WESTERN

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GRDC™ GRAINS RESEARCH & DEVELOPMENT CORPORATION

TRITICALE

SECTION 6

WEED CONTROL

INTEGRATED WEED MANAGEMENT (IWM) | MAJOR WEEDS IN WESTERN REGION | KEY WEEDS IN AUSTRALIA'S CROPPING SYSTEMS | HERBICIDES EXPLAINED | PRE-EMERGENT HERBICIDES | POST-PLANT PRE-EMERGENT HERBICIDES | IN-CROP HERBICIDES: KNOCK DOWNS AND RESIDUALS | APPLICATION AND CONDITIONS FOR SPRAYING | HERBICIDE TOLERANCE RATINGS, NVT | POTENTIAL HERBICIDE DAMAGE EFFECT | HERBICIDE RESISTANCE

Weed control

Key messages:

- Weed control in triticale is similar to that for wheat.
- There are mixed reviews on triticale's ability to compete with weeds. Triticale is a more vigorous crop than wheat so offers greater competition against weeds, [1] however, it grows a bit more slowly than spring wheat, so annual grasses and other weeds can be problematic. [2]
- Triticale may have some allelopathic effect which can inhibit the germination and growth of weeds but this effect is not as high as cereal rye. [3]
- Triticale is a relatively new crop and consequently may not have many, if any, herbicides recommended for it.
- Integrated weed management practices for becoming more common in Australian cropping systems with promising results.
- Good soil fertility along with vigorous germination and fast emergence may be one of the most efficient ways to reduce weeds through competition.

Australia's most comprehensive analysis of the cost of weeds in cropping systems has shown that the overall annual cost to Western Australian grain growers is $927 million or $117 per hectare. [4] Annual ryegrass (*Lolium rigidum*) is one of the most serious and costly weeds of annual winter cropping systems in south-western Australia (Photo 1). [5]

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

Source: FarmPress

Triticale is a relatively new crop in many parts of the world and as a consequence may not have many, if any, herbicides or pesticides recommended for it. Check on-label recommendations at www.apvma.gov.au. However, some studies indicate that triticale may be less tolerant to some herbicide cocktails than wheat. Newer herbicides as well as pesticides are now being released with recommendations for use on triticale in many parts of the world. [6]

MORE INFORMATION

Impact of weeds on Australian grain production

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

2 Northern Grain Growers (US). Triticale. http://northerngraingrowers.org/wp-content/uploads/TRITICALE.pdf

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

4 Lee N. (2016). Comprehensive study reveals cost of weeds to WA growers. https://grdc.com.au/Media-Centre/Media-News/West/2016/04/Comprehensive-study-reveals-cost-of-weeds-to-WA-growers

5 Peltzer S. (2016). Annual ryegrass. DAFWA. https://www.agric.wa.gov.au/grains-research-development/annual-ryegrass

6 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

Weed competitiveness of triticale

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

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

Triticale may have some allelopathic effect which can inhibit the germination and growth of weeds but this effect is not as high as its parent crop, cereal rye. [7]

Based on research from Southern NSW the most competitive crops in the face of annual ryegrass at 300plants/m^{-2} are oats > cereal rye > triticale > oilseed rape > barley > wheat> field pea > lupin. [8]

Suppression of the grass weed annual ryegrass, *Lolium rigidum* by wheat, triticale and rye was compared in field trials at Wagga Wagga in 1993. Triticale and Cereal rye appeared to be more competitive than wheat, with a biomass of annual ryegrass at maturity of 70 g/m^2 with triticale compared to 170 g/m^2 with wheat. Triticale has large seeds which lead to rapid early growth and the capacity to suppress weeds via good competitive ability. Early seedling vigour, superior height and broad leaves appeared to influence the greater competitive ability of the triticale and cereal rye. [9]

One study found that grazing systems involving triticale had an equal effect on weed control for some common weed species as the use of a herbicide. [10]

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

Triticale's potential as a herbicide substitute is of particular interest to organic growers, who could use this crop for partial control of weeds in their rotations. While triticale's 'competitiveness' is known, there is not a large database about its effectiveness for weed control when used in this manner. [11]

However, because triticale grows more slowly than spring wheat, annual grasses and other weeds can be problematic. To minimise weeds, prepare the seedbed so it is as clean as possible before planting, and be sure to practice crop rotation. Planting early will help with the quick establishment of a triticale stand and may stave off early weed pressure. Triticale can also be inter-seeded with another crop (including forage grasses or legumes) to aid in weed competition and nutrient management. [12]

Best management practices for weed control

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

- Seed at higher rates and ensure proper fertility, which can help control weeds in triticale.

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

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

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

10 Schoofs and Entz (2000) in Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org.

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

12 Northern Grain Growers (US). Triticale. http://northerngraingrowers.org/wp-content/uploads/TRITICALE.pdf

- Plan ahead. Chemical weed control options in triticale are limited. Select relatively clean fields to seed triticale.
- In the case of perennial weed problems, apply pre-harvest glyphosate or use as a pre-seed burn-off in direct seeded situations. Use in-crop herbicides to control or suppress broadleaf weeds.
- Use certified seed as this ensures that only triticale, and not weeds, is seeded. Certified seed is also more vigorous than bin-run seed.
- Seed early, as earlier sown triticale usually results in more competitive stand establishment, and provides a jump-start on the weeds.
- Seed shallow at between 0.5 to 1.5 inches (optimum 1.0 inch). Shallow seeding generally results in uniform seedling emergence that quickly covers the ground and competes with emerging weeds.
- Use good sanitary practices. Clean machinery and seeding equipment before seeding. [13]

6.1 Integrated weed management (IWM)

Adoption of Integrated Weed Management (IWM) tactics is crucial to sustaining long term profitable cropping rotations in Western Australia (WA). IWM achieves good weed control, helps manage herbicide resistance and drives down weed seed bank numbers.

An integrated weed management plan should be developed for each paddock or management zone based on five steps.

1. Review past actions. The history of herbicide use can be used to prioritise weed management tactics to avoid the use of high risk herbicide mode-of-action groups and identify those paddocks at risk (where weed populations can be prioritised for resistance testing)
2. Assess the current weed status (see also Herbicide resistance and Assessing weed population density)
3. Identify weed management opportunities within the cropping system. Ensure that the proposed changes to the weed management system are suited to the land, infrastructure, resources and the tactics are environmentally and economically sound.
4. Match opportunities and weeds with suitable and effective tactics.
5. Combine ideas using a rotational planner. A rotational planner needs to be drafted for each paddock and include details such as key weeds, soil type, soil pH, resistance issues, crop and pasture rotations, selected weed management tactics and plans for herbicide use.

In a well-integrated weed management plan, each target weed will be attacked using different tactics. Each tactic provides a key opportunity for weed control and is dependent on the management objectives and the target weed's stage of growth. Tactic should be combined in the same way herbicides from different herbicide mode-of-action (MOA) groups are rotated. Integrating tactics and MOA groups will reduce weed numbers, stop replenishment of the seedbank and minimise the risk of developing herbicide resistant weeds.

IWM tactics

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

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

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

There are several agronomic practices that improve crop environment and growth, along with the crop's ability to reduce weed competition. These include crop choice and sequence, improving crop competition, planting herbicide tolerant crops, improving pasture competition, using fallow phases and controlled traffic or tramlining. [14]

6.1.1 IWM for triticale

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

It is vital to control weeds early in the crop's growth. Once the crop grows it then becomes more competitive.

When sowing dual purpose varieties early, choose a paddock with low weed numbers and control weeds prior to the first grazing. Strategic grazing can be used to help manage weeds. Always check grazing withholding periods before you apply post-emergent herbicides when planning to graze the crop. [15]

IN FOCUS

The effect of cultivation and row spacing on the competitive ability of triticale against weeds

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

Historically, most of the experiments evaluating the effect of row spacing and level of cultivation in cereals have been performed on wheat hence there is little data specifically for triticale. By identifying the optimal row spacing and level of cultivation that enhance the competitive ability of triticale, it is expected that the findings will contribute to securing sustainable cereal yields by increasing the inclusion of triticale in cropping rotations, and thereby: (1) reducing the cost of weed control, (2) reducing weed induced crop yield loss, and (3) increasing uptake and utilisation of fertiliser inputs by the crop at the expense of weeds.

Unfortunately, growing conditions were less than ideal. Episodic heavy rainfall events early in the growing season caused waterlogging and poor establishment of triticale and late in the season, some degree of lodging. In addition to above average rainfall, temperatures were below average. This combination appeared to assist the growth of annual ryegrass present at high densities at the expense of triticale, the data for which was highly variable.

Under these conditions, there was no significant row spacing effect on triticale biomass, grain yield or 1000 grain weight. Cultivation, however, while not showing an early impact, increased triticale biomass and

14 Peltzer S. (2016). Developing an integrated weed management plan. DAFWA. https://www.agric.wa.gov.au/grains-research-development/developing-integrated-weed-management-iwm-plan

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

grain yield at harvest. In this trial, wet conditions appeared to affect the expression of competitive growth habits in both the crop and weed species present. The competitive ability was expressed more in the weed population than the crop.

A number of key experimental findings in this study validated the agro-ecological principles on which integrated weed management is based such as: (1) weeds that emerge prior or simultaneous to the crop impose the greatest weed-crop interference, particularly in those weed species that share similar morphology and phenology to cereal crops e.g. *L. rigidum*; (2) strong selection pressure from a given agronomic management practice will cause a shift in weed flora composition and may contribute to the development of single species becoming problem weeds e.g. *Fallopia convolvulus* under high crop densities; (3) early suppression of weeds, in terms of preventing germination or limiting biomass accumulation, is the most important aspect of crop competitive ability as even the most tolerant crops will have yield reductions if early weed-crop competition results in reduced crop tillering during early crop growth; and (4) the expression of competitive growth traits in cereal crops with strong genetic potential for competitive ability (e.g. triticale) is highly influenced by optimal plant densities which impose positive intra-specific competition. [16]

6.1.2 IWM trials in WA

In the northern wheatbelt of WA, focus paddock trials funded by GRDC and carried out in conjunction with the Department of Agriculture and Food WA (DAFWA) demonstrated that it is possible to profitably crop at high intensity, while eroding the weed seed bank and in-crop weed numbers.

This is despite originally having high levels of herbicide resistance. For 31 focus paddocks where IWM was used from 2001 to 2013, annual ryegrass (*Lolium rigidum*) seed bank populations fell 96% from an average 183 ryegrass plants/m^2 to only eight ryegrass plants/m^2.

At the same time, an average cropping intensity of 89% was maintained. The focus paddock project highlighted the importance of harvest weed seed control (HWSC) in reducing weed populations as part of an IWM plan. It found growers who had the most success at managing annual ryegrass were those who practiced HWSC by towing a chaff cart and/or using narrow window burning. In the eighth year of using this practice, these growers had no annual ryegrass in their focus paddocks and have averaged fewer than 1.5 ryegrass plants/m^2 ever since.

Crop competition and orientation

Crop competition and orientation are emerging as key non-herbicide weed control measures in WA.

These can include narrow row spacing, higher seeding rates, twin row seeding points, orientating crops to shade weeds in the inter-row, use of varieties that tiller well, high density pastures as a rotation option, brown manuring and inclusion of herbicide tolerant canola hybrids in crop rotations.

Research by the Department of Agriculture and Food WA (DAFWA) has shown that as crop density increases, crop biomass increases and weed growth and weed seed set fall due to crops out-shading and out-competing weeds for water and nutrients.

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

The challenge is to achieve this in a practical and cost effective way. Research has shown lifting seeding rates by 30–40 kg/ha, at a cost of about $15/ha, to establish 200 wheat plants/m^2 can halve weed seed set in a paddock.

A 2012 trial in Mingenew demonstrated a 65% reduction in annual ryegrass *(Lolium rigidum)* seed set without the use of in-crop herbicides as a result of high crop density – using seeding rates of 160 kg/ha.

At this trial, the efficacy of Sakura® (with the active pyroxasulfone) at label rates also increased from a 95 to a 99% reduction in annual ryegrass seed set when seeding rates and crop density increased.

At a Binnu trial in 2012, increasing crop density resulted in a significant reduction in wild radish (*Raphanus raphanistrum L.*) numbers with no in-crop herbicide used (Photo 2).

Photo 2: *Wild radish growing between cereal crop rows in a trial plot in WA's northern agricultural region investigating herbicide sequences to control wild radish.*

Source: GRDC

Using narrow or paired row seeding systems (where a single seeding boot creates paired crop rows - usually 75 to 100 mm apart) can also boost crop competition.

Existing machinery can be modified for paired row seeding so that the tyne spacing best for stubble handling and sowing speed can stay the same.

GRDC-funded trials run by DAFWA in the northern agricultural region in 2013 found there was potential for paired row seeding systems - using a Stiletto seeding boot mounted to a single tyne - to improve crop competition with weeds.

MORE INFORMATION

Narrow row spacing – more crop, fewer weeds.

Paired row sowing was able to increase crop germination, establishment and density and reduce crop row spacing to rows 75 mm apart, without adding extra tynes.

Narrow row spacing plots (at 15 cm) out-yielded wider row spacing plots (at 22 cm and 30 cm) by an average 240 kg/ha.

This is the equivalent of 16 kg/cm/ha of row spacing and is consistent with findings from a recent GRDC-funded review of 50 years of national row spacing trial data.

Variety selection also has a role in crop competition and it is recommended wheat varieties with high early vigour are used to out-compete weeds.

Using good crop agronomy during the growing season and soil health best practices (particularly liming to address soil acidity) are also factors to help boost crop competition.

Crop and herbicide rotation

Rotating crop types and herbicides with different modes of action (MOA) can help to reduce the risk of herbicide resistance evolution.
Changing between broadleaf crops and cereals allows different weed control tactics to be incorporated into an IWM strategy, such as rotating herbicide MOA or crop topping etc.

A fallow period between two crops, or a crop and pasture phase, can also be an ideal time to focus on weed control in that paddock.

It is vital to rotate herbicide and physical weed control measures during this phase.

Multiple and well-timed mowing or crop topping, silage or hay production with a follow-up non-selective herbicide or heavy grazing/spray grazing are good in-crop weed control measures.

Weed detection technology

A predominantly glyphosate fallow over summer to remove weeds and conserve moisture for the next crop is common practice in the northern agricultural region of WA.

To reduce the risk of glyphosate resistance evolving in fallow weeds, some growers are using weed-detecting technology to target and spray individual weeds that survive the glyphosate application with an alternative knockdown herbicide (Photo 3).

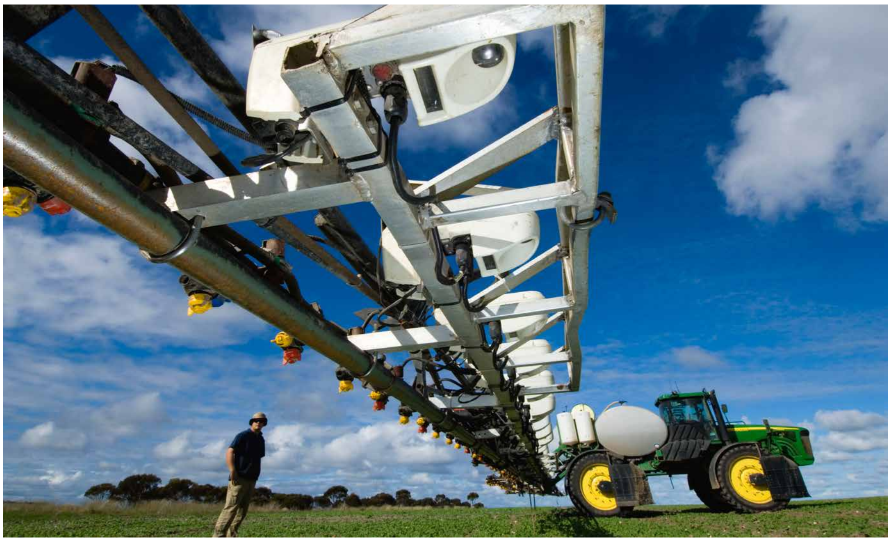


Photo 3: *Small sensors on a boom spray will detect broad leave weeds and a single spray will operatePrecision spraying results in significant savings in herbicides.*

Photo: Evan Collis, Source: GRDC

This technology is well suited to detecting and killing patches of weeds across large-scale properties, using optical sensors to turn on spray nozzles only when green weeds are detected. This reduces total herbicide use and cost per hectare (after taking into account the initial outlay cost for machinery).

This new technology also has potential to map troublesome weed patches so these areas can be targeted with a pre-emergent herbicide before sowing.

Sales of the two weed detecting systems available in Australia - WeedSeeker® and WEEDit® - continue to increase.

A minor use permit has been issued for all Australian states for herbicide use with Weedseeker and is valid to February 28, 2019 (it will be reviewed annually).

The permit (PER11163) allows growers to use about 30 different selective grass herbicides from seven MOA groups and higher rates of paraquat and diquat.

Harvest weed seed control (HWSC)

A major biological weakness of most WA cropping weeds is that their seed does not shatter before harvest, providing a good opportunity for removal at this time.

Common HWSC tactics used in WA include:

- collecting chaff in chaff carts
- burning or grazing chaff residue
- depositing chaff on narrow windrows for burning the next autumn
- using the Harrington Seed Destructor (HSD) system to pulverise and destroy chaff and weed seed fraction as it leaves the harvester
- diverting weed seeds onto permanent tramlines
- towing a baler behind the header to remove all harvest residue.

A major benefit of these systems, aside from lowering the seed bank over a few years, is removal of both resistant and susceptible weed seeds that have survived earlier herbicide applications.

This reduces the risk of herbicide resistance evolution and reduces selection pressure on herbicides.
Australian Herbicide Resistance Initiative (AHRI) research at 25 sites across southern Australia during the 2010 and 2011 harvest found that windrow burning, chaff cart and HSD systems were equally effective at removing annual ryegrass seed from cropping paddocks.

Each of the HWSC methods led to a 55% reduction in annual ryegrass germination the following year.
AHRI research has also shown that the HSD consistently destroys 95% of annual ryegrass, wild radish, wild oats and brome grass seed present in the chaff fraction.

All HWSC systems are limited by how many weed seeds enter the front of the harvester and, therefore, typically remove about 70–80% of annual ryegrass and wild radish seed from the crop.

See Section 12: Harvest, 12.7 Harvest weed seed management for more information.

Decision support - Ryegrass Integrated Management (RIM)

IWM involves complex interactions, multiple year timeframes, many possible interventions, major environmental influences and high levels of uncertainty.

The use of computer-based models can be a valuable tool to aid decision making. Developed by AHRI, with GRDC funding, the Ryegrass Integrated Management (RIM) model evaluates the long term profitability of ryegrass control methods and reducing the weed seed bank.

RIM enables users to assess the effectiveness and budget implications of 10-year cropping and weed management scenarios using up-to-date economic parameters.

MORE INFORMATION

The latest version of RIM has a user guide and video tutorials and is available for free download.

The RIM user guide

Weed seed wizard

Integrated weed management hub

It has options for four crops, three pastures and 43 practices that include herbicide use and rates, timing of application, soil preparation, crop type, grazing and HWSC options.

Graphs can be produced and exported to other software programs for analysing ryegrass survivors, gross margins across 10 years, yield loss from competition and ryegrass seedbank levels.

Decision support - Weed Seed Wizard

Weed Seed Wizard can investigate the impact of a wide range of IWM strategies (such as grazing, HWSC, increased crop competition, rotation change and various seed set controls such as crop topping and hay making) on weed and weed seed numbers.

This national simulation tool was developed by DAFWA in partnership with the University of Western Australia, University of Adelaide, the New South Wales Department of Primary Industries and the Department of Agriculture Fisheries and Forestry in Queensland and supported by GRDC.

The user enters site-specific weather data and soil type, the weed species to be investigated and information about past and future weed management.

The model uses real weather data and gives an estimate of crop yield loss as a result of weed pressure from a range of species.

6.2 Major weeds in Western region

6.2.1 Annual rye grass

Annual ryegrass (*Lolium rigidum*) is one of the most serious and costly weeds of annual winter cropping systems in south-western Australia. Annual ryegrass is highly competitive and can compete with a crop as early as the two-leaf crop stage. It is a winter to spring growing weed that can emerge from late autumn through to early spring. The number of emergence flushes and the density of plants that emerge are related to initial seedbank levels and the frequency and amount of rainfall.

Why is it a major weed?

As one of the most serious and costly weeds in southern Australia's winter cropping systems, annual ryegrass produces an extremely high number of seeds per plant. Dense stands (>100 plants/m^2) can produce up to 45,000 seed per square metre under ideal conditions. Annual ryegrass is highly competitive and can compete with crops as early as the two-leaf crop stage. Annual ryegrass also is a host for the bacteria *Clavibacter* spp., which cause annual ryegrass toxicity (ARGT) and can be infected by ergot fungus.

Identification

Annual ryegrass is hairless and has bright green, narrow leaves. The leaves are shiny, especially on the back of the blade. It has a wide ligule, long auricles and the emerging leaf is folded. The base (below ground) is often reddish purple in colour and seedlings exude a clear sap when crushed.

Mature plants are erect and up to 900 millimetres (mm) in height (Photo 4).

Photo 4: *Mature ryegrass in a cereal crop at the Harrington's Wagin farm, WA, during the 2010 harvest.*

Source: GRDC

The inflorescence (flowering stems) are flat and up to 300 mm in length. Spikelets have 3–9 flowers and the husk is almost the same length as the spikelet (Photo 5).

Photo 5: *Annual ryegrass head.*

Source: DAFWA

Seeds are relatively flat, 4–6 mm long, 1 mm wide and straw-coloured, with the seed embryo often visible through the outer layers. They are held securely to the flower stem and significant force is needed to detach them either as individual seeds or as part of the flower stem.

Herbicide resistance

Many populations of annual ryegrass have developed resistance to both selective and non-selective herbicides. Repeated use of herbicides from the same mode-of-action group (particularly the high-risk Groups A and B) have lead to herbicide-

MORE INFORMATION

Tactics for IWM against Ryegrass in WA

Ryegrass Integrated Management

VIDEOS

WATCH: Managing herbicide resistant ryegrass with IWM.

resistant individuals. Annual ryegrass has developed resistance to the following mode-of-action herbicide groups in Western Australia.

- Group A — 'fops' (for example, diclofop-methyl)
- Group A — 'dims' (for example, sethoxydim)
- Group B — sulfonylureas (for example, chlorsulfuron and sulfometuron)
- Group B — imidazolinones (for example imazapic)
- Group C — triazines (atrazine and simazine)
- Group C — substituted ureas (for example, diuron)
- Group D — trifluralin
- Group M — glyphosate
- Group Q — triazoles (for exampe, amitrole)

There are now more than 23 confirmed cases of glyphosate-resistant ryegrass populations in Australia mostly from cropping paddocks. There are at least three populations recorded in WA. There has also been a recent case of resistance to paraquat in annual ryegrass been found in South Australia. [17]

6.2.2 Wild radish

Wild radish (*Raphanus raphanistrum*) is highly competitive in crops and can cause a yield loss of 10–90%. The fibrous stems of wild radish make harvesting difficult by choking the header comb, it is an alternative host for a number of pests and diseases and it can cause animal health problems when grazed.

Why is it a weed?

Wild radish is easily distributed as an impurity in hay, chaff and grain. Seed pods often break into segments similar in size to wheat seed, and removing the contamination can be quite difficult. Wild radish sheds pods before crop harvest, enabling it to persist in cropping systems.

Wild radish is very competitive because the seedlings establish rapidly and grow relatively fast. The fibrous stems of wild radish make harvesting difficult by choking the header comb.

Moisture levels of harvested grain can be affected. During years with late rains, when wild radish continues to grow and remains green after crop maturity, the moisture squeezed from the wild radish stems during harvest often raises the grain moisture content above acceptable storage levels. It has allelopathic activity and extracts and residues can suppress germination, emergence and seedling growth of some crops and weeds.

Wild radish is also an alternative host for a number of pests and diseases and can cause animal health problems.

Distinguishing features

Wild radish is generally a winter and spring-growing annual that may grow up to 1.5m high (Photo 6). The cotyledons are heart-shaped and hairless with long stems. The first true leaves are irregularly lobed around the edges with one or more completely separated lobes at the base of the leaf blade.

17 Peltzer S. (2016). Annual ryegrass. DAFWA. https://www.agric.wa.gov.au/grains-research-development/annual-ryegrass?page=0%2C0

VIDEOS

WATCH: GCTV14: Early control wild radish.

WATCH: GCTV Extension files: Wild Radish – 1st spray.

WATCH: GCTV Extension files: Wild radish – 2nd spray.

WATCH: IWM: Weed seed bank destruction – wild radish seed.

Photo 6: *Wild radish plants growing above the surrounding cereal canopy.*

Source: GRDC

The seedling develops into a flat rosette, the leaves of which do not have a distinct stalk. Erect branches covered with prickly hairs arise from near the base as the plant matures. The rosette of lobed leaves does not persist.

Lower stem leaves are covered with prickly hairs and deeply lobed, with a rounded terminal lobe. When crushed, these leaves have a strong turnip-like odour. Upper stem leaves become narrower, shorter and often undivided.

Flowers are in clusters on the ends of stem branches (Photo 7). They have four petals, which alternate with four sepals. The petals may vary in colour; yellow or white petals are more common than purple, pink or brown. Petals often have light or dark distinct veins. The seed pod is constricted between the seeds and does not split lengthwise.

Photo 7: *Flowering head of wild radish, a very serious weed in the Northern WA wheatbelt.*

Photo: M Williams, Source: GRDC

MORE INFORMATION

Tactics for IWM against Wild radish

Herbicide resistant Wild radish: take back control.

Wild radish management and strategies to address herbicide resistance

It breaks up into distinct segments when ripe and during threshing it is often broken up into single-seeded segments. Each pod usually has three to nine seeds, ovoid to almost globular, yellowish to reddish brown and covered with white bran-like scales. There is no seed in the beak of the pod.

Wild radish can be confused with wild turnip (*Brassica tournefortii*), charlock (*Sinapis arvensis*), turnip weed (*Rapistrum rugosum*) or garden radish (*Raphanus sativus*).

Herbicide resistance

Populations (mostly in WA) have developed resistance to herbicides in the mode-of-action (MOA) Groups B, C, F and I. Group B resistance is the most common, followed by Group F.

- Group B — sulfonylureas (for example, chlorsulfuron)
- Group B — sulfonamides (for example, metosulam)
- Group B — imidazolinones (for example, imazapic)
- Group C — triazines
- Group C — triazinones (for example, metribuzin)
- Group F — pyridinecarboxamides (for example, diflufenican)
- Group I — phenoxys (2,4-D) [18]

6.2.3 Wild oats

Wild oats (*Avena fatua* and *A. ludoviciana*) represent a large cost to cropping. Wild oats are highly competitive and when left uncontrolled can reduce cereal yields by up to 80%. Greatest yield loss occurs when the wild oat plants emerge at the same time as the crop.

Why is it a weed?

The annual cost to the Australian wheat industry of wild oats during 1999 was estimated to be $80 million, with $60 million being spent on herbicides and their application and $20 million in lost yield.

They produce a large number of seeds and up to 20,000 seeds/m^2 can be produced by uncontrolled infestations.

Wild oats avoid early herbicide applications as a proportion of the seeds germinate later than the crop.

Wild oats are easily spread as contaminants of grain, hay and machinery. Up to 75% of wild oat seed can be collected at harvest, with seeds being transported up to 250 metres (m) from the parent plant by the harvest operation. Delaying harvest can reduce seed movement in the paddock and grain sample, as the delay means a greater proportion of the wild oats seeds will have shattered.

Wild oats act as a host for a number of important cereal diseases including cereal cyst nematode (*Heterodera avenae*), stem nematode (*Ditylenchus dipsaci*), rhizoctonia (*Rhizoctonia solani*), crown rot (*Fusarium graminearum*) and root lesion nematode (*Pratylenchus neglectus*).

Distinguishing features

Wild oats have a large ligule with no auricles and the leaves tend to be hairy with a slight bluish hue (Photo 8). The emerging leaf is rolled. The seedling leaves are twisted anticlockwise, the opposite direction to wheat and barley. Wild oat seeds are usually dark but can vary through to cream. Hairiness of seeds also varies.

18 Peltzer S. (2016). Wild radish. DAFWA. https://www.agric.wa.gov.au/grains-research-development/wild-radish?page=0%2C0

Photo 8: *Mature wild oats in a cereal paddock.*

Source: DAFWA

Wild oats tend to grow in discrete patches at low to moderate densities (up to 100plants/m^2) and can be confused with brome grass in the seedling stage. All *Bromus* spp. have tubular leaf sheaths and hairy leaves and sheaths while wild oats exhibit a rolled sheath and few hairs on the leaves.

Herbicide resistance

Wild oats can easily develop resistance to herbicides. Group A herbicide resistance, predominately to 'fop' herbicides (for example, Topik®), has been present in Australian populations of wild oats since the mid 1980s (Photo 9). In Western Australia, wild oats are currently resistant to:

- Group A — 'fop' (for example, diclofop-methyl)
- Group A — 'dims' (for example, tralkoxydim)

In Australia, wild oats are also currently resistant to Group B - sulfonylureas (for example mesosulfuron) and Group Z (for example flamprop-m-methyl). [19]

Photo 9: *Group A resistant Wild oats on the inter-row of a cereal crop.*

Photo: E. Leonard.

Source: GRDC

MORE INFORMATION

Tactics for IWM against Wild oats.

19 Peltzer S. (2016). Wild oats. DAFWA. https://www.agric.wa.gov.au/crop-weeds/wild-oats?page=0%2C0

6.2.4 Brome grass

Brome grass (*Bromus diandrus* and *B. rigidus*) is one of the most competitive grass weeds in wheat. It shows drought tolerance, better tolerance of phosphorus deficiency and a better responsiveness to nitrogen than wheat. For this reason, addition of nitrogen to a crop can aggravate a brome grass problem. Brome grass contaminates grain, the seeds contaminate wool, damage hides and meat and cause injury to livestock by entering their eyes, mouth, feet and intestines.

Why is it a weed?

Brome grass is one of the most competitive grass weeds in wheat. It is drought tolerance, more tolerant to phosphorus deficiency and a better response to nitrogen compared with wheat. Hence, addition of nitrogen to a crop can aggravate a brome grass problem.

Brome grass contaminates grain and in pastures the seeds contaminate wool, damage hides and meat and cause injury to livestock by entering the eyes, mouth, feet and intestines. Left uncontrolled in fallow or pasture phases, brome grasses will host and carry over cereal diseases to new crops. These diseases include: ergot (*Claviceps purpurea* (Fr.) Tul.), take-all (*Gaeumannomyces graminis* (Sacc.) v. Arx & Oliv.), powdery mildew (*Erysiphe graminis* DC.), septoria glume blotch (*Leptosphaeria nodorum* Muller), black stem rust (*Puccinia graminis* Pers.), brown rust (*Puccinia recondita* Roberge ex Desm.), barley net blotch (*Pyrenophora teres* Drechsler), sharp eyespot (*Rhizoctonia solani* Kuhn), bunt (*Tilletia caries* (DC.) Tul.), cereal yellow dwarf virus, cereal cyst nematode (*Heterodera avenae* Woll.) and root-knot nematode (*Meloidogyne* spp.).

Seed production can range from 600 to more than 3000 seeds per plant. The ability to shed a large proportion of seed before crop harvest is another important characteristic that makes brome grass a major weed.

Distinguishing features

Both species have erect seedlings with dull, hairy leaves that display red–purple stripes following the leaf veins (Photo 10). At the seedling stage brome grass may be confused with wild oats (*Avena spp.*) because both possess hairs on the leaves and stems (Table 1).

Table 1: *Distinguishing characteristics of Bromus diandrus and B. rigidus.*

Character	***B. diandrus* (great brome)**	***B. rigidus* (rigid brome)**
Leaf appearance	10 mm wide leaves, which are rough and have some long hairs. The hairs on the leaf blade point upwards. There are usually prominent purple stripes on the leaf sheath.	Wide leaves with sparse hairs and very erect panicle branches.
Inflorescence appearance	The inflorescence is loose and nodding and spikelet branches are longer than the spikelets.	The inflorescence is compact and stiff. Spikelets are often heavily pigmented with reddish to black colouring. The spikelet branches are shorter than the spikelets.
Seed appearance	The hardened scar on the seed is rounded.	The hardened scar on the seed is acute.

Source: DAFWA

Photo 10: *The two main problem species of brome grass - Diandrus (left) and Rigidous (right).*

Source: GRDC

MORE INFORMATION

Tactics for IWM against Brome grass

Herbicide resistance

In WA, there are brome grass populations that have developed resistance to:

- Group B — sulfonylureas (for example, sulfosulfuron)
- Group B — imidazolinones (for example, imazapic and imazapyr).
- Group C — triazines (for example, simazine)[20]

6.3 Key weeds in Australia's cropping systems

Click on the weed name below to be taken to further information on this weed.

Annual ryegrass (*Lolium rigidum*)

Barley grass (*Hordeum* spp.)

Barnyard grasses (*Echinochloa* spp.)

Black bindweed (*Fallopia convolvulus*)

Bladder ketmia (*Hibiscus trionum*)

Brome grass (*Bromus* spp.)

Capeweed (*Arctotheca calendula*)

Doublegee (*Emex australis*)

Feathertop Rhodes grass (*Chloris virgata*)

Fleabane (*Conyza* spp.)

Fumitory (*Fumaria* spp.)

Indian hedge mustard (*Sisymbrium orientale*)

Liverseed grass (*Urochloa panicoides*)

Muskweed (*Myagrum perfoliatum*)

20 Peltzer S. (2016). Brome grass. DAFWA. https://www.agric.wa.gov.au/grains-research-development/brome-grass?page=0%2C0

Paradoxa grass (*Phalaris paradoxa*)

Silver grass (*Vulpia* spp.)

Sweet summer grass (*Brachiaria eruciformis*)

Turnip weed (*Rapistrum rugosum*)

Wild oats (*Avena fatua* and *Avena ludoviciana*)

Wild radish (*Raphanus raphanistrum*)

Windmill grass (*Chloris truncata*)

Wire weed (*Polygonum aviculare* and *Polygonum arenastrum*) [21]

6.4 Herbicides explained

Herbicides play a vital role in integrated weed management programs. Knowledge of the mechanisms and activity of herbicides will improve the impact and sustainability of herbicides as a weed management tactic (Table 2).

Chemical weed control options in triticale varieties are in general similar to those for wheat, although some differences in tolerances are important. In all states the DPI or its equivalent produce a recommended herbicide usage publication which should be consulted before using herbicides with triticale.

It is important that care is taken to ensure crop and weed tolerances based on the label recommendations are adhered to. Additionally, weather conditions, herbicide rates, water dilution rates, and adjoining crops status need to be assessed and managed correctly. Whilst a range of chemical are registered for use in both wheat and triticale, some herbicides are only legal for use in wheat. Additionally, some herbicides are only legal to use at specific crop stages in triticale. [22]

Table 2: *Types of herbicides and their effects on weeds.*

Type of herbicide	Effect
Translocated herbicides	move to the site of action via the transport mechanisms within the plant; the xylem and phloem. The xylem transports water and nutrients from the soil to growth sites and the phloem transports products of photosynthesis (for instance, sugars) to growth and storage sites. It may take up to two weeks for symptoms to develop on the target weeds depending on herbicide rate, conditions and species.
Contact herbicides	have limited movement within the plant, so complete coverage of the target is critical. Compared to translocated herbicides (for example, glyphosate), contact herbicides (for example, paraquat, oxyfluorfen, diquat and bromoxynil) tend to show symptoms rapidly, usually within 24 hours.
Selective herbicides	will kill target weeds and not desired plants (the crop or pasture) when applied at a specified application rate.
Non-selective herbicides	(also called knockdown herbicides) such as glyphosate or paraquat will damage most plants.
Residual herbicides	remain active in the soil for an extended period of time (months) and can act on successive weed germinations.

21 GRDC (2014) Section 8. Profile of common weeds of cropping. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/common-weeds-of-cropping

22 Jessop RS, Fittler M. (2009). Triticale production Manual – an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

VIDEOS

WATCH: GCTV17: Herbicide partnership.

MORE INFORMATION

Herbicide uptake by plants

Disc seeding systems and pre-emergent herbicides

Type of herbicide	Effect
Non-residual herbicides	such as the non-selective paraquat and glyphosate, have little or no soil activity and are quickly deactivated in the soil. They are either broken down or bound to soil particles, becoming less available to growing plants. They also may have little or no ability to be absorbed by roots.
Post-emergent and pre-emergent	are terms that refer to the target and timing of herbicide application. Post-emergent refers to foliar application of the herbicide after the target weeds have emerged from the soil, while pre-emergent refers to application of the herbicide to the soil before the weeds have emerged.
Herbicides mixtures and sequential applications	involve the application of more than one herbicide, usually to increase the spectrum of weed species controlled but also for resistance management. A mixture involves the application of multiple products in a single application. Where herbicides are antagonistic and cannot be mixed together in a single tank, they are applied sequentially.

Source: DAFWA

6.5 Pre-emergent herbicides

Triticale is competitive against weeds once established. A pre-emergent knockdown should be applied with limited options available post emergence. There are herbicide options against broad-leaf weeds. [23]

Ideally a non-selective knockdown should be used when sowing main season varieties to reduce the reliance on post-emergent herbicides. [24]

Stay up to date with available herbicides and instructions for application with the APVMA and PubCRIS websites.

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

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.
- Both the positive and negative aspects of using pre-emergent herbicides should be considered in the planning phase. [25]

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

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

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

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

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

6.5.1 Understanding pre-emergent herbicides

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

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

Behaviour of pre-emergent herbicides in the soil

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

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

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

The important factors in getting pre-emergent herbicides to work effectively while minimising crop damage are: to understand the position of the weed seeds in the soil; the soil type (particularly amount of organic matter and crop residue on the surface); the solubility of the herbicide; and its ability to be bound by the soil. Managing all these factors is complex, but some rules of thumb are:

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

MORE INFORMATION

Understanding pre emergent cereal herbicides.

Using pre-emergent herbicides in conservation farming systems.

Gearing up to use pre-emergent herbicides.

GRDC Pre-emergent herbicides Factsheet.

How pre-emergent herbicides work.

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. [26]

Top tips for using pre-emergent herbicides:

- Only use pre-emergent herbicides as part of an integrated weed control plan including both chemical and non chemical weed control practices.
- Preparation starts at harvest. Minimise compaction and maximise trash spreading from the header
- Minimise soil disturbance allowing weed seeds to remain on the soil surface.
- Leave stubble standing rather than laying it over.
- Knife points and press wheels allow greatest crop safety. Avoid harrows.
- If using a disc seeder understand the mechanics of your machine and the limitations it may carry compared to a knife point and press wheel.
- Pay attention to detail in your sowing operation and ensure soil throw on the inter row whilst maintaining a seed furrow free from herbicide.
- Ensure the seed furrow is closed to prevent herbicide washing onto the seed.
- Ensure even seed placement, typically 3–5 cm of loose soil on top of seed in cereals for best crop safety.
- IBS rather than PSPE for crop safety.
- Understand herbicide chemistry. Choose the right herbicide in the right paddock at the right rate. [27]

6.5.2 Tactical spray fallow in the Western region

Use of a tactical spray fallow in low rainfall areas of the WA grainbelt can reduce risks associated with seasonal variability, herbicide resistant weeds and growing non-profitable crops in poor years.

By strategically knocking down weeds in fallow paddocks during the summer months or at seeding time (Photo 11) - and keeping these paddocks clean from weeds until the next year's sowing period - vital soil moisture for the next 18 months is conserved for the subsequent crop.

This next crop should be healthier, have a lower weed burden, produce more grain yield and be more likely to generate a higher two-year gross margin than growing two low-yielding cereal crops.

Other benefits of this type of extended tactical fallow include:

- Increased plant available water (PAW) and soil mineral nitrogen (N) availability to crops
- A wider and more reliable sowing window
- Less weed-vectored pests, nematodes and diseases
- Reduced levels of rust disease inoculum (via interruption of the green bridge)
- Reduced levels of aphid-vectored diseases. [28]

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

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

28 GRDC (2016). Hot topics: Tactical spray fallow in the western region. https://grdc.com.au/Media-Centre/Hot-Topics/Tactical-spray-fallow-in-the-western-region

Photo 11: *An aerial image taken in June 2016 shows the scale of the Mingenew tactical fallow trial site that is supported by the GRDC's Regional Cropping Solutions Networks (RCSN) Geraldton and Kwinana East port zone groups in Western Australia.*

Source: GRDC

MORE INFORMATION

Tactical spray fallow in the Western region

6.6 Post-plant pre-emergent herbicides

Post-sowing, pre-emergent herbicides use is when a pre-emergent herbicide is applied after sowing (but before crop emergence) to the seedbed. Application of pre-emergent herbicides pre-sowing and then incorporating them into the seed bed during the sowing process will often increase safety to crops because the sowing operation removes a certain amount of herbicide away from the seed row. This can conversely reduce weed control for the very same reason, as chemical is moved out of the seed row. In this case it is wise to include a water soluble herbicide into the mix aiming to have some herbicide wash into the seed furrow.

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

Post-plant pre-emergent herbicides are primarily absorbed 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. Best weed control is achieved from Pre-sowing, Pre-emergence application because rainfall gives the best incorporation. Mechanical incorporation pre-sowing is less uniform, and so weed control may be less effective. If applied pre-sowing and sown with minimal disturbance, incorporation will essentially be by rainfall after application. Weed control in the sowing row may be less effective because a certain amount of herbicide will be removed from the crop row.

6.6.1 Incorporation by sowing

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

Application of pre-emergent herbicides pre-sowing and then incorporating them into the seed bed during the sowing process will often increase safety to crops because the sowing operation removes a certain amount of herbicide away from the seed row. This can conversely reduce weed control for the very same reason, as chemical is moved out of the seed row. In this case it is wise to include a water soluble herbicide into the mix aiming to have some herbicide wash into the seed furrow.

Two trials conducted in 2013 evaluating the crop safety and efficacy of registered residual herbicides for the control of ARG in wheat.

The majority of treatments were managed by the incorporation by sowing (IBS) approach. IBS specifies the use of narrow point tynes on the planting equipment. This approach helps to ensure sufficient soil is thrown across the inter-row space to effectively 'incorporate' the herbicide, plus it removes most of the herbicide treated soil from the planting furrow to improve crop safety. The negative consequence is that IBS generally provides poor weed control in the zone immediately around the planting row. In many cases, post sowing pre-emergent application (PSPE) is also being evaluated as it provides more uniform weed efficacy but requires herbicides or rates with improved crop safety together with reduced incorporation characteristics.

Take home messages

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

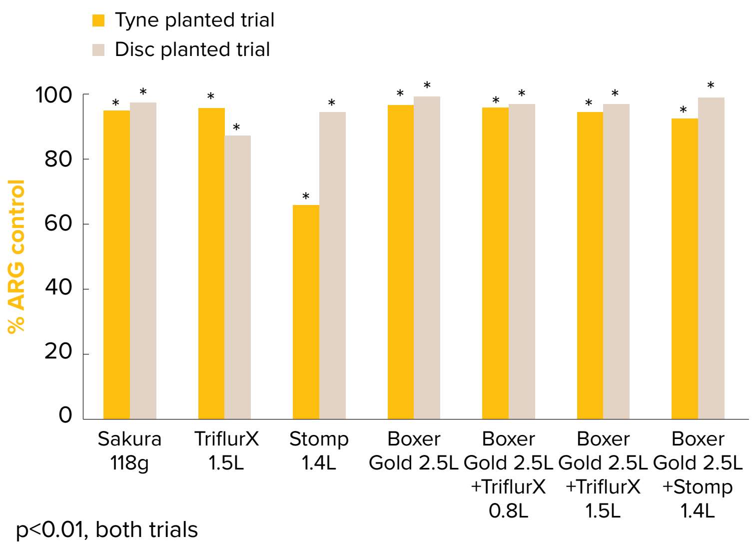


Figure 1: *Per cent annual ryegrass control based on counts (22/9/13, 94 days after planting) UTC = untreated control. All treatments applied in 70 L/ha total volume using AIXR110015 nozzles at 300 kPa * = significant ARG control compared to untreated within same trial.*

Source: GRDC

Efficacy summary

- High levels of ARG control were achieved by most IBS treatments
- The most consistent product 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 due to commercial crop safety concerns arising from the use of residual herbicides at planting for ARG 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 setup appears to have exaggerated crop safety issues by planting seed in an area with increased herbicide concentration
3. Observation suggested that small differences in planting depth may have impacted on crop safety in this scenario

This work reinforces some of the difficulties growers and agronomists face with the use of residual herbicides. Crop safety and efficacy are influenced by a range of factors including planting equipment, planting depth, soil type, stubble load together with rainfall quantity and timing. As an industry we need to have a more thorough understanding of the impacts from these (and perhaps other factors) to ensure we get the best from these important weed management tools. [29]

Stay up to date with available herbicides and instructions for application with the APVMA and PubCRIS websites.

6.7 In-crop herbicides: knock downs and residuals

6.7.1 Selective post-emergent herbicides

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

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

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

- The effectiveness of post-emergent herbicides is influenced by a range of plant and environmental factors. [30]

6.7.2 Knockdown herbicides for fallow and pre-sowing control

Knockdown herbicides (or non-selective) kill all plants when used in sufficient quantities, under suitable environmental conditions.

Benefits

- Knockdown herbicides effectively kill weeds and are cost-effective.
- Use of knockdown herbicides can improve the timeliness of sowing.
- Use of knockdown herbicides rather than cultivation will reduce the risk of erosion, improve soil structure and improve plant available soil water content.

Issues

- Consider the suitability of herbicide use for fallow or pre-sowing weed control by assessing environmental conditions.
- Stressed weeds will not be adequately controlled by knockdown herbicides.
- Overuse of knockdown herbicides will select for resistance.
- Suitable meteorlogical conditions for spraying can be limited, especially for weed control over the summer fallow.

6.7.3 Double knockdown

'Double knock' refers to the sequential application of two weed control tactics applied in such a way that the second tactic controls any survivors of the first tactic. A common combination is glyphosate followed by paraquat or paraquat/diquat.

Benefits

- Double knockdown delays or prevents the development of glyphosate resistance.
- Using a double knockdown strategy reduces the number of (potentially resistant) weeds to be controlled in crop.
- Excellent weed seedling control is achieved.

Issues

- Glyphosate should be applied first, followed by paraquat or paraquat/diquat.
- The timing between applications will vary depending on the main target weed species.
- Consider the main target weed species when choosing what herbicides to use in the double knockdown.
- Double knockdown is more expensive than a single herbicide application.
- Seasonal conditions will influence the scale of on-farm implementation (as a double knockdown takes more time than a single application). [31]

Stay up to date with available herbicides and instructions for application with the APVMA and PubCRIS websites.

Key points for in-crop herbicide application:

- Knowledge of a product's translocation and formulation type is important for selecting nozzles and application volumes.
- Evenness of deposit is important for poorly or slowly translocated products.
- Crop growth stage, canopy size and stubble load should influence decisions about nozzle selection, application volume and sprayer operating parameters.

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

31 Douglas A. (2016). Herbicides. DAFWA https://www.agric.wa.gov.au/herbicides/herbicides?page=0%2C1

- 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. [32]

In-crop herbicides will normally require a different set of nozzles compared to 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.

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

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

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

Consider 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
- 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. [33]

MORE INFORMATION

GRDC In-crop herbicide use Factsheet.

6.7.4 Fenceline weeds in the Western region

About one quarter of glyphosate resistant populations within broadacre cropping situations across Australia come from fencelines and other non-cropping areas of the farm.

Along paddock borders, where there is no crop competition, weeds can flourish and, if not controlled, set lots of seed (Photo 12). The traditional approach has been to treat these weeds with glyphosate to keep borders clean but after 20-odd years this option is now failing and paddock borders are becoming a significant source of glyphosate-resistant weed seed.

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

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

Photo 12: *With minimal crop competition, weeds can thrive along paddock borders.*

Source: GRDC

The control options used will generally be determined by whether the border in question needs to be kept bare or if vegetation is beneficial. In some situations, cultivation can be used to kill the weeds and provide a firebreak, but on light soils this may pose an erosion risk and mowing or slashing may be safer options. Another possible tactic is to continue using herbicides but to ensure that a clean-up operation is carried out before any survivors can set seed.

Planting the crop right to the fence and then baling the outside lap and spraying with a knockdown herbicide to kill any weeds and provide a firebreak is another option.

Spring is a traditional time for controlling weeds along the borders however the weeds present in spring are too large to be effectively treated with contact herbicides. Using a slasher with a spray nozzle is a better option for these survivors.

If possible, a move to herbicide control in autumn will provide better control and reduce the risk of herbicide resistant weeds setting seed.

Another option is to apply a high rate of diquat and paraquat to small weeds, followed with paraquat 14 days later.

Early treatment with a residual herbicide such as bromacil mixed with a knockdown such as paraquat also has a beneficial effect on seed set.

Weeds growing in and adjacent to head ditches and tail drains in irrigation areas are also of significant concern. Glyphosate resistant barnyard grass poses a high risk because the seed travels easily in irrigation water and can rapidly infest the crop area.

Fenceline trials in WA have investigating herbicide treatment alternatives to glyphosate for weed control in crop margin areas along fencelines, firebreaks and boundaries.

Results from 11 trials over three years showed that a single application of bromacil plus paraquat in May or June provided complete control of all weeds at all sites.

While bromacil is relatively expensive, only one application was needed to control all weeds, including summer weeds, for at least one year. But this highly residual herbicide needs to be used carefully and only where there are no trees or risk of wind erosion.

Where the use of bromacil is inappropriate, two control times are often needed – once early in the year, followed by another later in the year. Tank mixes of residual herbicides plus a knockdown give the best control for the first application.

In trials in 2014, an application in May of either simazine plus Alliance® (paraquat plus amitrole) or simazine, 2,4-D and paraquat, followed by a second application of atrazine and paraquat in August, gave very good control.

The addition of Alliance® improved control, especially where there were broadleaf weeds.

Other research outcomes included:

- Slashing followed by a spray later in the season provided good control in situations where weeds were actively growing and there was good spray coverage
- Glyphosate can still be used but intensive monitoring and complete seed set control is required to prevent resistance from developing
- The use of cultivation as a control option generally did not work well in this series of trials but has potential in the right situation

Be sure to adhere to herbicide labels and use full label rates when spraying weeds. [34]

6.7.5 Pre-harvest herbicide use

The application of herbicides late in the season to prevent weeds setting seed or to desiccate crops must be carried out with caution and in line with herbicide label recommendations. It is essential to check if these practices are acceptable to buyers, as in some situations markets have extremely low or even zero tolerance to some pesticide and herbicide residues.

Key points:

- **Correct usage:** Product labels must be followed and withholding periods adhered to for all herbicides. Off-label use without a permit is not allowed and can result in grain being unsaleable.
- **Residues:** Pre-harvest applications to crops increase the risk of detectable herbicide residues in harvested grain, potentially leading to breaches of maximum residue limits (MRLs). MRLs vary according to herbicide, crop and market and these need to be understood.
- **Registration:** Diquat, including Reglone®, is the only registered herbicide for preharvest weed control in barley. However, growers must be aware that some maltsters have certain restrictions on pre-harvest use of herbicides. Consult with buyers before use. weedmaster®DST® is now registered for pre-harvest use in canola and with higher use rates in wheat. It is the only glyphosate formulation registered for use in canola and for higher use rates in wheat.
- **Food safety:** Growers and their advisers need to be aware of the implications of their herbicide applications and the role they play in ensuring food health safety and in protecting the grain industry.
- **Be responsible:** Stewardship must be taken seriously by all sections of the grain value chain.

MORE INFORMATION

Pre-harvest herbicide use: Stewardship for pre-harvest application of herbicides in winter crops – Factsheet.

6.8 Application and conditions for spraying

Herbicides can be applied by a variety of means including boom sprayers (Photo 13), aerial spraying, misters, blanket wipers, rope wick applicators, weed seekers and back-pack sprayers. This section reviews the different types of methods to apply herbicides including nozzles and calibration of equipment.

34 GRDC. (2015). Hot topics: Fenceline weeds in the Western region. https://grdc.com.au/Media-Centre/Hot-Topics/Fenceline-weeds-in-the-western-region

MORE INFORMATION

[Choosing boom spray nozzles for particular conditions]

[Nozzles for spraying herbicides]

VIDEOS

WATCH: Nozzle Selection.

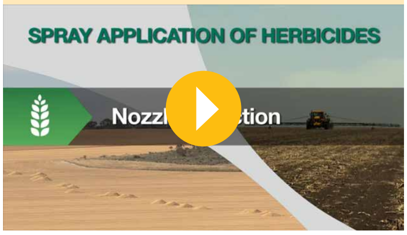


Photo 13: *Boom sprayers are one of many herbicide application methods available to growers.*

Photo: Brad Collis, Source: GRDC

6.8.1 Boom sprayer

A boom sprayer is the most common type of apparatus for applying herbicides in broadscale farming. A sprayer has many components, the most important being the nozzles, which split the herbicide into many small droplets that are projected through the air to the target. The nozzle is the only component of the sprayer that directly determines the effectiveness of spraying. All other components are necessary to position the nozzles and provide them with a continuous supply of herbicide at the correct pressure. Correct nozzle selection and operation are critical for successful spraying.

6.8.2 Misters

Misters are a useful but imprecise way of applying herbicides to large areas quickly. They rely on wind to drift the herbicide. If the wind is too light or the spraying speed too high, the swath width will decrease, possibly causing overdosing and wasted chemical. If the wind is too strong or gusty, it increases the swath width, which will reduce the chemical application rate and increase the risk of damage from spray drift.

6.8.3 Blanket wipers

Blanket wipers are made of a vertical strip of material attached to a horizontal frame. The vertical strip, or blanket, acts as the wiping surface making direct contact with the target weed. This equipment has been developed as an alternative to rope wick applicators. A non-selective herbicide is generally used with successful weed control dependant on the height differential between crop and weed. Wipers are used in broadacre application to control radish or mustard in lupins or chickpeas or to 'top' grasses in pasture. Units have been designed to fit all terrain bikes and hand held equipment has been developed for back yard and environmental use to treat weeds such as cape tulip, Paterson's curse, Guildford grass, arum lily, fressia and bracken fern. Herbicide can be selectively applied to these plants without damaging pasture legumes or native seedlings in revegetation areas. The best time to wipe weeds in crops is September to early October when the weeds are flowering and are 20–30 cm taller than crop or pasture plants.

6.8.4 Rope wick applicators

Rope wick applicators consist of a series of ropes impregnated with a non-selective herbicide, usually glyphosate. They are not widely used, but they can be useful for the control of tall weeds in a crop or pasture. Normal spraying with a non-selective herbicide would not be possible in this situation, however a rope wick applicator can be moved above the crop or pasture and wipe the herbicide only onto the taller weeds, hence selective control is obtained. This technique has been partially successful for controlling cape tulip, docks, rushes, thistles and bracken in pasture.

MORE INFORMATION

Spot spraying, chipping hand roguing and wiper technologies

Because they can only operate at slow speeds and the ropes are very expensive, rope wick applicators have not gained wide acceptance.

6.8.5 Detection technology

Detection technology (for example, Weedseeker and Weedit) uses infrared and near infrared light to detect green weeds and sprays only green plants in paddocks. In action, light-emitting diodes (LEDs) point two different light sources, infrared and near infrared, towards the ground. Green weeds have a different reflective signature to stubble or soil. The system can operate at speeds up to 20 kilometres per hour (km/h), requiring a stable boom to aid operational efficiency.

6.8.6 Calibration of spray equipment

The importance of having your spray equipment accurately set up and calibrated cannot be overstressed. Huge losses can be incurred through incorrect herbicide application. These can range from total failure of the herbicide to kill the weeds, to the extreme where an overdose of herbicides kills both weeds and crop, and may even leave residues in the soil. Even if overdosing does not cause crop damage, the extra cost of the herbicide applied unnecessarily can be significant.

Calibration method

There are many methods for calibrating, usually involving calculations. A simplified method designed for boom sprayers with nozzles at 50 cm spacings is summarised below.

- Measure the output of each nozzle for one minute. This should already have been done when choosing an even set of nozzles.
- Measure the combined output of all nozzles and divide by the number of nozzles. This gives average output per nozzle in millilitres per minute (mL/min).
- Decide on a speed of travel for spraying.
- Measure out a distance of 100m and record the time taken to cover the distance with the spray unit. It is important to calculate the speed on a surface similar to that being sprayed. You can calculate it by: speed (km/h) = 360 ÷ time (seconds) taken to travel 100m.
- Calculate the output using the following formula:

$$\text{Output in L/ha} = \frac{\text{Average output of a nozzle (mL/min)} \times 60}{\text{Nozzle spacing (cm)} \times \text{speed of spraying (km/h)}}$$

To calculate the amount of herbicide needed for each tank of spray, the tank size (volume) must be known. Dividing the tank size by the output (L/ha) gives the number of hectares that can be sprayed with each tank. Multiply the rate of herbicide required per hectare by the number of hectares that can be sprayed per tank to get the amount of herbicide added to each tank.

Example:

- Sprayer with a 1000 L tank; output 50 L/ha
- Number of hectares sprayed/tank: 1000/50 = 20ha
- If the rate of herbicide application is 2 L/ha, the amount of herbicide added to each tank is 2 x 20 = 40 L

To better judge the appropriate rate of herbicide and water requires continuous monitoring of conditions and results to establish the causes of failure or success. To achieve this you must keep records of every day's spray operations, and assessment of herbicide performance.

Herbicide performance is influenced by weather, soil moisture, growth stage and density of the weeds, herbicide rate, water rate, droplet size, and growth stage of the crop.

Record all of these for each paddock each time you use the sprayer. Weather conditions should be recorded at intervals during the spraying operation and for the preceding and following days.

A good marking system is essential to prevent overlap or missed areas when spraying. Overlap of the spray swath results in areas being sprayed twice, which waste both herbicides and time.

MORE INFORMATION

Herbicide application - Nozzles

Missed areas result in uncontrolled weeds, which can reduce yield, provide seeds for future generations or contaminate crops.

Misters are a useful but imprecise way of applying herbicides to large areas quickly. They rely on wind to drift the herbicide. If the wind is too light or the spraying speed too high, the swath width will decrease, possibly causing overdosing and wasted chemical. If the wind is too strong or gusty it increases the swath width, which will reduce the chemical application rate and increase the risk of damage from spray drift. [35]

6.8.7 How to reduce spray drift

The problem

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

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

In areas where a range of agricultural enterprises 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 (Photo 14).

Photo 14: *Reading the product label is even more important than before as requirements may have changed as the labels of currently registered pesticides are being reviewed to include comprehensive instructions on managing spray drift.*

Photo: Emma Leonard

Source: GRDC

35 Peltzer S. (2016). Herbicide application. DAFWA. https://www.agric.wa.gov.au/grains/herbicide-application?page=0%2C0

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

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

Before spraying

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

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

During spraying

- Always monitor weather conditions carefully and understand their effect on 'drift hazard'.
- Don't spray if conditions are not suitable, and stop spraying if conditions change and become unsuitable.
- Record weather conditions (especially temperature and relative humidity), wind speed and direction, herbicide and water rates, and operating details for each paddock.
- Supervise all spraying, even when a contractor is employed. Provide a map marking the areas to be sprayed, buffers to be observed and sensitive crops and areas.
- Spray when temperatures are less than 28°C.
- Maintain a downwind buffer. This may be incrop, for example keeping a boom's width from the downwind edge of the field.
- Minimise spray release height.
- Use the largest droplets that will give adequate spray coverage.
- Always use the least-volatile formulation of herbicide available.
- If there are sensitive crops in the area, use the herbicide that is the least damaging. [36]

Small droplets have a large surface area in relation to their mass. They are therefore easily blown by wind. The higher the wind speed at the time of spraying, the more likely are droplets to be blown away from the target.

Moreover, the liquid carrier may evaporate in hot dry conditions, thus reducing the droplet size in transit from spray nozzle to target.

All spraying systems produce a range of droplet sizes, although the range produced by Controlled Droplet Applicators is much narrower than that of conventional hydraulic nozzles. Therefore, spray drift is impossible to eliminate but it may be reduced to acceptable levels. This can be done by avoiding spraying in adverse

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

conditions (for example, during high winds and temperature inversions) and adjusting the boom spray operation.

As a rule of thumb, droplets with a mean diameter of 250µm (0.25 mm) or larger do not normally drift. So, by aiming for large droplet sizes, drift is reduced.

Smaller droplets are, however, more economical. They give better coverage for a given volume of spray and provide better penetration of foliage and attachment to leaf surfaces.

Large droplets have other disadvantages; they give an uneven cover of the target plant surface and tend to bounce off leaves. They are also less likely than smaller droplets to stick to vertical surfaces and the underside of leaves.

A recent development with nozzle design is air induction or injection. The air induction nozzle draws air into the system using a venturi action and then forms large droplets that are filled with air. These droplets because they are large do not drift as much as the small droplets. When they hit a target they then shatter into a large number of smaller droplets. This way the there is less drift, coverage of the target is still achieved when the large drops shatter into many smaller ones and the air filled drops do not bounce once they hit a target.

Misters and boom sprays produce many small droplets. Misters should never be used up-wind close to susceptible crops. Drift from boom sprays may be minimised by manipulation of the sprayer nozzles (for example, air induction nozzles), spraying height, reduced spraying pressure and tractor speed. Airfoils above booms have also directed the droplets downwards towards the targets.

A long droplet trajectory from nozzle to crop increases the chance of droplets evaporating. To minimise droplet travelling distance, choose wide spray angle flat fan nozzles (110°) rather than the narrow fan angle, for example, 80°, angled backwards at 45° and run the boom as low as possible above crop height.

Vapour drift is a problem with certain chemicals, mainly the volatile ester formulations. The spray vaporises from the soil or plant surface after spraying and may drift many kilometres to damage susceptible crops. This mainly occurs under hot, dry conditions. It can be avoided by use of amine formulations or low volatile esters.

Weather conditions affect both droplet drift and vapour drift. Avoid hot dry conditions and windy days. The best time to spray is in cool, moist conditions in the morning or early evening, but not when the weather is calm because then temperature inversion is likely which can lead to unpredictable spread of chemical droplets. A slight breeze blowing away from the susceptible crop is ideal. [37]

Ensure that herbicide application methods conform to state Legislation, the Aerial Spraying control Act, 1966 and ARRPA Regulations, 1976.

6.8.8 Weather Conditions to Avoid

Midday turbulence

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

High temperatures

- Avoid spraying when temperatures exceed 28°C.

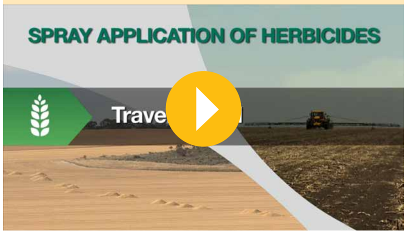
Humidity

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

VIDEOS

WATCH: Spray deposition.

WATCH: Travel Speed.



37 DAFWA. (2016). Avoiding spray drift. https://www.agric.wa.gov.au/residues-crops/herbicide-application-legal-aspects?page=0%2C0

MORE INFORMATION

Practical tips for spraying – GRDC Fact sheet

DAFWA- Herbicide drift

Wind

- Avoid spraying under still conditions.
- Ideal safe wind speed is 3–10 km/h, a light breeze. (Leaves and twigs are in constant motion.)
- 11–14 km/h (a moderate breeze) is suitable for spraying if using low drift nozzles or higher volume application, 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.

Do not spray under inversion conditions.

An inversion exists when temperature increases with altitude instead of decreasing. An inversion is like a cold blanket of air above the ground, usually less than 50 m thick. Air will not rise above this blanket; and smoke or fine spray droplets and particles of spray deposited within an inversion will float until the inversion breaks down.

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

Smoke generators or smoky fires can be used to detect inversion conditions. Smoke will not continue to rise but will drift along at a constant height under the inversion 'blanket'. [38]

6.9 Herbicide tolerance ratings, NVT

Some studies indicate that triticale may be less tolerant to some herbicide cocktails than wheat. Newer herbicides as well as pesticides are now being released with recommendations for use on triticale in many parts of the world. [39]

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

There is anecdotal evidence that triticale tolerates many of the same herbicides as wheat. In 2004 and 2005, trials in the US tested the tolerance of three triticale varieties (AC Alta, AC Ultima, and Pronghorn) with four herbicides registered for wheat: florasulam + MCPA ester, clodinafop-propargyl, thifensulfuron-methyl/tribenuron-methyl, and sulfosulfuron-methyl + 2,4-D ester. Herbicides were applied at the label rate (1×) for wheat and twice (2×) that rate. Crop injury, plant height, biomass, and seed yields were quantified. Neither florasulam + MCPA ester, clodinafop-propargyl, nor thifensulfuron-methyl/tribenuron-methyl at 1× or 2× use rates significantly injured triticale. Sulfosulfuron-methyl + 2,4-D ester reduced triticale height at the 1× and 2× rates, as well as reduced biomass and yield at the 2× rate. Florasulam + MCPA ester, clodinafop-propargyl, and thifensulfuron-methyl/tribenuron-methyl do not cause significant crop injury and can be used for weed control in spring triticale, but sulfosulfuron-methyl + 2,4-D ester is not recommended for use in triticale. [40]

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, a series of cultivar × herbicide tolerance trials are conducted annually.

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

39 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

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

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 pea, lentil, chickpea and faba bean. The intention is to provide data from at least two years of testing at the time of widescale commercial propagation of a new cultivar.

The good news is that >70% of all crop varieties are tolerant to most herbicides. The remaining varieties can experience yield losses of 10–30%, and in some cases, 50% yield loss has been recorded. 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 recently been combined under a national program.

6.10 Potential herbicide damage effect

Excessive herbicide treatments may limit germination in triticale. The successive effect of several herbicide variants (isoxaben, chlorsulfuron) on the germination and plant growth of triticale cultivars has been explored. Germinative energy and germinating power of winter triticale seeds, obtained from plants treated with herbicide, were generally lower, in particular for the isoproturon and chlorsulfuron variants. [41]

6.10.1 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)). 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. [42]

Make sure to read product labels for plant-back periods.

For example:

- Lusta – Registered in triticale, cereal rye, wheat, and oats. Activity occurs through root and foliar uptake. Plant-back recommendations on alkaline soils for triticale and wheat are none.
- Ally - Registered in triticale, wheat, barley and cereal rye. Activity by foliar translocation but also root absorption after rain. [43]

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

42 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

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

6.10.2 Herbicide residues in soils – are they an issue?

The move to conservation tillage and herbicide-tolerant crop cultivars means that many farmers are relying on herbicides for weed control more than ever before. Despite the provision of plant-back guidelines on herbicide product labels, site-specific factors such as low rainfall, constrained soil microbial activity and non-ideal pH may cause herbicides to persist in the soil beyond usual expectations. Because of the high cost of herbicide residue analysis, information about herbicide residue levels in Australian grain cropping soils is scarce.

In addition, little is known about how herbicides affect soil biological processes and what this means for crop production. This is especially the case for repeated applications over multiple cropping seasons. In Australia, herbicides undergo a rigorous assessment by the Australian Pesticides and Veterinary Medicines Authority (APMVA) before they can be registered for use in agriculture. However, relatively little attention is given to the on-farm soil biology – partly because we are only now beginning to grasp its complexity and importance to sustainable agriculture. Although a few tests are mandatory, such as earthworm toxicity tests and effects on soil respiration, functional services provided by soil organisms such as organic matter turnover, nitrogen cycling, phosphorus solubilisation and disease suppression are usually overlooked.

GRDC recently co-funded a five year project (DAN00180) to better understand the potential impacts of increased herbicide use on key soil biological processes. This national project, co-ordinated by the NSW Department of Primary Industries with partners in Western Australia (WA), South Australia (SA), Victoria (Vic) and Queensland (Qld), is focussed on the effect of at least six different herbicide classes on the biology and function of five key soil types across all three grain growing regions.

Main conclusions:

- Glyphosate, trifluralin and diflufenican are routinely applied in grain cropping systems and their residues, plus the glyphosate metabolite AMPA, are frequently detected at agronomically significant levels at the commencement of the winter cropping season.
- The risk to soil biological processes is generally minor when herbicides are used at label rates and given sufficient time to dissipate before re-application.
- However, given the frequency of glyphosate application, and the persistence of trifluralin and diflufenican, further research is needed to define critical thresholds for these chemicals to avoid potential negative impacts to soil function and crop production. [44]

MORE INFORMATION

Herbicide residues in soils, are they an issue?

6.10.3 Avoiding residual herbicide damage

When researching the residual activity and cropping restrictions following herbicide application, the herbicide label is the primary source of information and it should be read thoroughly.

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 (Lusta®) is used in wheat and barley, but it can remain active in the soil for several years and damage legumes and oilseeds. A real difficulty for growers lies in identifying herbicide residues before they cause a problem. Currently, growers rely on information provided on the labels about soil type and climate. Herbicide residues are often too small to be detected by chemical analysis, or if testing is possible, it is too expensive to be part of routine farming practice. Once the crop has emerged, diagnosis is difficult because the symptoms of residual herbicide damage can often be confused

44 GRDC. (2016). GRDC Update Papers: Herbicide residues, are they an issue? https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/herbicide-residues-in-soils-are-they-an-issue-northern

with, and/or make the crop vulnerable to, other stresses, such as nutrient deficiency or disease.

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

How can I avoid damage from residual herbicides?

Select a herbicide which is necessary for the weed population you have. Make sure you consider what the recropping limitations may do to future rotation options.

Read the herbicide label including the fine print.

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

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.

Be wary of compounding a residue problem by planting a herbicide resistant crop and spraying with more of the same herbicide group. You may get around the problem with residues in the short term, only to be faced with herbicide resistant weeds in the longer term. [45]

6.10.4 Conditions required for herbicide breakdown

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

6.11 Herbicide resistance

It is important to differentiate between herbicide resistance and herbicide tolerance.

Herbicide resistance is the inherited ability of an individual plant to survive a herbicide application that would kill a normal population of the same species. Whereas, herbicide tolerance is the inherent ability of a species to survive and reproduce after herbicide treatment at a normal use rate. There is no selection involved (through herbicide application) because the species is naturally tolerant.

Over 25 weed species in Australia currently have populations that are resistant to at least one herbicide 'mode of action' (MOA) group (Photo 15).

45 DEPI (2013) Avoiding crop damage from residual herbicides, Department of Environment and Primary Industries Victoria.

Photo 15: *Wild radish resistance is an emerging problem, but recent research by is finding control of the weed is effective with a two-spray approach, with the first spray at the two to three leaf stage, followed by a second spray at the five to six leaf stage.*

Photo: Simon Craig, Source: GRDC

Herbicide resistance is normally present at very low frequencies in weed populations before the herbicide is first applied. Variation exists within every population, with some individuals having the ability to survive the herbicide application.

A weed population is defined as resistant when a herbicide that once controlled the population is no longer effective (sometimes an arbitrary figure of 20% survival is used). The proportion of herbicide resistant individuals will rise due to selection pressure in situations where one herbicide MOA group is applied repeatedly.

Herbicide resistance is permanent in weeds and their progeny with dominant 'target site' resistance. With cessation of the use of that herbicide MOA group, the ratio of dominant target site resistant to susceptible individuals will remain the same – only the total number of weeds present can be reduced. Weeds with this type of resistance do not exhibit a fitness penalty.

How does a weed become resistant to a herbicide?

There are three major ways in which resistance may arise within a weed population:

1. Pre-existing resistance: Within any weed population there may be some plants that already contain a rare change in a gene (or genes) that enable them to survive the application of a particular herbicide that would normally kill this species. Genetic variation may alter physiological traits that enable herbicide uptake, translocation and activation at the site of action. Alternatively, changes may influence the plant's ability to detoxify herbicides, or enable transport to a site within the plant where the herbicide is not lethal. Each time the herbicide is applied, susceptible plants die and those with resistance survive.
2. Importation of resistance: It is possible that resistance may not be present in the population initially, but is introduced as a weed contaminant in crop seed or fodder, on machinery or on/in animals. This is particularly important for 'rarer' forms of resistance such as glyphosate resistance.
3. Natural dispersal: Weed seeds can also be spread by wind and water. Pollen can also be dispersed great distances although the percentage remaining viable at

MORE INFORMATION

Commonly used herbicides resistance terms

GRDC Herbicide resistance factsheet – Western region

distances greater than 10m is low. Floodwater also has the potential to move a wide range of weed seeds over large distances.

6.11.1 General principles to avoid resistance

Herbicides have a limited life before resistance develops, if they are used repeatedly and exclusively as the sole means of weed control, particularly in zero and minimum tilled systems. Resistance can develop within four to eight years for Group A and B herbicides and after 15 years for Group L and M herbicides (see Table 3 and Figure 2). 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 3: *Rules of thumb for the number of years of herbicide application before resistance evolves*

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

Source: Chris Preston, University of Adelaide, in DAFF

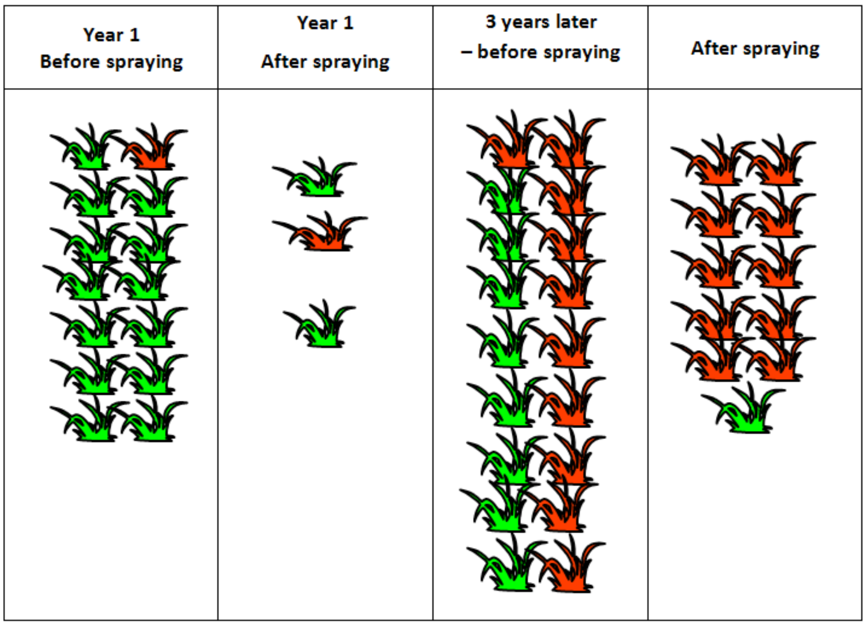


Figure 2: *How a weed population becomes resistant to herbicides.*

Source: GRDC

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

- Ensure survivors do not set seed and replenish the soil seed bank.

- Keep accurate paddock records of herbicide application and levels of control. Monitor weeds closely for low levels of resistance, especially in paddocks with a history of repeated use of the same herbicide group.
- Rotate between the different herbicide groups, and/or tank mix with an effective herbicide from another mode of action group. It is important to use effective ´stand-alone´ rates for both herbicides in the mix.
- Aim for maximum effectiveness to keep weed numbers low. The primary aim of weed control is to minimise their impact on productivity, and resistance is much less likely to develop in paddocks with fewer weeds than in heavily infested paddocks.
- Use a wide range of cultural weed control tools in your weed management plan. Sowing different crops and cultivars provides opportunities to use different weed management options on key weeds. Tillage is useful when it targets a major weed flush and minimises soil inversion, as buried weed seed generally persists longer than on the soil surface. Competitive crops will reduce seed production on weed survivors.
- Avoid introduction or spread of weeds by contaminated seed, grain, hay or machinery. Also, manage weeds in surrounding non-crop areas to minimise risk of seed and pollen moving into adjacent paddocks.

Specific guidelines for reducing the risk of glyphosate resistance are outlined in Table 4. Aim to include as many as possible of the risk decreasing factors in your crop and weed management plans.

Table 4: *Balancing the risk for weeds developing glyphosate resistance, devised by the national Glyphosate Sustainability Working Group with minor modifications for the Queensland cropping region.*

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

Source: DAFF

MORE INFORMATION

Australian glyphosate resistance register.

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

6.11.2 Options for herbicide resistance testing

There are a number of different methods of testing for herbicide resistance. Tests can be performed in situ (in the paddock during the growing season), on seed collected from the suspect area or by sending live plant samples to a testing service.

Resistance testing

This can be conducted on-farm or by a commercial resistance testing service.

In-situ testing

An in-situ test can be performed following herbicide failure in a paddock. The test should be done at the earliest opportunity, remembering that the weeds will be larger than when the initial herbicide was applied. Test strips should be applied using herbicide rates appropriate to the current crop growth stage and weed size, plus a double rate. The test strips should only be applied if the weeds are stress free and actively growing. To more accurately assess the level of control, conduct weed plant counts before and after application. Green or dry plant weights can be calculated for more accurate results.

Herbicide resistance seed tests

Seed tests require collection of suspect weed seed from the paddock at the end of the season. This seed is generally submitted to a commercial testing service.

There are two commercial seed testing services in Australia

- Peter Boutsalis, Plant Science Consulting
- John Broster, Charles Sturt University, +61 (0)2 6933 4001

Approximately 3000 seeds of each weed (an A4-sized envelope full of good seed heads) is required for a multiple resistance test. This equates to about one cup of annual ryegrass seed and six cups of wild radish pods.

Syngenta herbicide resistance Quick-Test™

The Syngenta herbicide resistance Quick-Test™ (QT) uses whole plants collected from a paddock rather than seeds, eliminating the problem of seed dormancy and enabling a far more rapid turnaround time. In addition, the tests are conducted during the growing season rather than out of season over the summer. A resistance status result for a weed sample is possible within four to six weeks. The QT, which was developed by Dr Peter Boutsalis while working for Syngenta in Switzerland, is patented in Australia.

For each herbicide to be tested, 50 plants are required. To reduce postage costs, plants can be trimmed to remove excess roots and shoots. Upon arrival at the testing service, plants are carefully trimmed to produce cuttings and transplanted into pots. After appearance of new leaves (normally 5–7 days), plants are treated with herbicide in a spray cabinet. The entire procedure, from paddock sampling to reporting results, takes between 4–6 weeks, depending on postage time and the herbicides being tested. Unlike paddock tests, the QT is performed under controlled conditions, so it is not affected by adverse weather conditions. The age of the plants is also less critical to the testing procedure. Trimming the plants prior to herbicide application means that herbicides are applied to actively growing leaves, thus mimicking chemical application to young seedlings. The Quick-Test™ has been used to test resistance in both grass and broadleaf weed species. During testing, both known sensitive and resistant biotypes are included for comparison.

Quick-Tests can be done with Peter Boutsalis, Plant Science Consulting.

6.11.3 Weedsmart- 10 point plan

WeedSmart, an industry-funded herbicide sustainability initiative, has developed a 10 Point Plan for implementing IWM systems.

1. Act now to stop weed seed set

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

- Destroy or capture weed seeds.
- Understand the biology of the weeds present.
- Remember that every successful WeedSmart practice can reduce the weed seedbank over time.

MORE INFORMATION

Strategic risk management factsheet

Farm business management factsheet

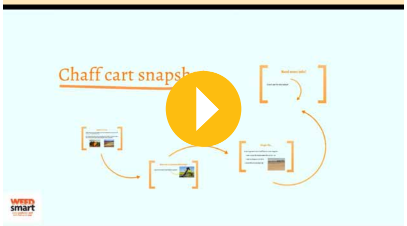
RIM model

VIDEOS

WATCH: Act now: Plan your weed management program

VIDEOS

WATCH: Chaff carts 101

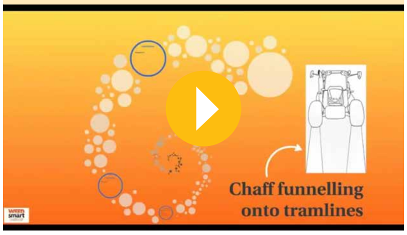


WATCH: Capture weed seeds at harvest: Harrington seed destructor

WATCH: Strategic narrow windrow burning

WATCH: The art of narrow windrow burning

WATCH: Chaff funneling onto tramlines



- Be strategic and committed—herbicide resistance management is not a 1-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. (Photo 16)
- Create and burn narrow windrows.
- Produce hay where suitable.
- Funnel seed onto tramlines in controlled traffic farming (CTF) systems.
- Use a green or brown manure crop to achieve 100% weed control and build soil nitrogen levels.

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

Photo 16: *Harrington weed seed destructor at work in the paddock.*

Source: GRDC

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

VIDEOS

WATCH: Capture weed seeds at harvest: Bale Direct System

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

3. Rotate crops and herbicide modes of action

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

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

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

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

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

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

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

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

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

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

Perhaps the best use for herbicide resistance tests is to use them in a game changing situation such as the discovery of a rare resistance gene (e.g. glyphosate resistance) or to determine if a patch of surviving weeds are any worse than what the grower has observed before. This bad patch of weeds gives insight into the future resistance profile of the farm if it is not contained and resistance testing in these situations can be very useful in building preventative strategies.

5. Never cut the rate

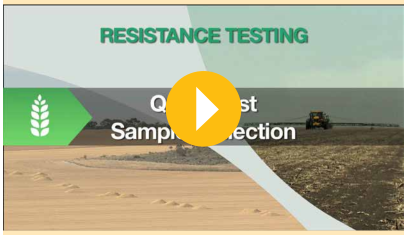
AHRI researcher Dr. Roberto Busi found that ryegrass receiving below the rate Sakura® evolved resistance not only to Sakura® but to Boxer Gold® and Avadex® too.

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.

VIDEOS

WATCH: IWM: Resistance Testing—'Quick-Test' sample collection



WATCH: IWM: Seed test—What's involved

WATCH: Don't cut the rate

WATCH: Don't automatically reach for glyphosate

WATCH: Manage spray drift

6. Don't automatically reach for glyphosate.

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

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

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

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

7. Carefully manage spray events

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

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

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

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

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

8. Plant clean seed into clean paddocks with clean borders.

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

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

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

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

- It is easier to control weeds before the crop is planted.
- Plant weed-free crop seed to prevent the introduction of new weeds and the spread of resistant weeds.
- A recent Australian Herbicide Resistance Initiative (AHRI) survey showed that 73% of grower-saved crop seed was contaminated with weed seed.

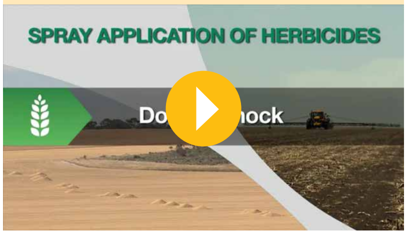
VIDEOS

WATCH: Plant clean seed into clean paddocks with clean borders

WATCH: Best results with double-knock tactic

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

WATCH: Spray application of herbicides—Double-knock



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

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

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

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

10. Employ crop competitiveness to combat weeds.

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

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

If you think you have resistant weeds

When resistance is first suspected, 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 mode of action 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 our crop and food science researchers via the Customer Service Centre for advice on sampling suspect plants for testing of resistance status..
2. Ensure all suspect plants do not set any seed.
3. If resistance is confirmed, develop a management plan for future years to reduce the impact of resistance and likelihood of further spread. [46]

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

VIDEOS

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

WATCH: Learn to think outside the drum

WATCH: Crop competition—Increasing wheat seeding rate

WATCH: Crop competition—Row spacing

MORE INFORMATION

CropLife Australia

Australian Glyphosate Sustainability Working Group

Australian Herbicide Resistance Initiative

Cotton Catchment Communities CRC (Weedpak)