Understanding pre-emergent cereal herbicides; how they work, interactions with seeder type, soil, weed kill and crop safety

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Water solubility, soil organic matter, seeding system, pre-emergent herbicides

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Take home message
The important factors in getting pre-emergent herbicide to work effectively while minimising crop damage are: to understand the position of the weed seeds in the soil; the soil type (particularly amount of organic matter and crop residue on the surface); the solubility of the herbicide; and its ability to be bound by the soil.

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

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

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

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

Characteristics of some common pre-emergent herbicides are given in Table 1.

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

Table 1. Water solubility, binding characteristics to soil organic matter and degradation half-life for some common pre-emergent herbicides.

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Water solubility (mg L(^{-1}))*</th>
<th>(K_{oc}) (mL g(^{-1}))**</th>
<th>Degradation half-life (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trifluralin</td>
<td>0.22</td>
<td>15,800</td>
<td>Very high 181</td>
</tr>
<tr>
<td>Pendimethalin</td>
<td>0.33</td>
<td>17,800</td>
<td>Very high 90</td>
</tr>
<tr>
<td>Pyroxasulfone</td>
<td>3.9</td>
<td>223</td>
<td>Medium 22</td>
</tr>
<tr>
<td>Triallate</td>
<td>4.1</td>
<td>3000</td>
<td>High 82</td>
</tr>
<tr>
<td>Prosulfocarb</td>
<td>13</td>
<td>2000</td>
<td>High 12</td>
</tr>
<tr>
<td>Atrazine</td>
<td>35</td>
<td>100</td>
<td>Medium 75</td>
</tr>
<tr>
<td>Diuron</td>
<td>36</td>
<td>813</td>
<td>High 75.5</td>
</tr>
<tr>
<td>S-metolachlor</td>
<td>480</td>
<td>200</td>
<td>Medium 15</td>
</tr>
<tr>
<td>Triasulfuron</td>
<td>815</td>
<td>60</td>
<td>Low 23</td>
</tr>
<tr>
<td>Chlorsulfuron</td>
<td>12,500</td>
<td>40</td>
<td>Low 160</td>
</tr>
</tbody>
</table>

*at 20 C and neutral pH  
**in typical neutral soils

Herbicides with greater water solubility typically need less soil moisture to be activated for absorption by the germinating seed. However, other soil factors, such as pH and soil organic matter, can have a major effect on herbicide availability.

Pre-emergent herbicides may be bound by soil components. Clay components can bind some herbicide, but the main component responsible for binding of pre-emergent herbicides is soil organic matter. The higher the soil organic matter content, the more herbicide will be bound. Australian cropping soils are typically low in soil organic matter by world standards and too much herbicide availability in the soil is more of a problem in Australia. Table 1 gives binding characteristics for some pre-emergent herbicides. The values are for the \(K_{oc}\), the soil organic carbon-water partitioning coefficient. High \(K_{oc}\) values mean that more herbicide will be bound to organic matter and less herbicide will be available to move in the soil solution. \(K_{oc}\) values for pre-emergent herbicides in Table 1 range from very high for trifluralin and pendimethalin to low for triasulfuron and chlorsulfuron.

The third factor is the rate of degradation of the herbicide in the soil. Herbicides can be chemically degraded in the soil, but more commonly they are degraded by microbes. Soil microbes require water and organic matter to be effective at degrading herbicides. The half-life of some common pre-emergent herbicides are given in Table 1. The half-life is the time it takes for half the original amount of the herbicide to be degraded. For example, prosulfocarb with a half-life 12 days will have 50% of the originally applied concentration left after 12 days, 25% after 24 days and 12.5% after 36 days. Long half-lives for herbicides typically mean long residual periods. Chlorsulfuron with a half-life of 160 days will have a longer re-cropping period than will triasulfuron with a half-life of 23 days.

Half-life is not necessarily a good predictor of the effective period of residual weed control. Weed control is achieved when the concentration of herbicide the germinating seed encounters is sufficient
to stop the weed from emerging or to incapacitate it after emergence. If the rate of herbicide originally applied is much greater than that required to control the weed, then considerable effective persistence of the herbicide can be achieved even with a short half-life. Likewise, if the rate of herbicide originally applied is only just higher than required to control the weed, then effective persistence will be relatively short.

Soil properties other than organic matter and clay content can also influence behavior of herbicides. The most important of these in Australia is soil pH, particularly with sulfonylurea herbicides. At high pH these herbicides become more water soluble and tend to move further in the soil profile as well as binding less to soil organic matter. This can result in sulfonylurea herbicides moving out of the root zone. High pH also reduces the breakdown of sulfonylurea herbicides by hydrolysis reactions, resulting in much longer persistence in the soil.

Some examples

With the foregoing information it is possible to make some broad predictions about the behaviour of pre-emergent herbicides under specific conditions. Trifluralin, for example, has very low water solubility and very high binding to organic matter. This means trifluralin will tend to stay where it is applied. Risks of damage to crops by trifluralin will occur when the crop is sown too shallow, resulting in insufficient separation between crop seed and the herbicide, or where soil containing the herbicide is moved into the crop row.

S-metolachlor (Dual Gold) has high water solubility and medium binding to organic matter in the soil. Therefore, this herbicide will readily move in the soil. Damage to sensitive crops, such as wheat, is more likely to occur in sandy soils with low organic matter and after heavy rainfall.

Pyroxasulfone (Sakura) has low water solubility, but does not bind strongly to organic matter. It is less likely to move through soil than S-metolachlor, but will do so in soil with low organic matter and can lead to crop damage under these circumstances. Due to its low water solubility, pyroxasulfone is best suited to situations where it is applied directly on top of the weed seed.

Cultivation and crop seeding systems

Pre-emergent herbicide behaviour is also influenced by soil preparation and the type of seeding system. Pre-emergent herbicides (other than triallate) are taken up by germinating seedlings through the roots or roots and mesocotyl (the part of the shoot immediately above the seed). Therefore, weed seeds will most likely absorb herbicide if the herbicide is at or below the seed in the soil profile.

At the end of the season, seed rain falls mostly on the surface of the soil. Some weed species, such as wild oats, have the ability to bury themselves into the surface of the soil, but most will remain on, or close to the soil surface. The aim with pre-emergent herbicides is to have as high a concentration of herbicide as possible where the weed seeds are positioned while minimising the amount of herbicide that reaches the crop seed. As a general rule, pre-emergent herbicides will be most effective if applied directly to the weed seeds. This has implications for the type of tillage and seeding equipment used with pre-emergent herbicides.

Cultivation prior to applying pre-emergent herbicides mixes the seed throughout the soil profile to the depth of cultivation (Figure 1). Using pre-emergent herbicides with pre-sowing cultivation means the weed seeds are separated from the herbicide. In this circumstance, either the pre-emergent herbicide has to be incorporated into the soil mechanically, or by rainfall or irrigation. As the weed seeds are spread through a greater volume of soil, the herbicide concentration will be more dilute at the weed seeds. Where the herbicide can cause crop damage, the crop seed needs to be sown below the band of soil that may contain damaging concentrations of herbicides.
Pre-sowing cultivation

Figure 1. Distribution of weed seed in the soil profile with pre-sowing cultivation.

At the other extreme, low disturbance disc seeding equipment leaves the weed seed on the soil surface and the herbicide sitting on top of the weed seed (Figure 2). This type of seeding system is not appropriate for use with herbicides, such as trifluralin and pendimethalin, which require mechanical incorporation to be effective. Pre-emergent herbicides with greater solubility are more appropriate for disc seeding equipment. However, because there is limited separation between herbicide and crop seed, products with high intrinsic safety to the crop need to be used.

Low disturbance disc

Figure 2. Distribution of weed seed in the soil profile with low disturbance disc seeding equipment.

Knife point seeding systems that throw soil out of the crop row and onto the inter-row are well suited to use with most pre-emergent herbicides (Figure 3). These systems have the advantage of being able to place the herbicide on top of the weed seed, to incorporate the herbicide with the soil moved from the crop seed row, and to create sufficient space between the crop seed and the herbicide to provide crop safety. However, as there is little herbicide left in the crop row, weeds are likely to emerge in the crop row.
Regardless of soil disturbance with seeding system, there are several other factors that need to be considered. Due to their very high binding to organic matter, herbicides such as trifluralin and pendimethalin will be bound to crop residue in stubble-retained systems. This is usually managed by increasing the application rate of these herbicides and/or removing some of the crop residue, through burning for example.

With respect to weed control, triallate behaves differently to other pre-emergent herbicides. This is because it is primarily absorbed by the emerging coleoptile rather than the roots. Therefore, triallate needs to be situated at or above the weed seed to be effective. In conventionally cultivated systems, triallate can be an effective wild oat herbicide. However, in direct drill no-till systems, wild oat seeds are too close to the surface, so triallate rates need to be increased to obtain control. An alternative is to mix trifluralin with triallate.

Due to its different action in the soil profile, addition of triallate to other grass pre-emergent herbicides generally results in increased levels of control. Essentially, the mixture allows weeds germinating both at the top of the soil profile and below the soil surface to be controlled.

**Summary**

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

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

6. Many pre-emergent herbicides can cause crop damage. Separation of the product from the crop seed is essential. In particular care needs to be taken with disc seeding equipment in choice of product and maintaining an adequate seeding depth.

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• AXIAL Selective Spray Topping reduces contribution of Wild Oat seed to the seed bank
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• Effective on ‘fop’ resistant biotypes
• Excellent tank mix compatibility
• Good crop safety
• Suitable for use in both wheat and barley

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The following products have been tested and have been shown to be physically compatible with AXIAL:

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- Brodal*
- Bulldock Duo*
- Clompyralid
- Decis Options*
- Diflufenican
- Dimethoate
- Folicur*
- Glean*
- Le-Mat*
- Metsulfuron-methyl
- Phosyn Bortrac*
- Phosyn Coptrel 500*
- Phosyn Mantrac 500*
- Phosyn Stopit*
- Phosyn Stopit N*
- Phosyn Zintrac FL*
- Sniper*
- Talstar® 100 EC

AXIAL applied on its own has excellent crop safety on wheat and barley from two leaf to flag leaf emergence.

Important Notes

• For the control of annual ryegrass, 300mL/ha of AXIAL must be used when mixing with a broadleaf herbicide
• Tank mixing AXIAL with herbicides containing Dicamba or 2,4-D is not recommended
• AXIAL must be applied in combination with ADIGOR for all tank mixes
• Variations in water quality, product formulations, environmental conditions, and water volumes can all affect the compatibility of any tank mix. Therefore it is recommended that a preliminary compatibility test (jar test) be carried out prior to the use of any tank mix with AXIAL
• Please refer to the label of the product being tank mixed for rates and constraints

AXIAL Compatibility Chart

Australian trial results show that AXIAL can be tank mixed with a range of key broadleaf herbicides.

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Biological Compatibility

TANK-MIX PARTNER

<table>
<thead>
<tr>
<th>2,4-D</th>
<th>Ally*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ally + MCPA</td>
<td>Conclude*</td>
</tr>
<tr>
<td>Alpha Cypermethrin</td>
<td>Dicamba</td>
</tr>
<tr>
<td>AMISTAR XTRA®</td>
<td>Eclipse*</td>
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<tr>
<td>Broadstrike*</td>
<td>Hotshot*</td>
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<tr>
<td>Conclude*</td>
<td>Jaguar*</td>
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<tr>
<td>Dicamba</td>
<td>KARATE ZEON®</td>
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<td>LOGRAN®</td>
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<td>Tordon*</td>
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<tr>
<td>Tilt XTRA®</td>
<td>Velocity*</td>
</tr>
</tbody>
</table>

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AXIAL Compatibility Chart

Compatible
Not compatible
Compatible with some loss of grass efficacy

^ Caution - temporary chlorosis

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Robust sterilisation of Avena seed through Selective Spray Topping of AXIAL

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Non-herbicide tactics to help suppress weed growth. Row orientation, spacing and variety selection as weed management tools

Greg Brooke, NSW DPI Trangie

Key words
Non-herbicide, Row orientation, Row spacing, Plant population, barley, weeds, integrated weed management.

GRDC code
UA00124

Take home message
- At Bithramere near Tamworth east-west crop row orientation in barley yielded the same as north-south sowing but reduced biomass of weeds (canola) by 30% compared with a north-south row orientation.
- At Merredin and Beverley in W.A east – west sowing gave 24% yield increase in cereals and a 37 to 54% suppression in weed biomass.
- At Trangie increasing the seed density of the barley varieties Hindmarsh and Granger improved their yield and also increased their competitiveness against weeds (oats).

The rise in herbicide resistance in Northern region cropping systems has meant that in some situations weeds are dictating more and more how farmers can farm. With multiple resistance occurring in some weed species, non herbicidal measures to control or at least help suppress weeds are of increasing necessity. For integrated weed management (IWM) systems to be effective, non-herbicide strategies are imperative.

Prior to the advent of selective in-crop herbicides and the introduction of the semi-dwarf gene, cereal cultivars were taller and by nature had more suppressive effect on weeds such as oats (Vandeleur & Gill 2004). A crops competitive effect is most highly correlated with its ability to generate a large leaf area index early in its growth stage (Coleman, Gill & Rebetzke 2001).

Several studies have been done amongst current cereal cultivars to determine whether some varieties are inherently better at suppressing weed growth than others.

Can the inherent ability of some varieties to accumulate biomass be put to effect against weeds?
What are the trade-offs in yield vs weed suppression from high vs low harvest index varieties?
Does increasing the crop sowing rate assist with weed competition? What are the effects of increasing seeding rate on variety performance and on weed suppression?
Does row orientation make any difference to either yield or weed suppression?

It is known that as a plant type barley is more competitive than wheat and for this reason barley is usually chosen for these plant competition trials.

Row orientation - does it make a difference?
Many paddocks in our northern region were originally set up for controlled traffic tramlines 15 years ago based on practicalities such as reducing headland area by choosing row direction according to the longest run of the paddock, so that row direction varies from paddock to paddock. In irrigation fields it is with fall of the paddock. Practicalities aside, what difference does row orientation make to crop yield and suppression of weeds?
Deliberately orienting crop rows at 90 degrees to the sunlight direction east – west (E-W) works on the principle that the crop will intercept more sunlight (photosynthetically available radiation) than will N-S sowing, giving weeds less chance to develop in the crop inter row. In winter when the sun is at a lower angle (solar plane) this shading of the inter row can confer advantages particularly in southern latitudes. Research from 2002 – 2005 conducted by Borger et al at Merredin and Beverley W.A. (latitudes S 31° to 32°) has shown both yield advantages as well as weed suppression from east/west row orientation compared with north/south.

Merredin in Western Australia is similar in latitude to Tamworth.

Annual TOTAL solar radiation at Merredin is very similar to annual TOTAL solar radiation at some eastern state sites eg. Merredin W.A 7036MJ/m²; Trangie NSW 6864MJ/m²; Goondiwindi NSW 7172MJ/m² (source CliMate app)

Within wheat and barley crops oriented east-west, in the W.A trials weed biomass (averaged throughout all trials) was reduced by 51 and 37%, and grain yield increased by 24 and 26% (compared with crops oriented north-south) (Borger et al.)

Weeds in these trials were sown wild radish (300 pod segments/m²) and annual ryegrass (“Safeguard” 200 seeds/m²)

At Bithramere near Tamworth in 2012, Matt Gardner et al. established a trial with two barley varieties- Hindmarsh(1) and Skipper(1) with a sown population of 44Y84(1) canola as a substitute weed. Row orientation, row spacing 30 cm vs 50 cm were evaluated. A row orientation of E-W conferred a reduction in weed (canola) biomass of 39%.

Skipper(1) being more vigorous than Hindmarsh(1) reduced weed (canola) biomass a further 30% and 42% over Hindmarsh(1) for the N-S and E-W sowing.

The weed fumitory was also prolific in the N-S sowing but was reduced almost to nothing in the E-W row orientation. (Matt Gardner pers comm.)

Row orientation had no significant impact on grain yield under high weed competition. When no weeds were present, the N-S orientation had a 6% and 7% yield improvement for the 30 and 50cm row spacing treatments. (Gardner et al. 2012)

Summer crop work in sorghum by Serafin, L and McMullen,G 2011 showed row orientation had no advantage in terms of yield. This is most likely because the sun is at a higher angle and also because of the relatively lower plant populations involved and the wider rows – 75cm. Importantly E–W sowing did not yield any less than did N-S sowing meaning it would be compatible with winter crop programs which deliberately oriented crop rows E-W for weed control.

Row spacing- does it make a difference?

The Bithramere2012 trial with 30 cm vs 50 cm showed no clear effects in reducing weed (canola) biomass, but the wider row spacing did incur a yield penalty of 11% in the nil weed treatment.

At Merredin W.A. two row spacings of 23 cm vs 60 cm were used and at Beverley WA two row spacings were studied at 18 cm vs 36 cm. Averaged throughout all trials, weed biomass was lower in crops with narrow row spacings (Borger et al.).

Varieties – are there differences?

Most published work has concentrated on crop type eg barley vs wheat vs canola vs lupins etc and not on varieties. Recent work with barley varieties shows there is as much difference between barley varieties as there can be between crop types.

The Bithramere trial with two barley varieties showed the more vigorous barley variety Skipper(1) reduced weed (canola) biomass by 30 – 40% over Hindmarsh(1)³.
Skipper also out-yielded Hindmarsh with both weeds present and not present and at both 30 and 50 cm row spacings.

Figure 1. Barley competition trial, Trangie 2013

Figure 1 summarises a barley competition trial conducted at Trangie in 2013 and shows the capacity of different varieties to yield both with and without weeds and the yield loss incurred by weeds (oats).

15 barley varieties were sown at 100 seeds per m$^2$ and 3 of these varieties were sown at double rate of 200 seeds per m$^2$. Row spacing was 33cm. The oat variety Yarran was surface sown as a substitute weed at 50 seeds per m$^2$ and was allowed to grow right through until maturity. The yield loss attributed to weeds averaged across all varieties was 0.3t/ha.

The popular and high yielding variety Hindmarsh both with and without weeds present was the highest yielding variety. Increasing the seed rate to 200 seeds/m$^2$ improved the yield of Hindmarsh both with and without weeds and also gave greater suppression of weeds. This is consistent with other seeding rate trial work with Hindmarsh in variety specific agronomy package (VSAP) trial work.

The variety Granger at 200 seeds/m$^2$ improved yield where weeds were present but only maintained yield where there were no weeds present.

Figure 2. Oat suppression by barley variety, competition trial, Trangie 2013

Figure 2 shows the effects of weed (oat) suppression by barley variety.
Varieties such as Hindmarsh which are lower biomass types proved less suppressive of weeds than bulkier types such as Grange, Fathom, Commander.

Increasing the seeding rate of Hindmarsh caused greater suppression of oat yield.

Granger at 200 seeds per m² gave the greatest reduction in oat yield.

Summary
Crop row orientation of E-W in winter cereals has given substantially greater suppression of weeds in both WA and Northern NSW trials.

Barley variety choice will impact the seed set of oats.

Increasing seeding rate of Hindmarsh and Granger from 100 seeds to 200 seeds per m² caused a further reduction in weed (oat) yield.

Increasing the seeding rate of ScopeCL did not improve yield or significantly increase suppression of oats in this trial.

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Tony Cook, NSW DPI Tamworth

Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994
Many grain growers in New South Wales and south-eastern Queensland have already noticed that the increasing resistance of wild (black) oats to post-emergent herbicides is affecting their in-crop control.

Wild oat resistance to Group A herbicides was first identified in southern New South Wales over twenty years ago, and now Group B and even Group Z herbicides are also becoming less effective on wild oats in many areas.

That escalation of the resistance issue means growers are looking for alternative management methods, both in terms of different herbicidal modes of action and non-chemical management practices.

So the addition of wild oats to the Sakura 850 WG label last year was very timely. The registration is for suppression of wild oats, based on average control levels of approximately 80% in extensive trial work. For many growers, that level of weed management will represent a much better result than they can now achieve with older post-emergent chemistry.

“This is a really useful extra registration for growers around here and up into Queensland,” explains local Bayer Technical Advisor, Angus MacLennan.

Stephen Fryer is one grower who has used Sakura across his entire wheat program and seen the benefits of wild (black) oats suppression as well as annual ryegrass control.

Stephen typically grazes sheep on lucerne pasture on half his farm at Parkes and sows the other half to wheat and barley.

“Sakura has really helped keep cropping viable in the areas like parts of WA where resistant populations of annual ryegrass were becoming almost unmanageable.

“Luckily, we don’t have such drastic problems with either annual ryegrass or wild oats yet. And adding Sakura to the rotation now can help keep things that way. It can relieve the pressure from wild oats and prevent big problems with annual ryegrass down the track.

“We need to use all the Integrated Weed Management practices available to help ensure that the viability of our current cropping rotations doesn’t come under threat.”

Suppression of brome grass was also added to the Sakura label last year, so it is now registered for use on seven weeds and has continued to demonstrate very high levels of control for extended periods on annual ryegrass, barley grass, annual phalaris, silver grass and toad rush in wheat (except durum wheat) and triticale.

Sakura® is a Registered Trademark of Kumiai Chemical Industry Co. Ltd.
The mechanisms of herbicide resistance: what are we selecting for and why?

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Key words
Target site, increased detoxification, reduced translocation

GRDC cod
UA00124

Take home message
For most herbicide modes of action there is more than one resistance mechanism that can provide resistance and within each target site, there are a number of amino acid modifications that provide resistance. This means that resistance mechanisms can vary widely between populations; although, some patterns are common. While some broad predictions can be made, a herbicide test is the only sure way of knowing which alternative herbicide will be effective on a resistant population.

Mechanisms of herbicide resistance – what are we selecting for and why?
Herbicide resistance has become a major concern for grain producers across Australia. Currently there are 41 weed species in Australia with resistance to one or more of 11 herbicide modes of action. Management of herbicide resistance usually relies on an understanding of the biology of the weed species and the herbicides that are still effective for control. At times the mechanisms of herbicide resistance that are common can provide information about potential cross-resistance to other herbicides and rules of thumb about herbicide management.

Every time a herbicide is used to kill weeds or stop their seed production it selects for resistance. How strongly herbicides select for resistance depends on the proportion of weeds that are controlled by each application and how frequently applications of the same mode of action are made. Herbicide applications that control a smaller proportion of weeds will select for both weak and strong resistance mechanisms, whereas applications that control a high proportion of weeds tend to select for stronger mechanisms only. However, any mechanism that is present in the weed population and can allow the weed to survive has the potential to be selected by herbicide use.

Generally mechanisms of herbicide resistance are divided into target site and non-target site mechanisms. However, within each category there are distinct resistance mechanisms.

Target site resistance mechanisms
Target site mechanisms involve a change to the protein that binds the herbicide resulting in a lack of inhibition of the biochemical pathway.

The most obvious of these is where a mutation within the target protein reduces or eliminates binding of the herbicide. This is the classic target site mutation and is typically seen as providing virtual immunity to the herbicide. However, that is not always the case and it is possible to have weak target site mutations as well as strong target site mutations. Target site mutations arise due to single point mutations in the underlying DNA that change an amino acid in the protein. This changed amino acid may either remove a bond required for binding the herbicide or change the shape of the binding pocket.

Target site mutations are common in weeds with resistance to Group A, Group B and triazine Group C herbicides, but also occur with resistance to Group D and Group M herbicides. With target site
resistance it is common to get cross-resistance to other herbicides of the same herbicide mode of action.

For most target sites there is more than one possible mutation that will provide resistance to herbicides. In many cases, different mutations give different levels of resistance and patterns of cross-resistance. For example, resistance selected by sulfonylurea herbicides may not result in resistance to the imidazolinone herbicides. Our data suggests that cross-resistance to imidazolinone herbicides occurs about 30% of the time with broadleaf weeds and 50% of the time with grass weeds. However, this is variable between species.

There are 8 different amino acids within the ALS protein where mutations are known to result in resistance to herbicides. Of these 4 give strong resistance to sulfonylurea herbicides and 6 give strong resistance to imidazolinone herbicides. Therefore, only some of the mutations provide resistance to both groups of herbicides. The reasons for this are that the different groups of herbicides bind differently in the binding pocket, so different mutations affect only one or both types of herbicides (Figure 1).

![Figure 1. Different mutations within a target site can result in different patterns of resistance. A target has a binding site where two chemically different herbicides, H1 and H2, can bind (A). The herbicides bind to different parts of the binding site. A mutation within the target site (B) may stop binding of one herbicide, but not the other. A different mutation elsewhere within the target site (C) may stop both herbicides from binding.](image)

A different situation has occurred with Group A herbicides. For ACCase there are 7 amino acids within the protein where mutations are known to provide resistance to herbicides. Most of these provide resistance to the fop herbicides, but only 3 provide any resistance to clethodim, with only 1 giving high level resistance on its own. Therefore, most target site mutations selected by fop herbicides can be controlled by clethodim. This has allowed growers in southern Australia to exploit fop herbicides first to control ryegrass and after those herbicides had failed, to use clethodim to control ryegrass. Once clethodim started to fail, higher rates were used as there was only one mutation that provided high resistance to clethodim.

The other type of target site resistance is where there are many more copies of the target site than would normally be present. In this type of resistance, the extra target sites act like a sponge soaking up the herbicide. This mechanism has so far only been seen with glyphosate resistant weeds. If this type of mechanism was to occur for another herbicide target site it would be expected to provide resistance to every herbicide in that mode of action.
Non-target site resistance mechanisms

Non-target site resistance mechanisms allow plants to survive application of the herbicide by not allowing sufficient herbicide to reach the target site. The weed may be initially affected by the herbicide application, but will survive and set seed.

The most common example of non-target site resistance is due to increased herbicide detoxification. With this resistance mechanism, there is more rapid breakdown of the herbicide inside the plant and less of the active herbicide reaches the target site to kill the plant. With this mechanism, the species has to start with some ability to metabolise the herbicide, but that becomes greatly enhanced in the resistant individuals. For this reason, enhanced metabolism is typically observed in herbicides that can be used selectively in the crop; such as Groups A, B, C, D and I.

The exact nature of the mutation that results in resistance due to enhanced herbicide degradation has not been identified. However, evidence points to the increased activity of several enzymes, rather than a single enzyme. One outcome of this type of mechanism is that it frequently leads to cross-resistance to herbicides of different modes of action. This seriously complicates resistance management with herbicides. Cross-resistance patterns tend to be highly variable and unpredictable, suggesting there are numerous types of enhanced herbicide detoxification occurring.

A variant on herbicide detoxification is reduced activation of the herbicide. Several herbicides are applied as pro-herbicides and rely on the plant metabolising them to the active compound. If the plant fails to do this, the herbicide will not work. This mechanism has been observed with triallate resistance in Canada, but has not been found in Australia.

A second non-target site mechanism involves changes to the translocation of herbicides within the plant. In this mechanism, the herbicide becomes trapped in the leaf tips and reduced amounts are present in the meristem and other parts of the plant. Where the herbicide has to be present in the growing tissue to kill the plant, reducing translocation will reduce the concentration of herbicide at the target site in these key tissues. This type of mechanism is common in weeds resistant to Group L and Group M herbicides, but has also been seen in weeds resistant to Group A herbicides.

There are several mechanisms whereby a plant can reduce the translocation of herbicides. The main mechanism seems to be through pumping the herbicide into the cell vacuole. As this involves specific transporters for the herbicide, resistance usually occurs to a single herbicide only. The exception to this is resistance to paraquat where cross resistance to diquat always occurs.

An alternative type of reduced translocation is where the herbicide is trapped in tissues that are then shed from the plant. This ‘rapid necrosis’ resistance resembles the plant response to pathogen attack, but on a massive scale where the whole leaves rapidly die and fall off taking the herbicide with them. This type of resistance has been observed for glyphosate resistance elsewhere, but not in Australia.

Two other types of non-target site resistance are theoretically possible, but have not been well documented. Reducing the absorption of the herbicide into the plant will reduce the concentration of herbicide at the target site. Such a mechanism is only likely to be effective for herbicides absorbed only or primarily through leaf tissue. The other type of mechanism is where the plant is able to avoid the detrimental effect of the herbicide action, usually through increased capacity to deal with oxygen radicals. This has been proposed as a mechanism of paraquat resistance for example, but is only a practical mechanism if the plant also has the ability to rapidly remove the herbicide from the target site.

What types of herbicide resistance are being selected and why?

We should expect that every mechanism of resistance that is present in a population will be selected by herbicide use. In practice what tends to happen is that the strongest resistance mechanism present becomes dominant. The strongest mechanism will have greater fitness under selection and so individuals carrying it will contribute more to the seed bank. In most broadleaf weeds target-site
resistance to the sulfonylurea herbicides is found most commonly because this typically provides 100 fold resistance to the herbicide. The types of resistance mechanisms known for the different herbicide modes of action in Australia are listed in Table 1.

**Table 1.** Herbicide resistance mechanisms that have been identified for different modes of action in Australia

<table>
<thead>
<tr>
<th>Mode of action</th>
<th>Target site mutation</th>
<th>Target site duplication</th>
<th>Increased detoxification</th>
<th>Reduced translocation</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>✓?</td>
</tr>
<tr>
<td>J</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>M</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Z</td>
<td></td>
<td></td>
<td></td>
<td>✓?</td>
<td></td>
</tr>
</tbody>
</table>

Due to variations in the strength of the resistance mechanisms between herbicides of the same mode of action, different herbicide selection can lead to different outcomes. A good example of this is that in the 1990s, diclofop-methyl (Hoegrass®) was the main selecting agent used against wild oats. Most of the resistant populations had target site resistance across the fop herbicides with some resistance to the dim herbicides. Later fenoxaprop-p-ethyl (Wildcat®) and clodinafop-propargyl (Topik®) became the most commonly used wild oat herbicides and a different type of resistance mechanism became common. This was a non-target resistance that gave cross-resistance to flamprop-methyl (Mataven®), but these populations often had susceptibility to other fop herbicides.

The patterns can also be different between weed species. Most of the resistance to Group B herbicides in annual ryegrass is target site resistance, generally because of the strong resistance provided by this mechanism to chlorsulfuron (Glean®) and triasulfuron (Logran®). In addition, at least 50% of the resistant populations have cross-resistance to imidazolinone herbicides. However, in brome grass, which has been selected mainly by iodosulfuron (Atlantis®) and pyroxasulam (Crusader®), most of the Group B resistance is low-level, non-target site resistance with little or no cross-resistance to imidazolinone herbicides.

Continued selection of the resistant populations with herbicides will result in stronger herbicide resistance, usually occurring through the stacking of resistance mechanisms. For example, when annual ryegrass became resistant to clethodim (Select®) at 250 mL ha⁻¹ it was discovered that most populations could be controlled by 500 mL ha⁻¹. Then populations became resistant to the higher rate by picking up extra target site mutations. When glyphosate resistant annual ryegrass first occurred in vineyards, some growers increased the rates of glyphosate in an attempt to control the ryegrass. What they selected for was annual ryegrass with two different mechanisms of resistance, a target site mutation and reduced herbicide translocation, which was much more resistant to glyphosate.

Weed species also become resistant to multiple modes of action by accumulating herbicide resistance mechanisms. This usually occurs through the sequential application of different modes of
action, but can also occur with herbicide rotations and the use of herbicide mixtures. Multiple resistance occurs more readily in outcrossing weed species, but can also occur in self-pollinated weed species. The worst case of multiple resistance is a ryegrass population with resistance to Group A, B, C, L and M herbicides. This population has a combination of target site and non-target site resistance mechanisms.

The role of herbicide testing

While it is possible to make some general predictions of the most common resistance mechanisms that will occur from specific types of herbicide selection, the diversity of resistance mechanism present and the variations in herbicide history mean that it is difficult to predict the resistance mechanism in any one population. This is where herbicide testing becomes useful, not so much to determine whether the population is resistant, but to identify herbicides that will still work. Frequently a population in one field will respond differently to alternative herbicides to a population in an adjacent field. This is because a different mix of resistance mechanisms has been selected. Therefore, a test conducted on a population from one field may not be a good predictor of what will happen in the adjacent field.

Contact details

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Crusader™ Herbicide controls both grass and broadleaf weeds in wheat, triticale and cereal rye crops.

**Crusader Herbicide:**
- Controls wild/black oats, phalaris and brome grass
- Suppresses annual ryegrass, barley grass and silver grass
- Is registered to control 21 broadleaf weeds either by itself or in combination with a partner herbicide
- Has useful activity on several other unregistered weeds
- Can be tank mixed with a wide range of broadleaf herbicide partners to increase control, manage resistance and/or to broaden the weed spectrum
- Will maintain high levels of grass control even when mixed with a broadleaf herbicide partner (i.e. no antagonism with compatible products)
- Allows rotational flexibility with short plantback periods that are independent of soil pH
- Has a wide crop application window
- Will control Group A resistant wild oats and other group A resistant grasses
- Can be used in a "grain and graze" cropping programme with a 4 week grazing WHP
- Is not registered for use in Durum wheat varieties and is damaging to barley and oat crops.

**For best results Crusader Herbicide**
- Should be used on small weeds (pre-tiller grasses, less than 6 leaf broadleaf weeds)
- Should be used on low weed densities (less than 150 plants per square meter)
- Should be applied to crops and weeds that are not under stress due to weather conditions, poor nutrition, disease or other stresses.

For further information consult your local Crusader Herbicide agent or the technical guide available from the website [www.dowagro.com/au/prod/Crusader.htm](http://www.dowagro.com/au/prod/Crusader.htm)

FallowBoss™ TORDON™ Herbicide is registered for the control of flaxleaf fleabane and many other broadleaf weeds in winter cereals, winter fallow and summer fallow.

FallowBoss contains three powerful active ingredients; 2,4-D, picloram and aminopyralid. Aminopyralid is the active that makes FallowBoss a faster, stronger and longer product to knockdown hard to control weeds and provides the residual control needed to keep crops and fallow paddocks clean of new weed germinations.

**FallowBoss:**
- Is registered to control fleabane in cereals and fallow situations
- Is registered in cereals at 300 mL/ha
- Is registered in fallow prior to planting sorghum at 700 mL/ha
- Is registered in fallow prior to planting winter cereals up to 1L/ha
- Has a narrow application window in winter cereals of Z14-31
- Will have plantback restrictions to sensitive crops.

For further information consult your local reseller or view the tech guide available from the website [www.dowagro.com/au/prod/fallowboss_tordon.htm](http://www.dowagro.com/au/prod/fallowboss_tordon.htm)
Arylex™ ACTIVE is a new herbicide for the control of broadleaf weeds with utility in multiple crops. Arylex is an innovative low-dose growth regulator herbicide for use in mixtures with other Dow AgroSciences proprietary herbicides creating a wide spectrum of products customised for specific geographies.

Discovered by and proprietary to Dow AgroSciences, Arylex is the first member of a new structural class of synthetic auxin herbicides (Group I mode of action) known as arylpicolinates. Postemergence use rates in cereals will typically range from 5-10 grams active/hectare depending upon target weed species and geography. The auxinic mode of action of Arylex will be effective in managing weed biotypes resistant to other modes of action such as ALS inhibitor herbicides, glyphosate and triazine herbicides.

Product concepts containing Arylex are being evaluated across the globe in all major cereal markets. Arylex will provide growers with a powerful, low-dose herbicide with a desirable environmental profile.

**Noteworthy Features**

- Effective post-emergence control of many common and economically damaging broadleaf weeds in cereals and other crops.
- Consistent weed control across variable climatic conditions (cold and dry conditions) allows for flexibility of application.
- Alternative mode of action to help manage resistant weed biotypes.
- Highly compatible with other agricultural chemical products.
- Low use rates resulting in low environmental load of the herbicide.
- Rapid degradation in soil and plant tissues allowing for crop rotation flexibility.
- Favourable environmental and toxicological profile

New products containing Arylex™ ACTIVE will be introduced onto the Australian market in 2015. The first product for the broadacre cereal market will be Paradigm™ Arylex ACTIVE Herbicide.

Paradigm will have extensive label claims for the control of many broadleaf weeds that are present in Australian broadacre cereal crops including brassica weeds, deadnettle, fumitory, thistles, bedstraw, bifora, poppies, and many more.

Paradigm will offer

- Broad spectrum broadleaf weed control
- Wide compatibility with other ag-chem products including grass herbicides
- Flexible rotational cropping opportunities
- Alternative mode of action for many weeds
- Low dose, easy to handle formulation with minimal tank clean out requirements.

More information will be made available soon through your local reseller or [www.dowagrosciences.com.au](http://www.dowagrosciences.com.au)
Herbicides and weeds – regional issues trials and developments

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Key words
Herbicides, resistance, glyphosate, wild oats, windmill grass, fleabane, sowthistle, barley grass

GRDC code
UQ00062, UA00124, GOA0002

Take home message
There are many weed related problems facing growers in the northern grain region. Herbicide resistance is the major issue, affecting many species and making many herbicide options redundant.

Most farmers will be dealing with some or many of the topics covered in this paper, making effective management difficult.

Research has found solutions for many of these issues, however there are some research needs for a good range of problems.

A great proportion of the solutions to our problems are still herbicide based and in the future will lead to other herbicide resistance problems.

Multiple resistant wild oats
Resistance to one mode of action herbicide is very common in most parts of the northern grain region, specifically for post-emergence herbicides. Farmers overcome this issue by selecting another post-emergence herbicide from a different mode of action. However, the steady increase in multiple resistant wild oats has forced farmers to make substantial changes.

The most recent wild oat survey for the northern region was completed in 2007 so getting a more precise understanding of the situation is difficult. Furthermore, this survey was focused on the SE Qld and N NSW regions. With this in mind, The Grain Orana Alliance has conducted a wild oat resistance survey in 2013. It was solely focused on the resistance issues of central western NSW and the results from this study will be eagerly sought when reported in 2014.

There are many cases of multiple or cross resistance occurring. In some cases the resistance can be to three herbicide groups (A, B and Z). However, in extremely serious cases of multiple resistance there is still a good chance that a few post-emergence herbicides will work. One example is a population of wild oats from Edgeroi that was confirmed resistant to Group A, B and Z herbicides, but was still susceptible to Verdict and high rates of Select.

The mechanisms controlling resistance within wild oat plants are complex. Unless a resistance test is used, you will remain in the dark as to which herbicides are likely to still work and which won’t.

Growers with wild oats that have resistance to one or two herbicides groups (either, A, B, Z, A and B or A and Z), could use a pre-emergence herbicide followed by the remaining useful post-emergence option and get excellent levels of control. Table 1 below best summarises this strategy.
### Table 1. Controlling group A resistant wild oats, North Star

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Rate of product/ha</th>
<th>Herbicide group(s)</th>
<th>Wild oat seeds per m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>----</td>
<td>----</td>
<td>90.7</td>
</tr>
<tr>
<td>Achieve® (post-em)</td>
<td>380g</td>
<td>A</td>
<td>43.8</td>
</tr>
<tr>
<td>Topik® (post-em)</td>
<td>65mL</td>
<td>A</td>
<td>180.9</td>
</tr>
<tr>
<td>Wildcat® (post-em)</td>
<td>300mL</td>
<td>A</td>
<td>123.3</td>
</tr>
<tr>
<td>Avadex® Xtra (pre-em)</td>
<td>1.6L</td>
<td>J</td>
<td>9.4</td>
</tr>
<tr>
<td>Trifluralin® 480 (pre-em)</td>
<td>1.5L</td>
<td>D</td>
<td>47.8</td>
</tr>
<tr>
<td>Mataven® 90 (SST)</td>
<td>1.875L</td>
<td>Z</td>
<td>0.4</td>
</tr>
<tr>
<td>Hussar® (post-em)</td>
<td>200g</td>
<td>B</td>
<td>2.3</td>
</tr>
<tr>
<td>Atlantis® (post-em)</td>
<td>330mL</td>
<td>B</td>
<td>4.2</td>
</tr>
<tr>
<td>Crusader® (post-em)</td>
<td>500mL</td>
<td>B</td>
<td>0.0</td>
</tr>
<tr>
<td>Avadex® Xtra (pre-em) + Hussar® (post-em)</td>
<td>1.6L + 200g</td>
<td>J + B</td>
<td>0.3</td>
</tr>
<tr>
<td>Avadex® Xtra (pre-em) + Atlantis® (post-em)</td>
<td>1.6L + 330mL</td>
<td>J + B</td>
<td>0.0</td>
</tr>
<tr>
<td>Avadex® Xtra (pre-em) + Mataven® 90 (SST)</td>
<td>1.6L + 1.875L</td>
<td>J + Z</td>
<td>0.0</td>
</tr>
<tr>
<td>Atlantis® (post-em) + Mataven® 90 (SST)</td>
<td>330mL + 1.875L</td>
<td>B + Z</td>
<td>0.0</td>
</tr>
<tr>
<td>Hussar® (post-em) + Mataven® 90 (SST)</td>
<td>200g + 1.875L</td>
<td>B + Z</td>
<td>0.0</td>
</tr>
</tbody>
</table>

SST = Selective Spray Topping – late post-emergence to prevent seed production.

However, there are some cases of multiple resistance to all three post-emergence herbicide groups. In this case, data in Table 1 would be irrelevant as no post-emergence option would be effective (refer to Table 2 instead). Reliance solely on pre-emergence herbicides would result in populations of wild oats increasing. Surviving plants from trifluralin and Avadex Xtra treatments tend to be large and produce more seed than what is lost from the germination process.

The radical step of changing crops may open the door to the use of other herbicides (Table 2). Although this wild oat population can be well managed in wheat with pre-emergence herbicides + Atlantis®, alternative crops can be grown with better weed control outcomes. Chickpeas grown on conventional row spacing or wide rows resulted in excellent control and utilised herbicides that have probably never been used for many years. The inter-row spraying of Gramoxone® in wide row chickpeas was successful and the inclusion of simazine, trifluralin and Avadex Xtra as a pre-emergent option was useful.
Table 2. Controlling multiple resistant (Groups A, B and Z) wild oats.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Treatments</th>
<th>Herbicide group(s)</th>
<th>Wild oat seed production per m²</th>
<th>Yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TT Canola</td>
<td>trifluralin + Avadex Xtra + atrazine + Sertin</td>
<td>D + J + C + A</td>
<td>0.5</td>
<td>0.82</td>
</tr>
<tr>
<td>Canola</td>
<td>trifluralin + Avadex Xtra + Dual Gold + Sertin</td>
<td>D + J + K + A</td>
<td>15</td>
<td>0.82</td>
</tr>
<tr>
<td>Clearfield® canola</td>
<td>Intervix®</td>
<td>B</td>
<td>469</td>
<td>0.41</td>
</tr>
<tr>
<td>Chickpea 35 cm row</td>
<td>trifluralin + Avadex Xtra + Simazine + Sertin</td>
<td>D + J + C + A</td>
<td>1</td>
<td>1.24</td>
</tr>
<tr>
<td>Chickpea 75 cm row</td>
<td>trifluralin + Avadex Xtra + Simazine + Gramoxone</td>
<td>D + J + C + L</td>
<td>11</td>
<td>0.87</td>
</tr>
<tr>
<td>Wheat</td>
<td>trifluralin + Avadex Xtra + Atlantis</td>
<td>D + J + B</td>
<td>14</td>
<td>0.94</td>
</tr>
<tr>
<td>Wheat</td>
<td>Sakura®</td>
<td>K</td>
<td>35</td>
<td>1.08</td>
</tr>
<tr>
<td>long fallow</td>
<td>Flame® + glyphosate</td>
<td>B + M</td>
<td>5</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Note: This population had confirmed complex resistance to groups A, B and Z, however it was shown in previous trials that it was partly susceptible to Atlantis and Sertin hence their inclusion.

The same principle applied when growing canola with the inclusion of atrazine, trifluralin, Avadex Xtra and Dual Gold.

Long fallowing paddocks is another alternative. It is important to note that the Flame treatment did not control wild oats well and a follow-up application of glyphosate was required to prevent seed set.

Poor wild oat control was reported in Clearfield canola after using Intervix. This population may exhibit some resistance to this herbicide without prior history of its strong levels of Hussar resistance (Group B) may infer other Group B herbicide resistance. This is a likely reason why Flame did not work well in the fallow. Despite the failure of Clearfield canola, Roundup Ready Canola should work since the population seems susceptible to glyphosate.

Another option is the use of Roundup Ready Canola. This provides excellent control of wild oats. In one experiment at Edgeroi that was infested with A, B and Z resistant wild oats, wild oat seed production was almost 100% prevented with one application of glyphosate. The flip side of this choice is increased risk of glyphosate resistant annual ryegrass not being controlled.

One crop in the north-west that is under more threat due to herbicide resistant wild oats is chickpeas. Although a wide range of post-emergence selective grass herbicides are registered, all are Group A herbicides. Unlike wheat, herbicides like Hussar, Atlantis and Mataven are not registered for use. The pre-emergence herbicides trifluralin and Avadex Xtra are options worthy of consideration and the inclusion of simazine could improve the control. However, if Group A resistance is present, chickpea growing would be totally reliant upon pre-emergence herbicides with in-crop options limited to inter-row tillage or wick wiping. There are two issues with relying solely on pre-emergence herbicides in chickpeas. These are;

1. Pre-emergence herbicides usually result in only 60-80% control under favourable conditions (not as effective as post-emergence herbicides – 85 to 95% control) and
2. That chickpeas do not compete well with weeds allowing the survivors of pre-emergence treatments to develop into large plants capable of large seed production.

There are numerous tactics that can be used to reduce the impact of wild oats. These are summarised in Table 3 and could be used in combination as an integrated weed management approach to maintain the usefulness of effective herbicides.

**Table 3. List of tactics that could be used to manage wild oats**

<table>
<thead>
<tr>
<th>Tactic</th>
<th>Wild oats - Likely control % (range)</th>
<th>Ability to incorporate into farming system (easy, mod, hard)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop choice and sequence</td>
<td>95 (30-99)</td>
<td>Easy to moderate</td>
</tr>
<tr>
<td>Improving crop competition</td>
<td>70 (20-99)</td>
<td>Easy to moderate</td>
</tr>
<tr>
<td>Herbicide tolerant crops</td>
<td>90 (80-99)</td>
<td>Easy</td>
</tr>
<tr>
<td>Burning crop residues</td>
<td>40 (0-80)#</td>
<td>Moderate to hard</td>
</tr>
<tr>
<td>Inversion ploughing</td>
<td>50 (40-60)#</td>
<td>Moderate to hard</td>
</tr>
<tr>
<td>Autumn tickle</td>
<td>40 (30-60)</td>
<td>Easy to moderate</td>
</tr>
<tr>
<td>Fallow and pre-sowing cultivation</td>
<td>40 (0-80)#</td>
<td>Easy to moderate</td>
</tr>
<tr>
<td>Knockdown herbicides for fallow &amp; pre-sowing control</td>
<td>80 (70-90)</td>
<td>Easy</td>
</tr>
<tr>
<td>Double knockdown (doubleknock)</td>
<td>99 (99-100)#</td>
<td>Easy to moderate</td>
</tr>
<tr>
<td>Pre-emergence herbicides</td>
<td>80 (70-90)</td>
<td>Easy to moderate</td>
</tr>
<tr>
<td>Selective post-em herbicides</td>
<td>80 (70-90)</td>
<td>Easy</td>
</tr>
<tr>
<td>Spray-topping with selective herbicides</td>
<td>90 (60-99)</td>
<td>Easy</td>
</tr>
<tr>
<td>Crop-topping with non-selective herbicides</td>
<td>30 (10-50)#</td>
<td>Easy</td>
</tr>
<tr>
<td>Pasture spray-topping</td>
<td>80 (70-90)</td>
<td>Moderate</td>
</tr>
<tr>
<td>Silage and hay – crops and pastures</td>
<td>97 (95-99)</td>
<td>Moderate to hard</td>
</tr>
<tr>
<td>Renovation crops – green or brown manuring, mulching etc</td>
<td>95 (85-99)#</td>
<td>Moderate</td>
</tr>
<tr>
<td>Grazing – actively managing weeds in pastures</td>
<td>75 (60-80)</td>
<td>Moderate to hard</td>
</tr>
<tr>
<td>Weed seed collection at harvest</td>
<td>70 (20-80)</td>
<td>Hard</td>
</tr>
<tr>
<td>Sow weed-free seed</td>
<td>85 (50-99)#</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

Source: Integrated Weed Management in Australian Cropping Systems (A training resource for farm advisors), Section 6-Weeds, weed 1 annual ryegrass (p151) and weed 18 wild oats (p200). Eds. McGillion, T. and Storrie, A.

# - no reference in IWM manual, so estimate was made by author of this paper.

Some of these tactics will be rather easy to incorporate into the farming system, as little or no adjustments to equipment are required. A few examples are changing to herbicide tolerant crops or crop topping with a non-selective herbicide. However, some new tactics may involve introduction of pastures or new machinery, therefore the costs to implement these changes could be prohibitive.
This table of tactics includes 19 different options. Many of these may not be applicable to your farm, but there are likely to be at least 6 to 8 that should be considered.

It is important to note that most of the tactics that involved a change in spray/herbicide strategy had an easier inclusion into the cropping system. In northern NSW we are fortunate to have a majority of our ARG and wild oat populations susceptible to most herbicides. Therefore, changes in weed management are likely to involve a change in herbicide selection (e.g. doubleknock, herbicide tolerant crops, crop-topping, using pre-emergence herbicides, etc.) as these relatively easy transitional options. As the level of herbicide resistance worsens, for instance multiple resistance to most pre- and post-emergence herbicides, the tactics required to manage the problem become increasingly harder to implement. This is what is happening in winter dominant rainfall areas in Australia.

Although it is easy to combat herbicide resistance with other herbicides from a different mode of action (herbicide group), it will place resistance selection pressure on these alternate herbicide groups. Some non-chemical options should be implemented to take the reliance off herbicides. The two most suitable options would include using adequate crop competition and the use of strategic cultivation that minimises soil moisture losses and structural damage.

**Glyphosate resistant windmill grass**

Due to the extended period of dry weather in the central west region of NSW in the past 18 months, no new research findings are available. Plans were to investigate to re-confirm the excellent control achieved with a paraquat + Group H herbicide. Discussions with many weed scientists and agronomists had also identified the research need into the potential of pre-emergence herbicides. The rationale behind this approach is to aim for better control when weeds are more susceptible to herbicides, emerging after rainfall, then to try control to larger plants that may be under some moisture stress. Therefore, a few more years of research are required before the possibility of a few more treatments is available to growers.

Current herbicide registrations for control of windmill grass in summer fallow are limited to Touchdown® Hi Tech. No other formulations of glyphosate are registered to control this weed. There are only two other products registered for selective control of this weed in various situations as listed in the table below.

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Active Ingredient</th>
<th>Use situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor®</td>
<td>Butoxydim</td>
<td>Various summer crops- e.g. mungbeans, cotton, sunflowers</td>
</tr>
<tr>
<td>Dacthal 900®</td>
<td>Chlorthal-Dimethyl</td>
<td>Various brassica and vegetable crops, cotton, lucerne and lawns</td>
</tr>
</tbody>
</table>

As of June 2012, the Grain Orana Alliance (GOA) successfully obtained a Pesticide Permit (number 13460) that allows the use of quizalofop based products at a rate of 0.5 to 1.0L/ha (10% active products) or 250 to 500mL/ha (20% active products). An application of paraquat must be made 7 days after application to ensure better control and to minimise the chance of Group A resistance developing. There are application directions that allow for consistently high levels of control; applying to 3 leaf to early tillering plants and to avoid spraying under moisture stress. GOA has shown that waiting more than 11 days after rain to apply herbicides will result in diminishing levels of control.

As of March 2013, there are 9 confirmed cases of glyphosate resistant windmill grass in Australia, three are located in NSW. Two of these infestations were located in summer fallows and the other on a roadside. It is highly likely that the number of cases of glyphosate resistance is far worse as seed is
easily moved by wind and continued use of glyphosate solely will ensure its gradual spread over the central west region of NSW.

**Group I resistant wild radish**

Late in 2013 a population of wild radish from the central west was confirmed resistant to phenoxy herbicides (Group I), reported as 50% resistant. This discovery has now placed many farmers around the central west district on ‘resistance alert’. The area of concern is approximately a 250km square region south of Nyngan. This region was subject to a long and frequent history of phenoxy use. Common farm practices have included the use of few pre-emergent herbicides and low rates of 2,4-D, MCPA and MCPA LVE formulations in the cereal dominant rotation, sometimes with the addition of a group B herbicide.

It is not uncommon for this weed to be sprayed several times in a summer fallow leading up to sowing of the winter crop, then often more than once in crop due to successive germinations. It is not uncommon that a population of radish in this area will receive 4 applications per year of a group I product.

Traditional rotations included lucerne phases however lucerne paddocks and paddocks being “spelled” from cropping are frequently dominated by wild radish as it is largely unpalatable and control options are more limited and expensive than in a cereal crop.

Paddock screening trials done by DPI, at a known resistance site, showed poor efficacy from group B products but very good results from those products containing group H (Precept® and Velocity®).

Approximately 15 samples of wild radish from around this region are going to be tested for group I resistance. From these results it will give a better snapshot of the distribution of this problem and should trigger more detailed resistance screening to determine other effective modes of action available to growers.

There is much to learn from the Western Australia wild radish experience. In the Geraldton region farmers have been dealing with Group I resistant wild radish for at least 5 years along with resistance to many other modes of action. A great deal of their weed management is based on weed seed collection or windrow burning with some assistance from glyphosate (within Roundup® Ready canola).

**Competition trials**

A few experiments have been completed in the past three years. One investigated the row spacing of wheat and its effects on fleabane numbers and the other studying the effects of wheat density on wild radish. Dry conditions at the end of the 2013 winter cereal season meant that drought effects dominated the experiment with most wild radish plants dying from extreme moisture stress regardless of crop density.

Crop competition is known to be a factor that reduces the germination and growth of fleabane. This was highlighted in a trial at Trangie Agricultural Research Centre (TARC), where increasing the row space of Crusader wheat from 33 cm to 66 cm resulted in a 120% increase in fleabane plants in the stubble immediately after harvest (Figure 1). The trial showed that the effect of row space is real and measurable, and can add significantly to other weed control practices. The trial showed no significant effect of seed rate on fleabane population post-harvest. Based on past trial results and the practicalities of row spacing, the ideal set up seems to be about 25 cm for disc seeders and about 30
cm for tine seeders for western areas, and potentially narrower for eastern regions.

![Graph showing the relationship between seed rate and row space vs. fleabane control]

**Figure 1.** Wide rows reduce crop competition with fleabane. This was shown at TARC with 66 cm row space resulting in 120% more fleabane in fallow than the 33 cm row space (sow time l.s.d. p < 0.05 = 0.34), with no significant effect of seed rate on subsequent fleabane population.

**Resistance in fleabane and sowthistle**

**Fleabane:** Glyphosate resistant fleabane is common in regions between the Liverpool Plains and the Darling Downs. Isolated infestations have been located in the central west parts of NSW and the national register of confirmed cases totals 57. All of these cases were discovered between 2010 and 2012. Knowing that fleabane has large seed production capacity and the seed is easily spread by wind, the potential for widespread glyphosate resistant fleabane throughout the northern grain region is possible.

There are concerns that the frequent use of 2,4-D and other group I herbicides may lead to resistance to this class of herbicide. In light of this, a comprehensive survey completed in summer of 2012/3 attempted to find Group I resistance. Approximately 50 fleabane samples were tested for susceptibility/resistance to 2,4-D amine. All samples were found to be susceptible to 2,4-D amine.

**Sowthistle:** The same survey mentioned above also determined the extent of Group I resistance in sowthistle. Seed was collected from sowthistle growing in winter cereals and summer fallows from 2012 and all were found to be susceptible to Group I chemistry.

In the past few years there was unease about survival of sowthistle following glyphosate applications. Recently screening work has identified two populations from the Liverpool Plains with elevated levels of tolerance to glyphosate. Table 5 shows that the “yellow” and the “CRK” biotypes to have reasonable survival rates and reproductive capability 42 days after the standard label rate of glyphosate (1.6L/ha or 720 g active ingredient per hectare).

The discovery of two populations of sowthistle with elevated survival rates following glyphosate may indicate a world’s first case of glyphosate resistant *Sonchus* species. Further research is underway to determine if a panel of glyphosate resistance experts deem this as glyphosate resistance.

This experiment was split into two separate growth stages. Results presented within are those following application to large rosette/early stem elongating plants. Anecdotal evidence suggests the recovery and reproduction of confirmed resistant biotypes following label rates of glyphosate to larger flowering plants is more pronounced and faster than those treated earlier. This could be due to greater expression of glyphosate resistance as plants develop and/or biological dilution of herbicide due to greater plant volume per unit area.
Table 5. Final assessments on sowthistle for plant survival, biomass control / production and reproductive capacity, made 42 days after treatment. Note: growth stage at treatment was large rosette to early elongating stage.

<table>
<thead>
<tr>
<th>Glyphosate rate g a.i./ha</th>
<th>Live plants (max = 1 plant per pot)</th>
<th>Green biomass as g/plant (% control)</th>
<th>Viable flower buds per plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Susceptible biotype</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>32.56 (0)</td>
<td>26.6</td>
</tr>
<tr>
<td>360</td>
<td>0.8</td>
<td>3.46 (89)</td>
<td>0</td>
</tr>
<tr>
<td>720</td>
<td>0.4</td>
<td>1.12 (97)</td>
<td>0</td>
</tr>
<tr>
<td>1000</td>
<td>0.4</td>
<td>0.56 (98)</td>
<td>0</td>
</tr>
<tr>
<td>“CRK” biotype</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>49.94 (0)</td>
<td>21.8</td>
</tr>
<tr>
<td>360</td>
<td>1</td>
<td>18.36 (63)</td>
<td>0.4</td>
</tr>
<tr>
<td>720</td>
<td>1</td>
<td>10.38 (79)</td>
<td>0</td>
</tr>
<tr>
<td>1000</td>
<td>1</td>
<td>19.06 (62)</td>
<td>0</td>
</tr>
<tr>
<td>“Yellow” biotype</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>59.26 (0)</td>
<td>16.8</td>
</tr>
<tr>
<td>360</td>
<td>1</td>
<td>32.84 (45)</td>
<td>6</td>
</tr>
<tr>
<td>720</td>
<td>1</td>
<td>18.92 (68)</td>
<td>0.2</td>
</tr>
<tr>
<td>1000</td>
<td>0.8</td>
<td>19.08 (68)</td>
<td>0</td>
</tr>
</tbody>
</table>

Implications to grains and cotton industries

Fallows, glyphosate tolerant crops and non-cropping areas are under threat of another glyphosate resistant species.

Group B resistance is already present within the QLD/NSW border region. It is likely that plants will develop multiple resistance to Groups B and M.

With the partial loss of effectiveness of glyphosate and Group B resistance in other parts of the northern grain region, there will be more selection pressure on Group I chemistry. Further to this, herbicide Groups C, G, H and L could be used more to take selection pressure off Groups B, I and M.

Due to its wind borne seed, glyphosate resistant sowthistle populations will spread rapidly, similar to fleabane. Surveys are presently underway to gauge the spread of resistance in the northern grain region. In time, southern regions should be surveyed to determine the extent of resistance to glyphosate.

Interim results from the survey work indicate that another two populations have similar tolerances to glyphosate as those discussed above. The location of these plants was within the Liverpool Plains. Sowthistle samples were collected further north and into the Darling Downs regions. The extended dry period in the central western parts of NSW has made it difficult to find samples to test.

Latest research to combat the glyphosate resistant threats (sowthistle)

With recent cases of suspected glyphosate resistance in common sowthistle, effective glyphosate alternatives are required. A field trial evaluated alternatives to glyphosate for fallow control of
common sowthistle and the impact of weed size. Treatments included alternative single and double knocks.

Located near Cecil Plains on the eastern Darling Downs, the field site had a dense (6-10 plants/m²) population of common sowthistle plants at two different growth stages (small <10cm diameter, and large >10cm diameter to elongating).

**Summary of results**

The most effective fallow treatments were the double knocks which were as equally effective on both small (97-100% control) and large (95-100% control) sowthistle plants (Table 6). Most double knock treatments provided 100% control, thereby stopping any weed seed production. Our results show that the double knock treatment is essential for the effective control of small and especially large sowthistle plants.

Antagonism between glyphosate and any tankmix partner was apparent. With reference to the data presented in Table 6, weed control from a single application of glyphosate (Roundup Attack® 1.23L/ha) ranged from 93 to 100% regardless of growth stage, whereas the levels of control when mixed with Amicide Advanced® 700, Tordon 75-D® and Starane Advance® were 2-43%, 12-62% and 40-64%, respectively. This phenomenon is not uncommon throughout the northern region, as agronomists constantly raise this issue with researchers. It is thought that the cause of this antagonism is the stress that glyphosate imposes on the plant which contradicts the conditions needed for effective hormonal activity.

Even though glyphosate was shown to be effective on this population of sowthistle, continued over-reliance on this herbicide is likely to lead to glyphosate resistance in this species. Growers with glyphosate susceptible populations should be using the double knock tactic to stop seed set on survivors. This is of particular importance in reducing weed density and herbicide resistance risk for the future.

While not tested on a glyphosate resistant population, it is likely the double knock tactic would also be effective. If a population of glyphosate resistant sowthistle is confirmed as part of our project, a pot study exploring the effectiveness of the double knock will take place.
Table 6. Visual biomass reduction of common sowthistle (*Sonchus oleraceus*) assessed 31 days after treatment where 0 - no control and 100% - total control. For double knock treatments, the second knock was applied 7 days after the first. LSD on transformed data = 29.24. Numbers in parentheses are transformed and should be used when comparing treatments using the LSD.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Herbicide rate/s (L/ha)</th>
<th>Small (&lt;10cm diameter) Average control (%)</th>
<th>Large (&gt;10 diameter to elongating) Average control (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roundup Attack*</td>
<td>1.23</td>
<td>100 (90) †</td>
<td>93 (81) †</td>
</tr>
<tr>
<td>Sprayseed</td>
<td>2</td>
<td>80 (69)</td>
<td>43 (39)</td>
</tr>
<tr>
<td>* Roundup Attack fb Sprayseed</td>
<td>1.23 fb 2.0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Amicide Advanced + Roundup Attack</td>
<td>0.65 + 1.23</td>
<td>43 (40)</td>
<td>2 (4)</td>
</tr>
<tr>
<td>* Amicide Advanced + Roundup Attack fb Sprayseed</td>
<td>0.65 + 1.23 fb 2.0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Tordon 75D + Roundup Attack</td>
<td>0.7 + 1.23</td>
<td>62 (52)</td>
<td>12 (19)</td>
</tr>
<tr>
<td>Starane Advance + Roundup Attack</td>
<td>0.6 + 1.23</td>
<td>64 (58)</td>
<td>40 (39)</td>
</tr>
<tr>
<td>* Starane Advance + Roundup Attack fb Sprayseed</td>
<td>0.6 + 1.23 fb 2.0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Sharpen + Roundup Attack</td>
<td>17g + 1.23</td>
<td>57 (49)</td>
<td>38 (38)</td>
</tr>
<tr>
<td>Sharpen + Roundup Attack fb Sprayseed</td>
<td>17g + 1.23 fb 2.0</td>
<td>97 (81) †</td>
<td>95 (80) †</td>
</tr>
<tr>
<td>Alliance</td>
<td>2</td>
<td>70 (59)</td>
<td>18 (19)</td>
</tr>
<tr>
<td>Sprayseed</td>
<td>2.4</td>
<td>92 (73) †</td>
<td>57 (49)</td>
</tr>
<tr>
<td>* Roundup Attack fb Sprayseed</td>
<td>1.23 fb 2.4</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Amicide Advanced + Roundup Attack</td>
<td>1.1 + 1.23</td>
<td>67 (60)</td>
<td>30 (31)</td>
</tr>
<tr>
<td>* Amicide Advanced + Roundup Attack fb Sprayseed</td>
<td>1.1 + 1.23 fb 2.4</td>
<td>100</td>
<td>99</td>
</tr>
<tr>
<td>Tordon 75D + Roundup Attack</td>
<td>1.0 + 1.23</td>
<td>88 (78) †</td>
<td>58 (49)</td>
</tr>
<tr>
<td>Starane Advance + Roundup Attack</td>
<td>0.9 + 1.23</td>
<td>97 (84) †</td>
<td>67 (55)</td>
</tr>
<tr>
<td>* Starane Advance + Roundup Attack fb Sprayseed</td>
<td>0.9 + 1.23 fb 2.4</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Sharpen + Roundup Attack</td>
<td>34g + 1.23</td>
<td>82 (66)</td>
<td>60 (52)</td>
</tr>
<tr>
<td>Sharpen + Roundup Attack fb Sprayseed</td>
<td>34g + 1.23 fb 2.4</td>
<td>100 (90) †</td>
<td>99 (87) †</td>
</tr>
<tr>
<td>Alliance</td>
<td>2.8</td>
<td>90 (75) †</td>
<td>50 (50)</td>
</tr>
</tbody>
</table>

fb - followed by, as part of a double knock  * - excluded from analysis as most values = 100
† - not significantly different to 100. To compare with treatments excluded from analysis.
Latest findings: residual herbicides on summer grasses

Residual herbicides will play an important role in the control of summer grass weed species barnyard, feathertop Rhodes and windmill grass. Little is known about the efficacy of some new and some existing residual herbicides on these weed species. Consequently, a pot trial was established to evaluate the efficacy, over time, of different residual herbicides on the control of grass weed species barnyard, feathertop Rhodes and windmill grass. Due to the confidentiality of unregistered treatments and GRDC policy, treatments presented for this experiment are expressed in broad herbicide mode of action groups.

For barnyard grass, Group D, Group G and Group G + K treatments have provided the best control for 0 and 4 week plantings. No treatments provided any control of barnyard grass for the 8 week planting.

The best treatments for feathertop Rhodes grass are from herbicide Groups D and K. Both treatments have provided sustained control with 53 and 68% control at the 8 week planting. Other treatments which provided good short-term control are from Group G, K, G + K and B(imi) + K.

The best treatment for windmill grass has been from a Group D herbicide which has provided long term control with 77% control for the 8 week planting. Other treatments which have provided good short-term control (0 and 4 week plantings) are from Group G, K, K + G and B + K.

This experiment will be repeated in 2014/15 with the aim to have many of these herbicides registered. Plant-back considerations are important and thus some research needs to be focused to determine if these new treatments are not too restrictive for the various cropping regimes of the northern grain region.

Clethodim damage in canola – impact and avoidance

The application of clethodim at rates of product of 500mL/ha have been reported to cause the following symptoms on canola:

- Delayed flowering
- Distorted flower buds
- Possible yield suppression

The current label states that if applications of herbicide above 250mL/ha are made, canola can not be greater than the large rosette stage (GS 29). Other warnings such as not applying twice in the crop, not applying to stressed canola or avoid adding crop oil are aimed to minimise this damage.

Recent research in the central west parts of NSW by GOA had resulted in variable results. Overall damage seemed to be light and it was difficult to ascertain whether some damage was attributed to frost or other abnormal conditions. Yield effects were negligible for most sites. It was concluded that more field experiments could be completed over several sites and years, or some of this work could be achieved under controlled climate conditions, but loses the realistic conditions of field based research.

Clearly growers need to be aware of the main factor driving such drop damage. There may also be varietal differences, about which little is known, however, farmers can control the timing and rate of herbicide and should be able to avoid such issues. As for controlling the conditions of canola at the time of application, spraying earlier may avoid moisture stress issues particularly in seasons when rainfall is light. Spraying early means late emerging grass weeds will not be controlled with in-crop sprays but these plants are likely to be suppressed by a rapidly closing canola canopy. Seed production from these weed could still be managed with non-chemical options such a wind-row burning.
Barley grass on the increase in the central west

It is common to see farming systems involving continuous cropping without fallow or delayed sowing. The practices of dry-sowing and cereal dominance in the crop rotation are leading to increasing problems with barley grass.

Extremely high populations of barley grass 40,000 seedlings per square metre are sometimes targeted in a cereal crop after dry sowing and spray failures are common on these high weed densities. This is usually with group B or C products and results in very poor control. It is also far in excess of label constraints which target a maximum of 100 seedlings per square metre (as per metribuzin label).

There are some things to be learnt from other farmers in Australia that have been battling this weed for many years.

- There is resistance to herbicide Groups A, B and L.
- Delayed sowing could allow the use of glyphosate but research has indicated doing this continuously may select for populations with delay emergence patterns.
- Barley grass is a surface germinating species and may not emerge after some soil inversion.
- Break crops (e.g. lupins or TT canola) in a rotation provide different herbicide options such as simazine and clethodim.
- Burning residues may result in 50% (0-75%) control of barley grass.
- Avoid totally relying upon post-emergence herbicides, herbicide such as trifluralin and Boxer Gold® can achieve reasonably good control.
- Barley grass can be strategically managed in pasture phase prior to sowing cereals. If timed correctly, pasture spray-topping can control 60% (50-90%) of barley grass. Stock grazing can also reduce barley grass by approximately 30%.

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Radial® is an optimised high performance broad spectrum fungicide for use in wheat and barley. With up to 6 weeks preventative disease control Radial® optimises the performance of your crop.

Product Overview
RADIAL® is a broad spectrum foliar fungicide for use in wheat and barley, combining market leading strobilurin and triazole active ingredients.
- Contains 75 g/L epoxiconazole and 75 g/L azoxystrobin
- Highly effective EC formulation optimised for Australian diseases and conditions
- Excellent crop safety - extensively tested on multiple varieties and situations
- Extended protectant activity
- Highly compatible with commonly used insecticides and fungicides
- Dual modes of action for resistance management

Mode of Action
RADIAL® is a combination of DMI (demethylation-inhibitors) and strobilurin (Quinone outside Inhibitors - Qols) group of fungicides and incorporates the combining market leading strobilurin and triazole active ingredients. The triazole active ingredient (epoxiconazole) acts to inhibit fungal growth in plant tissue. Azoxystrobin provides excellent protectant activity and has long residual activity. RADIAL® in infection, azoxystrobin provides excellent protectant activity and has long periods.

Features Benefits
- Mixture of highly effective strobilurin and DMI active ingredients
- Two modes of action for resistance management.
- EC formulation
- Unik EC and SC formulations the active ingredient is fully dissolved.
- Excellent preventative control
- Ability to protect the plant for longer periods.
- Provides greater disease control than standalone DMI treatments.
- Highly compatible.
  - Less need to perform multiple applications.

Standard Recommendations
Wheat
- Leaf Rust, Yellow Spot, Septoria Hodorum Blotch, Stem Rust, Stripe Rust and Powdery Mildew: 420 to 840 mL/Ha.
  - Apply when conditions favour disease development and prior to incidence of high levels of disease in the crop. Aim to apply between stem elongation and complete ear emergence (Z22-59).
Barley
- Leaf Rust, Leaf Scald, Net Form of Net Blotch and Powdery Mildew: 420 to 840 mL/Ha.
  - Apply when conditions favour disease development and prior to the incidence of high levels of disease in the crop. Aim to apply from jointing (Z20).

Repeat spraying may be required, particularly if infection pressure persists.

Triathlon® gives excellent control against mixed weed populations

TRIATHLON® is a unique broad spectrum herbicide for early broadleaf weed control in winter crops, incorporating 3 herbicide modes of action (MDA). When applied early in the crop TRIATHLON® is an effective management tool for a range of broadleaf weeds as well as hard to control Wild Radish. TRIATHLON® also provides residual activity to help control later germinating weeds.

Product Overview
TRIATHLON® is a unique broad spectrum herbicide for early broadleaf weed control in winter crops, incorporating 3 herbicide modes of action (MDA). When applied early in the crop TRIATHLON® is an effective management tool for a range of broadleaf weeds as well as hard to control Wild Radish. TRIATHLON® also provides residual activity to help control later germinating weeds.

Mod of Action
TRIATHLON® is a member of the nicotinic acid, nitrite and phenoxy groups of herbicides and acts by inhibiting cyanobacterial biosynthesis at the photosystem II (PS II) step and disrupting plant cell growth.

TRIATHLON’s primary activity is on emerged broadleaf weeds through foliar uptake, however, a level of pre-emergent residual weed control can be achieved that allows TRIATHLON® to control newly germinating weeds for up to 4 weeks following an application.

For herbicide resistance management TRIATHLON® is a Group E Group C and Group 1 herbicide and where possible should be used in rotation with herbicides from alternative MDA groups.

Standard Recommendations
Weeds:
- Registered to control or suppress 47 broadleaf weeds including, Wild Radish, Capselweed, Volunteer Canola, Fumitory and Hidge Mustard.

Application:
- Boom Sprayer: A minimum of 50 L/Ha of water should be applied to achieve the efficacy of herbicides and acts by inhibiting carotenoid biosynthesis at the photosystem II (PS II) step and disrupting plant cell growth.

TRIATHLON® at 500 mL/Ha

The pots on the left in both photos contain fully susceptible Wild Radish plants while the pots on the right contain a multiple herbicide resistant biotype. By Brasil, 2013.
When it comes to rapid control of hard to kill weeds, you can’t go past Alliance. What’s more, by combining group Q and L chemistry, Alliance provides a new option in managing resistant weeds.

- Unique dual mode of action
- Controls glyphosate resistant annual ryegrass biotypes
- Rapid speed of control on hard to kill weeds
- Short spray to sow interval

Alliance in action

Source: Trial ID: MS ALLIANCE-KD-09, Location: Currawana

Alliance is a registered trademark of Nufarm Australia. Spray.Seed is a registered trademark of Syngenta.