CURRENT STATUS OF RESISTANCE TO KNOCKDOWN HERBICIDES

VOLUME V

PRESENTED BY SYNGENTA

CURRENT STATUS OF HERBICIDE RESISTANCE

Within any weed population in a paddock there may be a small number of plants that are resistant to a herbicide or herbicides. The number of plants exhibiting this characteristic is initially extremely small and generally the population of weeds is considered "sensitive" to a certain herbicide (or group of herbicides having the same mode of action). However the repeated use of a herbicide will expose the weeds to a "selection pressure" which may lead to an increase in the proportion of resistant plants in the population. As a consequence, the proportion of resistant weeds may increase to the point that adequate control cannot be achieved by the herbicide.

The first case of herbicide resistance in weeds was identified in 1968 and less than 40 years later there are 182 herbicide resistant grass and broad-leaved weed species identified in about 60 countries worldwide. Resistance has been confirmed in a wide range of herbicides, belonging to most mode of action groups.

Globally, Australia is second only to the USA in terms of number of weed biotypes that have developed resistance to herbicides. The top 10 countries in terms of resistant weed biotypes are listed below.

Top 10 Countries	Number of Resistant Biotypes
USA	112
Australia	***47***
Canada	44
France	30
Spain	27
UK	24
Israel	20
Belgium	18
Germany	18
Japan, Italy, Malaysia	16

Source: www.weedscience.org 2006

THE EVOLUTION OF RESISTANCE

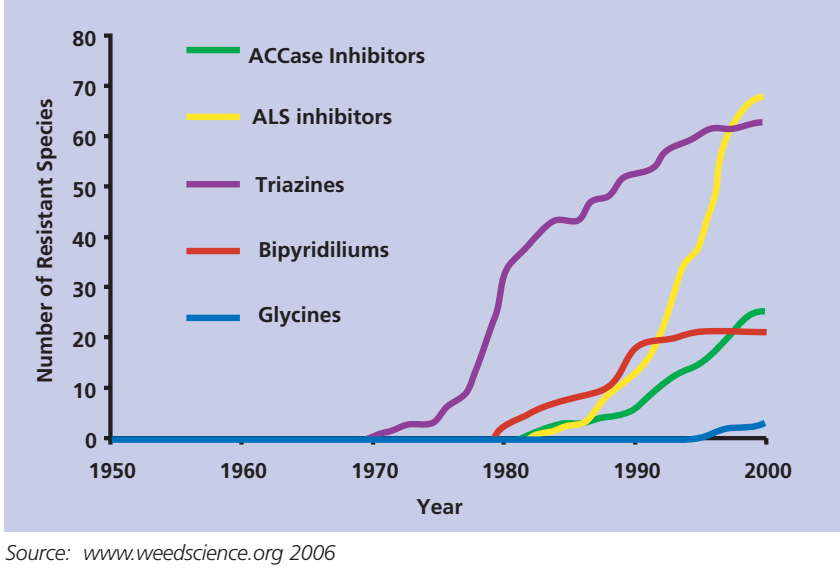
The increase in herbicide resistant weeds is partly related to the extent to which a herbicide is adopted for weed control. The triazine herbicides became an important part of weed control practices with widespread adoption during the 1960's. Atrazine, the most commonly used triazine, can be applied pre-emergent or post-emergent and provides control of a wide range of grass and broadleaf weeds in maize, sorghum, sugarcane, fruit and nut crops, forestry and tree plantations. It provided excellent residual activity giving season long weed control, was very safe to major crops in particular maize and sorghum and resulted in reduced reliance on traditional tillage methods to control weeds. Triazine herbicides were the first herbicides to allow a significant adoption of conservation tillage practices, which had major benefits for soil conservation. The consequence was an 'over-reliance' on triazines and resistance increased during the 1970's.

More recently resistance to sulfonylureas (ALS inhibitors) and 'fops' and 'dims' (ACC'ase inhibitors) has become widespread following the significant adoption of these products for selective control of weeds in crops. In Australia, cereal herbicides have become the main technique for weed management over the past 15 to 20 years and herbicide use for cropping and pasture manipulation has grown significantly since 1980. These herbicides:

- provided significant agronomic benefits;
- were very effective; and
- were safe to crops.

They allowed the development of new agronomic packages, including crop rotational options for cereals, such as narrow leaf lupins or canola. These crops in rotation almost completely depend on the availability of effective selective herbicides. Further control of grass weeds in pastures became possible and led to improved disease management in cereal crops. Herbicide resistance is now widespread in Annual Ryegrass *(Lolium rigidum)* and Wild Radish *(Raphanus raphanistrum)* in Australia. Resistance in Wild Oats is also prevalent but at much lower frequencies.

Now as we enter the 21st century this familiar pattern has the potential to be repeated with glyphosate. Glyphosate is recognised as a highly effective herbicide. It is off patent and has become relatively inexpensive. The increasing adoption of reduced tillage practices, earlier planting, glyphosate tolerant crops and in crop use of glyphosate has meant there is a heavy reliance on glyphosate for weed control. Glyphosate (glycine) and bipyridyl resistance is already evolving, although to a lesser extent than the selective herbicides, as it is indicated by the table below.



Source: www.weedscience.org 2006

RESISTANCE SURVEYS IN AUSTRALIA

Annual Ryegrass resistance in Australia is the world's worst case of herbicide resistance. Ryegrass may be simultaneously resistant to herbicides with different modes of action (herbicide groups). A random survey has been recently conducted across the wheatbelt of Western Australia to determine the extent of Annual Ryegrass resistance to commonly used Group A (ACC'ase inhibiting herbicides) and Group B (ALS inhibiting herbicides) by Powles, Owen and Walsh 2003. They found 67% of paddocks had some resistance to the Group A herbicide diclofop (active ingredient in Hoegrass*) and 88% had some resistance to the Group B herbicide chlorsulfuron (active ingredient in Glean*) from the 500 cropping paddocks sampled across areas of high and low cropping intensity. In some major cropping areas almost all paddocks contained a resistant population. In 1998 Powles found 6 Ryegrass populations from canola paddocks that were not killed by 6 L/ha of atrazine, Group C.

The following table captures the current global and Australian situation with regard to non-selective herbicide resistance.

Non-Selective Herbicide Resistance Fact File

Resistance - Globally	Glyphosate	Paraquat
First discovered	1996	1980
Location	Australia	Malaysia
Confirmed number of sites	680+	1,900+
Confirmed number of species	8	23
Estimated resistant ha infested	1.2 billion ha's +	6,000+
Confirmed number of countries	7	13

Resistance - Australia	Glyphosate	Paraquat
First discovered	1996	1983
Location	Vic	Vic
Confirmed Number of Sites	50	30+
Confirmed number of species	1 (Lolium)	4 (Hordeum x 2 Vulpia & Arctotheca)
Estimated resistant ha infested	400+	1,000+

Source: www.weedscience.org 2006

GLYPHOSATE RESISTANCE

Prior to 1996 there were no confirmed cases of glyphosate resistant weeds. The situation is now very different. Resistance has been confirmed in 7 weed species globally including Annual Ryegrass *(Lolium rigidum)* in Australia, USA and South Africa. Resistance has also been confirmed in Italian Ryegrass *(Lolium multiflorum)* in Chile and Brazil, Crowsfoot Grass *(Eleusine indica*) in Malaysia, Canadian Fleabane *(Conyza canadensis)* in the USA, Flax-leaf Fleabane (*Conyza bonariensis*) in South Africa and Spain, Ribwort (*Plantago lanceolata*) in South Africa and Common Ragweed (*Ambrosia artemisiifolia*) and Palmer Amaranth (*Amaranthus palmeri*) in the USA. It is suspected that the mechanism of resistance is due to a change in the movement of glyphosate to its site of action in the plastid (Lorraine et al. 1999). A summary of glyphosate resistance globally appears below, including weeds by country with confirmed glyphosate resistance.

Country	Weed
Australia	Annual Ryegrass *(Lolium rigidum)*
USA	Annual Ryegrass *(Lolium rigidum),* Canadian Fleabane *(Conyza canadensis),* Flax-leaf Fleabane (*Conyza bonariensis*), Italian Ryegrass *(Lolium multiflorum)*, Common Ragweed (*Ambrosia artemisiifolia*), Palmer Amaranth (*Amaranthus palmeri*)
South Africa	Annual Ryegrass *(Lolium rigidum),* Flax-leaf Fleabane (*Conyza bonariensis*), Italian Ryegrass *(Lolium multiflorum)*, Ribwort (*Plantago lanceolata*)
Chile	Italian Ryegrass *(Lolium multiflorum*)
Brazil	Italian Ryegrass *(Lolium multiflorum*)
Malaysia	Crowsfoot Grass *(Eleusine indica*)
Spain	Flax-leaf Fleabane (*Conyza bonariensis*)

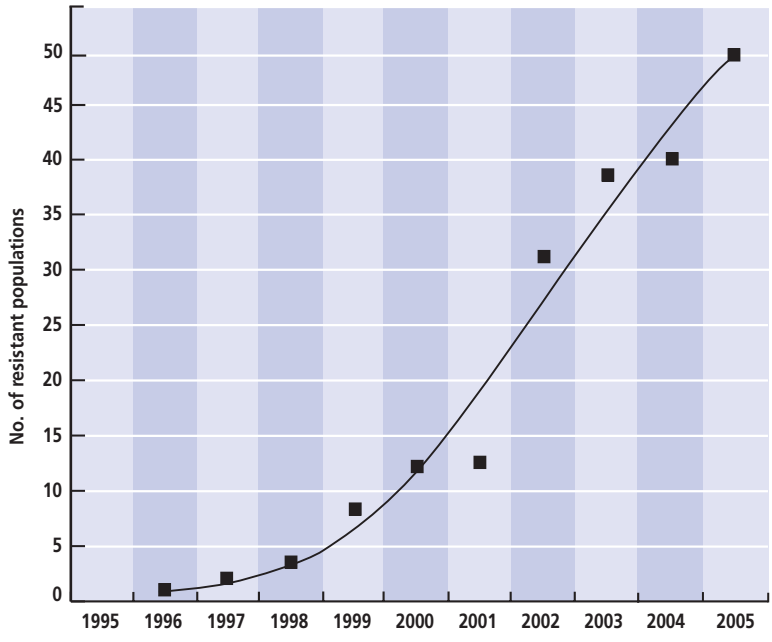
Source: www.weedscience.org 2006

Common to all cases of glyphosate resistant Annual Ryegrass in Australia are the following factors:

i) glyphosate is the major or only herbicide used;
ii) glyphosate has been used for 15 years or more; and
iii) there has been minimal or no soil disturbance. (Preston 2002)

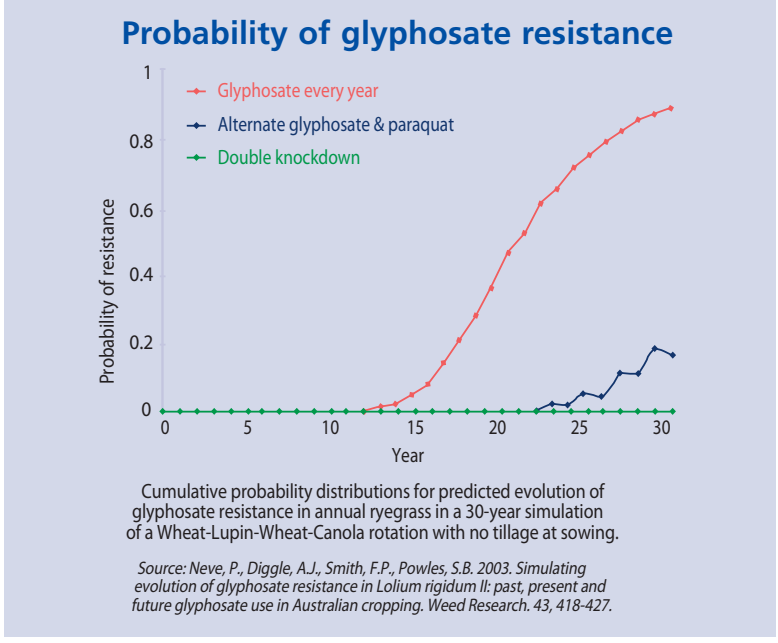
In Australia Annual Ryegrass resistance to glyphosate has been confirmed at 50 sites across NSW, Victoria, SA and WA. A recent survey in northern Australia has identified 6 other weeds with perceived high risk of developing glyphosate resistance. The drive to minimise soil disturbance coupled with weed resistance to many selective herbicides is placing increased pressure on glyphosate as the main weed control tool in Australia.

Development of Glyphosate Resistance in Australia 1995-2006



Source: NGSWG 2005

Figure 1: Confirmed glyphosate resistant sites in Australia. At the start of 2006 there were 50 confirmed cases.



Cumulative probability distributions for predicted evolution of glyphosate resistance in annual ryegrass in a 30-year simulation of a Wheat-Lupin-Wheat-Canola rotation with no tillage at sowing.

Source: Neve, P., Diggle, A.J., Smith, F.P., Powles, S.B. 2003. Simulating evolution of glyphosate resistance in Lolium rigidum II: past, present and future glyphosate use in Australian cropping. Weed Research. 43, 418-427.

The Double Knock was most successful at reducing populations at risk of resistance and extending the number of years to resistance (30+).

This photo shows one population of glyphosate resistant Annual Ryegrass with three different knockdown applications applied.

Source: Syngenta, Jealotts Hill, UK

Photo 1: As viewed from left to right:

Pot No 1: 1.6 L/ha of SPRAY.SEED® in a 80 L/ha of spray volume equivalent
Pot No 2: 1.4 L/ha of glyphosate MEA in 80 L/ha of spray volume equivalent
Pot No 3: 2.8 L/ha of glyphosate MEA in 80 L/ha of spray volume equivalent

This photo was taken 17 days after application. In normal circumstances you would expect the glyphosate treatments to have completely browned out after that period of time on annual weeds. However in this case it is evident the glyphosate pots have resisted the herbicide application and the Annual Ryegrass is growing out of any herbicidal effects, a common sign of resistance. These three pots also demonstrate that if an Annual Ryegrass population has developed resistance to glyphosate that it may still be susceptible to SPRAY.SEED.

FITNESS PENALTY AND GLYPHOSATE RESISTANCE

Following are some facts about glyphosate resistance fitness penalty associated with the resistant survivors.

- Plants carrying the resistance gene are on average less fit and produce less seed than those without the resistance gene. Hence the term Fitness Penalty.
- In the absence of herbicide application and over time, the number of resistant individuals in the population is expected to decline.
- Where resistance is common eg (Group B Herbicides like chlorsulfuron) the penalty is quite small and the time taken for resistance to decline will be quite long.
- Where resistance is rare eg (Group M herbicides like glyphosate) the fitness penalty is larger and the time taken for resistance to decline is shorter. One population tested indicated a reduction in the number of resistant individuals from 45% to 11% over 3 years, where glyphosate was removed from the system.
- Do not wait until resistance occurs as total removal of glyphosate from a cropping system for greater than 3 years is not ideal.
- The key to exploiting the fitness penalty is to cease using glyphosate. Whilst glyphosate continues to be used, the population is constantly being exposed to selection pressure, selecting for glyphosate resistant individuals.
- Consider occasionally using knockdown herbicides with a different mode of action where appropriate, eg SPRAY.SEED, rather than being forced to totally remove glyphosate for a period of time.
- The best strategy to manage glyphosate resistance is prevention. Avoid glyphosate resistance by rotating knockdown herbicides and employing other non-chemical weed management strategies.

Photo: courtesy Andrew Storrie

In the field glyphosate resistance typically appears as small patches which can become larger if not carefully managed, as indicated in the photo above.

There are currently 50 cases of confirmed glyphosate resistance in Annual Ryegrass in Australia – the incidence and discovery of which has been slowly increasing as indicated in the figure 1 table. In Australia the confirmed cases are widespread in their detection, however currently NSW has the highest concentration of confirmed cases with almost 70% of those discovered, located in NSW.

Glyphosate resistance in Australia

Situation	Confirmed Number of Cases at Location	Resistance to other herbicide groups
Chemical Fallow	Northern NSW x 17, North/Western NSW x 1	Unknown
Driveway	Murrumbidgee, NSW x 1	Unknown
Fenceline	Murrumbidgee, NSW x 1 South Eastern, NSW x 2, Eyre SA x 2 Yorke/Lower North SA x 1, Victoria x 1, Northern NSW x 1	A B Unknown
Firebreak	Eyre, SA x 1	Unknown
Irrigation Ditch	Murrumbidgee, NSW x 2, Northern Vic x 1, Central West NSW x 1	Unknown
No-Till	Goulburn, Vic x 1, Sth East SA x 1 Yorke/Lower North SA x 1 Wimmera, Vic x 1 Central, WA x 1 Midlands, WA x 1	A A, B, D A, B Unknown
Orchard	Central West, NSW x 1 Sth Eastern NSW x 1, Murrumbidgee, NSW x 1	A Unknown
Railway	Midlands, WA x 1	Unknown
Vineyard	Adelaide, SA x 1, Outer Adelaide, SA x 1 Adelaide, SA x 1, South West WA x 1 South East SA x 2, Lower North SA x 3	Unknown

The above table demonstrates that no particular segment – winter broadacre, summer broadacre or horticulture is immune to glyphosate resistance with cases confirmed in many varied use situations. Clearly the industry needs to adopt management strategies as a standard practice in all markets to ensure we do not encounter nor encourage the onset of resistance.

Source: NGSWG 2005 website, www.weeds.crc.org.au/glyphosate, 2006

GROWER PERCEPTIONS OF THE EFFECT OF GLYPHOSATE RESISTANCE ON FARM PROFIT

In March 2000 and 2001 a random survey of over 130 Western Australian farmers was conducted by the W.A. Herbicide Resistance Initiative (WAHRI) to measure grower perceptions on weed management practices, herbicides and herbicide resistance. As part of this larger study, information relating to glyphosate and its management was collected.

The study of 130 farmers indicated that no grower reduced the number of glyphosate applications per cropping paddock over the past 4 years. Only 6% of growers expected a reduction over the next 4 years. Their average number of reported glyphosate applications to typical cropping paddocks in their history was 11 in the intensively cropped regions. In this same area 19% of paddocks had received greater than 15 applications suggesting that many growers are facing higher glyphosate resistance risk. *(Llewellyn 2002)* Information collected included the perceived value of herbicides and the cost of herbicide resistance. Specifically growers were asked about their willingness to pay for land with various levels of resistance. Growers indicated they would pay approximately 25% less for land where no Group A and Group B herbicides would control Annual Ryegrass compared with land where the Annual Ryegrass was fully susceptible. If glyphosate resistance was present in addition to the Group A and B resistance, growers willingness to pay for land was less than half that for land with no resistance. See table below.

Growers Willingness to Pay for Land (WTP)

Economic impact of glyphosate resistance

Quite aside from its impact on weed control and subsequent crop yields, the development of glyphosate resistance could have a significant impact on property values.

Willingness to pay for land with resistant Annual Ryegrass populations

Resistance Status	*Land Value*
No resistance	100%
Resistance to diclofop	84% (-16%)
Resistance to diclofop and chlorsulfuron	80% (-20%)
Resistance to diclofop, chlorsulfuron and clethodim	75% (-25%)
Resistance to diclofop, chlosulfuron, clethodim and glyphosate	45% (-55%)

(Rick Llewellyn, WA Herbicide Resistance Initiative, 2002)

Change in growers willingness to pay (WTP) for land with Annual Ryegrass (ARG) with different levels of herbicide resistance, as a % of WTP for land with ARG with no resistance. NB resistance status is cumulative. eg glyphosate represents resistance to all Group A (eg diclofop and clethodim), Group B (eg chlorsulfuron) and Group M (eg glyphosate) herbicides.

Source: Rick Llewellyn 2002

Encouragingly about 60% of growers surveyed reported using the Double Knockdown technique in the past 4 years and up to 80% of growers expect to use the technique in the next 4 years. Although glyphosate resistance is not yet widespread, large numbers of previous applications and continued high reliance indicates that many growers are facing a significant risk of glyphosate resistance evolution in the future. *(Llewellyn 2002.)*

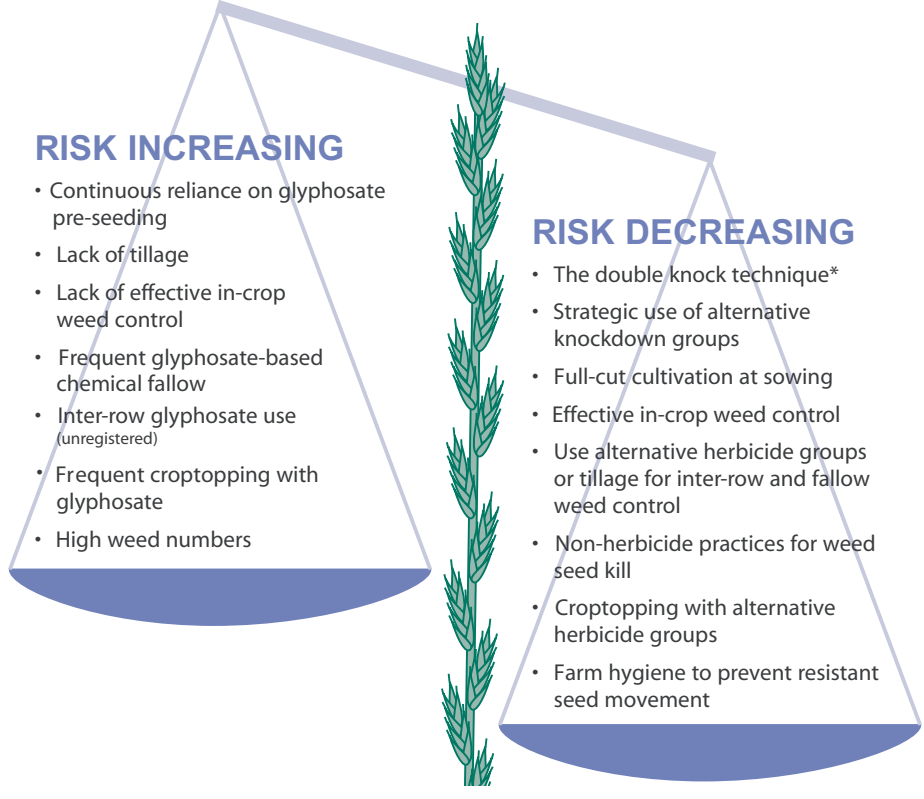
MAINTAINING GLYPHOSATE SUSTAINABILITY

Australia's Glyphosate Sustainability Working Group has launched the next step in its campaign: an interactive and all-encompassing information web site for farmers and their advisors. The web site is part of a national industry-wide initiative to drive a concerted approach to the sustainable use of the herbicide glyphosate. From its first meeting the Glyphosate Sustainability Working Group determined its goals of increasing industry collaboration and assisting the research, development and on-farm management effort would require a 'one-stop-information-shop'.

Found at http://www.weeds.crc.org.au/glyphosate, the new website will provide a register of glyphosate resistance discoveries and a comprehensive list of FAQ's on the issue of glyphosate resistance. The site also has an archive of news and research articles and importantly, a guide to keeping glyphosate resistance rare. The Glyphosate Sustainability Working Group consists of grains industry researchers and communicators, on-farm agronomy experts and agricultural chemical manufacturers.

Syngenta Crop Protection is an active and committed supporter of the Glyphosate Sustainability Working Group and welcomes the website as a key component in the campaign.

Tip the scales in your favor to minimise the risk of glyphosate resistance in annual ryegrass



All Group M herbicides are glyphosate herbicides

This guide has been produced by the National Glyphosate Sustainability Working Group, a collaborative initiative aimed at promoting the sustainable use of glyphosate in Australian agriculture, involving the CRC Australian Weed Management, Monsanto, Syngenta, Nufarm, WA Herbicide Resistance Initiative (University of WA), University of Adelaide, Charles Sturt University, University of Melbourne, Queensland DPI&F, Department of Agriculture WA, NSW DPI, CRT/Town & Country, AVCARE and the GRDC. 2005.

For more information see: http:/ /www.weeds.crc.org.au/glyphosate or e-mail: Rick.Llewellyn@uwa.edu.au

*The double knock technique is defined as using a full cut cultivation OR the full label rate of a paraquat-based product (Herbicide Group L) following the glyphosate (Herbicide Group M) knockdown application. Diagram based on original concept for minimising glyphosate resistance in annual ryegrass in southern Australian grain growing by Paul Neve, WAHRI, University of WA. Optimal management techniques for other weed species may differ.

GLYPHOSATE RESISTANCE POTENTIALLY NOT ONLY CONFINED TO ANNUAL RYEGRASS

Whilst the focus of glyphosate resistance in Australia has to date been on Annual Ryegrass (the only confirmed glyphosate resistant species in Australia), a recent survey indicates we should not become complacent about risk in other weed species.

The survey was recently conducted by Walker & Storrie et al. of more than 240 growers and agronomists in the northern region of Australia (central and Nth NSW and central and Sth Qld). The aim of the survey was to determine the weeds, herbicides and cropping systems at risk of developing herbicide resistance. Risk assessment ratings were calculated based on history of weed species to develop resistance elsewhere, herbicide mode of action, and paddock history including, herbicide use frequency, herbicide efficacy, use of tank mixtures, weed infestation level, use of tillage and non-chemical control methods. Amongst other herbicides including Groups; A, B, C and I, glyphosate was identified as being at potentially high risk to develop resistance to a number of weeds including: Liverseed Grass, Sweet Summer Grass, Sowthistle and Wild Oats in Qld and Barnyard Grass, Bishop's Weed and Liverseed Grass in NSW. This is farmer/agronomist perception and further analysis of the concerns raised is occurring.

The challenge from now on will be to devise strategies to reduce the risk of glyphosate resistance developing to these perceived high risk weeds and potentially other weed species.

STRATEGIES TO MINIMISE THE RISK OF GLYPHOSATE RESISTANCE

Sustainable weed-management systems require the integration of a range of methods, ie Integrated Weed Management (IWM). The selected strategies should be adapted to specific regional situations. Integrated strategies, embracing but not wholly herbicide-dependent, can be cost-effective and sustainable. Such integrated strategies are necessary to preserve the continued efficacy of herbicides in the long term.

The rotation of herbicides with different mode of action will slow the development of resistance to any one herbicide group. For non-selective weed control such as fallow weed control, pre-plant weed control or weed control in tree crops, the rotation of glyphosate with non-selective herbicides with different mode of action, ie SPRAY.SEED is highly recommended. Where minimum tillage is an important part of agronomic practice, then one important weed control option is significantly restricted in availability (tillage). In such situations dependence on glyphosate exclusively greatly increases the probability of resistance. In such cases it is essential to rotate the use of glyphosate with a knockdown herbicide of a different mode of action ie SPRAY.SEED. Other tactics that may be employed to help reduce risk of glyphosate resistance are: strategic use of full soil disturbance and utilising the Double Knock technique.

Work conducted by the Western Australian Herbicide Resistance Initiative (WAHRI) researchers (Neve et al, 2002) found the best way to employ the double knock was via the Double Knockdown technique. This involves applying glyphosate first followed by an application of SPRAY.SEED (with generally a 1 to 5 day break between applications) at full rates before sowing. This controls glyphosate resistant survivors and weeds that emerge between glyphosate application and sowing. Where the Double Knockdown is not possible, the second SPRAY.SEED application can be replaced with full cut cultivation at sowing, which will give a second knock to resistant survivors. The introduction of glyphosate tolerant crops will place further pressure on glyphosate. If glyphosate tolerant crops are grown, then similarly pre-plant knockdown can be achieved with SPRAY.SEED. Similarly glyphosate tolerant volunteer weeds can be managed with SPRAY.SEED.

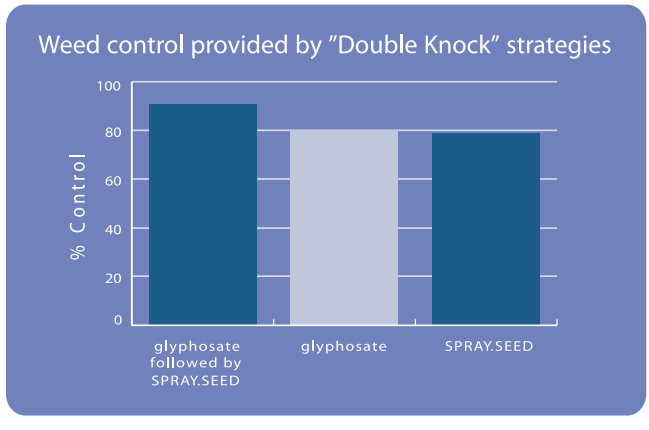
"DOUBLE KNOCK" TECHNIQUE

The Double Knock technique provides even more robust control of weeds of all sizes as part of an effective resistance management strategy.

Proven Benefits

The consecutive application of glyphosate and then SPRAY.SEED combines the strengths of both herbicides – and uses them to their best advantage. As a systemic herbicide, glyphosate is more effective at controlling larger or perennial weeds with established root systems. As a contact herbicide, SPRAY.SEED provides rapid burn-down of a broad spectrum of weeds and robust control under a wider range of growing and weather conditions. This approach provides a number of significant benefits compared to conventional weed control strategies.

- **Improved spectrum:** The combination of systemic and contact activity improves control of larger or hard-to-control weeds, meaning more soil moisture and nutrients are available for your crop.
- **Improved reliability:** The consecutive application of knockdown herbicides with different modes of action ensures that all weeds are controlled. This is particularly important if the initial application was made under high stress conditions.
- **Reduced need for in-crop herbicide applications:** The control of subsequent weed germinations and weed escapes reduces the need for post-emergent herbicides, thereby reducing selection pressure on selective herbicides.
- **Improved seedbed/crop establishment:** The inclusion of a contact herbicide means that sowing will be made into a desiccated rather than decaying seedbed. This is particularly important if trifluralin is to be included as a tank-mix in the second application.
- **Improved yields:** "Double Knock" programs can improve weed control by 10-15% compared to a single application of a knockdown herbicide, resulting in an average yield advantage of 150 kg/ha.



(Source: Syngenta trials, 1998-2002). Average of 19 trials in 5 states over 5 years.

BIPYRIDILIUM RESISTANCE

Resistance to the Bipyridyls (paraquat and diquat) was first confirmed in 1980. It has now been confirmed in 23 weed species in 13 countries around the world including 4 weed species in Australia, Capeweed *(Arctotheca calendula)*, Barley Grass *(Hordeum leporinum)*, Northern Barley Grass *(Hordeum glaucom)* and Silvergrass *(Vulpia bromoides)*.

Paraquat resistant Barley Grass can occur following a significant history of paraquat application, usually over more than 15 years. (Preston et al 1994)

Bipyridyl resistant weeds in Australia are most common in old established lucerne stands and have been relatively confined to those paddocks. The greatest risk to the spread of these weeds appears to be the transport of weeds such as Barley Grass in lucerne hay. Care needs to be taken to minimise the rate of spread of such weeds in hay. The potential for resistant Barley Grass spread can increase following dry seasons where there has been increased transport of hay stocks throughout the country. Rotating modes of action of herbicides and adopting additional cultural techniques for weed control will assist in controlling these species before weed numbers multiply. In a developed lucerne stand where the risk of paraquat resistant Barley Grass is highest, rotating with other herbicide groups will assist in the control of any paraquat resistant Barley Grass escapes prior to cutting hay. Winter cleaning with diuron mixtures is also a useful strategy to help manage resistance.

In addition to the discovery of paraquat resistant Barley Grass in lucerne, there have also been 2 populations found in 1995 in a no-till broadacre cropping system. Both populations had no prior history of a lucerne planting but did have a long history of paraquat use. Similarly with glyphosate, rotation and alternate methods of weed control should be applied versus a single practice.

Photo 2: Courtesy Chris Preston

As viewed from left to right, the 3 populations of Barley Grass (THL-1, VHG-1, SH-29) are all showing resistance to paraquat at 200 g/ha or 800 mL/ha of GRAMOXONE. Population THL-4 demonstrates efficacy on a susceptible population. Paraquat resistance may be due to the reduced translocation of paraquat from the leaves to the shoot meristem. (Preston et al. 1992)

There is now a confirmed case of Annual Ryegrass resistance to paraquat in South Africa. The situation had been characterised by consistent application of paraquat products over many years and limited use of alternate herbicide mode of action or alternate methods of weed control. This case again supports the need to rotate herbicide options and adopt a diverse weed management strategy to prevent the potential for onset of knockdown herbicide resistance and prolong the effective life of your knockdown herbicides.

SUMMARY OF BIPYRIDYL RESISTANCE GLOBALLY
Weeds by country with confirmed resistance to Bipyridyls

Country	Weed
Australia	Capeweed, Barley Grass, Northern Barley Grass, Silver Grass
Malaysia	Slender Amaranth, Sumatran Fleabane, Thickhead Ragleaf, Crowsfoot Grass, Saramollagrass, Blackberry Nightshade
Kenya	Cobbler's Pegs
Taiwan	Sumatran Fleabane
Egypt	Flax-leaf Fleabane
Japan	Flax-leaf Fleabane, Canadian Fleabane, Sumatran Fleabane, Philadelphia Fleabane, Mizuaoi, Native Hawksbeard
South Africa	Flax-leaf Fleabane, Annual Ryegrass
Canada	Canadian Fleabane, Virginia Peppercress
USA	Canadian Fleabane, Glossy Nightshade, Crowsfoot Grass
Belgium	Glandular Willowherb, Wintergrass, Dorred Duckweed
Sri Lanka	Sumatran Fleabane
Fiji	Columbian Waxweed
UK	Glandular Willowherb, Wintergrass

Source: www.weedscience.org 2006

STRATEGIES TO MINIMISE THE RISK OF BIPYRIDYL RESISTANCE

In order to prolong the effective life of paraquat/diquat it is important to integrate with its use a range of weed management methods. ie Integrated Weed Management (IWM). The selected strategies should be adapted to specific regional situations. Integrated strategies, embracing but not wholly herbicide-dependent, can be cost-effective and sustainable. Such integrated strategies are necessary to preserve the continued efficacy of herbicides in the long term.

The rotation of herbicides with different modes of action will reduce the risk of resistance to any one herbicide group. For non-selective weed control such as fallow weed control, pre-plant weed control or weed control in tree crops, the rotation of paraquat/diquat with non-selective herbicides with different mode of action, ie glyphosate, is highly recommended.

Where minimum / no tillage is an important part of agronomic practice, then one important weed control option is significantly restricted in availability (tillage). In such situations dependence on one knockdown mode of action exclusively increases the probability of resistance. It is essential to rotate the use of paraquat/diquat with a knockdown herbicide of a different mode of action, ie glyphosate.

Orchards, vineyards and long term perennial pasture eg (lucerne) where frequent applications of paraquat/diquat exist, pose the greatest risk for the development of paraquat/diquat resistance. This is due to a high number of applications per season, lack of tillage and sometimes reliance on a single herbicide mode of action (paraquat/diquat).

In orchards / vineyards paraquat/diquat may be rotated with glyphosate or glufosinate for broad-spectrum weed control or FUSILADE® for grass weed control and Jaguar* for broadleaf weed control. Alternatively residual herbicides such as diuron, ZOLIAR® or GESATOP® may be mixed or rotated with paraquat/diquat to help manage resistance.

In lucerne the options are more limited as there or no other non-selective herbicide options registered for use in lucerne. For grass control FUSILADE, Raptor*, Spinnaker* or GESATOP may be rotated or mixed with paraquat/diquat. For Broadleaf weed control Raptor, Spinnaker, GESATOP, Bromoxynil, 2,4-DB or Jaguar may be rotated or mixed with paraquat/diquat to help manage resistance.

Winter cleaning with diuron +/- SPRAY.SEED or GRAMOXONE® is generally the best and preferred option in pure lucerne stands.

Strategies to minimise the risk of paraquat/diquat resistance:

- Rotate paraquat/diquat use with other knockdown herbicides with a different mode of action eg glyphosate
- Rotate the use of paraquat/diquat with other selective herbicides with a different mode of action in perennial crops eg lucerne
- Consider utilising the Double Knock technique prior to sowing - at full label rates
- Consider using residual herbicides where applicable either alone or in mixture with group L herbicides
- Occasionally fully disturb soil with strategically placed cultivation
- Manage weed control escapes so they do not set seed
- Keep weed numbers as low as possible

More information on the Double Knock Techniques are available from your local Syngenta Crop Protection representative or a trained agronomist. Syngenta Crop Protection have global interests in both glyphosate (TOUCHDOWN), paraquat (GRAMOXONE) and diquat (REGLONE®) and promote the responsible use of knockdown herbicides to prolong their effective life. SPRAY.SEED 250 herbicide is a combination of both paraquat and diquat and is specifically used in Australia.

For more information on herbicide resistance, please visit:

www.doubleknock.com.au
www.paraquat.com
www.avcare.org.au
www.weeds.crc.org.au/glyphosate
wahri.agric.uwa.edu.au
www.weedscience.org
www.syngenta.com.au

REFERENCES

Brighton crop protection conference: weeds. Proceedings of an international conference, Brighton, 17-20 November 1997. **3:** 1119-1126.

Heap, I. **The International Survey of Herbicide Resistant Weeds.** Online. Internet. January 2006. Available www.weedscience.org

Herbicide Resistance Action Committee (HRAC). Online. Internet. December 10, 2002. Available www.plantprotection.org/hrac

Llewellyn, RS., **Make every effort to keep resistance rare**, Kondinin Group, Farming Ahead, No 130, 26-27, October, 2002.

Llewellyn, R.S. and Powles, S.B. (2001). **High levels of herbicide resistance in rigid ryegrass *(Lolium rigidum)* in the wheatbelt of Western Australia**. Weed Technology 15, 242-248.

Llewellyn, RS, 2002/03, **Grain Grower perceptions of the economic value and longevity of glyphosate**. Proceedings of the 11th Australian Agronomy Conference, Geelong 2003.

Llewellyn, RS., Lindner, RK., Pannell, DJ., Powles, SB., 2002, **Resistance and the herbicide resource: Perceptions of Western Australian grain growers**, Crop Prot. 21, 1067-1075

Llewellyn, Rick, 2003, Personal communication, NSW Agriculture

Lorraine-Colwill, D. F., T. Hawkes R., P. Williams H., S. Warner A.J., P. Sutton B., S. Powles B., and C. Preston. 1999. **Resistance to glyphosate in Lolium rigidum.** Pesticide Science. **55:** 489-491.

Lorraine-Colwill, DF; Powles, SB; Hawkes, TR; Preston, C , 2001. **Inheritance of evolved glyphosate resistance in Lolium rigidum (Gaud.). Theoretical and Applied Genetics.** 2001, 102: 4, 545-550

National Glyphosate Sustainability Working Group (NGSWG) Online January 2006. Available www.weeds.crc.org.au/glyphosate.

Neve, P., Diggle, A., Smith, P., Owen, M., Hashem, A., Preston, C., and Powles, S. (2002). **Glyphosate resistance in WA and Australia: Where are we at?** Crop updates, WA Dept of Agriculture, pp 57-58.

Powles, S. B. 1997. **Success from adversity: Herbicide resistance can drive changes to sustainable weed management systems.** 1997

Preston, C., **Glyphosate resistance on the increase,** Kondinin Group, Farming Ahead, No 131, 38-39, November, 2002.

Preston, Chris, 2002, Personal communication, CRC Weed Research, Waite Institute, Adelaide, SA.

Storrie, A., Cook,T, 2002, **Glyphosate resistance in northern New South Wales – A growing concern,** 13th Australian Weeds Conference WA – Papers and proceedings, 601 – 603

Walker, S., Osten, V., Storrie, A., Robinson, G., Cook, T., Galea, K., 2002, **Weeds at risk of developing herbicide resistance in the different cropping systems of the northern region**, 13th Australian Weeds Conference WA – Papers and proceedings, 620 – 621, 2002.

Walker, S., Storrie, A., Cook, T., Moylan, P., **The Northern Herbicide Resistance Reporter**, September, 2002.

For further information please contact the Syngenta Product Technical Advice Line:

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