Chapter 7
Herbicide Resistance

Compiled by Annie Johnson, Nathan Border, Bob Thompson and Andrew Storrie

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.

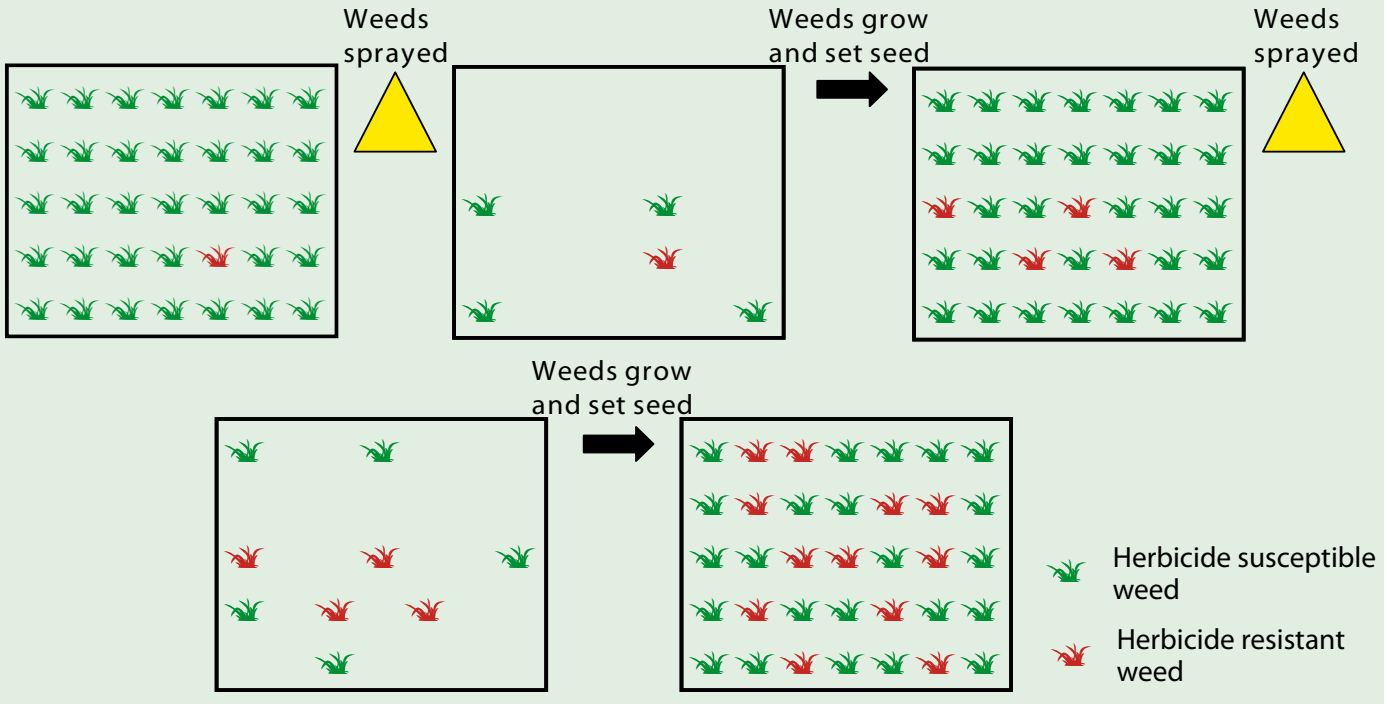

Table 7.1 Herbicide uses and the recommended frequency of application as developed by Croplife Australia. These recommendations are updated each year. For the most recent version see www.croplife.org.au

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.

References

Croplife (2005) *Herbicide Resistance Management Strategies*, Croplife and CRC for Weed Management. Available from www.croplife.org.au

Gill, G. (2004) Controlling weeds with herbicide resistance. Research Update, GRDC.

Heap, J. (1999) Herbicide resistance in weeds. Research Update, GRDC.

Hole, C. (2004) Crops and rotations to beat herbicide resistance putting effective management packages together. Research Update, GRDC.

Llewellyn, R. (2004) Meeting the new herbicide resistance challenges. Research Update, GRDC.

Preston, C. (2005) How to get glyphosate resistant weeds on your farm. Research Update, GRDC.

Preston, C. and Wakelin, A. (2004) Herbicide Resistance and its management. Research Update, GRDC.

Storrie, A. (2004a) Double knock, group A resistance in wild oats and sprayer decontamination. Research Update, GRDC.

Storrie, A. (2004b) Glyphosate resistance and group A resistance in wild oats, and fleabane management. Research Update, GRDC.

Storrie, A. (2005) Glyphosate resistant weeds – what's next if you don't make changes now. Research Update, GRDC.

Journal papers

Gorddard, R.J., Pannell, D.J. and Hertzler, G. (1996) Economic evaluation of strategies for management of herbicide resistance. *Agricultural Systems* 51:281–298.

Powles, S.B., Preston, C., Bryan, I.B. and Jutsum, A.R. (1997) Herbicide resistance: impact and management. *Advances in Agronomy* 58:57–93.

Powles, S.B., Lorraine-Colwill, D.F., Dellow, J.J. and Preston, C. (1998) Evolved resistance to glyphosate in rigid ryegrass (*Lolium rigidum*) in Australia. *Weed Science* 46: 604–607.

Swain, J.M. (1996) Industry perspectives of annual grass management and control in Australian agriculture. *Plant Protection Quarterly* 11:223.

Books

Storrie, A., Cook, T., Moylan, P., Maguire, A., Walker, S. and Widderick. M. (2006) *Managing Herbicide Resistance in Northern NSW*. GRDC and NSW DPI.

Chapter 8
Herbicide Use

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Photo: A. Johnson

Self propelled spray rig.

Herbicide selection may appear to be a complex choice. Plan your use of herbicides as part of your IWM strategy and rotations. Planning and farm records can prevent 'emergencies' and last minute decisions. Economics are a major factor and the cost of the choice can vary greatly depending on yield potential and the timing of application as well as product choice.

This chapter looks at herbicide selection and timing, as well as environmental conditions and how they affect herbicide application.

Herbicides vary in price but the most expensive herbicide is an application failure due to a wrong choice.

Herbicide selection and timing

Weed identification

Correct weed identification is essential when using herbicides. Weed growth stages determine the herbicide rate; weed and crop species the type of herbicide(s) as well as application factors such as water volume, adjuvant and droplet size. Labour availability can also determine herbicide choice.

Herbicides and herbicide mixes

If a single herbicide will not control all the weeds present consider a second application or a mix of herbicides.

Choose mixtures carefully and consider two separate applications if in doubt. Some mixtures are synergistic, that is, when combined they give better control than each individually. Many, however, can antagonise and reduce the efficacy of the application. Check the label of each product to see if the tank mix is chemically compatible. Product compatibility does not determine efficacy.

Rotating herbicides

Rotating herbicides can be more costly than using a single cheap reliable herbicide. Imagine the cost of weed control if resistance meant that the cheap products could not be used. Using a more expensive product every second or third year can save a lot of money in the long term.

Pre-emergent herbicides

Pre-emergent herbicides are a preventative control. Paddock records are important for keeping track of the number and types of weed seeds that may be present in the weed seed bank. Pre-emergent herbicides work best when there is high weed pressure or there is no post-emergent herbicide available.

Most pre-emergent herbicides are residual and are effective against weeds that germinate over a long period of time e.g. annual ryegrass. Residual herbicides protect the yield potential of the crop if herbicide application is expected to be delayed or difficult later on. Pre-emergents are often cheaper than post-emergent herbicides and some can be tank mixed with a knockdown herbicide prior to sowing.

There are several types of pre-emergent herbicide available. Some pre-emergents require incorporation, others are applied post-sowing pre-emergent with no incorporation, others still need to be incorporated.

Incorporated herbicides

Some of the herbicides that require incorporation are highly volatile (e.g. trifluralin) or act as fumigants. Poor weed control by incorporated herbicides can be a result of poor incorporation due to high stubble loads, cloddy seed beds, low soil moisture or equipment problems. The labels for incorporated products give several options for incorporation.

Post-emergent herbicides

Paddock records that track weed densities can help indicate when a post-emergent herbicide would be a better option than a pre-emergent.

Post-emergent herbicides are important when there are no pre-emergents available or are used to control weeds that were missed by pre-emergent applications.

Timing is important for post-emergent herbicides. The crop stages when the herbicide can be applied are outlined on the label example shown in Figure 8.1.

Herbicides with grazing or cultivation

If grazing or cultivation are combined with herbicides for weed control then herbicide selection and timing is also important.

After grazing or cultivating weeds or lucerne, allow time (labels will give directions) for the plants to put on fresh regrowth before spraying. The fresh foliage is what takes up the most post-emergent herbicides.

There may also be withholding periods before stock can graze a paddock after it has been sprayed. Check the product label before application and grazing.

If cultivating or planting a crop after a herbicide application allow sufficient time for the herbicide to be absorbed and translocated within the plant. Some herbicides such as paraquat and diquat work by "scorching" the plant tissue and do not require long times. Check the product label before sowing.

Figure 8.1 Example label: Post-emergent herbicide labels will give weed control periods for when weeds are most susceptible and when crops are most tolerant in the critical comment section

Crop	Weeds Controlled	State	Rate/ha	Critical comments
Wheat, barley and certain oat varieties	Capeweed, Fumitory-red, Fumitory-white, Indian hedge mustard, Paterson's curse, Rough Poppy, Turnip	NSW, Vic, SA only	1L	Spray actively growing weeds at the 2 to 6 leaf stage when cereals have 3 to 5 leaves on the main stem. Do not spray weeds after the 12 leaf stage.

NB: This is not a real label. Always read the label of the product being applied.

Table 8.1 The cost of spraying can significantly vary depending on the timing of spraying and weeds present.

Chemical fallow	Early Control 2–4 leaf or <3 cm diameter two weeks after germination		Late Control 6– 10 leaf or > 3 cm diameter one month after germination	
Herbicide	glyphosate (450 g/L) @ $5/L			
Weeds Controlled	Annual grasses	Sowthistle	Annual grasses	Sowthistle
Recommended rate	0.4 L/ha	0.8 L/ha	0.8 L/ha	1.6 L/ha
Cost chemical per hectare	$2	$4	$4	$8
Cost chemical 50 ha paddock	$100	$200	$200	$400
NB: These prices and rates are a guide only. Always check the label before using a product. Prices vary according to area and quantity.				

Timing of in crop herbicides

The timing of herbicide application is important to reduce weed competition and limit the effect of herbicides on the crop to maximise yield potential. Weeds begin to compete with the crop from emergence. Control weeds as soon as possible to give the crop a longer period to compensate for any competition. Later emerging weeds have less impact on yield potential as the crop is more competitive.

Most crops are only tolerant to post-emergent herbicides for a limited time.

Many products also have withholding periods before harvest, always check the label for details.

To avoid damage to the crops yield potential follow the label directions for crop growth stages when the herbicide can be applied (Figure 8.1).

Timing of weed control in fallow

To prevent soil moisture loss in the fallow, multiple emergence 'flushes' are better controlled with a residual herbicide or two to three timely applications of a knockdown herbicide rather than a single delayed high rate of herbicide to large weeds.

Herbicides are most effective when weeds are at the two- to four-leaf stage. In warm temperatures this can be within two to three weeks of rainfall. Delays often result in inadequate control of large weeds and a greater use of soil moisture.

Timing is especially important for weeds like heliotrope and fleabane which are very herbicide tolerant once past the small seedling stage. Product labels are required to indicate at what growth stages the weeds will be controlled (Figure 8.1).

Plant back periods

The plant back period is the recommended time after the use of herbicides that crops can be safely sown to avoid damage. Herbicide break down can be very slow and requires the right moisture and temperature conditions. The breakdown time of the herbicide may vary depending on soil type (especially pH) and seasonal conditions. For some herbicides applied on dry soil 15 mm of rain is required before the herbicide starts to breakdown. Problems with residual herbicides are mostly found following drought as dry conditions lengthen the time taken for herbicides to breakdown. Always check the label for plant back conditions such as soil type, rainfall required or other seasonal conditions.

Photo: K. Roberts

Herbicide damage in wheat.

Rate

Variable application rates are often listed on the product label (Figure 8.2). The choice of rate varies depending on some of the following factors

- Weed species present
- Weed and crop growth stage
- Weather conditions before and at time of spraying
- Application equipment
- Water rates
- Stubble load or tillage system.
- Soil type.

Incorrect rate and/or water volume can frequently result in poor weed control and crop damage. This results in a waste of time and money.

Higher and lower than label herbicide rates

Rates are set at the point where they will be most effective and not exceed the maximum residue limits. Higher than label rates are illegal and may damage crops and increase plant back periods.

A higher than label rate will not necessarily give better control. Excessive concentrations, especially of herbicides such as 2,4-D can cause localised cell damage in the weed which then restricts further herbicide translocation. Thus, higher than recommended rates can be counterproductive.

Lower than label rates while legal in NSW must be treated with care. The product manufacturer has no liability for failures when lower than label rates are applied. Trials over several locations have shown less consistent weed control over the years with reduced rates. A certain level of control may be achieved using lower rates but only with an increase in application efficiency. Using a lower rate could result in weed escapes, decreased yield of crops and pastures and increases in weeds the following year.

Lowering the herbicide rate to reduce costs can end up being a waste of money when it gives unsatisfactory control.

Efficacy is reduced by plant stress which can be brought on by adverse weather conditions, disease or insect attack. Herbicide and water rates may be adjusted to compensate for certain conditions. Follow the label, seek advice from an agronomist or chemical manufacturers, and if necessary, plan an alternate form of weed control.

Additives

A spray additive (adjuvant) can be part of the formulation or added to the spray tank at time of application. Additives can have a significant influence on the success of a herbicide application. They can be used to improve spray delivery and retention on the target and enhance uptake of the herbicide. They can buffer the solution to ensure the most efficient pH for the herbicide to be active.

For more information on spray additives refer to the book ***Weed Control in Winter Crops*** (NSW DPI).

Water rates

The mode of action of a herbicide can determine the water rate. Many pre-emergent products require low water rates. High water rates are needed for post-emergent products that 'scorch' the plant in order to maximise coverage. Correct water rates also can minimise crop damage with some post-emergent herbicides (e.g. terbutryn).

Increased water rates are used in less than favourable conditions such as increased temperatures and low humidity. Seek advice before altering rates.

Figure 8.2 An example label. Rates are based on weed types, growth stage and spraying conditions.

Crop/ Situation	Weeds Controlled	Growth stage	Rate L/ha	Critical comments
Fallow	Seedling grasses	2 to 3 leaf	1.0 to 1.2	Apply to young or well grazed weeds. In a mixed weed situation use the rate recommended for the growth stage of the hardest to kill weed species. Under less favourable conditions, or where spraying is delayed, or under dense weed stands, use higher rates. Apply in 50 to 100 L of clean water/ha. If vulpia is present add a wetter at 100 mL/100L water.
		4 leaf to early tiller	1.2 to 2.4	
		mid to fully tillered	2.4 to 3.2	
	Seedling brassica weeds	1 to 5 cm diam.	1.2 to 1.8	
		5 to 10 cm diam,	1.8 to 2.4	
		10 to 20 cm diam.	2.4 to 3.2	
	Other seedling broadleaf weeds	1 to 4 leaf, or 1 to 4 cm diam.	1.8 to 2.8	
		4 to 8 leaf, or 4 to 8 cm diam.	1.8 to 3.2	

NB: This is not a real label. Always read the label of the product being applied.

Figure 8.3 Example label. Rate recommendations may vary according to tillage system.

Crop/Situation	Rate/ha	Critical comments
Prior to sowing a crop or pasture with full soil disturbance by cultivation or sowing with a tyned implement.	400–800 mL/ha pre-tillering 800 mL–1 L/ha post-tillering	Full disturbance with cultivation or sowing with a tyned implement may start one day after treatment (seven days if certain listed weeds are present).
Prior to establishing a crop or pasture with an implement that gives minimal or no soil disturbance.	800 mL – 1.2 L/ha	Use lower rate on young weeds, increase to the higher rate where grasses reach full tillering.

NB: This is not a real label. Always read the label of the product being applied.

Tillage system

Some labels have varied rates according to the tillage system (Figure 8.3).

Equipment

Ensure the spray equipment is calibrated to deliver the required rate. A common cause of uneven weed control occurs when the required rate was not evenly applied. Speed or rough ground can cause the spray boom to 'bounce' resulting in uneven spray coverage. Calibrate the boom spray using measuring jugs and a stop watch to ensure the spray is delivering the required amount. See ***Weed Control in Winter Crops*** (NSW DPI).

Soil type

The product rate for soil incorporated herbicides such as trifluralin is dependant on the soil texture. Using the wrong rate for the soil texture could result in poor weed control or damage to the establishing crop or pasture.

Photo: T. McNee

Weeds sprayed in wheat.

Application Failure

If a treatment fails to control the weeds adequately the initial thought is to assume the herbicide lacked efficacy or that the weeds have 'resistance!' Often the reality is the failure can be attributed to

- Equipment calibration mistakes.
- Incorrect weed identification and/or growth stage.
- Incorrect product and/or rate.
- Application when the weeds are stressed.
- Using lower than the label rate. Under normal weather conditions, a below label rate will not give adequate control.
- Chemical may not have been stored under the recommended conditions or may be too old and may have lost efficacy (this happens more often with animal health products than herbicides). Some products if stored for too long may separate and 'settle' and can not be properly re-mixed.

In the event of an application failure look at the situation carefully and establish the reason(s). Take corrective action if possible.

➢ See page 77 for guidelines on when herbicide resistance is suspected.

Environmental conditions

This section will first describe how environmental conditions determine how much of the spray reaches the target. Second, it will show how environmental conditions affect crops and weed interactions with herbicides.

Environmental factors include wind speed, temperature, humidity, soil moisture, rainfall, dew and frost.

The herbicide application

The environmental conditions at the time of application determine how much of the spray reaches the target.

Low Temperatures

Plant growth is slow to dormant below 5°C so it is unlikely that weed control would be required at low temperatures. As the temperature drops herbicides become more viscous, creating problems with equipment and it is physically difficult to apply the correct rate. Some herbicides are more likely to cause crop damage at low temperatures, this will be specified on the label.

In water temperatures below 10°C some products will form a gel.

High temperatures

High temperatures during the application impact on the rate of evaporation of the spray droplets and the rate of volatilisation of the herbicide. Application during high temperatures may substantially reduce the quantity of the herbicide reaching the intended target.

Humidity and Delta T

Delta T indicates the drying ability of the air. Humidity affects the rate of evaporation and volatilisation of the spray droplets.

Low humidity increases, and high humidity reduces the risk of evaporation.

The relative humidity and/or Delta T are easily measured in the field using handheld electronic relative humidity meters or whirling psychrometers. Delta T is calculated by subtracting the wet bulb temperature from the dry bulb temperature.

Rain

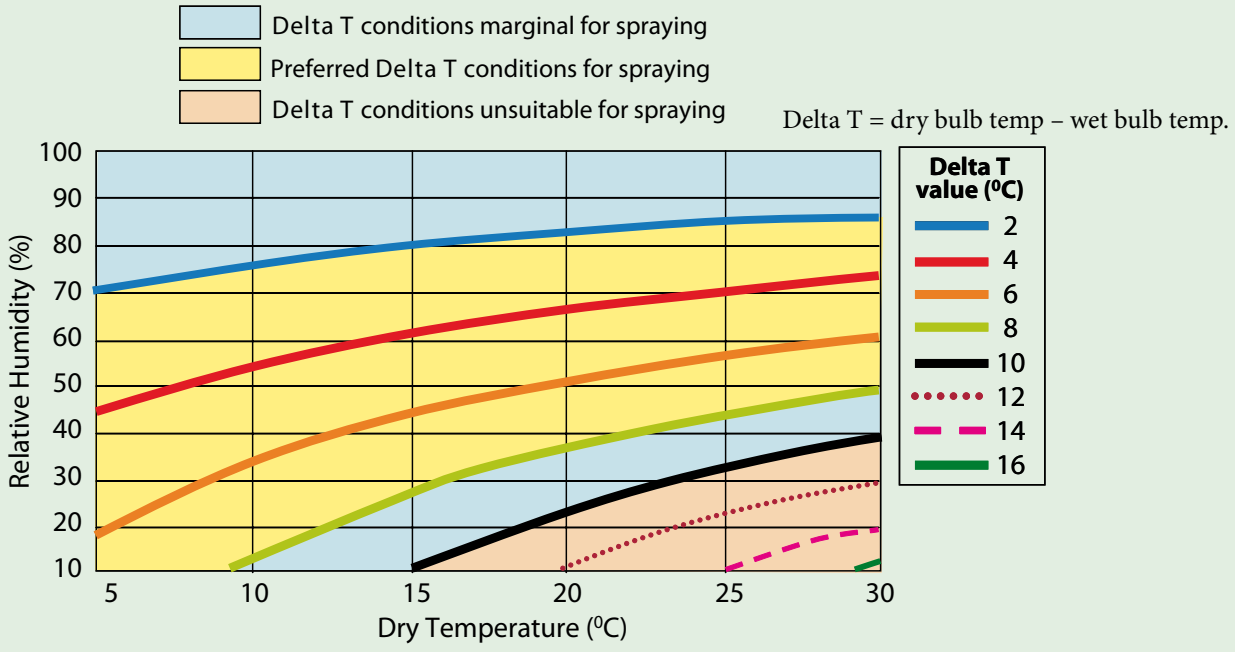
The herbicide label indicates the rain fastness of the product. The interval between spraying and rain is most important. The intensity and volume of rain also determines the degree to which the application is affected. Water soluble compounds are more vulnerable to rain than oil based products. Some adjuvants can decrease the interval between spraying and rain by increasing the rate of leaf penetration or binding to the leaf.

Dew

Some labels recommend against spraying when leaves are wet with dew e.g. dicamba.

Spraying is not usually affected by light dew. In some situations it can improve coverage and efficacy. Do not spray if weeds are covered in heavy dew, as dew may roll off the leaf carrying the applied herbicide with it.

Figure 8.4 Delta T is one of the standard indicators for acceptable spray conditions. When applying pesticides Delta T should ideally be between 2 and 8 and not greater than 10.



Source: Modified from Bureau of Meteorology, 2004.