups.
- Working hygienically so as not to introduce or spread resistant weeds in contaminated grain or hay.

Regular monitoring is required to assess the effectiveness of weed management and the expected situation following weed removal or suppression. Without monitoring, it is impossible to accurately assess the effectiveness of a management program or determine how it might be modified for better results. Effective weed management begins with monitoring weeds to assess current or potential threats to crop production, and to determine best methods and timing for control measures.

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

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

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

- Weed-seed germination and seedling emergence.
- Weed growth sufficient to affect crops if left unchecked.
- Weed density, height, and cover relative to crop height, cover, and stage of growth.
- The impact of the weed on crops, including harbouring pests, pathogens, or beneficial organisms; or modifying microclimate, air circulation, or soil conditions; as well as direct competition for light, nutrients, and moisture.
- Flowering, seedset, or vegetative reproduction in weeds.
- Efficacy of cultivation and other weed-management practices.

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

VIDEOS

WATCH: Learn to think outside the drum

WATCH: Crop competition: increasing wheat seeding rate

WATCH: Crop competition: row spacing

MORE INFORMATION

CropLife Australia

Australian Glyphosate Sustainability Working Group

Australian Herbicide Resistance Initiative

Cotton Info, Weed pack

Managing herbicide resistance in Northern NSW

Tips for monitoring

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

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