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GRDC GROWNOTES™

GRDC™ GRAINS RESEARCH & DEVELOPMENT CORPORATION

CEREAL RYE

SECTION 6

WEED CONTROL

CEREAL RYE: A WEED SUPPRESSOR | INTEGRATED WEED MANAGEMENT | WEEDS IN NORTHERN CROPPING SYSTEMS | NON-HERBICIDE WEED CONTROL IN THE NORTHERN REGION | HERBICIDES EXPLAINED | PRE-EMERGENT HERBICIDES | IN-CROP HERBICIDES: KNOCKDOWNS AND RESIDUALS | CONDITIONS FOR SPRAYING | HERBICIDE TOLERANCE RATINGS, NVT | POTENTIAL HERBICIDE DAMAGE EFFECT | HERBICIDE RESISTANCE | MONITORING WEEDS

Weed control

Key messages

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

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

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

Source: FarmPress

6.1 Cereal rye: a weed suppressor

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

Based on research from southern New South Wales (NSW), the competitiveness of crops against annual ryegrass (*Lolium rigidum*, at 300 plants per m^2) was in the order oats > cereal rye > triticale > oilseed rape > barley > wheat > field pea > lupin. [4]

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

2 Atlas of living Australia Ryecorn. http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2905471

3 MR Ryan, SB Mirsky, DA Mortensen, JR Teasdale, WS Curran (2011) Potential synergistic effects of cereal rye biomass and soybean planting density on weed suppression. Weed Science 59(2), 238–246, https://pubag.nal.usda.gov/pubag/downloadPDF.xhtml?id=49636&content=PDF

4 D Lemerle, B Verbeek, N Coombes (1995) Losses in grain yield of winter crops from *Lolium rigidum* competition depend on crop species, cultivar and season. *Weed Research* 35, 503–509, http://onlinelibrary.wiley.com/doi/10.1111/j.1365-3180.1995.tb01648.x/abstract

A study in southern NSW found that, in the first year, residues of cereal rye were no more effective, and in some cases less effective, against fleabane than residues of other cereals. However, all of the residues showed greater suppression of establishment of summer annual weeds than occurred in border areas without stubble. In the second year, cereal rye residue was equal best for suppression of both fleabane and witchgrass. Some crops were clearly more suppressive of in-crop weeds, including rye, likely due to reduced light at the soil surface and competitive canopy architectures. [5]

6.1.1 Allelopathic effects

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

The allelopathic effects of rye have been shown in field and laboratory studies to inhibit germination of some triazine-resistant weeds (barnyard grass, willow herb, horseweed). [6]

Rye has also been found to reduce total weed density an average of 78% when rye residue covered more than 90% of soil in a no-till study in Maryland, United States [7].

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

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

If weed suppression is an important objective when planting a rye–legume mixture, plant early enough for the legume to establish well. Otherwise, a pure stand is likely to work better. [8]

Remove cereal rye early to avoid problems from its allelopathic effect

It is usually the decaying green ‘ooze’ from cereal rye that can create problems for germinating grasses (such as maize), rather than the herbicide used to kill the rye (Photo 2). This toxic effect of the dying rye is what makes it a good cover crop choice for organic producers. A good rye stand reduces weed problems while the rye is growing. Producers then roll down the rye to terminate it (no herbicide is used) and plant their broadleaf crop. The decaying rye affects the germinating grasses, greatly reducing the grass-weed pressure while the crop is becoming established. The cover provided by the rye also reduces weed pressure by providing a mulch and by keeping the sun off the soil surface until the crop canopy forms.

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5 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/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2015/02/impact-of-crop-residues-on-summer-fallow-weeds

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

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

8 A Clark (Ed.) (2007) Cereal rye. In Managing cover crops profitably. 3rd ed. SARE Outreach Handbook Series Book 9. National Agricultural Laboratory, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition/Text-Version/Nonlegume-Cover-Crops/Cereal-Rye

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

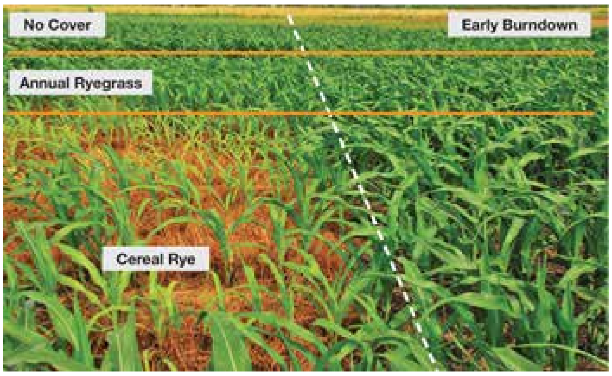

Photo 2: *Effects of a late kill of cereal rye on maize plants. The impact appears to be from a combination of the carbon penalty and allelopathy exerted by the cereal rye.*

Source: AgWeb

Some producers say that the germination problems are minimal if there is no rain to leach the 'ooze' down to the germinating seed during this establishment time. Others report that the germination problems can be reduced by planting the subsequent crop deeper so that not as much of the 'ooze' makes it down to the germinating seed. [9]

6.1.2 Managing volunteer rye

Volunteer rye may contaminate wheat, oats and barley. [10] Once the seed population of cereal rye is established in the soil, it can be a serious weed problem. Rye in wheat reduces yield by competition and reduces quality where its seed contaminates the harvested grain. Crop rotations where neither wheat nor barley is grown for two consecutive years greatly reduces the amount of cereal rye. [11]

Rye is not always a tall, robust plant; under stressful conditions, such as those found in tilled and chemical fallow fields, grassy field edges and roadsides, rye plants can still grow and produce seed despite attaining heights of less than 25 cm (Photo 3).

9 P Jasa (2012) Kill cereal rye early to avoid problems from its allelopathic effect. University of Nebraska, Cropwatch, 4 May 2012, http://cropwatch.unl.edu/kill-cereal-rye-early-avoid-problems-its-allelopathic-effect

10 Manure $ense (2009) Cereal rye: manure and livestock's new best friend. Michigan State University, February 2009

11 A Ogg, R Parker. (2000). Control of Volunteer crop plants. Washington State University. https://research.libraries.wsu.edu/xmlui/bitstream/handle/2376/5254/EB1523E.pdf?sequence=1

Photo 3: *Shorter stands of cereal rye can still produce seed heads.*

Source: NebGuide

Prevent seed source

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

To eliminate seed sources:

1. Plant clean seed. Volunteer rye seed is often found in cereal seed, especially wheat. Growers should buy only certified seed.
2. Remove any volunteer rye before it produces seed. Rye plants as short as 20 cm can produce viable seed.
3. Thoroughly clean harvesters before moving between paddocks.
4. Make sure that all rye is kept out of paddock edges, roadside ditches and other areas that may contaminate paddocks. [12]

Grazing volunteer weeds

Plants vary in their palatability and that under the 'right' stocking rate, animals will selectively graze the more palatable plants. This knowledge is useful when previously grown crops volunteer in the sown crop and herbicides are not available or their use would damage the crop.

For best results;

- introduce sheep early, before crop canopy closes
- use older sheep
- use low stocking rates
- spray weeds along fence line to concentrate sheep in crop
- remove sheep before they do much damage to crop
- remove sheep before flowering.

Observe grazing withholding periods if any chemicals are used in crop. [13]

Cultural practices

Growers can improve wheat's competitiveness with volunteer rye by using cultural practices that stimulate rapid emergence and vigorous seedling growth. For example, deep-banding N fertiliser near wheat seeds at planting, planting larger sized wheat seeds, increasing wheat seeding rates, reducing wheat-row spacing, and planting taller wheat cultivars that tiller profusely are all cultural practices that have been reported to improve wheat's competitiveness with weeds. [14]

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12 D Lyon, R Klein. (2007). Rye control in winter wheat. NebGuide. http://weedscience.unl.edu/extensionPublications/nebguides/g1483.pdf

13 Grain Legume Handbook (2008). Chapter 5: Weed control. GRDC. https://grdc.com.au/resources-and-publications/all-publications/publications/2008/03/2008-grains-legume-handbook

14 S Miller, C Alford, W Stump. (). Feral Rye – a serious threat to high quality wheat. University of Wyoming. http://www.wyomingextension.org/agpubs/pubs/B1157.pdf

These practices exert minimal impact on weeds when used alone, but combining several practices together greatly enhances wheat competitiveness. For example, applying N fertiliser earlier in a fallow season rather than just before planting slightly favours wheat growth over volunteer rye. Mowing can also be effective in controlling volunteer rye because of its tall growth habit and slow development. [15]

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

Chemical control

Grass control herbicides are now available which will control most grassy weeds in pulses. Volunteer cereals can also be controlled with some of these herbicides. Simazine alone and in mixtures with trifluralin in pulses can be used to control some other grasses that are not readily controlled by the specific grass herbicides. [16]

Post-emergence, non-selective herbicides such as glyphosate or paraquat can control volunteer rye and other winter annual grasses found in fallow fields. Glyphosate and paraquat do not provide residual weed control, so any volunteer rye plants that emerge after treatment will not be controlled. When coming in contact with soil, both herbicides are inactivated; therefore, all plants should be emerged prior to application. The effectiveness of both herbicides on volunteer rye decreases as plant size and maturity increase. Glyphosate is labelled for volunteer rye control in wheat as a wiper application. This technique requires at least a 25-cm height differential between the wheat and volunteer rye. Care must be taken to prevent any herbicide from contacting the wheat. Any herbicide that drops or otherwise contacts wheat will result in death. [17]

Selective chemical control of cereal rye may only be partially effective. [18]

Check the AVPMA website for up to date chemical control options.

6.2 Integrated weed management

The Grains Research and Development Corporation (GRDC) supports IWM. Download the Integrated Weed Management Manual.

Integrated weed management is a system for managing weeds over the long term, particularly the management and minimisation of herbicide resistance. There is a need to combine herbicide and non-herbicide methods into an integrated control program. Given that there are additional costs associated with implementing IWM, the main issues for growers are whether it is cost-effective to adopt the system and whether the benefits are likely to be long-term or short-term in nature.

The manual looks at these issues and breaks it down into seven clear sections, assisting the reader to make the development of an IWM plan a simple process.

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

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

1. Review past actions and history
2. Assess current weed status

15 R Anderson. (2004). Control strategies for jointed goatgrass, volunteer rye and downy brome. Central great plains research station. https://www.webharvest.gov/peth04/20041016034012/http://www.akron.ars.usda.gov/fs_control.html

16 Grain Legume Handbook (2008). Chapter 5: Weed control. GRDC. https://grdc.com.au/resources-and-publications/all-publications/publications/2008/03/2008-grains-legume-handbook

17 S Miller, C Alford, W Stump (2004) Feral rye: a serious threat to high quality wheat. University of Wyoming, http://www.wyoextension.org/agpubs/pubs/B1157.pdf

18 A Ogg, R Parker. (2000). Control of Volunteer crop plants. Washington State University. https://research.libraries.wsu.edu/xmlui/bitstream/handle/2376/5254/EB1523E.pdf?sequence=1

3. Identify weed management opportunities
4. Match opportunities and weeds with suitably effective management tactics
5. Combine ideas into a management plan. Use of a rotational plan can assist.

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

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

IWM tactics:

- Reduce weed seed numbers in the soil
- Control small weeds
- Stop weed seedset
- Hygiene—prevent weed seed introduction
- Agronomic practices and crop competition

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

Several agronomic practices can improve crop environment and growth, along with the crop's ability to reduce weed competition. These include crop choice and sequence, improving crop competition, planting herbicide-tolerant crops, improving pasture competition, and using fallow phases and controlled traffic or tramlining. [19]

6.2.1 Cover cropping for weed management

The critical period for weed suppression by the cover crop is typically during the first 30 days of cover crop growth. A cover crop's ability to suppress weeds is generally correlated with its early season biomass production rather than its biomass at maturity. Cover crops such as cereal rye maximise light interception with a dense canopy early in the season are the best at suppressing weed growth and weeds seed production (Photo 4). [20]

Photo 4: *Effect of seeding rate on weed suppression of a 90% legume and 10% cereal rye mixed cover crop. The higher seeding rate (left) was more effective in suppressing weeds than the lower seeding rate (right) which saw the emergence of weeds.* [21]

Research in NSW examined the ability of various grain crops and their residues, including cereal rye, to suppress weeds until subsequent planting the following year.

19 S Peltzer, A Douglas (2016) Crop weeds: integrated weed management (IWM). DAFWA, https://www.agric.wa.gov.au/grains-research-development/crop-weeds-integrated-weed-management-iwm

20 R Smith, RL Bugg, M Gaskell, O Daugovish, M Van Horn, (Eds.) (2011) Cover cropping for vegetable production: A Grower's Handbook (Vol. 3517). UCANR Publications.

21 SR Smith, RL Bugg, M Gaskell, O Daugovish, M Van Horn (Eds) (2011) Cover cropping for vegetable production: A Grower's Handbook (Vol. 3517). UCANR Publications.

Experiments were performed over three years in low-input grain production systems with moderate winter rainfall (<550 mm) without irrigation. Crops generally proved competitive with weeds during their establishment and growth. In addition, remaining crop residues were suppressive to summer annual weed establishment compared with borders without stubble. Some crops were clearly more suppressive of in-crop weeds, including rye, grazing and cereal barley, grazing and cereal wheat, and grazing and grain canola. In the third year of the study, cereal rye, oats and canola showed the greatest total weed suppression at 224 days after planting. [22]

Suppression of the grass weed annual ryegrass by rye, wheat and triticale was compared in field trials at Wagga Wagga in 1993. Cereal rye and triticale were more competitive than wheat, with a biomass of annual ryegrass at maturity of 70 g/m^2 with triticale compared with 170 g/m^2 with wheat. Early seedling vigour, superior height and broad leaves appeared to influence the greater competitive ability of the triticale and cereal rye. [23]

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 grains 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 are causing major cropping issues are:

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

Annual ryegrass (*Lolium rigidum*) is also becoming and increasing threat to the Northern cropping region.

22 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/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2015/02/impact-of-crop-residues-on-summer-fallow-weeds

23 D Lemerle, K Cooper (1996) Comparative weed suppression by triticale, cereal rye and wheat. Triticale: Today and Tomorrow, Vol. 5. Developments in Plant Breeding, 749–750.

6.3.1 Awnless barnyard grass

Photo 5: *Large glyphosate-resistant awnless barnyard grass.*

Photo: T Cook, Source: Agronomo

Awnless barnyard grass (Photo 5) has been a key summer grass problem for many years. It is a difficult weed to manage for at least three main reasons:

1. It has multiple emergence flushes (cohorts) each season.
2. It is easily moisture-stressed, leading to inconsistent knockdown control.
3. Glyphosate-resistant populations are increasingly being found.

Key points:

- Glyphosate resistance is widespread. Tactics against this weed must change from glyphosate alone.
- Utilise residual chemistry wherever possible and aim to control 'escapes' 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 management of ABYG in-crop and aim for strong crop competition.
- ABYG is a potential candidate for harvest weed-seed control where it germinates in spring in winter crops. [24]

Resistance levels

Prior to summer 2011–12, there were 21 cases of glyphosate-resistant ABYG. Collaborative surveys were conducted by NSW Department of Primary Industries (DPI), Queensland Department of Agriculture and Fisheries (QDAF) and Northern Grain Alliance (NGA) in summer 2011–12 with a targeted follow-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. Total application volume was 100 L/ha.

24 T Somes (2016) Can harvest weed-seed control work in the north. GRDC Ground Cover Issue 124, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-124-SeptemberOctober-2016/Can-harvest-weedseed-control-work-in-the-north

The main finding from this survey work 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.

Growers can no longer rely on glyphosate alone for ABYG control.

Residual herbicides (fallow and in-crop)

A range of active ingredients providing useful management of ABYG is registered for use in summer crops, e.g. metolachlor (products such as Dual Gold®) and atrazine, or in fallow, e.g. imazapic (products such as Flame®). The new fallow registration of isoxaflutole (Balance®) can provide useful suppression of ABYG but has stronger activity against other problem weed species. 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 chemistry being employed. Use of residuals together with camera spray technology (for escapes) can be a very effective strategy in fallow.

Double-knock control

This approach uses two different tactics applied sequentially. In reduced tillage situations, it is frequently glyphosate first followed by a paraquat-based spray as the second application or 'knock'. Trials have shown that glyphosate followed by paraquat gives 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. Even on glyphosate-resistant ABYG, a double-knock of glyphosate followed by paraquat is an effective tool. In the same situations, there has been little benefit from a Group A followed by paraquat application. Note that Group A herbicides appear more sensitive to ABYG moisture stress. Application on larger, mature weeds can result in very poor efficacy.

Timing of the paraquat application for ABYG control has generally proven flexible. The most consistent control is obtained from a delay of ~3–5 days, when lower rates of paraquat can also be used. Longer delays may be warranted when ABYG is still emerging at the first application timing; shorter intervals are generally required when weed size is larger or moisture stress conditions are 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. [25]

Double-knock is more expensive than a single herbicide application and it may not need to be applied every year. For more information on the costing of double-knock treatment for various weeds, see: Costs of key integrated weed management tactics in the northern region. [26]

6.3.2 Flaxleaf fleabane

For more than a decade flaxleaf fleabane *(Conyza bonariensis*) has been the major weed-management issue in the Northern cropping region, particularly in reduced tillage systems (Photo 6). Fleabane is also an issue in southern NSW.

25 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

26 F Scott, T Cook (2016) Costs of key integrated weed management tactics in the northern region. Primefact. NSW Department of Primary Industries, https://www.dpi.nsw.gov.au/biosecurity/weeds/weed-control/herbicides/costs-iwm-tactics-northern

Photo 6: *Flaxleaf fleabane is common through southern Queensland and northern NSW.*

Source: BCC

Fleabane is a wind-borne, surface-germinating weed that thrives in situations of low competition. Germination flushes typically occur in autumn and spring when surface-soil moisture levels stay high for a few days. However, emergence can occur at almost all times of the year. An important issue with fleabane is that knockdown control of large plants in the summer fallow is variable and can be expensive due to reduced control rates.

Key points:

- Utilise residual chemistry wherever possible and aim to control 'escapes' with camera-spray technology.
- This weed thrives in situations of low competition; avoid wide row cropping unless effective residual herbicides are included.
- 2,4-D is a crucial tool for consistent double-knock control.
- Successful growers have increased their focus on fleabane management in winter (crop or fallow) to avoid expensive and variable salvage control in the summer.

Resistance levels

Glyphosate resistance has been confirmed in fleabane. There is great variability in the response of fleabane to glyphosate, with many samples from non-cropping areas still well controlled by glyphosate, whereas fleabane from reduced tillage cropping situations shows increased levels of resistance. The most recent survey has 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 (fallow and in-crop)

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

Knockdown herbicides (fallow and in-crop)

Group I herbicides have been the major products for fallow management of fleabane, with 2,4-D amine the most consistent herbicide evaluated. Despite glyphosate alone generally giving 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 then 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 (MoA). 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 of six leaves. Currently, the only in-crop knockdown registration is for Amicide® Advance at 1.4 L/ha in either wheat or barley.

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.

Timing of the second application in fleabane is generally aimed at ~7–14 days after the first application. However, the interval to the second knock appears quite flexible. Increased efficacy is obtained when fleabane is actively growing or if 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 under moisture-stressed conditions. The high cost of fallow double-knock approaches and inconsistency in control level of large, mature plants are good reasons to focus on proactive fleabane management at other growth stages. [27]

VIDEOS

WATCH: GCTV4: Flaxleaf fleabane

6.3.3 Feathertop Rhodes grass

Feathertop Rhodes grass has emerged as an important weed-management issue in southern Queensland and NSW since about 2008 (Photo 7). FTR is another small-seeded weed species that germinates on, or close to, the soil surface. It has rapid early growth rates and can become moisture-stressed quickly. FTR is well established in central Queensland, and is now more common further south, and has been observed in southern NSW. Patches should be aggressively treated to avoid whole-of-paddock blow-outs.

27 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

Photo 7: *Seed heads of feathertop Rhodes grass.*

Source: BCC

Key points:

- Glyphosate alone or glyphosate followed by paraquat has generally poor efficacy.
- Utilise residual chemistry wherever possible and aim to control 'escapes' with camera spray technology.
- A double-knock of Verdict™ (haloxyfop) followed by paraquat can be used in Queensland prior to planting mungbeans where large spring flushes of FTR occur.
- Treat patches aggressively, even with cultivation, to avoid paddock blow-outs.
- FTR is a potential candidate for harvest weed-seed control where it germinates in spring in winter crops. [28]

Residual herbicides (fallow and in-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 in-crop situations. The only product currently registered for FTR control is Balance® (isoxaflutole) at 100 g/ha for fallow use.

Double-knock control

A double-knock of glyphosate followed by paraquat is an effective strategy on ABYG; however, the same approach 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 have a high risk of resistance selection, again requiring follow-up with paraquat.
- Many Group A herbicides have plant-back restrictions to cereal crops.

28 T Somes (2016) Can harvest weed-seed control work in the north. GRDC Ground Cover Issue 124, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-124-SeptemberOctober-2016/Can-harvest-weedseed-control-work-in-the-north

- Group A herbicides generally have a narrower range of weed growth stages for successful use than herbicides such as glyphosate; i.e. Group A herbicides will generally give unsatisfactory results on flowering and/or moisture-stressed FTR.
- Not all Group A herbicides are effective on FTR.

A permit (PER12941, for use of Verdict™ 520) has been issued for Queensland only for the control of FTR in summer fallow situations prior to planting mungbeans, see 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

While FTR has been a grass-weed threat from Queensland and moving south, windmill grass is more of a problem in central NSW and is spreading north. Windmill grass is a perennial, native species found throughout northern NSW and southern Queensland (Photo 8). The main cropping threat appears to be from the selection of glyphosate-resistant populations, with control of the tussock stage providing most management challenges.

Photo 8: *Windmill grass plant and seed head.*

Source: Native seeds

Key points:

- Glyphosate alone or glyphosate followed by paraquat has generally 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.

Resistance levels

Glyphosate resistance has been confirmed in windmill grass with three 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 west NSW, two were from fallow paddock situations.

Residual herbicides (fallow and in-crop)

Preliminary trials have shown a range of residual herbicides with useful levels of efficacy against windmill grass. These herbicides have potential for both fallow and in-crop situations. Currently, no products are registered for residual control of windmill grass.

Double-knock control

Similar to FTR, 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.

For information on a permit for NSW only for the control of windmill grass in summer fallow situations, visit APVMA.

Timing of the second application for windmill grass 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 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 initial application. [29]

6.3.5 Annual ryegrass

Annual ryegrass is one of the most serious and costly weeds of cropping systems in southern Australia, including southern NSW.

Annual ryegrass is a problem for a number of reasons:

- It produces an extremely high number of seeds per plant
- It is highly competitive
- Is a host for the bacteria *Clavibacter* spp. that cause annual ryegrass toxicity (ARGT)
- It can be infected by ergot fungus
- Many populations have developed resistance to both selective and non-selective herbicides

Annual ryegrass has become a major constraint to productive and profitable cropping systems in southern NSW over recent years. This has been accelerated as a result of ineffective weed control; caused possibly by poor post emergent herbicide options, and therefore, development of herbicide resistance.

Cropping intensity has also played a role, as crop rotations have tightened and leaned more towards no-till farming systems, which rely heavily on herbicides for weed control.

The importance of pre-emergent herbicides has therefore increased, along with the necessity to undertake agronomic strategies to maximise pre-emergent herbicide effectiveness.

A trial at Barellan was established to evaluate a range of pre and post emergent herbicide options applied to control ryegrass in both a stubble retained and stubble burnt no-till system.

29 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

The trial highlighted the value of pre-emergent herbicides in no-till farming systems, especially in the presence of stubble. However, the fact that under high pressure situations, even the best pre-emergent herbicides do not provide 100% control, unfortunately allows seed set for the following season.

In this trial, full control was only achieved by applying a pre-emergent herbicide in conjunction with a post emergent herbicide that had no resistance. In this case Atlantis was the product of choice. Unfortunately, in a commercial situation the cost of this practice is often difficult to justify.

Effect of pre-emergent herbicides on ryegrass

All pre-emergent herbicides performed extremely well and provided excellent weed control over the nil control. In most cases greater than 98% control of ryegrass was achieved when the first counts were performed in June.

As the season progressed, the residual effect of some of the herbicides was reduced. This in turn reduced the average weed control across all pre-emergent herbicides to 95.5% of the nil control.

There was a difference in the level of ryegrass control between the pre-emergent herbicides.

All products were very hard to differentiate in their control of ryegrass in the inter row, however within the plant row measurable differences were able to be identified.

Sakura® and Sakura® mixtures provided the highest level of control, followed by Boxer Gold® and then Trifluralin and Trifluralin mixtures (Figure 9).

This is most likely the result of varying residual activity between products, and their ability to wash into and provide weed control within the plant row.

Photo 9: *The ryegrass observed in the untreated control (left) compared to Sakura (right). The control was sprayed with two litres of Roundup three weeks prior to this photo aiming to minimise seed set.*

Source: GRDC.

Effect of stubble on pre-emergent herbicides

The presence of stubble increased the weed control achieved with pre-emergent herbicides. This result was unexpected, but consistent across the trial.

The reasons for this are not definite, however would likely be due to the effect that stubble may have had on surface soil moisture, where retained stubble showed wetter surface soil moisture than where the stubble was burnt. This wetter surface soil moisture may have resulted in the pre-emergent herbicides being active for a longer period of time and also more consistently during early crop growth when the ryegrass was germinating. Stubble is also known to reduce weed establishment, and this may have played a small role.

MORE INFORMATION

Managing annual ryegrass in cropping systems – pre and post emergent herbicide trial, Barrellan 2013

APVMA.

Interestingly, where the stubble was retained the crop was noticeably greener in October. This may be due to the nutrient value of the stubble becoming available at the end of the season.

Effect of post emergent herbicides on ryegrass

Post emergent herbicides were applied across the trial as a matrix at the perfect weed and crop growth stage and received favourable environmental conditions prior to and following application.

Unfortunately, this site highlighted the level of resistance to the post emergent herbicides, with only Atlantis providing a satisfactory level of control.

Boxer Gold (not registered for this purpose) only provided 30% control when used as a post emergent, and also caused slight crop damage.

The remaining herbicides provided little or no control, and would have been a waste of money in a commercial situation. [30]

6.4 Non-herbicide weed control in the Northern Region

Diversity in cropping systems and diversity in weeds in the Northern GRDC grains region calls for diversity in weed management solutions, including non-herbicide tactics.

Survey work in the region has identified more than 70 different weed species that impact on grain production and over 10% of these weed species have confirmed populations within Australia that are resistant to glyphosate and several other chemical MoAs (Table 1).

Table 1: *Confirmed herbicide resistance in weed populations 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: adapted from a table prepared by M Widderick, (QDAF), WeedSmart

A survey of common sowthistle determined populations as glyphosate-resistant if treated seedlings were surviving and reshooting 21 days after glyphosate application. In this test, glyphosate was applied at the upper label rate for small sized plants (up to five-leaf).

Although the majority of common sowthistle samples collected from central Queensland through NSW were still susceptible to label rates of glyphosate applied

30 B Haskins, A MacLennan. (2014). GRDC Update Papers: Managing annual ryegrass in cropping systems – pre and post emergent herbicide trial, Barrellan 2013. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Managing-annual-ryegrass-in-cropping-systems-pre-and-post-emergent-herbicide-trial-Barellan-2013

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 resistance genes being present in the population.

To keep these 'difficult-to-control' weeds in check will clearly require other, non-herbicide, tactics to reduce germination and weed seedset. QDAF researchers have been studying common weeds, particularly FTR, ABYG and common sowthistle, to find weaknesses in each weed's ecology to help identify non-chemical control tactics that could be part of an effective management system.

The QDAF weed research team are investigating non-chemical options, including various cover crops, crop competition, strategic tillage, strategic burning and harvest weed seed control options. Although growers are making good use of chemical strategies such as double-knock, residual herbicides, spot spraying and weed sensing technology to preserve herbicide efficacy, there is an urgent need to investigate non-chemical options that can be added to a weed management program to target resistant weeds in the Northern Region, as outlined in the WeedSmart 10 Point Plan [31].

6.4.1 Strategic tillage

Most growers are keen to preserve their no-till or minimum-tillage farming systems that have delivered significant benefits and so are very reluctant to re-introduce cultivation for weed-control purposes.

The QDAF weed research team has been investigating ways to use cultivation that will have maximum effect on driving down weed numbers while having least impact on the minimum-tillage farming system. The research explores the impact of different tillage operations in situations where the weed population has blown out and intensive patch- or paddock-scale management is required. The key is to understand weed ecology, particularly how seed in the soil seedbank, responds to different types of cultivation.

The team used small plots to determine the effect of burial at different depths on weed-seed persistence (long-term viability) and emergence. They also conducted experiments to determine the displacement of seed (glass beads were used to represent the seed) throughout the cultivated zone using four different types of machine—harrows, Gyral, offset discs and one-way discs—compared with the no-till control treatment.

Sowthistle emergence occurs primarily from seeds close to the soil surface, with up to 30% of viable seeds emerging over five months. Seed can emerge from a depth of up to 2 cm with approximately 4% emergence after six months. Seed buried below 5 cm is unable to emerge and can persist at depth.

Seed persistence (the percentage of viable seed after burial) in fleabane was most reduced when seed was buried to a depth of 2 cm and not disturbed for at least two years. Seed buried to a depth of 10 cm remained viable for over three years. FTR seed persisted for only 12 months regardless of being left on the surface or buried to 10 cm depth. ABYG, 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 and 2–5 cm zones whereas the offset discs and one-way discs achieving burial of about half the seed below 5 cm depth.

All species responded to increased tillage intensity with reduced germinations. The research suggests that infrequent but intense cultivation can be a useful weed-

31 WeedSmart (2016) Non-herbicide weed control in the Northern Region. WeedSmart, http://www.weedsmart.org.au/bulletin-board/non-herbicide-weed-control-in-the-northern-region/

management tool within an otherwise no-till farming system. Generally, once a deep cultivation has been done there should be no cultivation of that area or paddock for at least four years to avoid the risk of bringing seed back to the soil surface. [32]

6.4.2 Strategic burning

Feathertop Rhodes grass is known to colonise around mature plants and potentially spread to form distinct weedy patches. Killing the large plant at the centre of the colony is usually not possible with chemical treatments.

Strategic burning of early infestations of this weed can effectively reduce the biomass of the survivor plant and reduce the amount of viable seed present on the soil surface from 7500 seeds/m^2 to less than 500 seeds/m^2.

Growers have made effective use of a flame-thrower to burn large FTR plants during the fallow (Photo 10). [33]

Photo 10: *Strategic burning of early infestations of feathertop Rhodes grass in a fallow can reduce the biomass of the survivor plant and reduce the amount of viable seed present on the soil surface.*

Source: WeedSmart

6.4.3 Narrow windrow burning

There have been a few early adopters of narrow windrow burning (NBW) in southern NSW primarily due to the successes being achieved in Western Australia where NWB is commonly used to manage weed seeds at harvest. Although the data on weed reduction from WA was clear (99% control of annual ryegrass and wild radish seeds collected at harvest, AHRI 2007), there is still some hesitation regarding the practicalities of NWB in higher yielding systems of southern NSW.

One of the main advantages of NWB is that it is cheap to set up, requiring just a bit of thought and some welding skills. The hardest part is getting the chute design right.

Harvest height is a critical component of the NWB system. The rule of thumb is 'beer can' height, or approximately 15 cm, to ensure the majority of ryegrass or wild radish seed heads are captured.

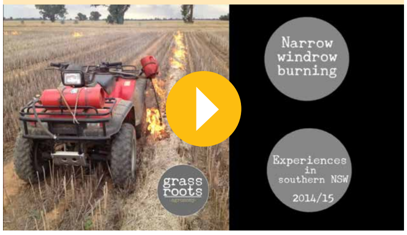
Burning efficiently and effectively is the hardest part of the NWB process. It is time consuming and the logistics need to be considered early on in the season. Choosing the right firelighter can make a big difference to the time involved, operator comfort and to the result achieved.

32 WeedSmart (2016) Non-herbicide weed control in the Northern Region. WeedSmart, http://www.weedsmart.org.au/bulletin-board/non-herbicide-weed-control-in-the-northern-region/

33 WeedSmart (2016) Non-herbicide weed control in the Northern Region. WeedSmart, http://www.weedsmart.org.au/bulletin-board/non-herbicide-weed-control-in-the-northern-region/

VIDEOS

WATCH: NWB Show and tell video 1: Paddock experiences in SNSW



MORE INFORMATION

Grassroots Agronomy: Narrow windrow burning in southern NSW

WeedSmart: Employ crop competitiveness to combat weeds

Key tips:

Lighting the windrow on the side facing downwind helps to produce a slower, hotter burn back over the top. Lighting on the upwind side can result in the fire burning too quickly across the top, leaving the middle unburnt. You can see this in the 'NWB experiences in southern NSW' video on YouTube.

For higher yielding cereal crops, burn in the morning when the straw is still damp (March/April).

If windrows get wet, wait at least two weeks before burning and make sure summer weeds have been controlled.

If possible, avoid stubble grazing in paddocks that have been narrow windrowed. Stock tend to kick the windrows around, increasing the risk of fire escape, but also creating tracks which can act as annoying firebreaks in the middle of a windrow.

With closer settlement in southern NSW, health risks associated with smoke inhalation need to be considered. [34]

6.4.4 Crop competition

Crop competition through narrower row spacing and/or increased planting density provides an effective offense against most weeds. For example, narrowing cereal rows from 50 to 25 cm spacing had the most marked effect on fleabane seedhead production with an additive advantage if the crop density is also increased from 50 to 100 plants/m^2 (Figure 1).

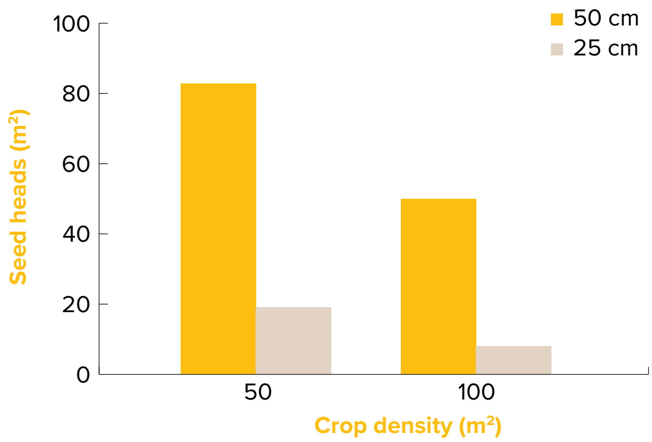


Figure 1: *Fleabane seedhead production at 25 and 50 cm row spacing and two planting densities of wheat.*

Source: M Widderick, QDAF, WeedSmart

Project work is continuing to investigate the options for increasing crop competitiveness in Northern crops (Photo 11). [35]

34 K Condon. (2015). Narrow windrow burning in southern NSW Grass roots agronomy.

35 WeedSmart (2016) Non-herbicide weed control in the Northern Region. WeedSmart, http://www.weedsmart.org.au/bulletin-board/non-herbicide-weed-control-in-the-northern-region/

Photo 11: *Crop competition through narrower row spacing and/or increased planting density provides an effective offensive against common sowthistle and flaxleaf fleabane.*

Source: WeedSmart

6.4.5 Cover crops

Summer fallow periods are heavily reliant on glyphosate for summer grass control. Preliminary research explored the potential role of cover crops in place of a chemical fallow for control of summer grass weeds. Summer cover crops such as cowpea, lablab and French millet have the potential to smother summer-growing weeds, particularly ABWG and FTR, and return large amounts of organic biomass to the soil.

French millet planted on its own, or in combination with the legumes, increased the amount of biomass produced. The higher the biomass production the greater the suppression of weeds.

Cover crops will tend to use fallow stored moisture, so the effect of two termination dates on subsequent crop yield and on weed numbers was investigated. Germination of FTR was found to be minimal after all of the cover crop treatments. The yield of the following wheat crop was comparable to the chemical fallow control and no yield differences were found between treatments. For ABYG, late termination of the cover crop reduced weed emergences before and after the following wheat crop, although there was a trend towards slightly reduced wheat yield compared with the early termination treatments, which tended to boost yield compared with the chemical fallow control.

The reduction in ABYG emergence and wheat yield are both likely due to reduced soil water following the late-terminated cover crops. Much more work is required to identify suitable cover crops and define the parameters for their use as a weed-management tactic in Australia. [36]

6.5 Herbicides explained

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

36 WeedSmart (2016) Non-herbicide weed control in the Northern Region. WeedSmart, http://www.weedsmart.org.au/bulletin-board/non-herbicide-weed-control-in-the-northern-region/

6.5.1 Residual and non-residual

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

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

6.5.2 Post-emergent and pre-emergent

These terms refer to the target and timing of herbicide application. Post-emergent refers to foliar application of the herbicide after the target weeds have emerged from the soil, whereas pre-emergent refers to application of the herbicide to the soil before the weeds have emerged. [37]

Herbicides are classified into a number of MoA groups. The group refers to the way a chemical works—their different chemical make-up and MoA (Table 2). [38]

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

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

List of commonly used products only. 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: NSW DPI

VIDEOS

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

6.6 Pre-emergent herbicides

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

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

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

Benefits and issues:

- The residual activity of pre-emergent herbicides controls the first few flushes of germinating weeds while the crop or pasture is too small to compete.
- Good planning is needed to use pre-emergent herbicides as an effective tactic. It is necessary to consider weed species and density, crop or pasture type, soil condition, and rotation of crop or pasture species.
- Soil activity and environmental conditions at the time of application play an important role in the availability, activity and persistence of pre-emergent herbicides.
- Positive and negative aspects of using pre-emergent herbicides should be considered in the planning phase. [39]

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

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

6.6.1 Understanding pre-emergent herbicides

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

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

Visit the APVMA website for up-to-date herbicide registrations.

6.6.2 Behaviour of pre-emergent herbicides in the soil

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

1. Solubility of the herbicide
2. How tightly the herbicide is bound to soil components
3. The rate of breakdown of the herbicide in the soil.

Characteristics of some common pre-emergent herbicides are given in Table 3. Water solubility of herbicides ranges from very low for trifluralin to very high for chlorsulfuron. Water solubility influences how far the herbicide will move in the soil profile in response to rainfall events. Herbicides with high solubility are at greater risk of being moved into the crop seed row by rainfall and potentially causing crop damage. If a herbicide moves too far through the soil profile, it risks moving out of the weed root-zone and failing to control the weed species at all. Herbicides with very low water solubility are unlikely to move far from where they are applied.

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

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

Herbicide	Water solubility (at 20°C and neutral pH)		*K*oc (in typical neutral soils)		Degradation half-life (days)
	(mg L)	Rating	(mL g)	Rating	
Trifluralin	0.22	Very low	15,800	Very high	181
Pendimethalin	0.33	Very low	17,800	Very high	90
Pyroxasulfone	3.9	Low	223	Medium	22
Triallate	4.1	Low	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

Source: GRDC

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

1. Soils with low organic matter are particularly prone to crop damage from pre-emergent herbicides (especially sandy soils) and rates should be reduced where necessary to lower the risk of crop damage.
2. The more water-soluble herbicides will move more readily through the soil profile and are better suited to post-sowing pre-emergent applications than the less water-soluble herbicides. They are also more likely to produce crop damage after heavy rain.
3. Pre-emergent herbicides need to be present at sufficient concentration at or below the weed seed (except for triallate which needs to be above the weed seed) to provide effective control. Keeping weed seeds on the soil surface will improve control by pre-emergent herbicides.
4. High crop-residue loads on the soil surface can inhibit pre-emergent herbicide action because they prevent the herbicide from contacting the seed. More water-soluble herbicides cope better with crop residue, but it is best to manage crop residue so that at least 50% of the soil surface is exposed at the time of application.
5. If the soil is dry on the surface but moist underneath there may be sufficient moisture to germinate the weed seeds but not enough to activate the herbicide. Poor weed control is likely under these circumstances. The more water-soluble herbicides are less adversely affected under these conditions.
6. Many pre-emergent herbicides can cause crop damage. Separation of the product from the crop seed is essential. In particular, care needs to be taken with disc seeding equipment in choice of product and maintaining an adequate seeding depth. [40]

Top tips for using pre-emergent herbicides

- Only use pre-emergent herbicides as part of an integrated weed-control plan including both chemical and non-chemical weed-control practices.
- Preparation starts at harvest. Minimise compaction and maximise trash spreading from the header.
- Minimise soil disturbance allowing weed seeds to remain on the soil surface.
- Leave stubble standing rather than laying it over.

40 C Preston (2014) Understanding pre-emergent cereal herbicides. GRDC Update Papers, 4 March 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Understanding-pre-emergent-cereal-herbicides

MORE INFORMATION

GRDC Update Paper: Understanding pre-emergent cereal herbicides

NSW DPI: Using pre-emergent herbicides in conservation farming systems

WeedSmart: Gearing up to use pre-emergent herbicides

GRDC Fact Sheet: Pre-emergent herbicides

GRDC Media Centre: How pre-emergent herbicides work

- Knife-points and press-wheels allow greatest crop safety. Avoid harrows.
- If using a disc seeder understand the mechanics of your machine and the limitations it may carry relative to a knife-point and press-wheel.
- Pay attention to detail in your sowing operation and ensure soil throw on the inter-row while maintaining a seed furrow free from herbicide.
- Ensure the seed furrow is closed to prevent herbicide washing onto the seed.
- Ensure even seed placement, typically 3–5 cm of loose soil on top of seed in cereals for best crop safety.
- Use incorporation by sowing (IBS) rather than post-plant pre-emergent (PSPE) for crop safety.
- Understand herbicide chemistry. Choose the right herbicide in the right paddock at the right rate. [41]

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

Post-sowing pre-emergent herbicide use is the application of pre-emergent herbicides after sowing (but before crop emergence) to the seedbed.

Absorption of PSPE herbicide occurs primarily through the roots, but there may also be some foliar absorption (e.g. 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 2–3 weeks of application. Assuming such conditions, best weed control is achieved from PSPE application because rainfall gives the best incorporation. Mechanical incorporation pre-sowing is less uniform, and so weed control may be less effective; however, with pre-sowing application and sowing with minimal disturbance, incorporation will essentially be by rainfall after application.

For pre-emergent herbicide controls in NSW, see Weed control in winter crops 2016 (Table 12, pp. 44–45).

6.6.4 Incorporation by sowing (IBS)

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

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

CASE STUDY

Crop safety and the use of pre-emergent residual herbicides

Two trials were conducted in 2013 evaluating the crop safety and efficacy of registered residual herbicides for the control of annual ryegrass in wheat and cereals. Most treatments were managed by the IBS approach, 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 'incorporate' the herbicide, plus it removes most of the herbicide-

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

treated soil from the planting furrow to improve crop safety. Consequently, however, IBS generally provides poor weed control in the zone immediately around the planting row. PSPE was also evaluated because it provides more uniform weed efficacy but requires herbicides or rates with improved crop safety together with reduced incorporation characteristics.

Key findings

Planting method:

- The use of a disc planter for IBS of residual herbicides resulted in significantly reduced wheat emergence for all four herbicides evaluated.
- The disc planter 'set-up' increased the risk of crop damage (Figure 2).
- The results reinforce the need to use only narrow-point tynes when using residual herbicides with IBS recommendations.

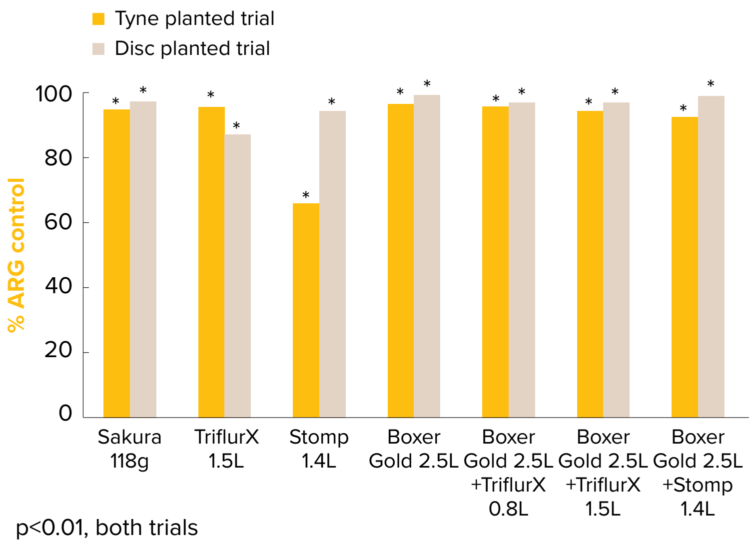


Figure 2: *Annual ryegrass (ARG) control based on counts 94 days after planting, as a percentage of the untreated control. All treatments applied in 70 L/ha total volume using AIXR110015 nozzles at 300 kPa. *Significant (P < 0.05) control compared with untreated within same trial.*

Source: GRDC

Herbicide efficacy:

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

Conclusions

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

1. Crop safety was significantly reduced when a disc planter was used for incorporation.
2. The disc set-up appears to have exaggerated crop safety issues by planting seed in an area with increased herbicide concentration.

3. Observation suggested that small differences in planting depth might have affected crop safety.

This work reinforces some of the difficulties growers and agronomists face with the use of residual herbicides. Crop safety and efficacy are influenced by a range of factors including planting equipment, planting depth, soil type, stubble load, and rainfall quantity and timing. A more thorough understanding of the impacts from these (and perhaps other) factors is needed to get the best from these important weed-management tools. [42]

6.7 In-crop herbicides: knockdowns and residuals

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

Benefits:

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

Issues:

- Careful consideration is needed when selecting the best post-emergent herbicide to use in any one situation.
- Application of post-emergent herbicides to stressed crops and weeds can result in reduced levels of weed control and increased crop damage.
- Crop competition is important for effective weed control using selective post-emergent herbicides.
- The technique used for application must be suited for the situation in order to optimise control.
- Always use the correct adjuvant to ensure effective weed control.
- Selective post-emergent herbicides applied early and used as a stand-alone tactic have little impact on the weed seedbank.
- Choose the most suitable formulation of herbicide for each situation.
- The effectiveness of post-emergent herbicides is influenced by a range of plant and environmental factors. [43]

For post-emergence herbicide controls for cereal rye in NSW, see Weed control in winter crops 2016 (Table 20, pp 64–68).

6.7.1 Key points for in-crop herbicide application

- Knowledge of a product's translocation and formulation type is important for selecting nozzles and application volumes.
- Evenness of deposit is important for poorly or slowly translocated products.

42 R Daniel, A Mitchell (2014) Pre-emergent herbicides; part of the solution but much still to learn. GRDC Update Papers, 5 March 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Pre-emergent-herbicides-part-of-the-solution-but-much-still-to-learn

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

- Crop growth stage, canopy size and stubble load should influence decisions about nozzle selection, application volume and sprayer operating parameters.
- Robust rates of products and appropriate water rates are often more important for achieving control than the nozzle type, but, correct nozzle type can widen the spray window, improve deposition and reduce drift risk.
- Travel speed and boom height can affect control and drift potential.
- Appropriate conditions for spraying are always important. [44]

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

In-crop post-emergent herbicides should be applied as an upper-end medium to lower-end coarse droplet spectrum depending on the particular herbicide being used. This must be combined with the relevant application volume to get enough droplets per square centimetre on the target to achieve good coverage. The nozzles must also be matched to your spray rig, pump and controller, and desired travel speed.

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

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

- Consider application timing—the younger the weeds the better. Frequent crop monitoring is critical.
- Consider the growth stage of the crop.
- Consider the crop variety being grown and applicable herbicide tolerances.
- Know which species were historically in the paddock and the resistance status of the paddock (if unsure, send plants away for a Weed Resistance Quick-Test.
- Do not spray a crop stressed by waterlogging, frost, high or low temperatures, drought or (for some chemicals) cloudy/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. [45]

MORE INFORMATION

GRDC Fact Sheet: In-crop herbicide use

6.8 Conditions for spraying

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

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

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

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

All grass herbicide labels emphasise the importance of spraying only when the weeds are actively growing under mild, favourable conditions (Photo 12). Any of the following stress conditions can significantly impair both uptake and

44 GRDC (2014) In-crop herbicide use. GRDC Fact Sheet July 2014, https://grdc.com.au/GRDC-FS-InCropHerbicideUse

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

translocation of the herbicide within the plant, likely resulting in incomplete kill or only suppression of weeds:

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

Photo 12: *Boom spray on crop.*

Source: DAFWA

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

6.8.1 Minimising spray drift

Before spraying

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

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

The Cotton Field Awareness Map is provided free of charge with the purpose of minimising off-target damage from downwind pesticide application, particularly during fallow spraying. Users can also access the map to check the location of the paddock(s) they may be planning to spray to assess the proximity of the nearest cotton crop.

During spraying

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

6.8.2 Types of drift

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

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

In 2006, the Australian Pesticides and Veterinary Medicines Authority (APVMA) restricted the use of highly volatile forms of 2,4-D ester. The changes are now seen with the substitution of lower volatile forms of 2,4-D and MCPA. Products with lower 'risk' ester formulations are commonly labelled with LVE (low volatile ester). These formulations of esters have a much lower tendency to volatilise, but caution should remain as they are still prone to droplet drift.

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

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

6.8.3 Factors affecting the risk of spray drift

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

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

Volatility

Many ester formulations are highly volatile compared with the non-volatile amine, sodium salt and acid formulations. Table 4 is a guide to the more common herbicide active ingredients that are marketed with more than one formulation.

Table 4: *Relative herbicide volatility.*

Form of active	Full name	Product example
NON-VOLATILE		
Amine salts		
MCPA dma	Dimethylamine salt	MCPA 500
2,4-D dma	Dimethylamine 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	Dimethylamine salt	Buttress®
Dicamba dma	Dimethylamine 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®

Form of active	Full name	Product example
Dicamba Na salt	Sodium salt	Cadence®
SOME VOLATILITY		
Ester		
MCPA ehe	Ethylhexyl ester	LVE MCPA
MCPA ioe	Isooctyl ester	LVE MCPA
Triclopyr butoxyl	Butoxyethyl ester	Garlon® 600
Picloram ioe	Isooctyl ester	Access®
2,4-D ehe	Ethylhexyl ester	2,4-D LVE 680
Fluroxypyr M ester	Meptyl ester	Starane® Advanced

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

Minimising drift

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

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

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

Table 5: *Nozzle selection guide for ground application. Volume median diameter (VMD): 50% of the droplets are less than the stated size and 50% greater. For flat-fan nozzle size, refer to manufacturers' selection charts as droplet size range will vary with recommended pressure; always use the lowest pressure stated to minimise the small droplets. (Adapted from P Hughes, DPI, Queensland)*

Distance downwind to susceptible crop	<1 km	1 to >30 km
Risk	High	Medium
Preferred droplet size (British Crop Protection Council) (to minimise risk)	Coarse to very coarse	Medium to coarse
Volume median diameter (µm)	310	210
Pressure (bars)	2.5	2.5
Flat-fan nozzle size	11,008	11,004
Recommended nozzles (examples only)	*Raindrop:* Whirljet® *Air induction:* Yamaho Turbodrop®, Hardi Injet®, AI Teejet®, Lurmark Drift-beta®	*Drift reduction:* DG TeeJet®, Turbo TeeJet®, Hardi® ISO LD 110, Lurmark® Lo-Drift

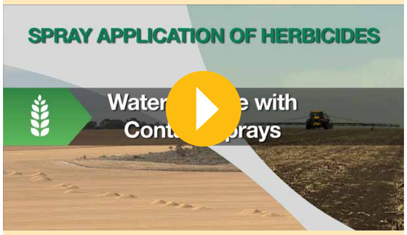
VIDEOS

WATCH: Nozzle Selection

WATCH: Travel Speed

WATCH: Spray deposition

WATCH: Water volume with contact sprays



WATCH: Application volume in stubble

Distance downwind to susceptible crop	<1 km	1 to >30 km
CAUTION	Can lead to poor coverage and control of grass weeds. Require higher spray volumes	Suitable for grass control at recommended pressures. Some fine droplets

Source: DPI NSW

Spray release height

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

Size of area treated

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

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

Capture surface

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

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

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

Weather conditions to avoid

Turbulence

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

Temperature

- Avoid spraying when temperatures exceed 28°C.

Humidity

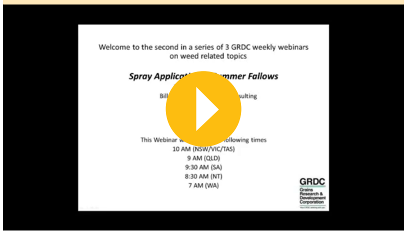
- Avoid spraying under low relative humidity conditions; i.e. when the difference between wet and dry bulbs exceeds 10°C.
- High humidity extends droplet life and can greatly increase the drift hazard under inversion conditions. This results from the increased life of droplets smaller than 100 microns.

Wind

- Avoid spraying under still conditions.

VIDEOS

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



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

Inversions

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

Do not spray under inversion conditions.

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

Smoke generators or smoky fires can be used to detect inversion conditions. Smoke will not continue to rise but will drift along at a constant height under the inversion 'blanket'. [46]

6.9 Herbicide tolerance ratings, NVT

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

The trials aim to provide grain growers and advisers with information on cultivar sensitivity to commonly used in-crop herbicides and tank mixes for a range of crop species including wheat, barley, triticale, oats, lupin, 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. [47]

In greenhouse trials in the US, cereal rye showed tolerance similar to oats for a range of residual herbicides (based on injury rating). Cereal rye had a higher potential for injury from the Group K herbicide S-metolachlor. [48]

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

To provide growers with clear information about the herbicide interactions of a variety for their region, four regionally based, herbicide tolerance screening projects have been established. The four projects have now been combined under a national program. [49]

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

47 NVT. Herbicide tolerance. GRDC, http://www.nvtonline.com.au/herbicide-tolerance/

48 B Hartzler, M Anderson. (2015). Effect of residual herbicides on cover crop establishment. IOWA State University. http://www.weeds.iastate.edu/mgmt/2015/CCherbicides.pdf

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

6.10 Potential herbicide damage effect

6.10.1 Avoiding crop damage from residual herbicides

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

What are the issues?

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

Growers rely on information provided on the labels about soil type and climate. Herbicide residues are often too small to be detected by chemical analysis, and if testing is possible, it is too expensive to be part of routine farming practice. Once the crop has emerged, diagnosis is difficult because the symptoms of residual herbicide damage can often be confused with, and/or make the crop vulnerable to, other stresses, such as nutrient deficiency or disease. [50]

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

Which herbicides are residual?

The herbicides listed in Table 6 all have some residual activity or planting restrictions.

Table 6: *Active constituent (and example proprietary product) by herbicide group (may not include all current herbicides).*

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: phenoxy carboxylic acids	2,4-Ds
Group I: benzoic acids	Dicamba
Group I: pyridine carboxylic acids	Clopyralid (Lontrel®)
Group K: chloroacetamides	Metolachlor
Group K: isoxazolines	Pyroxasulfone (Sakura®)

Source: AgVic.

50 Agriculture Victoria (2013) Avoiding crop damage from residual herbicides. Government of Victoria EDJTR,, 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

How to avoid damage from residual herbicides

Select a herbicide appropriate for the weed population. Consider what the re-cropping limitations may do to future rotation options.

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

If residues could be present, choose the least susceptible crops (refer to product labels). Optimise growing conditions to reduce the risk of compounding the problem with other stresses such as herbicide spray damage, disease and nutrient deficiency. These stresses make a crop more susceptible to herbicide residues. [51]

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

Photo: Dr Christopher Preston, Source: GRDC

MORE INFORMATION

NSW DPI: Herbicide residues in soil and water.

6.10.2 Plant-back intervals

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

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

Part of the management of herbicide resistance includes rotation of herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonylurea, triazines, etc.) may be an issue in some paddocks. Remember that plant-back periods begin after rainfall occurs. [52]

51 Agriculture Victoria (2013) Avoiding crop damage from residual herbicides. Government of Victoria EDJTR, 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

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

Table 7: *Residual persistence of common pre-emergent herbicides, noting residual persistence in broadacre trials and paddock situations.* [53]

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–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)	Med./high. 1 year residual in high pH soils. Has had observed, long-lasting (>3 months) activity on broadleaf weeds such as fleabane
Terbyne® (terbulthylazine)	6.5–139	High. Has had observed, long-lasting (>6 months) activity on broadleaf weeds such as fleabane and sowthistle
Triflur® X (trifluralin)	57–126	High. 6–8 months residual. Higher rates longer. Has had observed, long-lasting activity on grass weeds such as black/stink grass
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 sowthistle
Boxer Gold® (prosulfocarb)	12–49	Medium. Typically quicker to break down than trifluralin, but tends to reactivate after each rainfall event.
Sakura® (pyroxasulfone)	10–35	High. Typically quicker breakdown than trifluralin and Boxer Gold®; however, weed control persists longer than Boxer Gold®

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

Table 8: *Minimum re-cropping intervals and guidelines. NOTE: always read labels to confirm.*

Group and type	Product	pH(H2O) or product rate (mL/ha) as applicable	Minimum re-cropping interval (months after application), and conditions
B, sulfonylurea	Chlorsulfurons, e.g. Glean®, Siege®, Tackle®	<6.5	3 months
		6.6–7.5	3 months, minimum 700 mm
		7.6–8.5	18 months, minimum 700 mm
B, sulfonylurea	Triasulfuron, e.g. Logran®, Nugrain®	7.6–8.5	12 months, >250 mm grain, 300 mm hay
		>8.6	12 months, >250 mm grain, 300 mm hay
B, sulphonamide	Flumetsulam, e.g. Broadstrike®		0 months
B, sulfonylurea	Metsulfuron, e.g. Ally®, Associate®	5.6–8.5	1.5 months
		>8.5	Tolerance of crops grown through to maturity should be determined (small scale) previous season before sowing larger area
B, sulfonylurea	Metsulfuron + thifensulfuron, e.g. Harmony® M	7.8–8.5 Organic matter >1.7%	3 months
		>8.6 or organic matter <1.7%	Tolerance of crops grown through to maturity should be determined (small scale) previous season before sowing larger area
B, sulfonylurea	Sulfosulfuron, e.g. Monza®	<6.5	0 months
		6.5–8.5	10 months

Source: Pulse Australia

Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the sulfonylureas. On labels, this will be shown by plant-back periods, which are usually listed under a separate plant-back heading or under the 'Protection of crops etc.' heading in the 'General Instructions' section of the label. [54]

Conditions required for breakdown

Warm, moist soils are required to break down most herbicides through the processes of microbial activity. To be most active, soil microbes need good moisture and an optimum range of soil temperature of 18–30°C. Extreme temperatures above or below this range can adversely affect soil microbial activity and slow herbicide

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

MORE INFORMATION

Dow AgroSciences: Rotational crop plant-back intervals for northern Australia

breakdown. Very dry soil also reduces breakdown. In addition, when the soil profile is very dry, it requires a lot of rain to maintain topsoil moisture for the microbes to be active for any length of time.

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

6.11 Herbicide resistance

6.11.1 Herbicide resistance facts

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

Key messages

Resistance characteristics:

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

Action points:

- Assess your level of risk with the online glyphosate resistance toolkit.
- Aim for maximum effectiveness in control tactics, because resistance is unlikely to develop in paddocks with low weed numbers.
- Do not rely on the same MoA group.
- Monitor your weed control regularly.
- Stop the seedset of survivors. [55]

Herbicide resistance has become far more widespread, reducing the effectiveness of a wide range of herbicide MoAs (Photo 14). Rapid expansion of herbicide resistance and the lack of new MoAs require 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 prolonging the effective life of remaining herbicides, as well as for new products and MoAs that have not yet been released or indeed

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

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

Photo A Storrie, Source: GRDC

Herbicide resistance is an increasing threat across Australia's Northern grain region for both growers and agronomists. Already 14 weeds have been confirmed as herbicide resistant in various parts of this region, and more have been identified at risk of developing resistance, particularly to glyphosate.

In northern NSW, 14 weeds are confirmed resistant to herbicides of Group A, B, C, I, M or Z (see Table 9). As well, ABYG, liverseed grass, common sowthistle and wild oat are at risk of developing resistance to Group M (glyphosate) herbicides (see Table 10). Glyphosate-resistant annual ryegrass has been identified within ~80 farms in the Liverpool Plains area of northern NSW. [56]

56 A Storrie, T Cook, P Moylan, A Maguire, S Walker, M Widderick. 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 9: *List of confirmed resistant weeds in northern NSW.* [57]

Weed	Herbicide group and product/ chemical (examples only)	Areas with resistance in NSW	Future risk	Detrimental impact
Wild oats	A. Topik® and 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 tilled 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 widespread in Liverpool Plains. Group A and B resistance in central west NSW	Areas with predominantly summer fallows. Winter cropping areas	High High
Fleabane	M. Glyphosate	Spread uniformly across the region	Cotton crops and no-till or minimum tilled 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 tilled systems	Moderate
SowthistleA	M. Glyphosate	Liverpool Plains	Winter cereal dominated areas with minimum tillage	High

57 A Storrie, T Cook, P Moylan, A Maguire, S Walker, M Widderick. 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 10: *List of potential new resistant weeds in northern NSW.* [58]

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 tilled systems	Very high 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 tilled systems	Very high Very high
Other fallow grass weeds	M. Glyphosate	No-till or minimum tilled systems	High

In southern Queensland, seven weeds are confirmed resistant to Group A, B or C herbicides (Table 11). A further four weeds are confirmed resistant to glyphosate (e.g. Roundup®).

Table 11: *List of confirmed resistant weeds in southern Queensland.*

Weed	Herbicide group	Extent of resistance	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

58 A Storrie T Cook, P Moylan, A Maguire, S Walker, M Widderick. 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

Weed	Herbicide group	Extent of resistance	Future risk	Detrimental impact
Barnyard grass	M (e.g. glyphosate)	Western Downs	Summer fallows	Very High
• Flaxleaf fleabane • Common sowthistle	M (e.g. glyphosate)	Eastern and Western Downs	Fallows	Very High

Source: QDAF

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

Liverseed grass and wild oats are also at risk of developing resistance to Group M (glyphosate) herbicides (see Table 12). While no populations of glyphosate-resistant liverseed grass have been identified in Queensland, four paddocks in the Liverpool Plains area of northern NSW have liverseed grass that is resistant to glyphosate treatment.

Table 12: *List of potential new resistant weeds in central and southern Queensland.*

Weed	Herbicide group	Future risk	Detrimental impact
Wild oats	**M** (e.g. glyphosate)	No-till and minimum-till systems (S Qld)	**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: QDAF

Other broadleaf and grass weeds are also at risk of developing resistance, depending on weed numbers and management practices used. Read more about preventing herbicide resistance in specific weeds.

MORE INFORMATION

GRDC IWM Hub—Herbicide resistance.

How does resistance start?

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

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

6.11.2 General principles to avoid resistance

Herbicides have a limited life before resistance develops, if they are used repeatedly and exclusively as the sole means of weed control, particularly in zero and minimum tilled systems. Resistance can develop within four–eight years for Group A and B herbicides and after 15 years for Group L and M herbicides (see Table 13 and Figure 3). This can be avoided by:

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

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

Table 13: *Rules-of-thumb for the number of years of herbicide application before resistance evolves for each Mode of Action group.*

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

Source: Chris Preston, University of Adelaide, QDAF

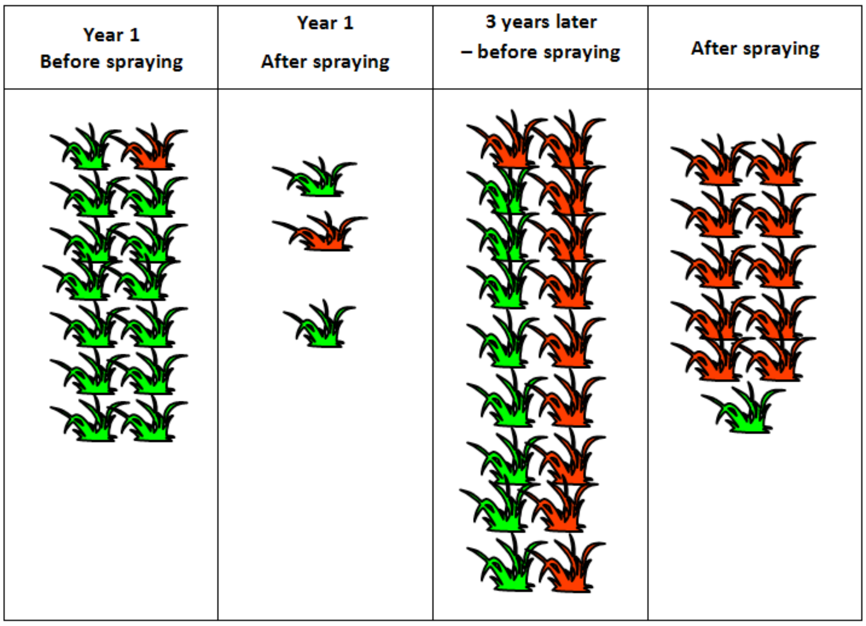


Figure 3: *How a weed population becomes resistant to herbicides.*

Source: GRDC

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

- Ensure survivors do not set seed and replenish the soil seedbank.
- Keep accurate paddock records of herbicide application and levels of control. Monitor weeds closely for low levels of resistance, especially in paddocks with a history of repeated use of the same herbicide group.
- Rotate between the different herbicide groups, and/or tank mix with an effective herbicide from another MoA group. It is important to use effective 'stand-alone' rates for both herbicides in the mix.
- Aim for maximum effectiveness to keep weed numbers low. The primary aim of weed control is to minimise their impact on productivity, and resistance is much less likely to develop in paddocks with fewer weeds than in heavily infested paddocks.
- Use a wide range of cultural weed-control tools in your weed management plan. Sowing different crops and cultivars provides opportunities to use different weed management options on key weeds. Tillage is useful when it targets a major weed flush and minimises soil inversion, as buried weed seed generally persists

longer than on the soil surface. Competitive crops will reduce seed production on weed survivors.

- Avoid introduction or spread of weeds by contaminated seed, grain, hay or machinery. Also, manage weeds in surrounding non-crop areas to minimise risk of seed and pollen moving into adjacent paddocks.

Specific guidelines for reducing the risk of glyphosate resistance are outlined in Table 14. Aim to include as many as possible of the risk-decreasing factors in your crop and weed management plans.

Table 14: *Balancing the risk for weeds developing glyphosate resistance, devised by the national Glyphosate Sustainability Working Group with minor modifications for the Queensland cropping region.*

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

Source: QDAF

Glyphosate-resistant weeds in Australia

Glyphosate resistance was first documented for annual ryegrass in 1996 in Victoria. Since then, glyphosate resistance has been confirmed in 11 other weed species. Resistance is known in eight grass species and four broadleaf species. There are four winter-growing weed species and eight summer-growing weed species. The latter have been selected mainly in chemical fallows and on roadsides (Figure 18).

Figure 4: *Winter fallow in northern NSW showing an early glyphosate-resistant sowthistle (Sonchus spp.) infestation.*

Photo: A Storrie, Source: GSWG

MORE INFORMATION

[Australian glyphosate resistance register.](http://)

[PDF: Strategic risk management FactSheet](http://)

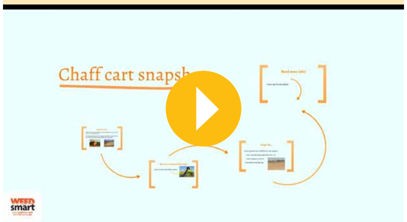
[PDF: Farm business management FactSheet](http://)

[Website: RIM model](http://)

VIDEOS

WATCH: Act now: Plan your weed management program

WATCH: Chaff carts 101



WATCH: Capture weed seeds at harvest: Harrington seed destructor

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

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

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

Farming practices under the vines in vineyards across Australia are heavily dependent on glyphosate for weed control. Therefore, it is highly likely that unconfirmed populations of glyphosate-resistant annual ryegrass are present in this system.

These unconfirmed glyphosate-resistant populations are not recorded on the register of glyphosate-resistant populations in Australia. [59]

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

6.11.3 10-point plan to weed out herbicide resistance

1. Act now to stop weed seedset

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

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

A couple of areas to consider include:

- understanding the biology of your weeds
- being consistent—every successful WeedSmart practice can reduce the weed seed bank over time
- being strategic and committed—herbicide resistance management is not a one-year decision
- being proactive—you may have to sacrifice yield in the short term to manage resistance.

2. Capture weed seeds at harvest

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

- Tow a chaff cart behind the header.
- Check out the new Harrington Seed Destructor (HSD) (Photo 15).
- Create and burn narrow windrows.
- Produce hay where suitable.
- Funnel seed onto tramlines in controlled traffic farming (CTF) systems.

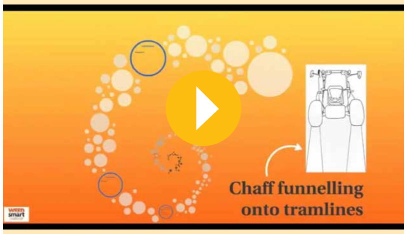
59 C Preston (2016) The Australian Glyphosate Sustainability Working Group. http://www.glyphosateresistance.org.au/

VIDEOS

WATCH: Strategic narrow windrow burning

WATCH: The art of narrow windrow burning

WATCH: Chaff funneling onto tramlines



WATCH: Capture weed seeds at harvest: Bale Direct System

- Use a green or brown manure crop to achieve 100% weed control and build soil N levels.

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

Photo 15: *Harrington weed seed destructor at work in the paddock.*

Source: GRDC

For information on harvest weed seed control and its application for the Northern grains region, see Section 12: Harvest.

3. Rotate crops and herbicide MoAs

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

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

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

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

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

Northern growers can rotate between summer and winter crops to change the weed spectrum.

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

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

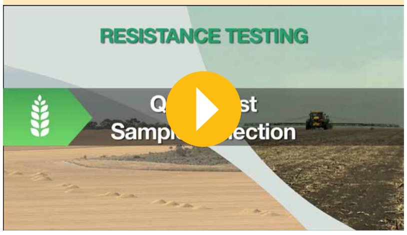
VIDEOS

WATCH: IWM: Weed seed vdestruction—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



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

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

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

Perhaps the best use for herbicide resistance tests is in a game-changing situation such as the discovery of a rare resistance gene (e.g. glyphosate resistance) or determining whether a patch of surviving weeds is any worse than the grower had observed before. This bad patch of weeds gives insight into the future resistance 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 receiving below-rate Sakura® evolved resistance not only to Sakura® but to Boxer Gold® and Avadex® too.

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

- Use best management practice in spray application.
- Consider selective weed sprayers such as Weedseeker® or Weedit.

6. Do not automatically reach for glyphosate

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

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

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

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

7. Carefully manage spray events

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

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

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

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

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

8. Plant clean seed into clean paddocks with clean borders

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

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

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

Lastly, roadsides and fence lines are often a source of weed infestations. Weeds here set enormous amounts of seed because they have little competition, so it is 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.

9. Use the double-knock technique

What is better than an attack on weeds? A second one. Come at them with a different strategy and any survivors left over do not stand a chance. That is the beauty of the double-knock.

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

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

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

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

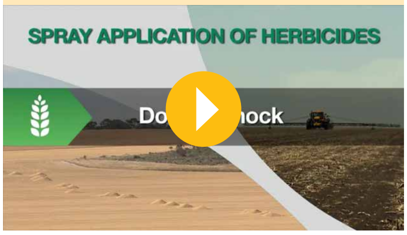
VIDEOS

WATCH: Best results with double-knock tactic

WATCH: Double-knock application—a grower's experience

WATCH: IWM: Double-knock applications—Extent of herbicide resistance in the North

WATCH: Spray application of herbicides—Double-knock



10. Employ crop competitiveness to combat weeds

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

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

If you think you have resistant weeds

When resistance is first suspected, we recommend that growers contact their local agronomist.

The following steps are then recommended:

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

If resistance is still suspected:

1. Contact the crop and food science researchers at QDAF via the Customer Service Centre for advice on sampling suspect plants for testing of resistance status.
2. Ensure that all suspect plants do not set any seed.
3. If resistance is confirmed, develop a management plan for future years to reduce the impact of resistance and likelihood of further spread. [60]

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

VIDEOS

WATCH: Learn to think outside the drum

WATCH: Crop competition—Increasing wheat seeding rate

WATCH: Crop competition—Row spacing

WATCH: Over the Fence North: Strategic approach to resistant weeds

Testing services

For testing of suspected resistant samples, contact:

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

6.12 Monitoring weeds

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

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

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

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

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

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

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

MORE INFORMATION

Visit CropLife Australia for herbicide resistance management strategies

Australian Glyphosate Sustainability Working Group

Australian Herbicide Resistance Initiative

WEEDpak

Managing herbicide resistance in northern NSW

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.

6.12.1 Tips for monitoring

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

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