**General Plenary Day 1**

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**Bridging the yield gap – how much are we leaving behind? Environmentally achievable yields vs actual yields**

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**Key words**

Wheat, yield, yield gap, exploitable yield gap, benchmarking, simulation

**GRDC code**

CSA00042 -Web based visualisation of spatial and temporal yield gap information for grain growers and strategic research investment planning.

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**Take home message**

Wheat growers in the GRDC northern grain zone averaged 1.7 t/ha (Ya) over the 1996-2010 period. This represented 47% of the water limited yield (Yw) which could have been obtained under current technology with best practice and well adapted varieties.

Closing the exploitable yield gap (80% of Yw – Ya) would increase yields by 1.2 t/ha to raise the regional average to 2.9 t/ha.

The yield gap varies from season to season and from one statistical local area (SLA) to the next. CSIRO will be making these yield gap maps available online through a GRDC funded project so that farmers and their advisers can examine their own yields relative their farms’ location.

Farmers can use these maps as a benchmarking tool. Are they achieving better or worse than their SLA’s average yields over the same period? How close are they to closing the exploitable yield gap and consistently achieving a relative yield of 80%?

Advisers could challenge themselves to diagnose the cause of the yield gap for those clients who have large exploitable yield gaps.

**Introduction**

Growth in global grain production has all but stalled (Grassini \textit{et al.}, 2013) yet the FAO estimate that global food security will require world grain production to increase by at least 60% between 2010 and 2050 (Alexandratos and Bruinsma, 2012). This is both a huge challenge for the world’s agronomists and an exciting opportunity for Australia’s grains industry. One promising pathway for increasing grain production is by closing the gap between yields currently achieved on farms and those that can be achieved by using the best adapted crop varieties and best crop and land management practices for a given environment (van Ittersum \textit{et al.}, 2013).

When discussing yield potential and possible new management practices that may be helpful to raise farm production it is important to define the terms used to benchmark production:

- \( Ya = \) Actual yield: yields achieved in commercial fields. Reflecting farmers’ natural endowment, access to technology, and their skill and exposure to real market economics (Evans and Fischer, 1999 as adapted by Hochman \textit{et al.}, 2009)
- \( Yw = \) Water-limited yield: simulated yield for the same conditions, climatic and crop management, as for Yatt, except for N supply which is non-limiting (Hochman \textit{et al.}, 2012).
Yw as defined here applies to current best practice. New technology can re‐define Yw by increasing the production frontier.

- Yg = Yield gap for rain‐fed crops: the difference between Yw and Ya
- \( Y_{\%} \) = Relative yield: calculated as 100 x Ya/Yw (Lobell et al., 2009)
- Exploitable yield gap: the difference between \( Y_{\%} = 80\% \) and Ya. Based on observations that farmers’ yields plateau at 80% of Yw, probably due to diminishing returns to investment and aversion to risk (Lobell et al., 2009; van Ittersum et al., 2013).

Before you can bridge the yield gap you need to know big it is! While farmers could sustainably aim for about 80% of their water limited yields, they first need to know what their target is and how close there are to achieving it. Advisers are already aware of the gap between their best and worst farmers but do they know to what extent this is determined by their environment or their Yw?

This talk is about a web based tool that will allow farmers and their advisers to benchmark their own wheat yields against the water limited wheat yields and the average wheat yields being achieved by others in their statistical local area (SLA).

Methods

A number of steps are required to derive maps of actual yields (Ya), water limited yields (Yw), yield gaps (Yg) and relative yields (\( Y_{\%} \)).

1. We obtained a land use map showing areas most likely to have produced winter cereal crops in the 2005 season at a spatial resolution of 1.1 km. This map was generated from ABARE–BRS (2010) dataset. It is based on remotely sensed NDVI data and census information to spatially disaggregate land use within area constraints provided by the agricultural census. A more detailed explanation of the procedure can be found in Bryan et al. (2009). We focused our efforts on all SLAs in Australia that grew a minimum of 5000 ha of wheat.

2. We determined Ya for each SLA. Farmers are surveyed annually by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) through its Australian Agricultural and Grazing Industries Survey (AAGIS). The annual data for wheat are aggregated up from individual farms to SLAs to 11 regions in three agro-climatic zones. The 11 regions in the Australian wheat-sheep zone are viewed by ABARES as the smallest unit for which their annual survey is designed to produce reliable wheat crop estimates (ABS, 2009). These data are available through the Agsurf website (http://abare.gov.au/ame/agsurf/agsurf.asp). The less frequently sampled Agricultural Census data provide reliable crop estimates at the SLA level. We found that where data existed at both regional and SLA level (17 years of data) there were very strong correlations between regional yield and SLA yields that allowed for reliable prediction of individual SLA yields from regional yields. This allowed us to estimate Ya for 259 SLAs in Australia for all years from 1996 to 2010. A fifteen year period was chosen as it is sufficiently long to represent climate variability but short enough to represent current technology and best practice.

3. We determined Yw by using APSIM simulation of a “continues wheat” crop from 1996 to 2010 for up to three dominant soil types within a 17 km of each of Silo’s met stations (patch point data) within the wheat land use map. A total of 11660 simulations were run to provide data for mapping Yw. The results of the soil types for each met station were weighted by the relative distributions of the soil type in the proximity of the met station. Soil data was derived from APSoil and ASRIS maps. Local kriging (Minasny et al., 2002) was used to smooth out the individual points and determine annual Yw values for each SLA.

4. We calculated Yg (=Yw-Ya) and \( Y_{\%} (=100 \times Ya/Yw) \) for each SLA and each year and mapped the results.
Results and discussion

The focus in this paper is on results in GRDC’s northern region. The annual Ya data were mapped into figure 1. These maps illustrate the spatial variability of yields with contrasting results often observed between neighbouring SLAs. This is most dramatically illustrated for 2004 where a blue zone (yields > 2.4 t/ha) borders against a red zone (yields < 1.4 t/ha). Equally the maps illustrate annual climate variability where generally good years like 1996, 1999 and 2010 contrast with years like 2000, 2002, 2006 and 2007.

The data layer for calculating Yw can be summarised by Figure 2 which overlays a map of the SLA boundaries with the winter cereal land use data layer (blue dots, each representing 1.1sq km) and meteorological data stations (diamond shapes) coloured to represent the most dominant soil type in their buffer zone. While the meteorological data are not uniformly distributed throughout the wheat growing areas, we are most fortunate in Australia to have such comprehensive meteorological and soil data at our disposal.

The annual Yw calculations were mapped into figure 3. As with Figure 1, these maps illustrate the spatial variability of water limited yields with contrasting results often observed between neighbouring SLAs. This is most dramatically illustrated for 2003 where a blue zone (yields > 4.5 t/ha) borders against a red zone (yields < 2.6 t/ha). Similarly, the maps illustrate annual climate variability where generally good years like 1996 1999 and 2010 contrast with years like 2002, 2006 and 2007. It is important to note that the scale of yields used in Figure 3 (from less than 2.6 to greater than 4.5) is higher than that used for Figure 1 (from less than 1.4 to greater than 2.4). This difference indicates the yield gap.

The annual yield gap is mapped in Figure 4. As with Ya and Yw, Yg varies in time and space. Significantly, low yielding years like 2002 tend to have small yield gaps while high yielding years like 2010 have larger yield gaps. There is a strong correlation \( r^2 = 0.72 \) between Yw and Yg (Figure 5) indicating that across all locations and seasons, the higher the yield potential the higher the yield gap. Maps of annual relative yields still show variations in space and seasons (Figure 6). The predominance of \( Y_e \) values less than 43% in 1998 reflects the extreme wet winter experienced in that La Niña year. Widespread waterlogging and crop disease issues associated with a wet winter were the likely causes of the low \( Y\% \) in 1998. In most years values greater than 63% appear sporadically in some SLAs.

Average annual values of Ya, Yw, Yg and \( Y_e \) (figure 7) per SLA show that some SLAs have larger yield gaps than others. This spatial difference holds true even when the yield gap is expressed as relative yields. For the 48 SLAs in the northern region Ya = 1.67 t/ha; Yw = 3.58 t/ha; Yg = 1.91 t/ha and \( Y_e = 46.6\% \). Compared with the national figures actual yields are lower than in the southern region and similar to the western region. However the northern region has the highest Yw value and thus the largest absolute yield gap and smallest relative yield (Table 1).
Figure 1. Actual wheat grain yields in Australia’s northern grain zone (aggregated at SLA level)
Figure 2. Data layers used as input to APSIM simulation for calculating water limited yields.
Figure 3. Water limited wheat grain yields in Australia’s northern grain zone (aggregated at SLA level)
Figure 4. Wheat yield gaps in Australia’s northern grain zone (aggregated at SLA level)
Figure 5. Correlation yield gap with water limited yield. Each value is based on 15 year means of SLA data. Data from 259 SLAs are included in the analysis.
Figure 6. Relative wheat yields in Australia’s northern grain zone (aggregated at SLA level)
Figure 7. Wheat yields and yield gaps in the northern grain zone – 15 year SLA averages (1996-2010)
much region farms’ sustainably

**Conclusion**

The key observation from this analysis of wheat crop yields is that over the period from 1996 to 2010 there was an average yield gap of 1.9 t/ha in the northern region. Relative to the average water limited yield of 3.6 t/ha, the average actual yield of 1.7 t/ha was 46.6%. If we accept that farmers can sustainably achieve a relative yield of 80%, as was demonstrated by leading farmers in the Wimmera and Mallee (van Rees et al. in review), then this study suggests that farmers in the northern region could achieve average yields of 2.9 t/ha or that there is scope to close the exploitable yield gap and increase average yields by 1.2 t/ha.

The northern region’s relative yields of 46.6% were 5.3% lower than relative yields in the southern region and 8.9% lower than in the western region. Hence there is more scope to boost yields in the northern region through better application of current technologies and best practice.

Individual farmers and their advisers need to focus more closely on their own yields relative their farms’ location. Are they achieving better or worse than their SLA’s average yields over the same period? How close are they to closing the exploitable yield gap and consistently achieving a relative yield of 80%? Advisers will be interested to know how close their best clients are to Yw and how much of a gap there is still there for them to exploit. If the answer is not much then these farmers will need to pioneer new technology breakthroughs to improve their yields. Advisers should also challenge themselves to diagnose the cause of the yield gap for those clients who have large exploitable yield gaps.

In the next few months we will develop a website in which farmers and advisers will be able to zoom into their farm location and obtain an instant benchmark relative to Ya, Yw, Yg and Y%. We are keen to test the usability and usefulness of this website with farmers and advisers. If you are keen to be among the first to test drive the system and help guide its development please contact me after the break.

**References**


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**Table 1.** Yield Gap results for the GRDC regions – 15 year (1996-2010) area weighted average values

<table>
<thead>
<tr>
<th></th>
<th>Ya (kg/ha)</th>
<th>Yw (kg/ha)</th>
<th>Yg (kg/ha)</th>
<th>Y%</th>
<th>SLAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern</td>
<td>1668</td>
<td>3580</td>
<td>1912</td>
<td>46.6%</td>
<td>48</td>
</tr>
<tr>
<td>Southern</td>
<td>1827</td>
<td>3519</td>
<td>1692</td>
<td>51.9%</td>
<td>117</td>
</tr>
<tr>
<td>Western</td>
<td>1651</td>
<td>2977</td>
<td>1326</td>
<td>55.5%</td>
<td>63</td>
</tr>
<tr>
<td>National</td>
<td>1806</td>
<td>3477</td>
<td>1671</td>
<td>51.9%</td>
<td>259*</td>
</tr>
</tbody>
</table>

* of the 259 SLAs used in the national analysis 31 fall outside GRDC regions


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

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**Key words**

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

**GRDC code:**

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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.

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**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>Koc (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</td>
</tr>
<tr>
<td>Pendentimethalin</td>
<td>0.33</td>
<td>17,800</td>
<td>Very high</td>
</tr>
<tr>
<td>Pyroxasulfone</td>
<td>3.9</td>
<td>223</td>
<td>Medium</td>
</tr>
<tr>
<td>Triallate</td>
<td>4.1</td>
<td>3000</td>
<td>High</td>
</tr>
<tr>
<td>Prosulfocarb</td>
<td>13</td>
<td>2000</td>
<td>High</td>
</tr>
<tr>
<td>Atrazine</td>
<td>35</td>
<td>100</td>
<td>Medium</td>
</tr>
<tr>
<td>Diuron</td>
<td>36</td>
<td>813</td>
<td>High</td>
</tr>
<tr>
<td>S-metolachlor</td>
<td>480</td>
<td>200</td>
<td>Medium</td>
</tr>
<tr>
<td>Triasulfuron</td>
<td>815</td>
<td>60</td>
<td>Low</td>
</tr>
<tr>
<td>Chlorsulfuron</td>
<td>12,500</td>
<td>40</td>
<td>Low</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 Koc, the soil organic carbon-water partitioning coefficient. High Koc values mean that more herbicide will be bound to organic matter and less herbicide will be available to move in the soil solution. Koc values for pre-emergent herbicides in Table 1 range from very high for trifluralin and pendentimethalin 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
The 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.
Figure 3. Distribution of weed seed in the soil profile with knife point seeding systems.

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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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.

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Alliance is a registered trademark of Nufarm Australia. SpraySeed is a registered trademark of Syngenta.
Pre-emergent herbicides: part of the solution but much still to learn

Richard Daniel and Anthony Mitchell, Northern Grower Alliance

Key words
Residual herbicides, annual ryegrass, crop safety, incorporation by sowing

GRDC code
NGA00003: GRDC Grower Solutions for Northern NSW and Southern Qld

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

The issue
The widespread adoption of minimum tillage has provided many agronomic and sustainability benefits to our farming system. However it is a system that has led to an overreliance on knockdown herbicides to achieve effective weed management. As a consequence we are faced with management issues in two main ‘herbicide-driven’ scenarios; control of herbicide resistant weeds e.g. annual ryegrass (ARG) and selection of weed species with higher levels of natural herbicide tolerance e.g. feathertop Rhodes grass.

Residual herbicides are an important tool to assist in the control of weeds in both these scenarios but the issues that have always dogged residual products will be important to better understand and manage e.g. consistency of efficacy across varied soil types, incorporation requirements and stubble loadings, plantback restrictions and how to best maximise crop safety without reducing weed efficacy.

This paper deals with results from two trials conducted in 2013 evaluating the crop safety and efficacy of registered residual herbicides for the control of ARG in wheat.

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

What was done?
At a site near Mullaley NSW, the grower had adjoining paddocks which he intended to plant with the same wheat variety (Crusader1) but with two different planters; a tyned planter in one paddock and a single disc in the second. The trials were located within ~300m of each other.

Both trials were sprayed and planted on the 20/6/13, with a single tank of each treatment used to spray both trials. Planting occurred immediately after herbicide application.
Soil type

Although the two trials were located within 300m of each other, there were distinct differences in the soil type. The soil type where the disc planter was used was a black vertosol with the tyne planter used in a lighter red soil.

Rainfall

The site had good planting moisture with ~48mm of rain received in the three weeks prior to planting. Table 1 shows the rainfall received between planting and the assessment of crop establishment, three weeks after planting. There was a total of 31 mm received in the first 9 days after planting. The only rainfall in the first week after planting was 4mm on day 4. It was not considered that this level of rainfall would have created a high risk scenario.

Table 1. Rainfall in first 21 days after planting

<table>
<thead>
<tr>
<th>Date (days after planting)</th>
<th>24/6 (+4)</th>
<th>27/6 (+7)</th>
<th>28/6 (+8)</th>
<th>29/6 (+9)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall (mm)</td>
<td>4</td>
<td>16.6</td>
<td>7.0</td>
<td>3.4</td>
<td>31</td>
</tr>
</tbody>
</table>

Crop safety results

Figure 1 shows the wheat emergence data relative to the untreated. The actual plant population of the untreated in the disc sown trial was ~108 plants/m² and ~66 plants/m² when planted by tynes. NB the two planters were not set up to plant an equivalent rate of seed.

Figure 1. Wheat emergence as a % of untreated (11/7/13, 21 days after planting)
UTC = untreated control. All treatments applied in 70 L/ha total volume using AIXR110015 nozzles at 300 kPa

* = significantly reduced wheat emergence compared to untreated within same trial

In the tyne planted trial, the mixture of Boxer® Gold with either the 1.5L/ha rate of TriflurX® (480g ai/L trifluralin or Stomp® 440 (440g ai/L pendimethalin) resulted in significantly reduced wheat emergence compared to the untreated. There was no significant difference between the untreated and any other treatment.

In the disc planted trial, all treatments significantly reduced wheat emergence compared to the untreated. TriflurX alone, Boxer Gold alone and all Boxer Gold mixtures also significantly reduced wheat emergence compared to Sakura® or Stomp alone.
Depth of sowing

Depth of sowing can impact on crop safety with disc planted seed generally shallower than tyne plantings. Seedlings were dug up to measure the effective planting depth with the results shown in Table 2. Samples were also evaluated from the ‘guess rows’ in the disc planted trial as it appeared that wheat emergence was less affected in those rows.

### Table 2. Mean depth of sowing under different planting configurations

<table>
<thead>
<tr>
<th>Planting configuration</th>
<th>Tyne</th>
<th>Disc</th>
<th>Disc ‘guess rows’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean depth (cm)</td>
<td>2.2</td>
<td>1.7</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Depths shown are a mean from ~40 seedlings in each comparison

An unregistered PSPE application of Boxer Gold was also evaluated in both trials. This treatment was expected to cause the greatest level of crop damage as there was no removal of herbicide above the planting furrow.

This treatment actually resulted in significantly improved emergence counts compared to the IBS treatment in the disc sown trial. This suggested that the single disc setup was actually causing greater levels of crop damage by concentrating treated soil over the planting furrow rather than ‘removing’ treated soil.

**Crop safety summary**

- Wheat emergence was significantly reduced by all herbicide treatments when disc planting was used for IBS
- Sakura or Stomp alone were significantly safer than TriflurX or Boxer Gold alone or Boxer Gold in mixture with either TriflurX or Stomp when planted with discs
- Crop safety was dramatically improved when the tyne planter was used for IBS with only Boxer Gold plus Stomp or TriflurX 1.5L/ha significantly reducing plant stand
- Depth of sowing may have contributed to crop safety with the guess rows in the disc planted area appearing less affected although only marginally deeper (~2mm)
- Soil type may also have contributed to the varied level of crop affect between the two sites
**Efficacy results**

In the tyne planted trial there was a population of ~13 ARG plants/m² in the untreated. Similar levels of ARG control were achieved by all IBS treatments (~93-97% control) with the only exception being Stomp. Stomp provided significantly lower levels of control than the other IBS treatments at 94 days after planting (Figure 2). Boxer Gold applied PSPE in this trial also resulted in significantly poorer control than the IBS treatment.

In the disc planted trial there was a more variable population of ~7 ARG plants/m². There was no significant difference in level of ARG control between any herbicide applied as IBS (~87-99% control). Boxer Gold applied PSPE provided similar levels of control to the IBS treatment (Figure 2).

![Graph showing % ARG control](image)

**Figure 2.** % annual ryegrass control based on counts (22/9/13, 94 days after planting)
UTC = untreated control. All treatments applied in 70 L/ha total volume using AIXR110015 nozzles at 300 kPa
* = significant ARG control compared to untreated within same trial

**Efficacy summary**

- High levels of ARG control were achieved by most IBS treatments
- The most consistent product were Boxer Gold or Sakura
- Weed control from Boxer Gold was significantly reduced in one of the two trials when applied by PSPE

**Conclusions**

This work was conducted due to commercial crop safety concerns arising from the use of residual herbicides at planting for ARG control. These two trials highlighted some key points:

1. Crop safety was significantly reduced when a disc planter was used for incorporation
2. The disc setup appears to have exaggerated crop safety issues by planting seed in an area with increased herbicide concentration
3. Observation suggested that small differences in planting depth may have impacted on crop safety in this scenario
This work reinforces some of the difficulties growers and agronomists face with the use of residual herbicides. Crop safety and efficacy are influenced by a range of factors including planting equipment, planting depth, soil type, stubble load together with rainfall quantity and timing. As an industry we need to have a more thorough understanding of the impacts from these (and perhaps other factors) to ensure we get the best from these important weed management tools.

Acknowledgments

Our sincere thanks to Josh Bell for his patience and co-operation with these trials and Aaron Goddard (Landmark) for trial site assistance

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Reviewed by:

John Cameron

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**AXIAL®** - ultimate performance, flexibility and crop safety

- Robust activity on Wild Oats, Phalaris and Annual Ryegrass
- AXIAL Selective Spray Topping reduces contribution of Wild Oat seed to the seed bank
- Widest crop application window, GS 12-39
- Effective on ‘fop’ resistant biotypes
- Excellent tank mix compatibility
- Good crop safety
- Suitable for use in both wheat and barley

### Physical Compatibility

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

- Alpha-cypermethrin
- Brodal®
- Bulldock Duo®
- Clopyralid
- 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.

### Biological Compatibility

**TANK-MIX PARTNER**

- 2,4-D
- Ally®
- Ally + MCPA
- Alpha Cypermethrin
- AMISTAR XTRA®
- Broadstrike®
- Conclude®
- dicamba
- Eclipse®
- Hotshot®
- Jaguar®
- KARATE ZEON®
- LOGRAN®
- Lontrel®
- MPCA LVE
- Paragon®
- Precept®
- Starane®
- Tigrex®
- TILT®
- TILT XTRA®
- Tordon®
- Velocity®
- Mataven-M (1.875 L/ha)
- Topik 240 EC (65 mL/ha)
- Axial (200 mL/ha)

### 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 DCAMBA 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

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Herbicides and weeds – regional issues trials and developments

Tony Cook and Greg Brooke, NSW DPI
Michael Widderick, Qld DAFF &
Maurie Street, GOA

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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.
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

<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.
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>
<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.

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><strong>Susceptible biotype</strong></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><strong>“CRK” biotype</strong></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><strong>“Yellow” biotype</strong></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&lt;sup&gt;+&lt;/sup&gt;</td>
<td>1.23</td>
<td>100 (90) †</td>
<td>93 (81) †</td>
</tr>
<tr>
<td>Sprayseed&lt;sup&gt;+&lt;/sup&gt;</td>
<td>2</td>
<td>80 (69)</td>
<td>43 (39)</td>
</tr>
<tr>
<td>* Roundup Attack&lt;sup&gt;+&lt;/sup&gt; fb Sprayseed&lt;sup&gt;+&lt;/sup&gt;</td>
<td>1.23 fb 2.0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Amicide Advanced&lt;sup&gt;+&lt;/sup&gt; 700 + Roundup Attack&lt;sup&gt;+&lt;/sup&gt;</td>
<td>0.65 + 1.23</td>
<td>43 (40)</td>
<td>2 (4)</td>
</tr>
<tr>
<td>* Amicide Advanced&lt;sup&gt;+&lt;/sup&gt; 700 + Roundup Attack&lt;sup&gt;+&lt;/sup&gt; fb Sprayseed&lt;sup&gt;+&lt;/sup&gt;</td>
<td>0.65 + 1.23 fb 2.0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Tordon 75D&lt;sup&gt;+&lt;/sup&gt; + Roundup Attack&lt;sup&gt;+&lt;/sup&gt;</td>
<td>0.7 + 1.23</td>
<td>62 (52)</td>
<td>12 (19)</td>
</tr>
<tr>
<td>* Tordon 75D&lt;sup&gt;+&lt;/sup&gt; + Roundup Attack&lt;sup&gt;+&lt;/sup&gt; fb Sprayseed&lt;sup&gt;+&lt;/sup&gt;</td>
<td>0.7 + 1.23 fb 2.0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Starane Advance&lt;sup&gt;+&lt;/sup&gt; + Roundup Attack&lt;sup&gt;+&lt;/sup&gt;</td>
<td>0.6 + 1.23</td>
<td>64 (58)</td>
<td>40 (39)</td>
</tr>
<tr>
<td>* Starane Advance&lt;sup&gt;+&lt;/sup&gt; + Roundup Attack&lt;sup&gt;+&lt;/sup&gt; fb Sprayseed&lt;sup&gt;+&lt;/sup&gt;</td>
<td>0.6 + 1.23 fb 2.0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Sharpen&lt;sup&gt;+&lt;/sup&gt; + Roundup Attack&lt;sup&gt;+&lt;/sup&gt;</td>
<td>17g + 1.23</td>
<td>57 (49)</td>
<td>38 (38)</td>
</tr>
<tr>
<td>* Sharpen&lt;sup&gt;+&lt;/sup&gt; + Roundup Attack&lt;sup&gt;+&lt;/sup&gt; fb Sprayseed&lt;sup&gt;+&lt;/sup&gt;</td>
<td>17g + 1.23 fb 2.0</td>
<td>97 (81) †</td>
<td>95 (80) †</td>
</tr>
<tr>
<td>Alliance&lt;sup&gt;+&lt;/sup&gt;</td>
<td>2</td>
<td>70 (59)</td>
<td>18 (19)</td>
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<tr>
<td>Sprayseed&lt;sup&gt;+&lt;/sup&gt;</td>
<td>2.4</td>
<td>92 (73) †</td>
<td>57 (49)</td>
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<tr>
<td>* Roundup Attack&lt;sup&gt;+&lt;/sup&gt; fb Sprayseed&lt;sup&gt;+&lt;/sup&gt;</td>
<td>1.23 fb 2.4</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Amicide Advanced&lt;sup&gt;+&lt;/sup&gt; 700 + Roundup Attack&lt;sup&gt;+&lt;/sup&gt;</td>
<td>1.1 + 1.23</td>
<td>67 (60)</td>
<td>30 (31)</td>
</tr>
<tr>
<td>* Amicide Advanced&lt;sup&gt;+&lt;/sup&gt; 700 + Roundup Attack&lt;sup&gt;+&lt;/sup&gt; fb Sprayseed&lt;sup&gt;+&lt;/sup&gt;</td>
<td>1.1 + 1.23 fb 2.4</td>
<td>100</td>
<td>99</td>
</tr>
<tr>
<td>Tordon 75D&lt;sup&gt;+&lt;/sup&gt; + Roundup Attack&lt;sup&gt;+&lt;/sup&gt;</td>
<td>1.0 + 1.23</td>
<td>88 (78) †</td>
<td>58 (49)</td>
</tr>
<tr>
<td>* Tordon 75D&lt;sup&gt;+&lt;/sup&gt; + Roundup Attack&lt;sup&gt;+&lt;/sup&gt; fb Sprayseed&lt;sup&gt;+&lt;/sup&gt;</td>
<td>1.0 + 1.23 fb 2.4</td>
<td>100</td>
<td>98</td>
</tr>
<tr>
<td>Starane Advance&lt;sup&gt;+&lt;/sup&gt; + Roundup Attack&lt;sup&gt;+&lt;/sup&gt;</td>
<td>0.9 + 1.23</td>
<td>97 (84) †</td>
<td>67 (55)</td>
</tr>
<tr>
<td>* Starane Advance&lt;sup&gt;+&lt;/sup&gt; + Roundup Attack&lt;sup&gt;+&lt;/sup&gt; fb Sprayseed&lt;sup&gt;+&lt;/sup&gt;</td>
<td>0.9 + 1.23 fb 2.4</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Sharpen&lt;sup&gt;+&lt;/sup&gt; + Roundup Attack&lt;sup&gt;+&lt;/sup&gt;</td>
<td>34g + 1.23</td>
<td>82 (66)</td>
<td>60 (52)</td>
</tr>
<tr>
<td>* Sharpen&lt;sup&gt;+&lt;/sup&gt; + Roundup Attack&lt;sup&gt;+&lt;/sup&gt; fb Sprayseed&lt;sup&gt;+&lt;/sup&gt;</td>
<td>34g + 1.23 fb 2.4</td>
<td>100 (90) †</td>
<td>99 (87) †</td>
</tr>
<tr>
<td>Alliance&lt;sup&gt;+&lt;/sup&gt;</td>
<td>2.8</td>
<td>90 (75) †</td>
<td>50 (50)</td>
</tr>
</tbody>
</table>

<sup>fb</sup> - followed by, as part of a double knock  <sup>*</sup> - excluded from analysis as most values = 100  
<sup>†</sup> - 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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