Weed Resistance in RR Crops – An update

October 2011

"Just spraying Roundup was so easy…There is no ease anymore."

Introduction
Weed resistance is now a serious problem for farmers growing glyphosate tolerant Roundup Ready (RR) crops in the US and South America.

Crop management has become more complex, and the cost of weed control is rising. When one weed in RR cotton reaches a particular stage in its growth farmers have to resort to hand weeding. RR crops can also cause problems by coming up as volunteer plants/weeds in other RR crops (eg, RR maize in RR soya).

US farmers find themselves in a weak position because Monsanto has market control over the supply of seeds and herbicide packages used on RR soya, maize and cotton, which means switching to cheaper non-GM crop varieties is not always possible or straightforward. Monsanto is the “dominant firm” and is currently subject to Federal investigations in the US.

Weed resistance to glyphosate is also a problem for the environment and people because the current solution offered by Monsanto is to use extra, and sometimes stronger, applications of glyphosate and, increasingly, glyphosate in mixtures with different herbicides throughout the growing period – from soil applications before the seeds are sown to crop applications at an advanced stage of growth prior to harvest.

Glyphosate resistance in weeds has also developed in non-GM crops and in weeds on non-crop land where glyphosate has been used repeatedly on the same area over a number of years for weed control. However use on RR crops is the main driver behind the rapid escalation in the problem.

In January 2010 GM Freeze published a review of the escalating glyphosate resistance problem for farmers using Monsanto’s Roundup Ready soya, maize and cotton. In June 2011 we published a joint report with Greenpeace International on the full range of glyphosate’s impacts on health and the environment, as well as weed resistance. This briefing provides updates on the ongoing escalation of glyphosate resistance that continues to undermine the credibility and viability of genetically modified herbicide tolerant (GMHT) crops and the methods Monsanto and their rivals hope will deal with the problems created by the over use of Roundup on RR crops.

The development of glyphosate resistant weeds shows no sign of slowing. The pesticides “arms race” continues.

Background
Weed resistance is now a significant agronomic, socio-economic, health and environmental problem in areas where Roundup Ready GMHT crops have been grown over a number of years and where Roundup/glyphosate has been the only, or very dominant, means to control weeds.

The situation is now so serious that some pro-GM crop commentators are urgently calling for action to prevent the loss of glyphosate as a herbicide in GMHT crops. In 2010 two new weed species joined the global list of glyphosate resistance (Blue grass, Poa annua, in Missouri and Australian fingergrass, Choris truncate, in New South Wales), bringing the total to 21. In addition new locations for eight previously confirmed species were found in 2010, and four in 2011 so far.

The glyphosate resistance genes in weeds may have been present in weed genomes before RR crops were introduced in 1996 or may have arisen from mutations since then. The heavy use of...
glyphosate has resulted in the weed biotypes with the resistance genes present being selected for, and the spread has been very rapid in some species.\textsuperscript{v}

The US has the worst problem, with resistance in 13 species confirmed at 73 locations (see Figure 1).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Number of locations (blue) and and weed species (red) with resistance by country (data from International Survey of Herbicide Resistant Weeds, 2011)}
\end{figure}

NB Each location can represent one to thousands of fields.\textsuperscript{vi}

In the early years of RR technology, glyphosate proved effective in controlling troublesome weeds and was therefore attractive to farmers because it made weed control simpler and cheaper. However it was often those same troublesome weeds that first developed resistance to glyphosate.\textsuperscript{vii} For instance:

\begin{itemize}
\item Palmer Amaranth (\textit{Amaranthus palmeri}) in maize cotton and soybeans in the US since 2005. In North Carolina estimates put the number of sites infested at up to one million.

\item Horseweed (\textit{Conyza canadensis}) in cotton, soybeans and maize since 2000 and in soybean in Brazil in 2005. Up to 100,000 sites are infested in Delaware alone.

\item Johnsongrass (\textit{Sorghum halepense}) in soybeans in Argentina since 2005 and the US since 2007. Current estimates are that up to 100,000 acres are infested in Argentina.
\end{itemize}

\textbf{A troublesome weed: Palmer Amaranth}

The first glyphosate resistant Palmer Amaranth in RR cotton was confirmed in Macon County, North Carolina in 2004. By 2010 the problem was out of control, leading Robert Nichols of Cotton Incorporated to say, “\textit{We are facing the exponential expansion of this weed in verified data that has been collected collectively by weed specialists.}”\textsuperscript{viii}
At a seminar in 2010 dealing largely with glyphosate resistance in Palmer Amaranth in cotton, one speaker identified three affects of allowing resistance to go unchecked:

- Increased complexity and cost of weed control in cotton and soya.
- Compromising conservation tillage in the short-term and possibly long-term.
- Possible cascade of resistance of resistance in post emergence broadleaf herbicides.

The same speaker also confirmed that the mechanism for resistance to glyphosate in Palmer Amaranth was different in different locations, suggesting that the problem was not solely one of pollen or seed movement but could spring up spontaneously anywhere glyphosate was overused. It is also possible to find two different weed species with glyphosate resistance in the same field, adding to the complexity of weed control.

Several of the most problematic weeds are already resistant to other herbicides. In the US Horseweed (Conza canadensis) is already resistant to three herbicide modes of action, including glyphosate, in soya fields. In addition glyphosate resistant volunteer plants cause problems in other RR crops (eg, RR maize in RR soya and RR canola in RR sugar beet). The latter problem arose because seeds were transported in the stomachs of migrating geese from Canadian canola (oilseed rape) fields to US sugar beet crops – gene transfer over hundreds of miles.

Glyphosate resistance in weeds is not exclusive to GMHT crops, but there appears to be consensus among weed scientists that its development has been accelerated by the overreliance on glyphosate in RR soybeans, cotton and maize. Duke and Powles note, “Most of the documented cases of evolved GR [glyphosate resistant] weeds in the past 6 years have been in GR crops.”

It is has been acknowledged that resistance is also undermining the use of zero tillage in GM crops, “Because glyphosate is the herbicide most often used in no-till and minimum-till systems, GR [glyphosate resistant] volunteer crop plants and glyphosate-resistant or tolerant weeds will jeopardize the sustainability of those systems”, according to Mallory-Smith and Zapiolo.

The situation in South America is following a similar pattern to that in the US.

Since GM Freeze published its 2010 briefing the sense of the urgency of the need to develop strategies to prevent resistance to glyphosate developing has greatly increased among weed scientists. The following video clips are worth watching to get a sense of how seriously weed scientists, industry and the media are taking this issue in relation to RR cotton.

- Larry Steckel, University of Tennessee
- Robert Nicols, Cotton Incorporated
- Georgia Farm Monitor

Rival companies are also seeking to take market share from Monsanto (see below) by exploiting the resistance problem. Monsanto’s once impregnable position as market leader for GM seeds and herbicides is now under threat, so much so that one investment advisor is citing, “The company’s overdependence on glyphosate and glyphosate tolerance, at a time of increasing need for weed treatment to move away from that molecule,” in its recommendation to sell Monsanto shares.

**Monsanto’s reaction**

Monsanto is taking the problem of the rapid development of glyphosate resistance very seriously, as it represents a threat to their main sources of income. A report on a recent NFU fact-finding visit to the US said, “Companies such as Monsanto have significant concerns over resistance development and actively try and provide education and breeding companies are frequently stacking events to allow different modes of action.”

Monsanto has embarked on major changes in weed management in RR crops, which still includes...
the use of glyphosate on its own, but also in combination with other herbicides. This is increasing herbicide usage on these crops. So instead of the promised decrease in pesticide use on GM crops, the arrival of resistant weeds has resulted in herbicide use increasing on RR crops. Analysis of USDA data has found increases in herbicide use in all the crops where RR maize, cotton and soya beans varieties dominate.\textsuperscript{xoxi, xoi and xiii}

Previous attempts to control resistant weeds by increasing the rate at which glyphosate is applied have proved unsuccessful, yet Monsanto appears to have no intention of taking responsibility for the failure of their technology:

\begin{quote}
\textit{“Growers must be aware of and proactively manage for glyphosate-resistant weeds in planning their weed control program. When a weed is known to be resistant to glyphosate, then a resistant population of that weed is by definition no longer controlled with labelled rates of glyphosate. Roundup agricultural herbicide warranties will not cover the failure to control glyphosate-resistant weed populations.”}\textsuperscript{xxiv}
\end{quote}

The company has published guidance on how to deal with the growing weed resistance problems in RR crops\textsuperscript{xxv} and has already started to develop prevention strategies based on three approaches using different combinations of herbicides and timing of applications:

- **The first method** is the use of tank mixtures of glyphosate and other herbicides (for instance 2,4-D was recommended for marestail\textsuperscript{xxvi}) pre-sowing to “burn down” weeds.

- **The second approach** is to produce GM seeds with several herbicide tolerant genes (gene “stacking”) by crossing GMHT varieties with different tolerant genes so different herbicides can be applied to the growing crop in rotation or in tank mixes to ensure that weeds resistant to glyphosate will be killed by other herbicides. For instance Monsanto has recently announced an agreement with the German pesticide and biotechnology company BASF to develop crops stacked with glyphosate and dicamba tolerant genes.\textsuperscript{xxvi}

- **The third method** is to use herbicides that remain active in the soil (residual herbicides or residuals), which kill seedling weeds as soon as they germinate. Monsanto has secured co-operation with other companies to include their soil residuals in their “weed management platform” and charge farmers more for the privilege. In October 2010 the FMC Corporation agreed to allow their “Authority” herbicides to be used with RR crops as part of Monsanto’s offer to farmers struggling with resistant weeds.\textsuperscript{xxvii} These residual soil-acting herbicides are based on sulfentrazone in combination with other herbicides, depending on the formation. Previous to this Monsanto also announced a link-up with the Valent Corporation’s subsidiary the Sumitomo Chemical Co. Ltd to include flumioxazin-based residual herbicides in the RR soya “platform”\textsuperscript{xxviii} in South America. On the same day Monsanto signed a similar agreement with the Makhteshim Agan Group\textsuperscript{xxix} to use their herbicides. Earlier in 2010 Monsanto received approval to use an Acetochlor based formulation for early emergence weed control in cotton.\textsuperscript{xoxi}

**Rivals step in**

The declining effectiveness and rising costs of RR crop management has opened the door for other biotechnology corporations to challenge Monsanto’s dominance of the US seed and herbicide markets. Recently Dow Chemical Company announced it had applied for approval of a GM soya bean with three stacked herbicide tolerance genes (for glyphosate, glufosinate and 2,4-D) as a rival to RR soya.\textsuperscript{xxvii} Dow hopes this technology, called Enlist, will be approved by 2013, and also aims to get a second double-stacked version of Enlist (dropping the glyphosate tolerance gene) onto the market by “mid decade”.

Bayer CropScience and weed scientists in the US are pushing glufosinate ammonium tolerant crops (previous called Liberty Link, or LL, but now branded Ignite) to tackle troublesome weeds\textsuperscript{xxxiii} because (at present) there are no weeds resistant to it. This is hardly surprising given the relatively low level of use (compared to glyphosate) since glufosinate was first marketed in 1993.
Bayer have launched a campaign called “Respect the Rotation”, based on the rotation of crops tolerant to different herbicides and rotating different herbicides, aimed at giving the company a big slice of the herbicide crop and associated herbicide markets. However what is proposed is likely to be complex and costly as farmers are also told to:

- Monitor weeds in the fields very closely.
- Burn off all weeds in field before planting.
- Apply herbicide correctly at the right time and right dose.
- Control “escaped” weeds by spot applications, row wicking, cultivation or hand weeding.
- Prevent weeds from setting seeds.
- Clean all equipment to prevent resistant weeds seeds being transported between fields and farms.

One of the risks of the rotating different herbicide tolerant crops is that they could be mistakenly sprayed with the wrong herbicide, which would cause a complete loss of the crop.

This problem may add another layer of complexity – coloured flags to tell farmer what herbicide to use. Bayer are proposing that fields with GM crops with different herbicides tolerances should be marked with coloured flags to avoid them being sprayed with the wrong chemical mixture. Ironically the colour chosen by Bayer for Roundup Ready flags is white, Ignite is green and conventional crops red.

Toxic burden
The moves by Bayer and Dow to increase their share of markets previously dominated by Monsanto RR genes illustrates how the use of GM herbicide tolerance technology is another stage in the pesticides arms race that began in the early 1950s. Farmers will be spraying cocktails of herbicides just to kill one species of weed. The myth that GMHT technology will reduce herbicide usage is now fully exposed.

Lessons learned?
It is clear that the overuse of Roundup on RR crops has come close to making glyphosate obsolete in many areas on the US and South America, and that only when it is used in combination with other products can it be effectively applied by growers. The outcome is an increase of pesticide usage and the toxic burden on the environment from a cocktail of chemicals now needed to control weeds in RR crops. The herbicides being used with glyphosate, such as 2,4-D and dicamba, were approved many years ago (1967 and 1940s respectively). Both weedkillers kill broadleaf weeds, and the safety of both to human health, the environment and water quality has been challenged. Both can be volatile in certain formulations, and in hot conditions can re-evaporate after spraying and drift onto susceptible crops or sensitive habitats.

Future options for chemical weed control are limited by the lack of new chemical herbicides in the pipeline. There has been no new herbicidal chemical introduced since the early 1990s, and there is no sign that a new chemical is anywhere near commercial production.

Overreliance on glufosinate ammonium by growing Liberty Link GM crops would also risk weed resistance developing, and this weedkiller comes with concerns about its mammalian toxicity, mobility in the soil and impact on non-target organisms. Monsanto signed an agreement with Bayer CropScience in 2009 allowing each company access to their respective herbicide tolerant traits in oilseed rape. It is clear that Monsanto has every intention of marketing Roundup along with other herbicides. In March 2010 the company increased manufacturing capacity for the herbicide by 20% by extending their US manufacturing plant.

There is a growing body of evidence casting serious doubts about the safety of glyphosate for human health, wildlife and the soil/plant health and calls have been made for its approval to be
urgently reviewed.xlii

The real solution
The long-term solutions are to adopt agroecological farming methods and move away from arable monocultures. In agroecological systems weed control depends on a combination of crop management approaches that accept a certain level of weed presence does not impact on the yield and crucially provides food and shelter for farmland wildlife throughout the year. These methods, advocated for organic/agroecological farming systems where no herbicides are used, include:

- Vigilance and quick control of resistant populations.
- Crop rotation and avoidance of monoculture forces different weed populations and densities thus preventing the establishment of a resistant population.
- Crop breaks – fallow or temporary grazing systems.
- Mechanical weeding.
- Rouging crops to pull isolated weed to prevent them seeding.
- Cultivating soil to kill weed seedlings.
- Mulching using cover crop or weed residues to reduce weed populations.

Conclusion
Weeds resistant to glyphosate are present in most major RR crops in the US and South America to the extent that the easy weed control techniques that attracted farmers to adopt the technology are a thing of the past.

Farmers are now faced with increasingly complex weed management strategies, higher costs and a supplier (Monsanto) that appears to want to shirk responsibility if weed control fails due to resistant weeds being present in the crop. In some cases, such as Palmer Amaranth in RR cotton, growers have had to resort to hiring labour to hand pull weeds at their own expense.xliii Far from making life simpler for farmers, RR crops are leading farmers down a path of greater chemical dependency combined with hand weeding if weeds get out of control.

The plans to control weed resistance put forward by biotechnology companies is for greater use of herbicides in different combinations. This might be good news for their shareholders, but it is bad news for farmers, people and the environment.

Notes
Assessment of the Active Substance G
organised by the University of Arkansas. See www.youtube.com/watch?v=2_iJhIgTOJM&feature=related
Steckel L, 2011. “New technology and the future of pigweed control”. Presentation to the Pig Posium organised by the University of Arkansas. See www.youtube.com/watch?v=2_iJhIgTOJM&feature=related
Georgia Farm Monitor, 2010. See www.youtube.com/watch?v=ZUl_pp3NJUC&NR=1
Monsanto, undated. “Glyphosate Resistant Weed Biotypes”. See www.monsanto.com/weedmanagement/Pages/Glyphosate-ResistantWeedBiotypes.aspx
Monsanto, press release 2 November 2010. “BASF and Monsanto Announce Progress in Dicamba Formulations”.
Monsanto, press release 19 October 2010. “Monsanto, Sumitomo Chemical and Valent Announce Long-Term Crop Protection Collaboration”.
Monsanto, press release 19 October 2010. “Monsanto and Makhteshim Agan Announce Strategic Crop Protection Collaboration Crop Protection Leaders Bring Together Makhteshim Agan’s Proven Molecules and Monsanto’s Weed Management System”.
Bayer CropScience, undated a. “Respect the Rotation” See www.bayercropscience.us/our-commitment/respect-the-rotation
Steckel L, 2011. “New technology and the future of pigweed control”. Presentation to the Pig Posium organised by the University of Arkansas. See www.youtube.com/watch?v=2_iJhIgTOJM&feature=related
GM Freeze and Greenpeace International, 2011. Herbicide Tolerance and GM Crops: Why the world should be ready to round up glyphosate.
Steckel L, 2011. “New technology and the future of pigweed control”. Presentation to the Pig Posium organised by the University of Arkansas. See www.youtube.com/watch?v=2_iJhIGtOJM&feature=related