Herbicide Resistance Management Strategies

Developed by the CropLife Australia Herbicide Resistance Management Review Group and industry researchers

Valid as at 22 June 2018

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HERBICIDE RESISTANCE

Herbicides have proven to be the most efficient and cost effective methods of weed control in farming systems.Their use has enabled farmers to practice large scale conservation agriculture which has delivered substantial productivity gains.

Whilst the use of herbicides has been rewarding to farmers, the selection of resistant weed populations to the products that would otherwise control them is a challenge for the longer term sustainability of modern agriculture.

In spite of this, no herbicides have been lost to agriculture as a result of herbicide resistance; they are today, and will remain, an integral part of food production through their effective use in combination with other weed control practices. (HRAC 2018)

1.1. Evolution of herbicide resistance

Herbicide resistance evolves following the intensive use of herbicides for weed control. In any weed population there are likely to be a small number of individuals that are naturally resistant to herbicides due to genetic diversity, even before the herbicides are used. When a herbicide is used, these individuals survive and set seed whereas the majority of susceptible plants are killed. Continued use of a herbicide or herbicide group will eventually result in a significant fraction of the weed population with resistance.

There are four main factors that influence the evolution of resistance. These are:

- **The intensity of selection pressure.**
  This refers to how many weeds are killed by the herbicide. It is good practice to use robust labelled rates of herbicides to control weeds, as this will lead to the highest and most consistent levels of weed control. Failure to control weeds adequately will lead to increases in weed populations and put pressure on all herbicides used.

- **The frequency of use of a herbicide or mode of action group.**
  For most weeds and herbicides, the number of years of herbicide use is a good measure of selection intensity. The more often a herbicide is applied the higher the selection pressure and the higher the risk of herbicide resistance developing.

- **The frequency of resistance present in untreated populations.**
  If the frequency of resistant genes in a population is relatively high, such as with Group B herbicides, resistance will occur quickly. If the frequency is low, such as with Group M herbicides, resistance will occur more slowly.

- **The biology and density of the weed.**
  Weed species that produce large numbers of seed and have a short seed bank life in the soil will evolve resistance faster than weed species with long seed bank lives. Weed species with greater genetic diversity are more likely to evolve resistance. Resistance is also more likely to be detected in larger weed populations.

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Definitions of resistance

Weed Resistance – Resistance is the naturally occurring inheritable ability of some weed biotypes within a given weed population to survive a herbicide treatment that would, under normal use conditions, effectively control that weed population. Selection of resistant biotypes may result in control failures (HRAC 2018).

Cross Resistance – Cross resistance exists when a weed population is resistant to two or more herbicide modes of action. The presence of a such a mechanism can complicate the selection of alternate herbicides as tools to control a resistance situation. It is for this reason that integrated weed management strategies must be adopted.

Resistance Mechanisms – The resistance mechanism refers to the method by which a resistant plant overcomes the effect of a herbicide. Broadly there are two main mechanisms of resistance including target site mechanisms and non target site mechanisms. Target site mechanisms involve a change to the protein that binds the herbicide resulting in a lack of inhibition of the biochemical pathway. Non-target site resistance mechanisms allow plants to survive application of the herbicide by not allowing sufficient herbicide to reach the target site (Preston 2014).

Herbicide Mode of Action – Refers to the biochemical mechanism by which a herbicide causes growth to cease in target weeds. Herbicides can be classified into groups according to their mode of activity within the plant (HRAC 2018).

1.2. Background to herbicide resistance globally and in Australia

Globally, the first case of herbicide resistance in weeds was identified in 1964. Currently, there are more than 250 resistant grass and broadleaf weed species in more than 70 countries worldwide (Heap 2018).

Herbicide resistance has developed a strong foothold in Australian agriculture since it was first reported in annual ryegrass in 1982. It has spread and diversified to become a key constraint to crop production in all states generally with a history of intensive herbicide use.

1.3. Current impact on weed management in Australia

Today, resistance has been confirmed in a range of grass and broadleaf weed species (Refer to the List of Herbicide Resistant Weeds document). More worrying still, resistance has now developed to 11 distinctly different herbicide chemical groups. This significantly reduces herbicide options for the grower. Cases of multiple resistance have also been commonly reported where, for example, annual ryegrass proves resistant to two or more chemical groups.

1.4. Action by industry and researchers

CropLife Australia, with support from the CRC for Australian Weed Management and the Grains Research and Development Corporation (GRDC), introduced a classification system for herbicides enabling farmers and advisers to understand the mode of action grouping. It is mandatory for all herbicide product labels in Australia to carry the designated mode of action group letter in a prominent position. Herbicide mode of action groups are important to consider when making buying decisions, however, resistance management strategies require continual implementation.

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MODE OF ACTION

2.1. Mode of action matters!

The main reason resistance has developed is because of the repeated and often uninterrupted use of herbicides with the same mode of action. Selection of resistant strains can occur in as little as 3-4 years if no attention is paid to resistance management. Remember that the resistance risk is the same for products having the same mode of action. If you continue to use herbicides with the same mode of action and do not follow a resistance management strategy you are creating future problems for yourself. Mode of action matters.

2.2. Mode of action labelling in Australia

In order to facilitate management of herbicide resistant weeds, all herbicides sold in Australia are grouped by mode of action. The mode of action is indicated by a letter code on the product label. The mode of action labelling is based on the resistance risk of each group of herbicides. Australia was the first country to introduce compulsory mode of action labelling on products. The letters and codes used in Australia are unique because they were the first, they are compulsory and they reflect the relative risk of resistance evolving in each group. Since the introduction of mode of action labelling in Australia, other countries have adopted mode of action classification systems, however caution should be shown if cross-referencing mode of action between Australia and other countries, as many other countries use a different classification system.

The herbicide mode of action grouping and labelling system in Australia was revised in 2007. This is the first major revision of the classification system since its introduction. The original groupings were made several years ago based on limited knowledge about modes of action. Groupings have now been changed to improve the accuracy and completeness of the modes of action to ultimately enable more informed decisions to be made about herbicide rotation and resistance management. The general intent of groups based on their risk has not changed. However, six additional herbicide mode of action groups were created to more accurately group herbicides.

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HERBICIDES ARE GROUPED BY MODE OF ACTION AND RANKED BY RESISTANCE RISK

Growers and agronomists are now better aided to understand the huge array of herbicide products in the marketplace in terms of mode of action grouping and resistance risk by reference to the mode of action chart. All herbicide labels now carry the mode of action group clearly displayed such as:

GROUP	A	HERBICIDE

Know your herbicide groups to make use of this!

Not all mode of action groups carry the same risk for resistance development, therefore specific guidelines for Groups E, O, P and R have not been developed to date because there are no recorded cases of weeds resistant to members of these groups in Australia.

Products represented in Group A and Group B are **HIGH RESISTANCE RISK** herbicides and specific guidelines are written for use of these products.

Specific guidelines are also included for the **MODERATE RESISTANCE RISK** herbicides, Groups C, D, F, G, H I, J, K, L, M, N Q and Z herbicides.

INTEGRATED WEED MANAGEMENT STRATEGIES

Strategies are designed to minimise the development of resistance by adopting Integrated Weed Management (IWM) strategies. Do not rely on a single strategy to keep resistance at bay but integrate them into the crop production program. Some of the key strategies are:

- Rotation of herbicide mode of action groups within and across years. (Refer to specific guidelines for each herbicide mode of action group.)
- Apply two or more different herbicide modes of action on a particular weed. For example:
    - tank mix two or more compatible herbicides with different modes of action which are all effective on the target weed and recommended on the product labels. Apply each herbicide at full label rates
    - use herbicides which already contain two or more actives with different modes of action which are all effective on the target weed
    - “double-knock” where two herbicides with different modes of action are applied to the target weed in sequential applications
- Keeping accurate records of your herbicide applications on a paddock basis.
- Reading the herbicide product label and literature carefully and follow the instructions.
- Always using robust label rates to ensure maximum weed control.

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INTEGRATED WEED MANAGEMENT STRATEGIES (cont.)

- Rotatation of crop and variety.
- Identification and monitoring your surviving weed populations. (Keep good records of weed populations).
- If a weed control failure is suspected do not use the same product or product from the same mode of action group.
- Testing – confirm resistance status.
- Additional cultural weed control techniques to reduce seed banks, eg. burning, cultivation, varied sowing, competitive crops and varieties, green manuring, grazing and collection and/or destruction of weed seed at harvest.
- Control weed escapes before the weeds set and shed viable seed.
- Do not introduce or spread weeds by contaminated seed, grain, livestock, machinery or hay.
- Crop and pasture topping.
- Attend training courses, eg. GRDC IWM course, *ChemCert* and field days.
- Additional information can be obtained from:
  - CropLife Australia (www.croplife.org.au),
  - Australian Glyphosate Sustainability Working Group (www.glyphosateresistance.org.au),
  - Grains Research & Development Corporation (www.grdc.com.au),
  - WeedSmart (www.weedsmart.org.au),
  - International Information on Herbicide Resistent Weeds (weedscience.org) and
  - State Government Departmental publications.
- Detailed programs for herbicide resistance management for weed control in canola, cotton and rice are included (refer CropLife Australia website www.croplife.org.au).
  - Cotton - Liberty Link® Cotton, Roundup Ready Flex® Cotton, are available from Bayer, Monsanto and Nufarm.
  - Canola - Roundup Ready Canola® and Clearfield® Production Systems are available from Monsanto, BASF, Nufarm and Crop Care.
- Seek advice from local advisers (agronomists).
- Consider using alternative methods of weed control to reduce weed numbers before applying herbicides. If applying herbicides to high density weed populations and/or to crops that are poor competitors with limited weed control options, always follow-up with tactics that prevent seed from returning to the seed bank.

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INTEGRATED WEED MANAGEMENT STRATEGIES (cont.)

Weed control options for IWM

	Herbicidal	***Non-herbicidal***
Crop phase	- Crop topping - Knockdown herbicides eg. double knock strategy before sowing - Selective herbicides before and/or after sowing – but ensure escapes don't set seed - Utilising moderate resistance risk herbicides - Use mixtures and/or sequences of different modes of actions	- Rotate crops - Rotate varieties - Grow a dense and competitive crop - Cultivation - Green/brown manure crops - Varied sowing times - Cut crops for hay/silage - Burn stubbles/windrows - Collect and/or destroy weed seeds at harvest - Grazing
Pasture phase	- Spray topping - Winter cleaning - Selective herbicides – but ensure escapes don't set seed - Use mixtures and/or sequences of different modes of actions	- Good pasture competition - Hay making or silage - Cultivation - Grazing
Fallow phase	- Chemical fallow - Optical spot spray technology - Use mixtures and/or sequences of different modes of actions - Selective herbicides – but ensure escapes don't set seed - Knockdown herbicides eg. double knock strategy	- Cultivation - Grazing - Burning

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Risk of herbicide resistance development

Management Option	Low	Medium	High
Herbicide mix or rotation in cropping system	> 2 modes of action	2 modes of action	1 mode of action
Weed control in cropping System	Herbicide and many non herbicidal methods	Herbicide and some non herbicidal methods	Herbicide only
Use of same mode of action per season	Once	Twice	Many times
Cropping system crop Rotation	Diverse range of crops grown in rotation	Some crop rotation	Limted or no crop rotation
Weed density	Low	Moderate	High
Number of applications / Field	0-5	5-10	10+
Weeds which set seed and enter seedbank	None / Minimal	Some	Most

Adapted from HRAC resistance risk table 2018

Diversity is the key to managing resistance. Incorporate as many diverse weed control and cropping system practices as possible to minimize the risk of herbicide resistance development.

Keep yourself informed and be pro-active in the fight-back against resistance.

For further information on resistance management strategies, consult your reseller agronomist, farm consultant or Departmental Agronomist, or refer to the GRDC Integrated Weed Management Manual.

You can do something to reduce the impact!

Follow the latest resistance management strategies described in this document.

Note:
In the specific guidelines for each mode of action group in the following pages, the boxes contain the chemical families, followed by a list of active constituents, with the trade name of the first registered product or successor in parentheses.

For a complete list of registered products containing each active constituent, refer to the website of the Australian Pesticides and Veterinary Medicines Authority (APVMA) at www.apvma.gov.au for the PUBCRIS database.

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5. SPECIFIC GUIDELINES FOR GROUP A HERBICIDES

GROUP	A	HERBICIDE

High resistance risk

Globally herbicide resistance to Group A herbicides has been confirmed and documented in more than 40 grass weed species across more than 40 countries. Group A resistance is extensive and prolific with tens of millions of hectares affected, in fact it is the second most likely herbicide mode of action to develop resistance with only the Group B mode of action more likely.

Group A resistance commonly exists across wide areas of Australia in the grass weed species including more than 20,000 populations ofannual ryegrass, annual veld grass, more than 5,000 populations ofwild oats, phalaris, more than 200 populations of brome grass, crabgrass, crowsfoot grass and more than 200 populations of barley grass. Resistance has developed in broadacre and vegetable situations.

Research has shown that as few as 6 applications to the same population of annual ryegrass can result in the selection of resistant individuals. A population can go from a small area of resistant individuals to a whole paddock failure in one season.

1. Fops, dims and dens are Group A herbicides and carry the same high resistance risk.
2. Where a Group A herbicide has been used on a particular paddock for control of any grass weed, avoid using a Group A herbicide to control the same grass weed in the following season, irrespective of the performance it gave.
3. Frequent application of Group A herbicides to dense weed populations is the worst case scenario for rapidly selecting for resistance.
4. Where resistance to a member of Group A is suspected or known to exist, there is a strong possibility of cross resistance to other Group A and Z herbicides. Therefore use other control methods and herbicides of other mode of action groups in a future integrated approach.

All the above recommendations should be read in conjunction with the Integrated Weed Management (IWM) strategies

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CHEMICAL FAMILY	ACTIVE CONSTITUENT (FIRST REGISTERED TRADE NAME)
GROUP A	**Inhibitors of acetyl co-enzyme A carboxylase (Inhibitors of fat synthesis/ACC'ase inhibitors)**
Aryloxyphenoxypropionates: *(Fops)*:	clodinafop (Topik®), cyhalofop (Barnstorm®), diclofop (Cheetah® Gold*, Decision®*, Hoegrass®), fenoxaprop (Cheetah® Gold* , Wildcat®), fluazifop (Fusilade®, Fusion®*), haloxyfop (Verdict®), propaquizafop (Shogun®), quizalofop (Targa®)
Cyclohexanediones: *(Dims)*:	butroxydim (Falcon®, Fusion®*), clethodim (Select®), profoxydim (Aura®), sethoxydim (Cheetah® Gold*, Decision®*), tralkoxydim (Achieve®)
Phenylpyrazoles: *(Dens):*	pinoxaden (Axial®)

* ***This product contains more than one active constituent***

List of chemical families, approved active constituents and, in parenthesis, the trade name of the first registered product or successor. Refer to the APVMA website (www.apvma.gov.au) to obtain a complete list of registered products from the PUBCRIS database.

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6. SPECIFIC GUIDELINES FOR GROUP B HERBICIDES

GROUP	B	HERBICIDE

High resistance risk

Globally herbicide resistance to the Group B herbicide mode of action has been confirmed and documented in more than 150 grass and broadleaf weed species across more than 40 countries. Resistance to Group B is extensive and prolific, with tens of millions of hectares affected, in fact it is the most likely herbicide mode of action to develop resistance.

Group B resistance exists in Australia in 26 species (9 grasses) including more than 20,000 populations of annual ryegrass, more than 200 populations of barley grass, brome grass, more than 200 populations of wild oats, paradoxa grass and crabgrass and in at least seventeen broadleaf weeds including more than 5,000 populations of wild radish, common sowthistle, black bindweed, charlock, more than 2000 populations of prickly lettuce, more than 1,000 populations of Indian hedge mustard, Mediterranean (wild) turnip and turnip weed. Resistance has developed in broadacre, rice and pasture situations. In respect to rice three broadleaf weeds, namely dirty dora, arrowhead and starfruit are known to have Group B resistant populations.

Research has shown that as few as four applications to the same population of annual ryegrass can result in the selection of resistant individuals and as few as six applications for wild radish. A population can go from a small area of resistant individuals to a whole paddock failure in one season.

A significant challenge facing growers managing Group B resistance is the control of brome grass and barley grass in winter cereal crops. Group B herbicides are presently the only in-crop herbicides that provide effective control of these grass weeds and this poses a severe risk of Group B resistance for growers with cereal dominant rotations.

If a pre-emergent application is made with a Group B herbicide for broadleaf or grass weed control, monitor results and, if required, apply a follow up spray; preferably with a non-Group B herbicide for control of escapes and to avoid seed set. If a follow up group B (post-emergent herbicide) is applied; ensure that complete weed seed set control is achieved.

Whether using group B herbicides as a pre-emergent, or post-emergent application; consider the use of registered tank mixes with herbicides from other modes of action.

When using a group B herbicide for post-emergent broadleaf or grass weed control, this should be preceded by a pre-emergent herbicide treatment with other modes-of-action.

1. Avoid applying more than two Group B herbicide treatments in any four year period on the same paddock. Where more than two treatments are applied introduce alternative control measures to avoid seed set and seed shed in the paddock.
2. A Group B herbicide may be used alone on flowering wild radish only if a Group B herbicide has not been previously used on that crop.
3. In all cases if there are significant escapes following the herbicide application consider using another herbicide with a different mode of action or another control method to stop seed set.

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4. **Imidazolinone tolerant crops (Clearfield Systems):** Where OnDuty, Midas and Intervix are used refer to the Clearfield Production Systems – best management practice guide. If Sentry is to be used pre-emergent; consult the Crop Care Best Management Guide

All the above recommendations should be read in conjunction with the Integrated Weed Management (IWM) strategies

GROUP B	**Inhibitors of acetolactate synthase (ALS inhibitors), acetohydroxyacid synthase (AHAS)**
Imidazolinones: *(Imis):*	imazamox (Intervix®*, Raptor®,), imazapic (Bobcat I-Maxx®*, Flame®, Midas®*, OnDuty®*), imazapyr (Arsenal Xpress®*, Intervix®*, Lightning®*, Midas®*, OnDuty®*), imazethapyr (Lightning®*, Spinnaker®)
Pyrimidinylthiobenzoates:	bispyribac (Nominee®), pyrithiobac (Staple®)
Sulfonylureas: *(SUs):*	azimsulfuron (Gulliver®), bensulfuron (Londax®), chlorsulfuron (Glean®), ethoxysulfuron (Hero®), foramsulfuron (Tribute®), halosulfuron (Sempra®), iodosulfuron (Hussar®), mesosulfuron (Atlantis®), metsulfuron (Ally®, Harmony®* M, Stinger®*, Trounce®*, Ultimate Brushweed®* Herbicide), prosulfuron (Casper®*), rimsulfuron (Titus®), sulfometuron (Oust®, Eucmix Pre Plant®*), sulfosulfuron (Monza®), thifensulfuron (Harmony®* M), triasulfuron, (Logran®, Logran® B-Power®*), tribenuron (Express®), trifloxysulfuron (Envoke®, Krismat®*)
Triazolopyrimidines: *(Sulfonamides)*:	florasulam (Gangster®*, Paradigm®*, Vortex®*, X-Pand®*), flumetsulam (Broadstrike®), metosulam (Eclipse®), pyroxsulam (Crusader® Rexade®*)

* ***This product contains more than one active constituent***

List of chemical families, approved active constituents and, in parenthesis, the trade name of the first registered product or successor. Refer to the APVMA website (www.apvma.gov.au) to obtain a complete list of registered products from the PUBCRIS database.

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7. SPECIFIC GUIDELINES FOR GROUP C HERBICIDES

GROUP	C	HERBICIDE

Moderate resistance risk

Globally herbicide resistance to the Group C herbicide mode of action has been confirmed and documented in more than 70 grass and broadleaf weed species across more than 40 countries. Resistance to the Group C mode of action is common, in fact it is the third most likely herbicide mode of action to develop resistance.

Group C resistance exists in 8 weed species across more than 100 weed populations including more than 50 populations of annual ryegrass, more than 20 populations of wild radish, liverseed grass, squirrel tail fescue (silver grass), dwarf (stinging) nettles, Indian hedge mustard and barnyard grass ("at risk weeds").

In all situations the resistance status of "at risk weeds" should be determined prior to sowing. Resistance has developed in broadacre, horticultural and non-crop situations. CropLife Australia gives specific guidelines for the use of Group C herbicides in all situations and particularly in triazine tolerant (TT) canola, and canola with both glyphosate tolerance and triazine tolerance (TT-RR canola) following increasing reports of resistance development: -

- For "at risk weeds", avoid using Group C herbicides as the only means of control in the same paddock in consecutive years.
- Watch and record weed escapes in paddocks with a long history of Group C use.
- Control survivors to prevent seed-set using a herbicide with a different Mode of Action to Group C or use another weed management technique.
- Avoid dry sowing in heavily weed infested paddocks. Wait for a germination of weeds after the opening rains in weedy paddocks and use a pre-plant knockdown or cultivation to maximise weed control at this stage.

1. **TT Canola**
   - Growing TT Canola in a paddock treated with triazine herbicides in the previous season is a high resistance risk and is not recommended.

   - For ryegrass control, use simazine, atrazine, metribuzin or terbuthylazine plus a pre-emergence herbicide with a different mode of action (eg trifluralin) prior to sowing. If necessary follow-up with a post emergent herbicide with a different mode of action (eg clethodim) to control escapes from pre-emergent treatments.

2. **TT-RR Canola**
   - Refer to the specific guidelines for Group M herbicides in addition to those given here for triazine herbicides.

All the above recommendations should be read in conjunction with the Integrated Weed Management (IWM) strategies

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CHEMICAL FAMILY	ACTIVE CONSTITUENT (FIRST REGISTERED TRADE NAME)
GROUP C	**Inhibitors of photosynthesis at photosystem II (PS II inhibitors)**
Amides:	propanil (Stam®)
Benzothiadiazinones:	bentazone (Basagran®, Basagran® M60*, Lawnweeder plus®*)
Nitriles:	bromoxynil (Barrel®*, Buctril®, Buctril® MA*, Eliminar C®*, Flight®*, Jaguar®*, Talinor®*, Triathlon®*, Velocity®*), ioxynil (Actril DS*,Totril®,)
Phenylcarbamates:	phenmedipham (Betanal®)
Pyridazinones:	chloridazon (Pyramin®)
Triazines:	ametryn (Amigan®*, Gesapax® Combi*, Krismat®, Primatol Z®), atrazine (Gesapax® Combi*, Gesaprim®, Primextra® Gold*), cyanazine (Bladex®), prometryn (Bandit®*, Cotogard®*, Gesagard®), propazine (Agaprop®), simazine (Brunnings RTU Path Weeder®*, Gesatop®,Yates Onceyear Path Weeder®*), terbuthylazine (Firestorm®*, Palmero TX®*, Terbyne®), terbutryn (Agtryne® MA*, Amigan®*, Igran®)
Triazinones:	hexazinone (Bobcat I-Maxx®*, Velpar® K4*, Velpar® L), metribuzin (Aptitude®*, Sencor®)
Uracils:	bromacil (Hyvar®, Krovar®*), terbacil (Eucmix Pre Plant®*, Sinbar®)
Ureas:	diuron (Karmex®, Krovar®*, Velpar® K4*), fluometuron (Bandit®*, Cotogard®*, Cotoran®), linuron (Afalon®), methabenzthiazuron (Tribunil®), siduron (Tupersan®), tebuthiuron (Graslan®)

* ***This product contains more than one active constituent***

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8. SPECIFIC GUIDELINE FOR GROUP D HERBICIDES

GROUP	D	HERBICIDE

Moderate resistance risk

Globally herbicide resistance to the Group D herbicide mode of action has been confirmed and documented in more than 10 grass and broadleaf weed species across more than 5 countries.

Group D resistance exists in Austalia in 3 weed species including 5,000 populations of annual ryegrass and dense flowered fumitory. Resistance has generally occurred after 10 -15 years of use of Group D herbicides.

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.

To assist in delaying the onset of Group D resistance, rotate and/or tank mix with herbicides from other modes of action.

Use Group D herbicides at robust rates eg the maximum label rates to ensure high levels of weed control particularly when targeting annual ryegrass.

All the above recommendations should be read in conjunction with the Integrated Weed Management (IWM) strategies

GROUP D	**Inhibitors of microtubule assembly**
Benzamides:	propyzamide (Kerb®)
Benzoic acids:	chlorthal (Dacthal®, Prothal®*)
Dinitroanilines: (DNAs):	oryzalin (Rout®*, Surflan®), pendimethalin (Stomp®), prodiamine (Barricade®), trifluralin (Jetti Duo®*, Treflan®)
Pyridines:	dithiopyr (Dimension®)

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9. SPECIFIC GUIDELINES FOR GROUP F HERBICIDES

GROUP	F	HERBICIDE

Moderate resistance risk

Globally herbicide resistance to the Group F herbicide mode of action has been confirmed and documented in 4 weed species across 3 countries.

Group F resistance exists in Australia in 2 weed species including more than 1,000 populations of wild radish and more than 50 populations of Indian hedge mustard. Resistance has generally occurred after a long history of use of Group F herbicides. The number of populations with Group F resistance is increasing following increased use of these herbicides.

Avoid applying 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. Always use the label rate of herbicide whether or not a single active ingredient (eg. Diflufenican) or combinations of active ingredients are applied (eg. Diflufenican/MCPA, picolinafen/MCPA), apply to weeds at the labeled growth stage and ensure that no weeds set and shed viable seed. Control survivors to prevent seed set with a herbicide with a different Mode of Action to Group F or use another weed management technique.

All the above recommendations should be read in conjunction with the Integrated Weed Management (IWM) strategies

GROUP F	**Bleachers: Inhibitors of carotenoid biosynthesis at the phytoene desaturase step (PDS inhibitors)**
Pyridazinones:	norflurazon (Solicam®)
Pyridinecarboxamide:	diflufenican (Brodal®, Gangster®*, Jaguar®*, Spearhead®*, Tigrex®*, Triathlon®*, Yates Pathweeder®*), picolinafen (Eliminar C®*, Flight®*, Paragon®*, Sniper®)

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10. SPECIFIC GUIDELINES FOR GROUP H HERBICIDES

GROUP	H	HERBICIDE

Moderate resistance risk

Resistance to the Group H herbicide mode of action is known for a number of populations of *Amaranthus* species in the United States, which demonstrates the potential for weeds to develop resistance to this mode of action. Continuous usage of Group H herbicides in the United States has resulted in resistance in *Amaranthus* species in a relatively short time.

There are currently no known weeds resistant to Group H herbicides in Australia however resistance to this mode of action is inevitable given its continued usage

1. **Broadacre cropping**
   Of particular concern in Australia is the potential for development of Group H resistance in wild radish. In some areas, because of a lack of alternate herbicide options growers are heavily reliant on Group H herbicides for control of wild radish populations. It is essential to integrate additional cultural weed control techniques to reduce the seed bank and minimise seed set, thereby decreasing the selection pressure on Group H herbicides.

2. **Fallow**
   In high summer rainfall areas, weed control in fallow is heavily reliant on herbicides. Multiple sprays are often required to maintain a clean fallow between winter crops. Integrated Weed Management principles should be incorporated wherever possible, including cultivation - the double knock technique, grazing and combining more than one mode of action in a single application.

   To assist in delaying the onset of Group H resistance, rotate and/or tank mix with herbicides from other modes of action.

3. **Rice**
   Where benzofenap has been applied to rice, a follow-up application of MCPA or bentazone and MCPA is recommended where appropriate to provide a secondary mode of action. To reduce the likelihood of resistant weeds developing it is recommended that products containing benzofenap (eg. Taipan®) not be used in consecutive rice crops.

Synergistic interactions have been documented for several Group H and Group C herbicide combinations. Where possible, apply a Group H herbicide in combination with a Group C herbicide to maximise efficacy. Always use the label rate of herbicide whether or not a single active ingredient (eg. isoxaflutole) or combinations of active ingredients are applied (eg. isoxaflutole + simazine, pyrasulfotole/bromoxynil).

All the above recommendations should be read in conjunction with the Integrated Weed Management (IWM) strategies

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CHEMICAL FAMILY	ACTIVE CONSTITUENT (FIRST REGISTERED TRADE NAME)
GROUP H	**Bleachers: Inhibitors of 4-hydroxyphenyl-pyruvate dioxygenase (HPPDs)**
Isoxazoles:	isoxaflutole (Balance® Palmero TX®*)
Pyrazoles:	benzofenap (Taipan®), pyrasulfotole (Precept®*,Velocity®*)
Triketone:	Bicyclopyrone (Talinor®*)

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11. SPECIFIC GUIDELINES FOR GROUP I HERBICIDES

GROUP	I	HERBICIDE

Moderate resistance risk
Globally herbicide resistance to the Group I herbicide mode of action has been confirmed and documented in more than 30 grass and broadleaf weed species across more than 20 countries. Resistance to the Group I mode of action is common.

Group I herbicides exists in Australia in 4 weed species includingcapeweed, common sow thistle, more than 1,000 populations of wild radish and more than 50 populations of Indian hedge mustard. Resistance has occurred after a long history of use of Group I herbicides. The number of populations with Group I resistance is increasing.

Of particular concern is that apart from the resistance being in wild radish which is the most important broadleaf weed in broadacre agriculture, some populations may also have resistance to other modes of action eg. Group F herbicides which can be important for control of wild radish in lupins where other selective non Group I options are limited. Because of the long soil life of wild radish seed, measures to reduce seed return to the soil would be useful for this weed. Wild radish seed that is confined to the top 5 cm soil has a shorter life than seed buried deeper.

As a general rule in high resistance risk situations

1. Avoid applying 2 applications of Group I herbicides alone onto the same population of weeds in the same season. To assist in delaying the onset of Group I resistance, rotate and/or tank mix with herbicides from other modes of action.

2. Where possible combine more than one mode of action in a single application. Each product should be applied at rates sufficient for control of the target weed alone to reduce the likelihood of weeds resistant to the Group I herbicide surviving.

All the above recommendations should be read in conjunction with the Integrated Weed Management (IWM) strategies

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GROUP I	**Disruptors of plant cell growth (Synthetic Auxins)**
Arylpicolinate:	Florpyrauxifen, halauxifen (ForageMax®*, Paradigm®*, Pixxaro®*, Rexade®*)
Benzoic acids:	dicamba (Banvel®, Banvel M®*, Barrel®*, Casper®*, Lawnweeder plus®*, Mecoban®, Methar Tri-Kombi®*, Nuturf Millennium®*)
Phenoxycarboxylic acids: *(Phenoxys):*	2,4-D (Actril DS®*, Amicide®, Fallow Boss Tordon®*, Methar Tri-Kombi®*, Pyresta®*, Vortex®*), 2,4-DB (Trifolamine®), dichlorprop (Lantana 600®), MCPA (Agtryne® MA*, Banvel M®*, Barrel®*, Basagran® M60*, Buctril® MA*, Flight®*, Lawnweeder plus®*, MCPA, Midas®*, Paragon®*, Precept®*, Silverado®*, Spearhead®*, Tigrex®*, Tordon 242®*, Triathlon®*), MCPB (Legumine®), mecoprop (Mecoban®, Mecopropamine®, Methar Tri-Kombi®*, Multiweed®*)
Pyridine carboxylic acids: *(Pyridines):*	aminopyralid (Fallow Boss Tordon®*, ForageMax®*, Grazon Extra®*, Hotshot®*, Stinger®*, Vigilant II®*), clopyralid (Lontrel®, Nuturf Millennium®*, Spearhead®*), fluroxypyr (Hotshot®*, Pixxaro®*, Starane®), picloram (Fallow Boss Tordon®*, Grazon Extra®*, Tordon®, Tordon 242®*, Tordon Regrowth Master®*, Trinoc®*, Vigilant II®*), triclopyr (Garlon®, Grazon Extra®*, Tordon Regrowth Master®*, Tough Roundup® Weedkiller*, Ultimate Brushweed®* Herbicide)
Quinoline carboxylic acids:	quinclorac (Drive®)

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12. SPECIFIC GUIDELINES FOR GROUP J HERBICIDES

GROUP	J	HERBICIDE

Moderate resistance risk

Globally herbicide resistance to the Group J herbicide mode of action has been confirmed and documented in more than 10 weed species across more than 6 countries.

Group J resistance exists in Australia in 3 weed species including 2 populations of serrated tussock, 6 populations of Giant Parramatta grass and more than 50 populations of annual ryegrass that are confirmed resistant to Group J herbicides.

To assist in delaying the onset of resistance, where possible rotate or tank mix Group J herbicides with herbicides from other modes of action.

Use Group J herbicides at robust rates eg the maximum label rates to ensure high levels of weed control particularly when targeting annual ryegrass.

All the above recommendations should be read in conjunction with the Integrated Weed Management (IWM) strategies

GROUP J	**Inhibitors of lipid synthesis (Not ACCase inhibitors)**
Benzofurans:	ethofumesate (Tramat®)
Chlorocarbonic acids:	2,2–DPA (Dalapon®, Yates Onceyear Pathweeder®*****, flupropanate (Frenock®**)**
Phosphorodithioates:	bensulide (Prefar®)
Thiocarbamates:	EPTC (Eptam®), molinate (Ordram®), pebulate (Tillam®), prosulfocarb (Arcade®, Boxer® Gold*), thiobencarb (Saturn®), triallate (Avadex®, Jetti Duo®*), vernolate (Vernam®)

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13. SPECIFIC GUIDELINES FOR GROUP K HERBICIDES

GROUP	K	HERBICIDE

Moderate resistance risk

Globally herbicide resistance to the Group K herbicide mode of action has been confirmed and documented in 5 weed species across 7 countries

Resistance to Group K herbicides in Australia has developed in one population of annual ryegrass. Further development of resistance in the near future is likely given the reliance on Group K herbicide chemistry for weed control across large areas of Australia..

Where possible, avoid the use of Group K herbicides on dense ryegrass populations. Consider using alternative methods of weed control to reduce weed numbers before applying herbicides.

Use Group K herbicides at robust rates eg the maximum label rates to ensure high levels of weed control particularly when targeting annual ryegrass.

To assist in delaying the onset of resistance, rotate Group K herbicides with herbicides from other modes of action.

All the above recommendations should be read in conjunction with the Integrated Weed Management (IWM) strategies

CHEMICAL FAMILY	ACTIVE CONSTITUENT (FIRST REGISTERED TRADE NAME)
GROUP K	**Inhibitors of cell division / Inhibitors of very long chain fatty acids (VLCFA inhibitors)**
Acetamides:	napropamide (Altiplano®*, Devrinol®)
Chloroacetamides:	dimethenamid (Frontier®-P, Outlook ®), metazachlor (Butisan®), metolachlor (Boxer® Gold*, Dual® Gold, Primextra® Gold*), propachlor (Prothal®*, Ramrod®)
Isoxazoline:	pyroxasulfone (Sakura®)

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14. SPECIFIC GUIDELINES FOR GROUP L HERBICIDES

GROUP	L	HERBICIDE

Moderate resistance risk

Globally herbicide resistance to the Group L herbicide mode of action has been confirmed and documented in more than 30 weed species across 16 countries

Group L resistance exists in Australia in annual ryegrass, and in 2 species of barley grass across more than 100 populations, blackberry nightshade, crowsfoot grass, capeweed, pennsylvanian cudweed, squirrel-tailed fescue (silver grass) and small square weed. Most instances have occurred in long-term lucerne stands treated regularly with a Group L herbicide but Group L resistant barley grass has also occurred in no-till situations.

The following factors are common to most cases of Group L resistance:

- A Group L herbicide is the major or only herbicide used;
- A Group L herbicide has been used for 12 – 15 years or more; and
- There has been minimal or no soil disturbance following application.

The risk of resistance to Group L herbicides is higher in zero tillage broadacre cropping. Other high resistance risk situations include: irrigated clover pivots, orchards, vineyards or pure lucerne stands where frequent applications of a Group L herbicide are made each season, cultivation is not used and there is reliance on a Group L herbicide alone for weed control.

To assist in delaying the onset of resistance, consider alternating Group L herbicides with herbicides from other modes of action. For example, (Group N) eg glufosinate or (Group Q) eg amitrole or (Group M) eg glyphosate.

Below are strategies that address these high resistance risk situations to reduce the risk of Group L resistance developing.

Zero Tillage

1. Rotate Group L herbicides with other knockdown herbicides with a different mode of action For example (Group M) eg glyphosate. A full label rate for the weed size targeted should be used for resistance management.
2. Consider utilising the double knock technique[1] where glyphosate is sprayed first followed within 1 - 7 days by a paraquat application. A full label rate for the weed size targeted should be used for the paraquat application for resistance management.
3. Consider occasional mechanical cultivation to aid weed control.

[1] *The double knock technique is defined as using a full cut cultivation OR the full label rate of a paraquat-based product (Group L) following the glyphosate (Group M) knockdown application*

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Lucerne

1. If using a Group L herbicide for winter cleaning, where possible include another mode of action eg. Group C.
2. Use alternative modes of action to selectively control grass and broadleaf weeds.
3. Rotate Group L herbicides with other knockdown herbicides with a different mode of action for example (Group M) eg glyphosate prior to sowing lucerne and prior to sowing future crops in that paddock.

Horticulture

1. Rotate Group L herbicides with other knockdown herbicides with a different mode of action. For example (Group N) eg glufosinate or (Group Q) eg amitrole or (Group M) eg glyphosate
2. Where possible use residual herbicides (that are effective on the same weeds as the Group L herbicides) where applicable either alone or in mixture with Group L herbicides.
3. Where possible use alternative modes of action to selectively control grass and broadleaf weeds.
4. Consider using the double knock technique where glyphosate is sprayed followed within 1-7 days by a paraquat application. A full label rate for the weed size targeted should be used for the paraquat application for resistance management.

All the above recommendations should be read in conjunction with the Integrated Weed Management (IWM) strategies

CHEMICAL FAMILY	ACTIVE CONSTITUENT (FIRST REGISTERED TRADE NAME)
GROUP L	**Inhibitors of photosynthesis at photosystem I via electron diversion (PSI inhibitors)**
Bipyridyls:	diquat (Reglone®, Spray Seed®*), paraquat (Alliance®*, Gramoxone®, Spray Seed®*)

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15. SPECIFIC GUIDELINES FOR GROUP M HERBICIDES

GROUP	M	HERBICIDE

Moderate resistance risk

Globally herbicide resistance to the Group M herbicide mode of action has been confirmed and documented in more than 30 weed species across more than 25 countries.

Resistance to Group M herbicides is significant given it is the most important and most widely used herbicide.

Group M resistance occurs in Australia in more than 1,000 populations of annual ryegrass, more than 200 populations of awnless barnyard grass, brome grass, more than 50 populations of common sow thistle, feathertop rhodes grass, more than 100 populations of flax-leaf fleabane, liverseed grass, sweet summer grass, wild radish and windmill grass.

The following factors are common to all cases of Group M resistance:

- Lack of rotation of other herbicide modes of action;
- A Group M herbicide has been used for 12 – 15 years or more; and
- There has been minimal or no soil disturbance following application.

Given the very important role of glyphosate in Australian farming systems, the Australian agricultural industry has developed strategies for sustainable use of glyphosate. For more information refer to the Australian Glyphosate Sustainability Working Group website http://www.glyphosateresistance.org.au

A number of these cases of resistance to glyphosate have occurred in horticultural (vines, tree crops & vegetables) and non-cropping situations (eg. airstrips, railways, firebreaks, fencelines, roadsides, driveways, irrigation ditches, around sheds), with the balance occurring in no-till broadacre cropping systems.

To assist in delaying the onset of resistance, consider alternating Group M herbicides with herbicides from other modes of action. For example (Group L) eg paraquat, or (Group N) eg glufosinate or (Group Q) eg amitrole.

Given the demonstrated propensity of weeds to develop resistance to multiple herbicide classes, Integrated Weed Management principles should be incorporated wherever possible to minimise the risk of selecting for glyphosate resistance. Strategies may include the use of cultivation, the double knock technique[2], strategic herbicide rotation, grazing, baling etc.

For further information:

- http://www.monsanto.com/global/au/products/pages/roundup-ready-herbicide.aspx
- http://www.cottoninfo.com.au/publications/herbicide-resistance-management-strategy

All the above recommendations should be read in conjunction with the Integrated Weed Management (IWM) strategies

[2] *The double knock technique is defined as using a full cut cultivation OR the full label rate of a paraquat-based product (Group L) following the glyphosate (Group M) knockdown application.*

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CHEMICAL FAMILY	ACTIVE CONSTITUENT (FIRST REGISTERED TRADE NAME)
GROUP M	**Inhibitors of 5-enolpyruvyl shikimate-3 phosphate (EPSP) synthase**
Glycines:	glyphosate (Arsenal Xpress®*, Broadway®*, Firestorm®*, Illico®*, Resolva®*, Roundup®, Tough Roundup® Weedkiller*, Trounce®*, Yates Pathweeder®*)

This product contains more than one active constituent
List of chemical families, approved active constituents and, in parenthesis, the trade name of the first registered product or successor. Refer to the APVMA website (www.apvma.gov.au) to obtain a complete list of registered products from the PUBCRIS database.

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16. SPECIFIC GUIDELINES FOR GROUP Q HERBICIDES

GROUP	Q	HERBICIDE

Moderate resistance risk

Globally herbicide resistance to the Group Q herbicide mode of action has been confirmed and documented in 7 weed species across 4 countries.

Group Q resistance exists in Australia with 3 populations of annual ryegrass resistant to amitrole. This has only occurred in 3 populations and this type of resistance is rare in Australia.

To assist in delaying the onset of resistance, consider alternating Group Q herbicides with herbicides from other modes of action for example. (Group L) eg paraquat, (Group N) eg glufosinate or (Group M) eg glyphosate.

Consider using alternative methods of weed control to reduce weed numbers before applying herbicides.

All the above recommendations should be read in conjunction with the Integrated Weed Management (IWM) strategies

CHEMICAL FAMILY	ACTIVE CONSTITUENT (FIRST REGISTERED TRADE NAME)
GROUP Q	Bleachers: Inhibitors of carotenoid biosynthesis unknown target
Isoxazolidinones:	clomazone (Altiplano®*, Command®)
Triazoles:	amitrole (Alliance®*, Amitrole®, Brunnings RTU Pathweeder®*,Illico®*, Firestorm®*, Yates Onceyear Pathweeder®*,)

* ***This product contains more than one active constituent***

List of chemical families, approved active constituents and, in parenthesis, the trade name of the first registered product or successor. Refer to the APVMA website (www.apvma.gov.au) to obtain a complete list of registered products from the PUBCRIS database.

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17. SPECIFIC GUIDELINES FOR GROUP Z HERBICIDES

GROUP	Z	HERBICIDE

Moderate resistance risk

Globally herbicide resistance to the Group Z herbicide mode of action has been confirmed and documented in 5 weed species across 4 countries.

Group Z resistance exists in Australia in more than 200 populations of wild oats resistant to flamprop. Many of these flamprop resistant wild oats also show cross resistance to Group A herbicides. There is also endothal resistance confirmed in annual poa (winter grass).

To assist in delaying the onset of resistance, rotate with herbicides from other modes of action.

Consider using alternative methods of weed control to reduce weed numbers before applying herbicides. These may include summer crop rotations, delayed sowing to control wild oats with a knockdown herbicide, higher seeding rates, brown manuring to stop seed set, etc.

All the above recommendations should be read in conjunction with the Integrated Weed Management (IWM) strategies

CHEMICAL FAMILY	ACTIVE CONSTITUENT (FIRST REGISTERED TRADE NAME)
GROUP Z	**Herbicides with unknown and probably diverse sites of action**
Arylaminopropionic acids:	flamprop (Mataven L®)
Dicarboxylic acids:	endothal (Endothal®)
Organoarsenicals:	DSMA (disodium methylarsonate) (Methar®, Trinoc®*), MSMA (monosodium methylarsonate) (Daconate®)

* ***This product contains more than one active constituent***

List of chemical families, approved active constituents and, in parenthesis, the trade name of the first registered product or successor. Refer to the APVMA website (www.apvma.gov.au) to obtain a complete list of registered products from the PUBCRIS database.

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