Integrated Weed Management and the implications of herbicide tolerant crops

A report for

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Foreword

For twelve years, as Australia debated the merits of genetically modified crops, many other countries especially Canada and USA enthusiastically adopted the technology. In 2008 approval was given for Australian farmers to grow herbicide tolerant genetically modified (HTGM) canola. This study is about the management of weeds in those HTGM crops that have been grown overseas. The opportunity for Australia is that we can learn from the successes and failures of the long term use of GM technology.

Farmers, agronomists and regulators in Australia need to know that while this technology has many advantages; if it is abused through poor management the price is high. If weeds develop resistance to the herbicide glyphosate it will limit farmers' management decisions and add complexity and cost to winter cropping systems. The timeline for new herbicides to replace glyphosate are an unknown. It is possible that there will be no new herbicide modes of action developed.

It is important that for all those involved, whether they be growers, regulators or seed companies, the management of HTGM canola needs to be top level. Growers need to maintain an integrated weed management program that includes non herbicide weed control methods. There is also a need to limit the time period between HTGM canola crops to reduce the pressure on glyphosate. Regulators and technology providers need to monitor what growers are doing and both encourage and enforce responsible use of HTGM technology.

The comments and opinions expressed in this paper are my own and are based on my personal findings. No responsibility can be attributed to Nuffield Australia or any affiliated party.

Acknowledgments

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Abbreviations

HR – Herbicide resistant
HTGM - herbicide tolerant genetically modified

IT- Imadidazolinone tolerant

MOA - mode of action
NTSR- non target site resistance
RR-Roundup Ready

TT – Triazine tolerant

Plain English Compendium

Integrated Weed Management. IWM is a strategy for controlling weeds in agricultural situations that involves use of several different modes of weed control, rather than just relying on herbicide applications to do the task. Techniques that can be used include burning stubbles to reduce the weed seed bank, cultivation, biological controls such as insects that prey on weed species and making hay. Maximising crop health and vigour is also an IWM strategy, in that it allows the crop to compete more strongly with weed species.

Herbicide tolerance The ability of a crop to survive an application of an herbicide that would normally harm the crop. Herbicide tolerance can be introduced into a crop by either traditional breeding techniques or by genetic modification. Herbicide tolerance is used for difficult to control weeds or weeds that are genetically similar to the crop.

LD50 An experimental measurement of the toxicity of chemicals, the LD 50 is the oral dose of a substance that is lethal to 50% of a group of rats.

Reduced tillage/no-till/zero-till Conventional agricultural practice involved cultivation prior to sowing of a crop or pasture to kill weeds and prepare the seed bed. No-till, or zero-till involves replacing this cultivation with a pre-sowing knockdown herbicide application. The seed is then directly drilled into the soil through the crop residue. Special seeding equipment is required to do this. Among the benefits of no-till are increased moisture conservation, reduced soil erosion, improved soil structure and carbon content, and reduced fuel use.

Herbicide drift Herbicide drift occurs when a chemical sprayed onto an area affects an adjacent non-target area. It occurs more commonly under certain climatic conditions, and can cause major damage or death to the non-target crop species.

Weed shift The collection of weed species present in a site is known as the weed spectrum, and it varies according to many factors, such as climate, soil fertility, competition from other plant species etc. In any given site, a change in the management of that site can result in a change in the variety of weed species seen, a phenomenon known as weed shift.

Contents

Executive Summary

- Herbicides have changed the way farmers grow crops by allowing them to practice reduced tillage, but weeds have developed resistance to herbicides.
- It costs approximately $200 million and 10 years to develop a new herbicide, but the number of new herbicides coming to the market is decreasing because of less research, higher development costs and higher environmental standards. The last new mode of action was discovered in 1991.
- Genetically modified herbicide tolerant crops have been grown commercially in North America since 1996. Soybeans, canola, corn, cotton, alfalfa and sugar beets have been released.
- Positives of the technology have been simple and effective weed control, perception of easy management, permitting uptake of no-till cropping & higher end profits (but not always)
- Negatives have been weed shifts, weeds developing resistance to glyphosate, gene flow in species and between species and a need for a strong degree of management to deal with issues like herbicide drift and volunteer weeds in following crops
- Canada has been successful in using the technology with higher profits and cleaner paddocks. The USA has also had success but the lack of crop rotation, and the continuous growing of herbicide resistant genetically modified crops is leading to major issues with glyphosate resistant weeds especially in cotton.
- Herbicide tolerant genetically modified crops aren't the only place weeds are developing resistance to glyphosate. Fallow systems and use along roadsides are also developing resistant weeds.
- The European Union is proposing to change pesticide legislation from a risk based to a hazard based system. If the parliament's proposals are adopted UK farmers will lose 85% of their herbicides and all of their fungicides and insecticides.
- Denmark has a low pesticide regime that has forced farmers to limit the amount of herbicides they apply

- Arable organic farmers in Europe use techniques like crop rotation, high seeding rates, cover crops, mechanical weeding and cultivation to control weeds. Organics has its own issues with generally lower yields and the amount of cultivation burning diesel which runs contrary to organic principles of long term environmental sustainability.
- Australian farmers will benefit from access to herbicide tolerant genetically modified canola varieties which should have better weed control and yields than the triazine tolerant varieties they now grow. There needs to be limits (possibly by regulation) to the amount of time between herbicide tolerant genetically modified canola crops. Farmers also need to use integrated weed management techniques like pre-emergent herbicides, diverse rotations, rotation of knockdown herbicides and non herbicide methods.
- It is important that the Australian industry gets the management of herbicide tolerant genetically modified crops right. If we have weeds that develop resistance to glyphosate it could limit growers' ability to continue to use reduced tillage. The timeline for a glyphosate replacement is an unknown.

Introduction

Weed control has always been one of the main challenges in arable farming systems. Traditionally cultivation and long fallows were used to reduce the seed bank and together with rotations involving grazing, farmers were able to keep weed populations low.

In the 1940's that began to change with the introduction of herbicides like 2,4-D. The number of herbicides increased until in the 1970's and 1980's there was a rapid expansion of the number of herbicides. Farmers had never known anything like it. Suddenly they had a huge range of chemical options that were relatively cheap and easy. This situation gave rise to many desirable farming practices. Now Australian farmers could farm their land with techniques different to what their forebears had brought from Europe. Now they could reduce the amount of tillage and retain stubbles, all very desirable practices in our challenging environment. Unfortunately this now means that many farmers are dependent on herbicides as their main weed control tool. This can be an undesirable situation as weeds such as ryegrass and wild radish have developed resistance to herbicides. Farmers can also lose the use of herbicides with the stroke of a politicians or bureaucrats pen as has happened in Europe.

In 2008, NSW and Victoria lifted their moratorium on growing genetically modified herbicide tolerant canola. Australian farmers now have another tool for the management of weeds and to help them deal with the herbicide resistant weeds they already have. Proponents of the technology assert that this will be a major step forward but opponents claim that farmers will end up with bigger herbicide resistance problems.

This study was undertaken to see what twelve years of growing herbicide tolerant crops in North America has meant for weed management. I wanted to see what changes had occurred and see what mistakes have been made so that we in Australia don't repeat them.

I also visited Europe looking at weed management without herbicide tolerant genetically modified crops. I wanted to see how farmers are dealing with fewer herbicide options and if organic arable farming has some techniques that are applicable to southern Australian winter cropping systems.

The aim of this study was not to discuss the merits of genetically modified crops. Many others have done that before this report. I will make a few comments, but the goal of my scholarship is to provide information to Australian farmers so that they can responsibly and sustainably use herbicide tolerant genetically modified crops.

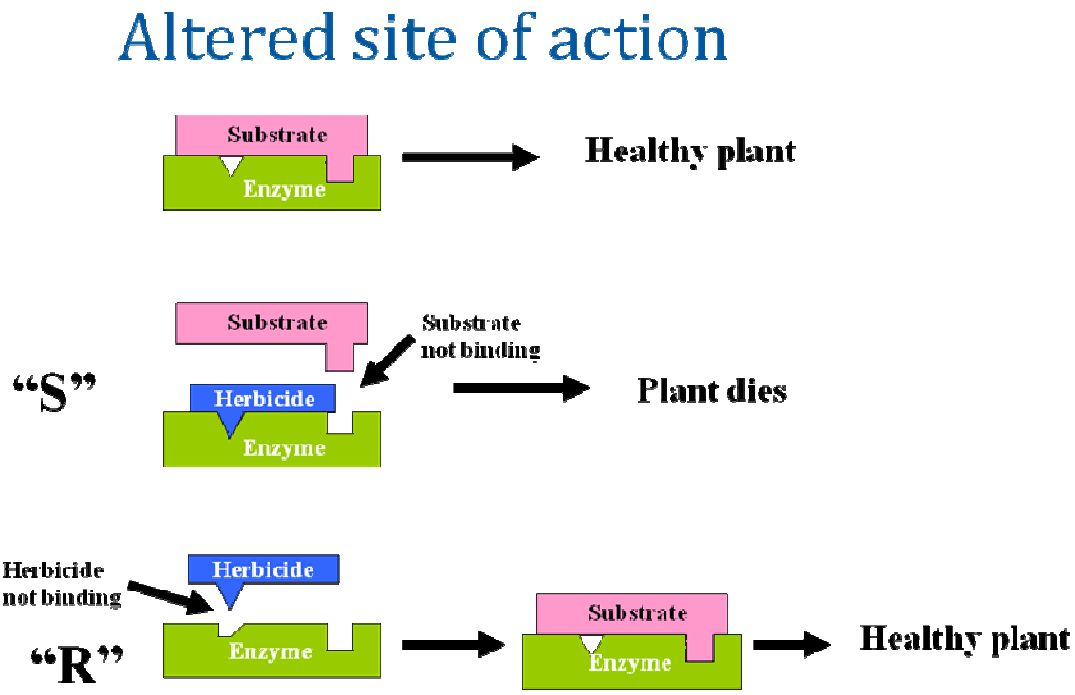
History of herbicides and herbicide resistance

Ever since the first farmers began to grow plants as crops agriculture has been battling weeds. For thousands of years plants that the farmer doesn't want in his fields have been competing with the plants they do want for space, nutrients and water. The samples of barley found in the tomb of the ancient Egyptian pharaoh Tutankhamun (circa1325BC) were contaminated with weed seeds.

The first selective herbicides available to farmers were 2,4-D and MCPA, released in 1947. Since then farmers have had an increasing range of herbicide options to use to control weeds. Herbicides have often been the most reliable and least expensive method of weed control and have allowed farmers to change the way they farm. Herbicides have allowed plant breeders to move from tall competitive varieties to shorter, less competitive but higher yielding varieties. Herbicides have allowed farmers to move away from cultivation to no-till systems. This has allowed farmers to better utilise their moisture and improve soil carbon levels as well as minimise soil erosion. This has meant that they are more dependent on herbicides for weed control.

All herbicides act by binding or interacting with one or more plant proteins which causes negative effects on the weed's metabolism or growth. Prior to the late 1960's there were few reports of herbicides not working effectively. Around 1970 in the United States previously very susceptible populations of common groundsel (Senecio vulgaris) stopped dying when they were sprayed with triazine herbicides. This was the first recorded incidence of herbicide resistance (HR). The standard definition of HR is "*the evolved capacity of a previously susceptible weed population to withstand an herbicide and complete its life cycle when the herbicide is used at normal rates in an agricultural situation*". By 1980, 32 different weed species had populations that were resistant to triazine herbicides. As more herbicides became available to farmers so have more weeds become resistant. As of October 2008 there are 184 species of weeds that have resistance to herbicides. The main weeds in wheat with resistance are; in Australia ryegrass (Lolium rigidum), in Europe blackgrass (Alopecuros myosuroides), and worldwide wild oats (Avena spp).

Herbicide resistance can occur in several ways. Target site resistance occurs when there is a modification of the herbicide binding site (usually an enzyme) which precludes an herbicide from actively binding.



Hanwen Wu 2008

Non Target Site Resistance (NTSR) is resistance due to mechanisms other than target site modification. NTSR can be caused by mechanisms such as enhanced metabolism, reduced rates of herbicide translocation and sequestration. Such mechanisms reduce the amount of herbicide that reaches the target site.

Cross Resistance is when a single resistance mechanism confers resistance to several herbicides. Examples of cross resistance are wild oats with resistance to both "fops" and "dims" or ryegrass resistant to both group A's and group B's. This can happen even though the weed may never have been sprayed with the second chemical.

Multiple Resistance is when a weed population is resistant to two or more Modes of Action (MOA).

Herbicides act by targeting specific plant processes and this is called the mode of action. There are currently 14 MOA's and in Australia all herbicides are classified into groups of

MOA's which are named with a letter from A to N. For example group L MOA's work by inhibiting photosynthesis at photosystem I. Group A herbicides work by inhibiting fat (lipid) synthesis (the enzyme acetyl COA carboxylase). Each MOA group can have sub groups as group A does. Group A herbicides can be divided into four subgroups, generally referred to by the last three letters in the names of the active ingredient of the herbicide. Products like Hoegrass, Verdict and Topik are all "fops". Select and Acheive are "dims". Fusion and Decision are a combination of both fops and dims and Axial is a "den". Even though they are all different they still are using the same MOA to kill weeds. Rotating chemicals from different subgroups won't always work to kill resistant weeds. It is a better practice to rotate MOA's instead.

Why and how do weeds become resistant to an herbicide?

Herbicide resistance occurs because of either mutation or genetic diversity. In all weed species, there are plants that are naturally resistant to herbicides. These are usually a very small part of the population. Depending on the weed species and the herbicide MOA the frequency of naturally resistant plants can vary from 1 plant in 10,000 for a group B herbicide to 1 plant in 1 billion for a group M herbicide. Repeated use of a single herbicide group and a lack of non-herbicide methods of weed control can let the naturally HR plants become an increasingly higher percentage of the species population until it is almost 100% herbicide resistant. Once a population is resistant it is easily spread by machinery or water spreading seed. It can also be spread by pollen in some species. The development of HR can happen quite quickly and for an example we need to look no further than a weed that dominates southern Australian farming systems – ryegrass (Lolium rigidum).

"*Ryegrass is one of the most genetically diverse weeds we have and has resistance to herbicides that haven't even been found yet"* Deerpak Kaunden Herbicide Resistance Leader, Syngenta International

Ryegrass is a plant that has adapted to Australian conditions extremely well and has developed herbicide resistance very quickly. As part of a mixed farming system many farmers have planted ryegrass for an extremely productive pasture. It is when they started growing crops that ryegrass then became a weed. Ryegrass is a very competitive plant that has an ability to produce an enormous amount of seed. Even if you had only one resistant plant of ryegrass per

hectare of crop, that plant can produce up to 6000 seeds. In the next year if 20% of that seed grew there would be 1200 resistant plants per hectare producing 7.2 million seeds. If in year three 20% of those seeds grew there would be 1.44 million plants per hectare producing 5.7 billion seeds. As you can see with ryegrass a small problem can evolve into a very large problem very quickly. Dealing with herbicide resistance is a numbers game and for growers living with herbicide resistance that means using multiple methods of weed control to limit the number of weed seeds produced. Just rotating MOA's isn't the solution. As early as 1982 ryegrass in South Australia was found to have developed resistance to 7 different MOA's (Herbicide Resistance Action Committee).

There has been resistance in farmers to implement an effective herbicide resistance strategy until they have a serious problem. Most farmers consider herbicide resistance avoidance a low priority and don't want to change their weed control programs because of financial and logistical constraints. Herbicide resistant genetically modified (HRGM) crops offer cost effective and easy to use solutions but as we will see later can create even bigger herbicide resistance issues if not used with care.

Herbicide Development

Market research studies have consistently reported that farmers believe that the agri-chemical industry will keep bringing forward new products that will solve the herbicide resistance situation. I feel growers may be disappointed as new herbicides and especially new MOA's are likely to be limited. Governments are also placing higher environmental standards on both new and existing herbicides. There are fewer new herbicides being released and many of the herbicides that farmers now depend on are being removed from the market. This is happening because the herbicide is either failing the new environmental standards or the cost of re registration is higher than the market can justify. This can have a dramatic impact on a farmer's ability to control weeds. The parsnip industry in the UK is a good example. The parsnip grower only had 6 herbicide options for weed control, but in 2008 they lost 4 of those. Australian farmers must realise that the herbicide options they have today may not be available to them in the future, not just because they have weeds resistant to them.

The number of new herbicide registrations has declined over the past 15 years. In 1990 250 patent applications were filed but this number dropped to less than 70 in 2003. This has occurred for a number of reasons. Industry consolidation has reduced the number of companies conducting research from 35 in 1985 to 11 in 2005. It is likely that there are fewer research laboratories and personnel looking for new herbicides.

The high cost of getting an herbicide to the market is also impacting research. In 1995 it cost around $152 million to get an herbicide from discovery to the market. In 2000 that figure had risen to $184 million and today it would be well over $200 million. It takes on average 10 years to bring a new herbicide to the market and the developer has between 7 and 9 years of patent protection to recover their investment.

With the general low profitability of farming and the high efficiency and relatively low cost of herbicides already on the market it is not surprising that companies are cautious about spending large sums of money on trying to find new herbicides. Most of the major players make no secret of the fact that they are concentrating on the main world crops like corn, cereals and rice.

The introduction of HTGM crops has also impacted on the development of new herbicides. Companies have limited research and development budgets and many choose to split that budget between development of herbicides and research into biotechnology. The growing of HTGM crops also impacts the market for selective herbicides. The soybean industry in the USA is a good example. In 1997 the year Roundup Ready soybeans were introduced, the market for selective herbicides was around $1.5 billon. By 2005 this had dropped to under $300 million. It is not hard to see that companies are not very interested in developing new selective herbicides for a market that has dropped by 80% in less than 10 years.

Despite the difficulties, herbicide manufacturers are spending large sums of money in the search for new herbicides. They are all keen to find new MOA's, which is a difficult task. The last discovery of a new MOA was in 1991. The search for new herbicides also has a set of conflicting criteria. On the one hand it is very desirable for a new herbicide to have a low impact on the environment, i.e. low rates, short residual, low toxicity, low water solubility and easily broken down by the soil. On the other hand it is desirable for an herbicide to have persistence, soil mobility and be highly toxic to weeds. Despite the difficulties and expense,

herbicide manufacturers are still searching for new compounds, new modes of action and new knockdown herbicides. They will find them but the timeline will be long and uncertain.

Herbicide tolerant genetically modified crops

Roundup and Roundup Ready genetically modified crops

Glyphosate is the only group M herbicide, discovered by Monsanto in the early 1970's and marketed by them as Roundup. It is a non selective broad spectrum that works by blocking the pathway of shikimate, which is used by the plant to make amino acids.

Glyphosate is a particularly effective herbicide because most plants metabolically degrade it very slowly or not at all. Its relatively slow mode of action allows it to move throughout the plant before symptoms occur.

It is also a very safe herbicide with a reported acute oral LD50 > 5000mg/Kg in rats. This is because animals do not have a shikimate pathway.

Glyphosate is a very popular herbicide in Australia mostly used in southern winter cropping agriculture as a knockdown herbicide killing all plants that emerge before planting. It has been one of the main reasons that farmers have been able to take up no-till farming systems and even move towards zero till.

In 1996 Monsanto released to the North American market genetically modified crops that were tolerant to glyphosate marketed as Roundup Ready (RR). For the first time farmers could spray a growing crop with glyphosate and not hurt that crop while killing the weeds. RR soybeans and canola was introduced in 1996. RR cotton came in 1997 and corn in 1998. Alfalfa (lucerne) was released in 2005 but is currently under a court imposed moratorium while sugar beets had a release in 2006.

Take up of crops like soybeans, canola and cotton was rapid and in North America today 90% of soybeans, 85% of cotton and 50% of the corn is Roundup Ready.

The take up of all GM crops around the world has been rapid. In 2006 102 million hectares of GM crops were grown (not all herbicide tolerant) an increase of 71% from 2002. There are 22 countries that grow GM crops with the largest being USA, Argentina, Brazil, Canada, China and India. Globally RR crops account for almost 95% of the herbicide tolerant genetically modified (HTGM) crops grown.

The reason that HTGM crops have become so popular is because they have lots of positives such as

- Simple and effective weed control
- Perceived to be easy to manage
- Have allowed an easy uptake of no-till cropping and take advantage of what is has to offer
- Higher end profits (but not always)

But no technology is 100% positive and there have been issues

- Weed shifts
- weeds developing resistance to glyphosate
- Gene flow in species and between species
- Requires a strong degree of management to deal with issues like herbicide drift and volunteer weeds in following crops

The Liberty Link system

Bayer has its own HTGM system called Liberty Link based around the herbicide glufosinate. It is the only group N herbicide and marketed as Basta or Liberty. The system has not been as popular as Monsanto's but it's becoming more popular with Canadian canola growers. Growers in the U.S. feel that in soybeans and corn the varieties available aren't good enough and that the herbicide isn't as effective.

Monsanto announced in April of 2008 that from 2010 (subject to approval) that they will be adding the glufosinate tolerance gene to their corn varieties in what they call Smart Stax.

These varieties will be tolerant to glyphosate and glufosinate as well as having the Bt genes for both above and below ground insect control.

I won't be looking at the Liberty Link system at depth in this report. At this point in time glufosinate has a very limited use as a HTGM technology in southern Australian farming systems. Glufosinate need daytime temperatures to be above 18 degrees Celsius at application and ideally for several days before and after. When Australian farmers would need to be applying the product on growing crops the temperature is rarely that high. It is also an herbicide that is not as effective on grass weeds. Most Canadian farmers that use glufosinate tank mix clethodim (a group A commonly known as Select) to help control their grasses.

Positives of HTGM crops

There is no doubt that growers of HTGM crops have found that their weed management has been easier and more effective. Cotton, canola, soybean and sugar beet crops in North America before the introduction of RR technology all had weeds that were difficult to control with existing herbicides. Most of the options were expensive and many didn't do a very effective job, while some of the herbicides actually harmed the crop. Glyphosate on the other hand, is very effective at killing most weeds and if used properly does no harm to the HTGM crop. Management is made easier because growers can now just plant and spray. If the season is late or difficult growers know that they can get away without a knockdown because they will have effective and reasonably cheap in crop weed control.

The Canadian Canola Council surveyed growers in 2001 about their opinions to HTGM crops. Over 80% said that weed control was more effective and 59% indicated that HTGM canola helped them to manage or delay herbicide resistance. Another reason for growing HTGM given was that growers could use the technology to clean up weedy paddocks, especially broadleaf problems.

The take up of HTGM has been matched with a huge take up in reduced tillage and no-till systems. Now that growers had effective weed control many felt they no longer needed to cultivate. This has meant a massive reduction in the consumption of fuel. The Canadian Canola council estimates that Canadian growers are saving 31.2 million litre of diesel a year by reduced tillage. A study conducted in Europe in 2004 looking at the sugar beet industry

concluded that energy requirements would be cut by 50% by growing HTGM sugar beet. This study looked at herbicide manufacturing, transport and field operations.

The adoption of HTGM crops has also seen a massive drop in the amounts of more toxic herbicides being put into the environment. Critics often refer to the amount of herbicide used and cite that more herbicide is being used. This can be true because glyphosate is not a low volume herbicide. They are ignoring the fact that glyphosate is replacing many herbicides that are far more toxic to both humans and the environment even if they are used in smaller amounts. Depending on the crop there can be dramatic reductions in herbicide use. In 2001 a review of the American soybean industry concluded that growers had replaced 3.27million kilograms of other herbicides with 2.45 million kilograms of glyphosate a saving of over 800 thousand kilograms.

Canola, soybean and cotton growers all have said that they are making more money by growing HTGM crops. Research seems to back them up as we will see when we look at each individual crop.

The Negatives of HTGM crops

Weed shift is not something unique to HTGM crops. Weed shift is when the species of weeds in the paddock changes. Every time farmers change their management system weed shift occurs. . Weeds respond to the changes in the new system and the ones that the system suits the most then dominate.
Farmers have seen weed shift when they changed from cultivation to no-till systems.

Growing a HTGM crop once every three or four years shouldn't have a big impact on weed spectrums. This is certainly the case in Canada where both growers and agronomists I spoke to hadn't perceived a change.

When HTGM crops are grown continuously there is definitely weed shift occurring with an increase in perennial weeds and weeds with a natural tolerance to glyphosate.

I was fortunate enough to visit a long term trial conducted by Kansas State University at Colby Kansas. This is a trial that has been running for 12 years looking at weed shift with RR crops. The trial has been replicated at 4 other sites across Nebraska, Wyoming and Colorado.

At Colby they have grown either continuous RR corn or a rotation of RR corn and RR soy. It is all no-till and no pre-emergent herbicides except glyphosate have been used. Both rotations have received four different herbicide treatments

- Full rate of glyphosate
- Half rate of glyphosate
- Conventional in crop herbicides
- Alternate of glyphosate one year and conventional herbicides the next

The results are very interesting and show how much management has an effect on weed populations.

Conventional herbicides

The plots were very weedy with lots of grass weeds. The crops were also showing damage from the herbicides.

Full rate of Glyphosate

These plots were the cleanest for weeds especially in the more competitive corn. There was an increase of perennial weeds like Kochia (Kochia sp.), Russian thistle (Salsola iberica) and Mares tail (Equiseteum arvense). Glyphosate resistant weeds have not yet happened despite the only weed control being 36 continuous applications of glyphosate. Dr Phil Stahlman who is head of these trials believes that resistant weeds are only two or three years away.

Half rate of glyphosate

These plots had lots of Palmer Amaranth (Amaranthus palmeri) starting to take over as well as the species mentioned in the full rate trial above. It was interesting to note that after six years yield had dropped dramatically because of weed competition. The yields for the continuous corn trial were over 40% lower in the half rate compared to the full rate trial.

Alternating glyphosate and conventional herbicides

These trials results were very similar to the half rate results.

In all the trials that received glyphosate the weeds had adapted by germinating after the last application of glyphosate. The corn/soybean rotation was also not effective because in the 20 inch rainfall site it is probably too dry for soybeans and so they don't compete with weeds very well.

This trial really shows that when you only use one herbicide (glyphosate) and one management technique (in crop herbicides), weed shift and resistance are inevitable. It also shows that weeds that have a natural tolerance to glyphosate like mares tail have an advantage. Farmers in Australia have already seen this with no-till and using glyphosate for a knockdown, with weeds like marshmallow (Malva parviflora) becoming more prevalent.

Weed resistance to glyphosate has happened because of an over reliance on just using glyphosate for weed control. When we look at the American experience of growing HTGM crops we will see how this has happened.

Gene flow in a species is an issue with crops like canola and corn. It is not something unique to HTGM crops as pollen has been moving genes within species since time began. It is something that the North Americans have done little to manage and therefore most of the canola and corn has some degree of contamination.

Research has been done by several studies into how far pollen carries genetic material. One conducted here in Australia by the CSIRO looked at pollen flow from imidazoline (group B non GM) tolerant (IT) canola to conventional canola. A total of 63 paddocks from South Australia, Victoria and NSW were surveyed, with samples taken in conventional canola 0-5 km away from the IT canola. Large samples of seed were collected at 3 sites in each paddock, the edge closest to the IT, the middle and the far edge. The results found that 69% of the sites had no IT genes and the remainder had less than 0.25%. This was lower than some overseas studies possibly because of our drier weather making pollen less viable and less bees.

The European Union, which is possibly the most difficult market for GM products, has accepted a tolerance level of 0.9%. Studies in the US have shown this to be workable using

buffers. The width of those buffers is controversial, with politics confusing the science. Those who would like to see a tolerance set at zero have unrealistic expectations about the ability to totally eliminate pollen movement and need to remember that the crops they grow are also contaminating their neighbours. This could become an issue if highly specialist GM crops (for medical or industrial purposes) are grown that need to be kept pure.

Gene shift between species is much less of a problem. The Canadians tried to cross HT canola with weeds like wild mustard and wild radish in both field and green house experiments. Hybrids between the crop and weed were extremely rare and the hybrid had poor vigour and was often sterile. It appears that the herbicide tolerance gene is not very inheritable with only 50% of the first generation inheriting the trait. After four generations it was under 1%. The myth that Canada is overrun with a super weed of herbicide resistant wild mustard is just that – a myth.

Gene flow does raise the issue about what plants should be HTGM. As genetic technology advances and traits such as drought tolerance, frost tolerance and nitrogen efficiency are developed thought should be given to whether those plants should be herbicide tolerant as well. A gene that gives a plant a fitness advantage could give that plant a competitive edge in the wild. If it is herbicide tolerant to one or more herbicides it could make it a difficult plant to manage. This doesn't mean that we shouldn't develop or use those traits, it just means we need to think through carefully how we use them.

HTGM crops are not plant, spray and forget. They still require a high degree of management and farmers need to be aware of issues such as herbicide drift, record keeping and volunteers as weeds. None of these issues are major but, if ignored, they can turn into disasters if not managed properly.

Growers need to be aware of herbicide drift. Even though farmers have been applying glyphosate for a long time it is usually at planting as a knockdown. With RR crops they are applying it during the growing season when spray drift can be quite damaging. If applied properly when conditions are right it shouldn't be an issue.

Record keeping is an imperative. Everyone involved with the management and care of a HTGM crop needs to know which crops are HTGM and which are not. This is not just for

segregation at harvest but growers need to remember that non RR crops are just as susceptible to glyphosate as weeds are. In the early days of RR crops in North America more than one crop was wiped out with the wrong herbicide.

It is also important to have long term records so that growers are prepared to deal with volunteers as weeds in following crops. Farmers need to remember to add an extra product to their knockdown such as 2,4-D, bromoxinal, Oxyfluorfen or a group B. Better still, use a different herbicide group to glyphosate for their knockdown.

A Canadian study looked at the persistence of volunteers and found that most germinated in the first year after the HTGM crop. If the growers are using no-till, there were no volunteers germinating in the third crop grown after the HTGM crop. If the farmers are aware of the issue it's easy to deal with.

The North American Experience

The Canadian experience

Over 95% of canola grown in western Canada is herbicide tolerant to glyphosate, glufosinate or imidazolinone. It is giving them effective weed control and higher profits. Take up was rapid and within five years of introduction over 80% was HTGM. Growers like the technology because of easier management and better control of weeds like mustard (Sinapis arvesis) stinkweed (Thlaspi arvense) cleavers (Galium aparine) and storks bill (Erodium cicutarium). All of these had been difficult and expensive to control in conventional canola.

Most growers use canola as part of a rotation with wheat, barley and sometimes peas. The standard recommendation from agronomists is to grow canola only once every four years. Some growers have been growing it more often but are running into issues with disease and insect pests.

Canada is a good example of how growing HTGM crops has encouraged the uptake of no-till. Timeliness is important because of a short growing season, the combination of no-till and HTGM crops have allowed farmers to plant earlier. They now no longer need to wait for

weeds to germinate before planting. Farmers can plant confident of good control of weeds in crop.

Weeds developing resistance to glyphosate has not been an issue yet. Most Canadian farmers practice good integrated weed management even though the tactics they are using often aren't specifically aimed at weed control. Farmers are using vigorous varieties and high seeding rates in both canola and cereals. Recommended rates for canola are 5-6 Kg/ha and for cereals 120Kg/ha. Nearly all of the canola varieties grown are hybrids. Growers like them because of their vigour and yields up to 30% higher than open pollinated varieties.

A lot has been said by some critics of GM about the amount of hybrids grown in Canada and the fact that you can't keep seed from them. The facts are growers have a choice and they are choosing hybrids because they get better weed control because of the better seedling vigour and the higher yields put more money in their pockets. In 2008 there were eight seed companies offering a total of thirty varieties of Roundup Ready canola so growers do have choice.

Liberty Link canola is also popular with farmers with it planted on 40% of canola acres in 2006. They have good varieties and growers like to rotate the technologies because some are concerned that they may be using too much glyphosate.

Farmers are making higher profits from HTGM canola. Agriculture and Agri-food Canada conducted a three year trial beginning in 2001 looking at profitability and how effective weed management was with different herbicide regimes.

Effect of in-crop herbicide treatments on weed biomass and net returns in canola.

Herbicide	**Weed biomass (kg/ha)**	**Net return ($/ha)**
Glyphosate x 1	296	**$354**
Glyphosate x 2	136	$321
Ethalfluralin (E)*	1393	$286
Sethoxydim (S) + Ethametsulfuron (Eth)	1182	$245
E + S + Eth + Clopyralid	410	$165

*Ethalfluralin was applied to the soil surface in the fall. Adapted from O'Donovan et al. (2006)

The trial was conducted in three locations, Beaver Lodge, Lacombe and Lethbridge and the results were quite significant.As you can see the non glyphosate treatments had more weeds and returned less dollars a hectare. It is not surprising that farmers have embraced HTGM canola.

Eastern Canada uses HTGM soybeans and corn. Around 65% of soybeans are HTGM and 40% of corn. They are usually grown in a rotation that includes winter wheat. Few growers practice no- till because low soil moisture is rarely an issue.

Just as in western Canada growers like the technology because of better weed management and higher profits. They too have not had issues with weeds developing resistance to glyphosate. The fact that growers have at least three crops in the rotation, that they rotate herbicides and that they are still cultivating, is keeping them from problems.

The American experience

Soybeans, corn & cotton

The United States of America grew 54.6 million hectares of genetically modified crops in 2006. Not all of those crops were herbicide resistant but the vast majority were. The big three crops of soybeans, corn and cotton make up a very high proportion of the total area.

Many farmers in the Midwest states of the U.S. grow a continuous rotation of just corn and soybeans. This is usually corn- soy- corn- soy but in recent years some growers are extending the rotation to Soy - corn –corn because of the record prices of corn. There is a mix of tillage systems with the wetter states like Iowa and Illinois tending towards cultivation while drier areas like eastern Kansas and Nebraska tend to no-till systems.

U.S. growers took up Roundup Ready (RR) soybeans very quickly. Within three years of introduction 95% of soybeans grown were HTGM. There were several reasons why growers embraced the technology so quickly. Weed control in soybeans had been difficult with the only options either a group B herbicide or a group G. Growers didn't like the group G herbicide because it can damage the crop and so were using group B's on approximately 80% of the crop. Water hemp (Amaranthus rudis) is a native North American plant that was

regarded as a minor weed before it developed resistance to the group B's. Before RR weed control in soybeans was not satisfactory and growers were resorting to hand chipping of weeds. When RR soybeans became available growers took it up because weed control was good and management seemed easy.

Farmers in the U.S. seem to have a love/hate relationship with companies like Monsanto. They love the RR technology but don't particularly like paying the higher seed costs. One of the consequences has been a reduction in seeding rates by between 20–30%. Soybeans are a crop whose yields are not affected by seeding rate but a lower rate means that the crop is less competitive against weeds.

When RR soybeans were released the seed companies claimed the yields matched conventional varieties. Growers dispute that, but still embraced the technology because of the advantages. Today the GM varieties are better and that is where most of the research money is going because GM has such a large share of the seed market. Approximately 5% of the market is conventional varieties for human consumption. As in Canada, they are receiving a premium and segregation isn't an issue. Even with the higher seed costs growers admit they are making higher profits growing GM and don't want to go back to conventional varieties.

RR corn was introduced in 1998 but the take up was slow. The early varieties didn't perform as well as conventional varieties and growers had plenty of effective herbicide options. As late as 2005 RR corn was only 20% of the market. That changed when Monsanto introduced the Bt gene for control of rootworm. Rootworm had been a big problem in places like Iowa and they were difficult to control. The only way growers could get seed with the new Bt gene was Roundup Ready. Now that they were paying for the RR technology whether they used it or not most decided to use glyphosate for their weed control. By using RR corn it also took away issues with drift from the RR soybeans.

This has led to a situation where a grower can just use glyphosate for weed control because they are growing a RR crop every year. The U.S. growers don't seem to like the Liberty Link system and so there is no rotation of herbicides.

"Roundup Ready technology made ordinary farmers into good farmers.....but only for a while"

Phil Stahlman Weed scientist Kansas State University

Going to a total RR system in the corn-soybean rotation has, I believe, made farmers lazy with many just using glyphosate for weed control. When they started growing RR crops it was easy to just go out with glyphosate and the weed kill and profits were good. Many are trying to cut costs by cutting rates or delaying the in crop application of glyphosate as late as they can so that they only need one application. This is putting a lot of pressure on the herbicide to kill some very large weeds, some that have a natural tolerance to glyphosate. I feel that this is also false economy as what they save in herbicide they have lost in nutrient removal by the weeds. Where cultivation is the norm, because it is a form of non herbicide weed control they are currently staying on top of glyphosate resistant weeds. Even so there is an increasing incidence of fields with weeds like water hemp, giant ragweed (Ambrosia trifida) and horse weed (Conyza canadensis) becoming problems.

The better farmers are still using pre-emergent herbicides and are very aware about applying glyphosate in ideal application conditions and not cutting herbicide rates. Weeds scientists I spoke to believe that glyphosate resistance will explode in the next 5 years in the corn- soy rotation. With current practices farmers are removing susceptible weed populations by using glyphosate several times every year.

RR cotton was introduced to the U.S. market in 1997 and was taken up quite rapidly to where it is currently 85% of the area grown. The amount of RR cotton varies from region to region. In California less than 60% is RR while in the southern states like Georgia, Florida, Mississippi, Louisiana and Missouri RR accounts for 98-100% of cotton planted.

Before RR cotton, growers' typical weed management involved a pre-plant tillage, 3-5 herbicides applied at least 3 times during the cropping season and 2 in crop cultivations between the rows. When they went to RR this changed to one application of glyphosate before planting, and then 4 applications of glyphosate in crop. They no longer needed to cultivate so the majority became no-till farmers and today approximately 100million hectares are no-till

RR cotton. A survey of fields in Georgia in 1999 shows why no-till RR cotton became so popular.

Technology	Tillage	Yield (lbs/acre)	Revenue @ 0.65 $/lb ($/acre)	Variable Costs	Returns above Variable Costs ($/acre)
Bt	conv	656	426.4	202.63	223.77
BtRR	strip	1185	770.25	224	546.25

When it comes to weeds, cotton is a poor competitor and needs 8 weeks of weed free growth following planting to make maximum yields. One of the biggest problem weeds for the southern states is Palmer Amaranth (Amaranthus palmeri). It is a weed that has vigorous growth and the ability to set seed. Before the advent of RR cotton, growers had palmer amaranth already resistant to group B's and atrazine. Up to 10 years of continuous cotton with the only weed control being up to five applications of glyphosate a year has, not surprisingly, led to problems.

Glyphosate-Resistant Palmer Amaranth in cotton Hoke County North Carolina. Photo courtesy Cotton Incorporated.

It's believed in the state of Georgia that there is somewhere between one hundred thousand and one million hectares of cotton country with some level of glyphosate resistant palmer amaranth. In the next couple of years this is expected to rise to 30% of the total cotton area.

Even though they are having problems, growers are still using glyphosate on fields with resistant weeds because they are paying the tech fee.

This situation is as close as agriculture has come to the feared "super weed" that opponents of GM technology rail about. It is probable that somewhere in the U.S. a field has palmer amaranth that is resistant to group B's, atrazine and glyphosate. This has NOT occurred from gene shift but from very bad management on the part of the U.S. cotton industry. A field in that situation has very limited herbicide options. They do have a group G herbicide but how long can one herbicide last when it's the only option?

It is expected that new HTGM technologies won't be available till 2014 so major changes will have to be made in how cotton is grown. Growers are going to have to return to tillage, cover crops and rotations with other crops. One could easily argue that they should have been doing that all along. It is expected that growers will spend an extra $400 million a year in extra herbicide trying to deal with the situation they are in.

The reasons for failure

Why is it that a technology that is so successful in Canada has developed or is developing so many issues in their neighbour, the U.S.A? Opponents of GM are quick to say the technology is inherently flawed and doomed to failure but if that was the case Canada would be having just as many problems. At the end of the day the technology has not failed. What has failed has been the management of the technology and just plain out bad farming practices.

The lack of rotation of herbicide groups and crops together with a general lack of non herbicide methods has come together in creating a glyphosate resistant weed problem. The bad farmers reaped the rewards for awhile but now there is a price to pay.

"Tell the farmers of Australia to rotate their crops and their herbicides"

Herb Mattson Farmer Colby Kansas

Growing HTGM crops doesn't automatically give you glyphosate resistant weeds. What management strategies growers adopt will determine if and when they get resistance. The U.S.

cotton industry is a good example. They have now made the same mistakes three times, first with atrazine then group B's and now glyphosate.

Part of the reason of the poor management of HTGM crops in the U.S.A. lies at the feet of the Farm Bill and its programs. Corn, soybeans and cotton are three of the big five crops that receive the bulk of the government assistance. The U.S. national research council looked at the effect of farm programs and it found that they have an enormous influence on the way farmers manage their farms. It also found that the commodity programs promoted specialisation in one or two crops and penalised those farmers who adopted rotations. It felt that farmers often are more responsive to subtle economic effects from the programs than the biological and physical constraints on their farms. I contend that some (not all) of the farmers in America are farming the government programs and therefore making bad agronomic decisions that are creating issues like glyphosate resistant weeds.

Criticism also needs to be levelled at Monsanto. Insisting that the Bt gene for rootworm in corn be only available with Roundup Ready was, I feel, a short sighted decision that in the longer term will compromise the technology. I realise that developing GM technologies is a very expensive process and companies need to recoup their expenses and make a profit. When Monsanto insist on putting all their technologies in the one plant they are shortening the life of all the technologies and in the long run cutting their profits. As Monsanto is no longer conducting research into new herbicides where do they go as a company if and when most of the soybean, corn and cotton acreage in the United States is covered in glyphosate resistant weeds?

Despite the fact that glyphosate resistance has happened, at this point of time it is on a relatively small percentage of the area planted to HTGM crops. The better farmers who are not relying on glyphosate to do all the work of killing weeds are not having issues. They are using other herbicides as well as cultivation and crop rotation to manage their weeds. Even so there is a strong possibility that the area with glyphosate resistant weeds could increase both dramatically and quite quickly.

The mistakes of America are the lessons for Australia. HTGM crops need to be part of a much wider integrated weed management system and does not replace it.

Other pressures on glyphosate

HTGM crops aren't the only cropping systems that are placing pressure on glyphosate and having weeds resistant to glyphosate. Australia has the dubious distinction of being the first country in the world to develop resistance to glyphosate in a cropping system. This occurred on the Liverpool plains in Northern NSW with ryegrass and barnyard grass.

A number of factors led to resistance developing. The region receives 60 % of its annual rain in the summer so growers can grow either summer or winter crops. They are almost exclusively no-till and relied on glyphosate to control weeds in their fallow period. They didn't use residual soil herbicides because they want to be able to opportunity crop and not be limited by residues.

Barnyard grass is a fast growing grass that can set seed in three weeks from emergence. This has often forced growers to apply glyphosate when conditions are less than ideal. Dust and heat can often reduce the effectiveness of the glyphosate applied. Again we see the dependence on just one herbicide leading to problems.

Australia is not alone in using lots of glyphosate for weed control in no till fallows. Low rainfall in the high plains of western Kansas and eastern Colorado means that farmers often only grow two crops in three years. They are also no-till farmers and they use fallows to store up moisture. Up to five applications of glyphosate can be used and it is often at the same timing as if it had been in crop with a HTGM. Problems have not yet developed but there are concerns weeds like Kochia are very close to developing resistance.

Local governments and landowners like railways are also not very creative when it comes to weed management. Many tend to use glyphosate continuously without rotating herbicide groups or considering non herbicide options.

European experiences

New European Pesticide legislation

Europe has always been at the forefront in the regulation of pesticides and this continues. Currently Europe uses a risk based system for approving pesticides that has seen a large number of pesticides removed from the market. The current legislation was introduced in 1991 and required all pesticides to be reregistered. This has meant that the number of available compounds available to farmers has dropped from around 1000 to 350. There have been two reasons for the drop. Either the pesticide, like trifluralin and the triazines, has failed the registration process or manufacturers decided that the cost of re-registration was too high for the amount of product sold.

The European Union is currently debating new legislation for the regulation of pesticides. The new system will move from a risk based system to a hazard based system. The current proposals will ban any pesticide product that is carcinogenic, mutagenic, an endocrine disrupter or that fails certain soil persistence criteria. There are several different proposals being discussed, but if the European parliament's proposals are adopted it will mean that farmers in the UK will lose 85% of the current pesticides available to them. In a study conducted in the UK by the Pesticide Safety Directorate it found that if the parliamentary proposals are put in place, it will have a massive effect on crop production with a possibility of dramatic yield decreases. It found that UK farmers would have no knockdown or pre-emergent herbicides. They would only have group A's for grass weed control and fluroxypyr (group I) for broadleaf weed in cereals. In canola they would only have clomazone (group F) for broadleaves. The story is the same for other crops like potatoes, sugar beet, parsnips and carrots. They will have only very limited herbicide options. It also means no insecticides or fungicides. Even organic farmers will be affected with products like copper and rotenone being removed from the market as well.

The ironic part of this review is that it is only for pesticides. They are also reviewing industrial chemicals but keeping them on a risk based system. Products in food like food colouring and

preservatives aren't being reviewed. A product like alcohol if sprayed on a crop would be banned because it is probably carcinogenic, mutagenic, and reproductively toxic and may also be an endocrine disrupter. Yet because it's not a pesticide but a foodstuff there is no issue.

The changes are being pushed by green groups who would like to see a reduction in the amount of herbicides in the environment. It is supported by the European civil service who believe that the changes will force pesticide manufactures into developing new safer products.

The decision about how far the Europeans will go with their regulations will be decided late in 2008 or 2009. It is unlikely that the final form of legislation will be as far reaching as the parliamentary proposals. What it does seem is that they will have a hazard based system from 2010. I believe the Europeans have some difficult decisions to make. They admirably want to reduce the amount of herbicides in their environment. They also don't at this point in time want to use HTGM technology. Their consumers want cheap quality food in an increasingly hungry world. It will be interesting to see what choices they make.

These proposed changes send a warning signal to Australian farmers. We are often complacent about legislation that affects how we farm. While it is unlikely that we will see changes as dramatic as Europe is proposing in Australia any time soon, it is a reminder that a stroke of a pen can have dramatic effects on how we farm. We need to remember that the herbicides we rely on today will not always be available to us in the future.

Low herbicide use and organics in Denmark

Denmark has been a country at the forefront in actively reducing the amount of pesticides used by their farmers. Farmers in Denmark have a far smaller range of herbicides available to them than farmers in Australia. Products like Sprayseed, simazine, atrazine trifluralin, diuron and 2,4-D have been removed from the market. This has forced farmers to change how they manage and deal with their weeds.

Many farmers I spoke to feel that the regulations have made Danish farmers better, smarter and more efficient than their European counterparts. At the same time farmers feel frustrated as the government keeps shifting the goal posts, raising standards before the previous targets have been achieved.

In Denmark farmers have adapted to lower herbicide use by being very efficient with the herbicides they do have. Rates have commonly been cut by half and more as farmers have developed strategies to minimise their use. Many of the farmers I spoke with made the comment that how you apply an herbicide is more important than rate. Air assisted sprayers, low drift nozzles, high water rates are all regularly used as well as trying to spray when conditions are ideal.

Other non herbicide strategies have also helped with weed management. Cultivation has always been part of farming in Denmark and this is still standard practice. Many farmers use mouldboard ploughs and will turn the soil over to a depth of 25-30 cm, often immediately after harvest. In Eastern Denmark, on the island of Sjælland the topsoil is a deep black glacial loam or clay which allows the farmers to plough as deep as they like. They then will cultivate again with a Horsch type system to produce a seedbed. This is a cultivation train with offset discs, levellers, tines harrows and press wheels popular in Western Europe.

Horsch tillage system Slagelse Sjælland Denmark

There are also farmers moving towards a minimum till system which removes the mouldboard from the system and uses just the Horsch style system. They cultivate no more than 10 cm deep and will often cultivate only 3 or 4 cm deep to encourage a germination of weeds that they then kill with glyphosate before seeding. Trials have been conducted at the University of

Aarhus research facility at Flakkebjorg, looking at tillage systems. They have shown almost no difference in yield or weed populations between a full tillage system using the mouldboard and the minimum tillage system. They did find that in the direct drilling (cultivation at seeding only) trials, that while yields are the same, there was an increase in grass weeds.

Herbicide resistance has not been a big problem in Denmark. Cultivation has been part of the solution but so has good rotations with a wide variety of sowing dates. A common rotation is oilseed rape, winter wheat, spring barley, winter wheat and spring barley again. The wheat is planted in September and the spring barley in April. They tend to alternate their herbicides from pre-emergent to in crop herbicides. They also use high seeding rates with 180kg a hectare in cereals the standard rate.

All of this has meant that weed management in conventional farming systems is still manageable despite the restrictions. It may not be easy but farmers are adapting to low pesticide regulations while still maintaining yields and keeping on top of their weeds.

Organics is also a small but important part of Danish agriculture. The government encourages organic agriculture with generous subsidies and the farmers I visited seemed to be managing their weed issues well.

Like conventional farmers cultivation and rotation are the two main management tools that are used to control weeds. Organic farmers grow oilseed rape, wheat and barley too, but add crops such as white clover, red clover, grass seed's, sweet corn, peas and oats. They also grow green manure crops like mustard which is ploughed under with the mouldboard before it sets seed. The clovers are cut or grazed several times a year to remove the grass weeds.

Danish organic farmers try and grow more competitive varieties and use higher seeding rates than conventional farmers. Seeding rates in organic oilseed rape are 8-10kg/ha (3-5kg/ha conventional) and in cereals 200kg/ha or more. They also use seeders that spread the seed over the whole area and not in rows to out compete the weeds. Part of the reason for higher seeding rates is that most organic farmers use a heavy harrow for early weed control which also gives some crop mortality. Ideally farmers harrow cereal crops several times. The first will be just before the crop emerges and then again either before the two leaf stage or waiting till the crop

is stronger after the 3 leaf stage. This technique may have possibilities for Australian farmers as it is a relatively low cost and quick operation.

The amount of cultivation depends on what crop the farmer is growing. With winter crops some will try and delay seeding to gain an extra cultivation. This can be a difficult balancing act as the later seeding can cost yield. Spring crops like peas and barley have a short lifespan which allows the farmer to have long fallows, sometimes as long as nine or ten months. The fallows are cultivated with a variety of tillage equipment including mouldboard ploughs, blade ploughs and the Horsch style ploughs.

Organic farmers growing high value crops like sweet corn and other vegetables use techniques like gas powered flame throwers or inter row cultivation. There is a variety of machines available that use tines, brushes stars or rotary hoes for cultivating between the rows. Most of these machines are expensive and cover only a few hectares an hour.

Organic agriculture has its own challenges to face. Perennial, deep rooted weeds like thistles aren't easily controlled with cultivation or rotation. Yields are usually lower than conventional farmers and organics can use large amounts of energy creating greenhouse gas emissions. This is expensive and runs contrary to organic principles of long term environmental sustainability. Despite this, organic techniques such as extended and more diverse rotations, green manures and heavy harrows could have a place in conventional Australian farming systems.

Recommendations of growing HTGM crops in southern Australian farming systems

The first question that should be answered is whether growing HTGM canola is something that Australian farmers should be doing. If we look to the Canadian experience the answer in my opinion is yes. I believe that growers will get better yields from RR canola than they do from the triazine tolerant varieties that most grow now. I also believe that weed control will be better and profits higher even with increased seed cost and technology fees. The big advantage as I see it will be in years when we have late and difficult starts. Farmers will be able to plant their canola dry confident that they will be able to get good weed control in crop.

Monsanto and the regulators are to be commended for putting into place a code of conduct. This should remain in place as it has with the Australian cotton industry. RR cotton has been grown in Australia since 2001 with no issues of glyphosate resistant weeds. They have a resistance management plan whose fundamental core is that farmers must go through their paddocks after application of glyphosate and control any resistant weeds. Currently canola growers need to be accredited by completing a course that looks at issues such as paddock selection & crop management, co-existence, herbicide resistance management, and segregation management. I feel that this stewardship program needs to remain in place indefinitely with growers being reaccredited every 5 years.

Australian growers will need to be proactive in the management of HTGM crops and especially RR canola. These are the recommendations that I feel are needed to try and prevent weeds developing resistance to glyphosate.

- use a pre-emergent herbicide and not totally rely on glyphosate
- grow hybrid varieties with good seedling vigour to give weeds strong competition
- Spray when conditions are good and when weeds aren't stressed
- Budget to apply glyphosate twice in crop. It is better to kill the weeds when they are small and come back with a second application if needed
- Check the quality of the water they are using to spray with. If it's not up to scratch add products like Liase to get better weed kills
- Grow canola only once every 3 or 4 years on an individual paddock. The more diverse the rotation and the less in crop applications of glyphosate should extend its life. Monsanto should make this part of the agreement to grow RR canola and if they won't the regulators should make it part of the registration.
- Monitor their paddocks after application and be prepared to use another herbicide if results are not up to scratch.

- Rotate their knockdown herbicides and be aware of volunteers

- Use non herbicide methods of weed control like increased seeding rates in the following cereals or burning everything that passes through the header either with a chaff cart or in the row

- Not expect it to solve their herbicide resistance problems in one year. If the weed seed bank is high one year of HTGM crops won't reduce it to zero. They should possibly look at making silage or brown manuring a problem paddock the year before RR canola

- Consider occasional cultivation

Australian farmers will need to overcome the urge to sit back and relax about weed management because they have HTGM technology. If they use it as part of a wider IWM strategy there is potential to drive down weed numbers to very low levels. The smaller the number of weeds means a lower chance of resistance developing.

Australia has benefited from the uptake in no-till farming systems. Soil erosion has been reduced, soil carbon levels increased and crops are using water more efficiently. A report recently released by the Australian Farm Institute looked at the value of environmental services provided by Australian farmers. It concluded that reduced tillage techniques in northern NSW between the 1970's and 2002 had an environmental value of $1.2 billion. The introduction of glyphosate has enabled farmers to adapt to their environment and farm in a way that suits the Australian climate. If there were widespread glyphosate resistant weeds it would limit farmer's ability to continue to no-till.

At the end of the day it is in everyone's interests that we make glyphosate last as long as we can. It has cost herbicide and seed companies lots of money to develop this technology and understandably they want to see profits as quickly as they can. I argue it is also in their interest to make the technology last. If companies won't make a mandatory period between HTGM crops the regulators should. As we have seen in the past growers in Australia have pushed rotations with the consequence of weeds developing resistance quite quickly. With the long drought that we have endured farmers need all the profits they can get and will be tempted to

push the rotation. Glyphosate is too important to the Australian farming system to let that happen. The last thing Australia needs is to return to the days of multiple cultivations and all the issue that went with that. The timeline for a glyphosate alternative is an unknown. We have to assume that there may not be another mode of action developed and that we need to care for the ones we have. We as an industry need to decide how we use HTGM technology. The results, success or failure, depend on the decisions we make.

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John W. Wilcut, Robert L. Nichols, Scott B. Clewis, Jimmy Summerlin, Donnie K. Miller, Andrew Kendig, James M Chandler, David C. Bridges, Barry Brecke, Charles E. Snipes & Steve M. Brown. January 2003

WHERE ARE THE NEW HERBICIDES MODES OF ACTION
Hansjoerg Kraehmer, Arno Schulz, Bernd Laber 2007

Farmers, researchers, Weed scientists, agronomists and consultants with whom I had personal contact

TIM ANDERSON

DR LUCY CARTER

PAUL CHAMBERS

GRAHAM CHARLES

GREG CONDON

MATT CORDINGLEY

ELLEN DANGAARD-BØRSTING

DR IAN DENHOLM

ART DIGGLE

EUGÈNE DRIESSEN

JEANEE FALK

DR HELLEN FERRIER

JESPER HANSEN

DR NEIL K. HARKER

DR BOB HATZLER

JOHN HOLMES

SOREN ILSØE

DEEPAK KAUNDEN

STEVE LAROQUE

PROF. DEDRIE LEMERLE

PROF. JOHN LUCAS

LESLIE MAE

HERB MATSON

DARRYL MERTENS

JIM & DANNELLE MERTENS & FAMILY

TOM & SHIRLEY MERTENS

DAVID MOORE

DR STEPHEN MOSS

ALBERT NUEFELD

DR ROBERT L. NICHOLS

DR JOHN O'DONOVAN

ARDERS OLESEN

DR MIKE OWEN

ROD PIERCE

IAN PIGGOT

DR CHRIS PRESTON

ANNE REES

GLEN RIETHMULLER

ØLE SCHOU

CRAIG SHAW

MARK SPINNEY

DR PHIL STAHLMAN

BEN STANLEY

JOHN & PAT STANLEY

RICK TAILLIEU

CALVIN TREACY & FAMILY

KELLY TURKINGTON

DR HAN WEN WU

MARIA ZAPIOLA