Chapter 7
Herbicide Resistance

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Photo: A. Johnson

Annual ryegrass.

Herbicides are an important part of weed control as they are cheap and easy to use over large areas in a short amount of time. In Australia, herbicide resistance has been detected to seven of the major herbicide groups (Table 7.1). Herbicide resistance can be delayed by using simple methods such as mode of action rotation, use of herbicide mixtures and rotating between cropping and pasture phases.

Control of resistant weeds is not simply achieved by changing chemicals. Reliance on one herbicide mode of action to solve the resistance problem in another mode of action increases the risk of multiple resistance developing (resistance to both chemicals).

Companies have indicated that new herbicides are difficult and costly to develop. The current herbicides that we have must be treated as a limited resource and they need to be used strategically in an Integrated Weed Management (IWM) program if they are to retain their utility for the future.

There are a range of non herbicide weed management strategies that can be integrated with herbicides to prolong their life. Effective weed management is about maintaining the usefulness of herbicides as well as good weed control.

Why do weeds develop resistance?

Resistant weeds are naturally present in most paddocks in low numbers, even if herbicides have not been applied. Weeds not controlled by a herbicide application are either spray escapes or are naturally resistant survivors. If the resistant weeds set seed, the proportion of resistant weeds in the paddock increases. Resistant weeds will eventually dominate the population if high selection pressure is continued by repeatedly using the same herbicide group.

Once a weed population is resistant to a herbicide it is also resistant to other herbicides with the same mode of action. Changing brand names will not control these weeds. Be aware of the mode of action group of the product, and use different chemical modes of action. Multiple resistance (to more than one mode of action) has developed in some weed populations of annual ryegrass and wild radish.

Once resistance has developed in a paddock it will be impossible to totally eradicate all the resistant individuals. It will be necessary to adopt an IWM plan that keeps the numbers of resistant individuals at very low levels in future crops.

The rate at which herbicide resistance appears in a population is affected by the selection pressure placed on the population, the initial frequency of the resistance gene and the total number of weeds treated.

Resistance may develop in one location under certain conditions but may not develop in another location under similar conditions.

Herbicide groups and rotation

Herbicides are grouped by the mode of action of their active ingredient. When weeds are resistant to a herbicide, they have one or more ways of stopping the herbicide from working in the plant.

Each product's mode of action is indicated by a letter code on the product label. For example, Hoegrass® is a Group A herbicide. Annual ryegrass that is resistant to Hoegrass® will probably be resistant to Targa®, Fusilade®, Verdict®, Correct® and many other Group A herbicides in the same class within that mode of action and might even be resistant to other classes.

Weeds are more likely to develop resistance to Group A and B herbicides than Group M herbicides. The risk of herbicide resistance developing increases as the frequency of naturally resistant individuals present increases.

In annual ryegrass the gene for Group A resistance is so common (possibly as frequent as 1 in 1 000 000) that any paddock could have some resistant plants before a herbicide is used. Group A ryegrass resistance is commonly observed after six to eight applications of a Group A products. These do not need to be consecutive applications.

Glyphosate resistant weeds may be as rare as one in 10 million to one in a billion. Naturally occurring glyphosate resistance weeds may not always be present in every paddock.

Figure 7.1 Resistant weeds are naturally present in most paddocks and can dominate the population if a different herbicide mode of action or another form of weed control is not used to control them.

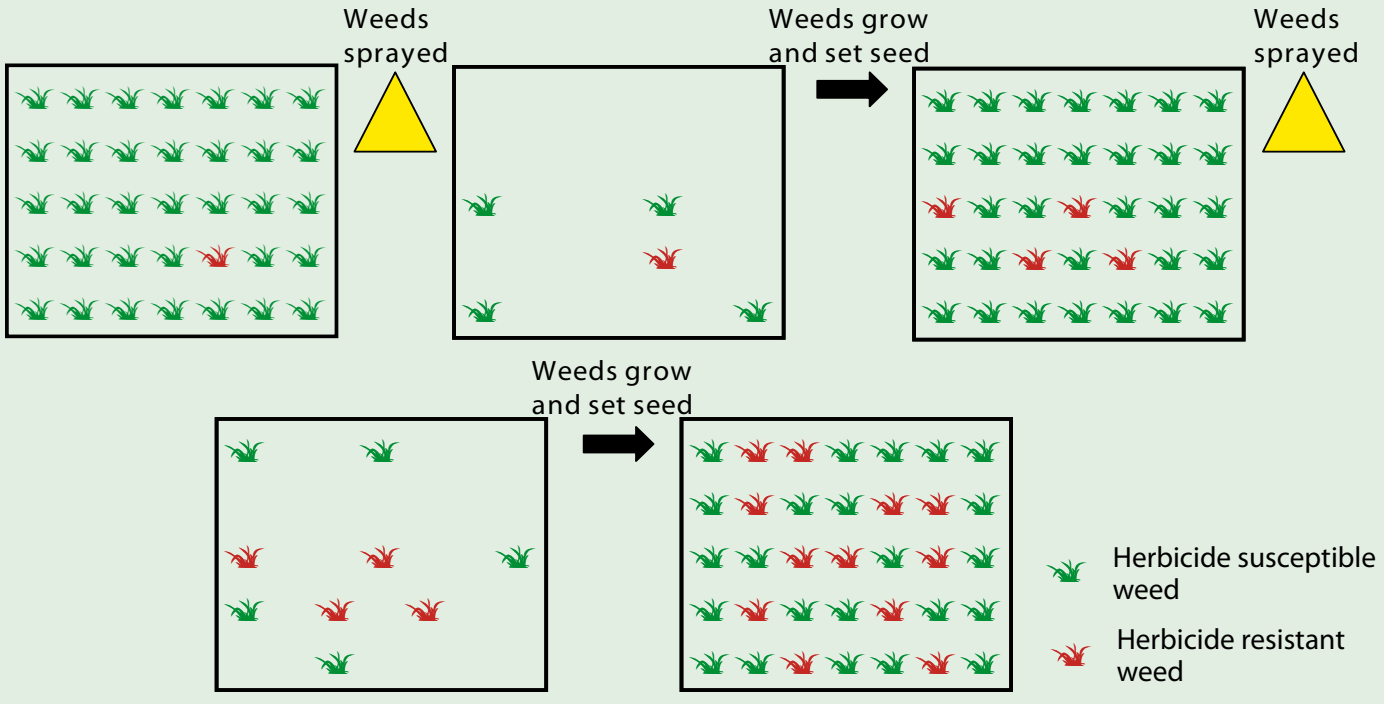

Table 7.1 Herbicide uses and the recommended frequency of application as developed by Croplife Australia. These recommendations are updated each year. For the most recent version see www.croplife.org.au

Group	Uses	Resistance developed in Australia	Recommended use
A	Post-emergent control of annual ryegrass, wild oats and a wide range of grasses in broadleaf crops and some cereal crops.	annual phalaris, annual ryegrass, barley grass, brome grass, lesser canary grass, northern barley grass, paradoxa grass, summer grass and wild oats	Avoid using a group A herbicide to control the same grass weed in consecutive seasons irrespective of the performance it gave. In all cases try and ensure surviving weeds from any treatment do not set and shed seed.
B	Pre- and post-emergent control of a wide spectrum of weeds including annual ryegrass and many broadleaf weeds in winter crops.	african turnip weed, annual ryegrass, barley grass, black bindweed, charlock, common sowthistle, iceplant, indian hedge mustard, lincoln weed, Paterson's curse, prickly lettuce, summer grass, turnip weeds, wild mustard, wild oat, wild radish and wild turnip	Do not apply more than one application of a group B herbicide in a season. Apply no more than 2 group B herbicides in any four year period on the same paddock. For post-emergent use tank mix with another mode of action or follow up spray with non group B herbicide. If there are significant grass weed escapes following the herbicide application consider using a non selective control method to control seed set.
C	For pre-plant soil applied residual weed control in wheat and post-emergent contact herbicides for selective grasses and broadleaf weeds in broadleaf crops.	annual ryegrass, barnyard grass, liverseed grass, stinging nettles and wild radish	Do not use group C herbicides in consecutive years. A maximum of 2 applications per season for triazine. May be used as a pre-plant followed by a post-emergent application. The total amount of triazine used is not to exceed 3 kg a.i./ha per year. For triazine tolerant canola, avoid dry sowing in heavily weed infested paddocks. Wait for a second weed germination after the opening rains in weedy paddock situations. Use another control method such as a pre-plant knockdown herbicide or cultivation. No weeds should be allowed to survive this stage.
D	Pre-plant soil incorporated herbicides for control of annual grasses and selected broadleaf weeds.	Annual ryegrass, dense flowered fumitory	Avoid using group D herbicides every year. Where possible, avoid the use of group D herbicides on dense ryegrass populations. Consider using alternative methods of weed control to reduce weed numbers before applying herbicides.
F	Soil incorporated pre- or post-emergent herbicides with some residual control.	wild radish	Do not apply group F herbicides in any two consecutive years unless one application is a mixture with a different mode of action that is active on the same weed, or a follow up spray is conducted (using a different mode of action) to control escapes.
G	Contact herbicide for pre- or post-emergent control. Control of weeds prior to establishment of pastures or crops.	Nil	Rotate herbicide modes of action.
I	Late post-emergent control for a wide range of broadleaf weeds in cereals. Broad spectrum weed control in fallows.	wild radish	Avoid applying 2 applications of straight Group I herbicides on the same populations of weeds in the same season. Prevent seed set. Where possible combine several different modes of action in the one application, each at rates sufficient to control the target weed alone to reduce the likelihood of weeds resistant to group I herbicide surviving.

K	Post-sowing pre-emergent for selective control of certain grasses and broadleaf weeds in legumes or pasture. Selective spray topping for wild oats in wheat.	Nil	Rotate herbicide modes of action.
L	Non selective weed control in lucerne. Pre-harvest desiccation for broadleaf crops and non selective weed control. Broad spectrum weed control in fallows.	barley grass, capeweed, northern barley grass, silver grass and vulpia	Rotate mode of action groups. Occasional mechanical cultivation for weed control. In lucerne, where possible use a mixture of diuron for winter cleaning.
M	Broad spectrum knockdown weed control in fallows or pre-harvest in cereals.	annual ryegrass	Development of group M resistance is rare. Use cultivation, the double knock technique and strategic rotation.
N	Registered for horticulture only. Knockdown control of broadleaf and grass weeds.	Nil	Rotate herbicide modes of action.
Multiple resistance is defined as the expression of more than one resistance mechanism within individual plants and can lead to simultaneous resistance to herbicides with different modes of action. Multiple resistance can develop from using several herbicides, but can also occur by repeated use of a single herbicide. A combination of huge numbers over vast areas, large genetic variation, cross pollination and strong selection pressure are factors responsible for the appearance of multiple resistance in ryegrass.			
NB: Products within groups can be used for widely different purposes. Always check the label for each particular product before use. Assess the efficacy of a product after application. If failure is suspected do not use the same product or a product from the same mode of action group to control the escapes.			

Preventing herbicide resistance

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

- Ensure survivors do not set seed and replenish the seed bank.
- Keep accurate paddock records of herbicide applications 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 of control to keep weed numbers low. The primary aim of weed control is to minimise the impact of weeds on productivity, and resistance is much less likely to develop in paddock with fewer weeds than in heavily infested paddock. Apply herbicides with properly calibrated equipment under the best conditions. Treat small weeds.
- Avoid the introduction or spread of weeds by contaminated seed, grain, hay or machinery. Also, manage weeds in surrounding non-crop areas to minimise the risk of seed and pollen moving into adjacent 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.

What to do if you suspect herbicide resistance

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

- Was the herbicide applied in conditions and at a rate that should kill the target weed?
- Were the suspect plants shielded from herbicide contact or have emerged after the herbicide application?
- Does the pattern of surviving plants suggest a spray miss or other application problem?

The CRC for Australian Weed Management recommends that if resistance is still suspected to contact your advisor agronomist who may need to collect mature seed samples for testing.

If herbicide resistance is suspected, action needs to be taken to prevent weed seed set. Options include, cutting the crop for silage or hay, green manuring or rotating to a pasture phase.

Case Study 7.1 Managing wild oats herbicide resistance. By Kathi Hertel

Name	Rob Shanks.
Property	"Marathon" Dubbo and "Glen Lossie" Collie (3000 ha)
Enterprise	Enterprise includes wheat, barley, oats, triticale, canola, albus lupins, faba beans, hay, silage and straw production. Livestock include cattle and sheep (wool and prime lambs).
Landscape and soil	Mostly flat with some slightly undulating country. Soils are heavy grey clays to clay loams to sandy loams.
Rainfall	"Marathon" – 525 mm; "Glen Lossie" – 460 mm. Non seasonal.
Advantages	Flexibility of crop types to the large range of soil types. This offers considerable scope for diversity of enterprises and value-adding such as straw production. Cereal hay production is an excellent means to manage problem weeds.
Disadvantages	Lifestyle pressures. Have had to go away from relying on contracting for harvest and haymaking because of the timeliness required to produce hay specifications to established markets. Undersown pastures can slow up rotary harvesters which resulted in an increase in harvesting costs.
Future directions	Want to become less reliant on cash crops or opportunity cropping. Aiming to be producing a product at a specified price under contract.

Wild oats herbicide resistance

In 2002, in a third year consecutive wheat crop, clumps of 20–30 wild oat plants remained after the crop had been sprayed with the selective grass herbicide Topik® (Group A).

With a history of three selective grass herbicide applications within a four year period, herbicide resistance was suspected. Testing confirmed Group A resistance in 5% of the paddock's wild oat population.

A management strategy aimed to eradicate the resistant population was then implemented, incorporating a number of control measures (Table 7.2). This strategy involves regular monitoring for wild oat germinations and controlling wild oat plants before seed set.

Table 7.2 Herbicide resistance management program.

2002	Wild oat resistance to Group A's confirmed in wheat crop.
	Wild oats topped with 3.0 L/ha Mataven® (Group K) with excellent results.
	The harvestor was cleaned after paddock with resistance was harvested to prevent any spread to other paddocks.
2003	Wild oats was allowed to germinate in autumn and then heavily grazed by sheep.
	Paddock sprayed with Roundup CT® (Group M) at the end of July .
	A small population of late germinating wild oats were sprayed with Roundup CT® at the end of September.
2004	Lucerne and medic pasture sown in autumn. Lucerne was spray topped with Gramoxone® in spring.
2005	Low density of wild oats remaining in lucerne spray topped.
2006	Ongoing pasture management to maintain competitive pasture and continued monitoring of any wild oat germinations.

Photo: K. Hertel

Rob Shanks.

Weed management

Weed populations are monitored to maintain minimal populations using a combination of management approaches including strategic herbicide applications and rotations, competitive crops and pasture phases, green manure crops, haymaking and silage, and utilising grazing sheep.

Light germinations of volunteer cereals are crash grazed with large mobs of sheep from March to May. In large paddocks, an electric fence is used to increase grazing pressure. "Observations made over the years appear to show that the grazed areas are better in the following years in terms of both weed control and nitrogen levels."

If crops (field peas) are green manured, they are ploughed in during the first week of September. Silage is cut in mid to late September, prior to weed seed set.

Hay wheats are sown where there are heavy wild oat infestations. Timing of hay cutting is dictated by the wild oats not the wheat and is before the wild oats reaches the milky dough stage. Normal crop rotation follows in subsequent years.

Table 7.3 Calender of operations.

January – March	fallow management as required.
April	sow oats into established lucerne, sow albus lupins, canola, faba beans and soft wheat. Weed control as required.
May	sow main wheats. Sow barley, oats, triticale.
June	finish sowing if necessary.
July/August	monitor weeds and control as necessary.
September	late crop top application of Mataven® if necessary, thistles controlled in lucerne, spray top ryegrass in lucerne.
mid October	cut hay and silage.
November	harvest cereals, bale forage wheats, windrow and harvest canola and faba beans.
December	straw baling, fallow weed control where necessary.

Weed spectrum observations

Wild radish tends to be biggest problem weed in the red soil type country. On black soils, wild oats and melons are the worst weeds. These particular weeds are targeted before beginning the cropping phase in paddocks.

Rotations

The crop rotations and pasture phases are aimed at minimising weed populations and strategically rotating herbicides to prevent further development of herbicide resistance (Figure 7.2). Grazing plays a major role in delaying herbicide resistance. Silage is cut in paddocks with heavy infestations of ryegrass or broadleaf weeds. Wheat for hay is grown where there are large wild oat populations. Green manure crops are also used to minimise weed populations.

Figure 7.2 Rotations for (a) black and (b) red soils

(a) canola → PH wheat → grazing oats/soft wheat → wheat undersown lucerne and medic → 4–5 years lucerne and medic

OR

hay wheat → PH wheat → pulse → wheat grazing oats → wheat undersown with lucerne and medic → 4–5 years lucerne and medic

(b) canola → PH wheat → pulse → barley → oats/soft wheat → wheat undersown with lucerne and subclover.

Fallow phase

The biggest problem in summer fallows is effective control of melons. The melons are sprayed with 2,4-D amine (taking care of drift due to cotton grown in the area, which is 2,4-D sensitive) combined with heavy sheep numbers to control the melons.

Cereal crop phase

Glean® (Group B) is applied as a post-emergent herbicide in wheat and barley. Glean® is applied pre-emergent as there have been crop germination problems in cold conditions. A late post-emergent herbicide, 2,4-D amine (Group I) is used to control any volunteer canola. The treatments are the same if triticale is grown.

Oats has an early post-emergent mixture of Glean® and MCPA amine (Group I) to control capeweed and Paterson's curse in some paddocks.

Broadleaf crop phase

Conventional or triazine tolerant varieties of canola are grown. Treflan® (Group D) is usually applied as another chemical rotation for ryegrass and wild oats.

Pulse crops are grown using a variety of herbicides. Treflan® is used in faba beans and chickpeas as a pre-emergent herbicide. Lupins and chickpeas have a post-sowing pre-emergent (PSPE) application of simazine (Group C). Spinnaker® (Group B) is applied PSPE in field peas.

Pasture

Lucerne and medic, or clover (depending on soil type) is generally undersown with the last wheat crop using Treflan® pre-emergent to target ryegrass, wild oats and wireweed.

On red soil country, wild radish is controlled during the first year with Spinnaker® (Group B).

In the last year of the pasture, grasses and thistles are removed using a knockdown herbicide and 2,4-D amine respectively. Galvanised or Bathurst burrs are chipped if required.

Half the lucerne is removed by cultivation and half by using herbicide. If the lucerne to be removed by cultivation it is heavily grazed up until cultivation. If using chemical removal the stock are removed two to three weeks before the herbicide application. The lucerne is allowed to grow back to early flowering and Roundup CT® and 2,4-D amine are used to kill the lucerne.

Case Study 7.2 Glyphosate Resistance

There is a risk when using glyphosate. As of April 2006 there were 54 reported populations of glyphosate resistant annual ryegrass (24 in broad acre cropping) in Australia.

The following increase the risk of glyphosate resistance developing

- Continuous reliance on glyphosate alone for weed control prior to sowing the crop.
- Frequent crop topping with glyphosate.
- Frequent glyphosate based chemical fallows.
- Lack of tillage at any stage.
- High weed numbers.
- Lack of effective in crop weed control.

The following reduce the risk of glyphosate resistance developing.

- Strategic use of the double knock technique e.g. glyphosate shortly followed by a paraquat and diquat application.
- Strategic use of alternative knockdown herbicide groups such as Group L (paraquat) or Group I (2,4-D, dicamba), or tillage for fallow weed control .
- Full cut cultivation at sowing.
- Effective in crop weed control e.g. Groups A, B or C.
- Non herbicide practices for weed seed kill, e.g. grazing or cutting for hay.
- Farm hygiene to prevent resistant seed movement.

Source: Storrie, 2005; A. Storrie, pers. comm.

Economics of delaying resistance

Economic studies have proven that herbicide resistance is so expensive to manage in crops that it is worth rotating to pastures for the purpose of delaying resistance.

Pasture phases, a long fallow or hay production may not have a production value as high as cropping but have a higher value if they are used to delay herbicide resistance.

The pasture and/or fallow phase can be used to significantly reduce the seed bank and prevent the resistant population from dominating the total weed population and spreading across the farm. For this to occur, the weeds in pastures and/or in fallow need to be *effectively controlled*. If the pasture or fallow phase is a no management phase the herbicide resistance management benefits are lost.

Additional benefits from a fallow or pasture phase include: grazing pastures or hay production to generate income; to encourage nitrogen fixation and to reduce deep drainage; and conservation of soil moisture and nutrients in a long fallow which increases yield potential in the following crops.

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