TWN

Third World Network
Email: twnet@po.jaring.my
Websites: www.twnside.org.sg, www.biosafety-info.net
Address: 131 Jalan Macalister, 10400 Penang, MALAYSIA
Tel: 60-4-2266728/2266159 **Fax:** 60-4-2264505

Briefings for MOP 4

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4th Meeting of the Parties to the Cartagena Protocol on Biosafety, 12-16 May 2008, Bonn, Germany

Special threats to the agroecosystem from the combination of GE crops & glyphosate

By Jack A. Heinemann and Brigitta Kurenbach
Centre for Integrated Research in Biosafety and School of Biological Sciences, University of Canterbury, Christchurch, New Zealand

Weeds are an important problem in agriculture. The cost of weeds has been estimated at US$20 billion in the USA (reported in Basu et al., 2004) and A$3-4 billion in Australia (Sinden et al., 2004). Generally, these costs are incurred by both loss of crop because of the direct influence of weeds and the cost of weed control. In Korea, 5-10% of rice yield is lost to weedy rice (Chen et al., 2004). "Volunteer wheat and barley, at 7 to 8 plants/m^2 (6 to 7/yd^2) can reduce canola yield by 10 to 13%" (Canola Council, 2007). The DuPont company estimates that without some form of weed control "the average crop losses for U.S. corn, soybean and cotton growers would be approximately 65%, 74% and 94%, respectively" (DuPont, 2008).

Herbicides are used for weed-control by many kinds of farmers as well as by those who control roadside and urban weeds. Glyphosate has come to dominate the herbicide market. While glyphosate has been available since the 1970s, the introduction of commercial genetically engineered/modified (GE/GM) glyphosate-tolerant/resistant crops in the mid-1990s has brought a new level of concern (Service, 2007).

All herbicides have their environmental and human health costs and glyphosate-based formulations are no exceptions (e.g. see research by Kremer et al., 2005, Larson et al., 2006, Relyea, 2005, Richard et al., 2005). In this article, we will not address the human health or nontarget effects of glyphosate or its commercial formulations *per se*. Precisely the "question that must be addressed is whether or not the most recent major change in agroecosystems, the adoption of herbicide-resistant crops, represents a different risk than previous changes" (p.302 Owen and Zelaya, 2005) in agroecosystems. We will argue that whatever you may feel about glyphosate, it is a tool being lost to the majority of the world's farmers and farming land because of the use of GE herbicide-tolerant crops.

Glyphosate's current prominence is linked to the adoption of GE crops that endure otherwise lethal levels of the commercial formulations. This is referred to as herbicide tolerance (HT) or resistance, a concept defined by the particular concentration of chemical that different plants can withstand. "The results of this unprecedented change in agriculture have been many, but perhaps most dramatic is the simplification of weed-control tactics; growers can now apply a single herbicide (glyphosate) at elevated rates of active ingredient and at multiple times during the growing season without concern for injury to the crop" (p.301 Owen and Zelaya, 2005). For example, "the use of tank mixtures and sequential applications of more than one herbicide has declined as many growers have elected to rely exclusively on glyphosate for weed control in soybean, which may increase the risk of selecting for glyphosate-resistant weeds. The number of active ingredients used on at least 10% of the treated soybean hectares has declined from 11 in 1995 to only one (glyphosate) in 2002" (p. 302 Young, 2006).

Like other herbicides, there is a price to pay for using commercial formulations of glyphosate. Glyphosate formulations can have non-target effects. That is, they either can be toxic to some animals (e.g. see Relyea, 2005, Relyea et al., 2005, but also challenge by Thompson et al., 2005) or tissues (e.g. Richard et al., 2005), or inhibit non-target enzymes resulting in other unintended effects. An example of the latter is inhibition of ferric reductase resulting in iron deficiencies in some cropping systems (Ozturk et al., 2008). Although glyphosate is claimed to have a lower toxicity to humans than many other alternative herbicides (Alan, 2000), these claims may be oversimplifications of the true impact of glyphosate-based commercial formulations which rely on a number of other chemicals that can be toxic (Richard et al., 2005).

However, the combination of glyphosate's effectiveness on a broad range of plants, and the fact that it is now "off-patent" makes it a convenient and ever more affordable option (Service, 2007). Accepting that there are downsides of glyphosate (Box), it does remain an option for some kinds of conventional farmers and may have advantages over other herbicides in some contexts.

Whatever the final verdict is on the benefits and harms of glyphosate-based herbicides, and the use of this and other herbicides as a distraction from efforts to develop a more environmentally sustainable form of agriculture (e.g. Badgley et al., 2007, Mancini et al., 2008), in the meantime glyphosate is being used - and in unprecedented amounts - primarily because of GE crops. The amounts and the patterns of glyphosate use made possible by these crops is driving the evolution of glyphosate resistance among weeds (Powles, 2008) and in turn driving up glyphosate use (Young, 2006). That is, as a special result of using HT GE crops, responsible conventional farmers are losing one of their tools.

Importantly, the use of glyphosate for about 20 years before the introduction of glyphosate-tolerant crops did not result in many reports of glyphosate-tolerant weed populations. But its use in the last 10 years has (Powles, 2008, Service, 2007).

Glyphosate use has changed with GE cropping

Glyphosate is primarily used as a "burndown" agent with conventional crops. It is usually applied early in the season before planting or after harvest to purge weeds, or between rows in perennial crops, and it is also used outside of agriculture to control weeds in urban and industrial areas (Powles, 2008, Reddy, 2001). In these applications, glyphosate still has a significant role to play, at least until the world finds a way to feed itself without using herbicides.

While resistance had arisen before the introduction of HT crops, burndown did not create large resistance problems, presumably because this pattern of usage neither exposed as many weeds to glyphosate nor did it stifle a diversity of companion techniques for controlling weeds, such as the use of biocontrol, hand-weeding or rotations with other herbicides, reducing the selection for resistance to any particular herbicide (Graef et al., 2007, Powles, 2008). Resistance arising in burndown applications was most likely to be observed where the use of glyphosate was intensive and usually resulted in replacing other weed-control strategies (Powles, 2008). As Zelaya et al. (p.669 2007) observed: "Glyphosate-resistant crop systems are suggested to be simple and without great environmental consequences. However…there are major ecological and economic consequences from these presumed simple systems."

In contrast, with the introduction of GE glyphosate-tolerant crops the herbicide can be used throughout the cropping year and at higher concentrations (Owen and Zelaya, 2005, Powles, 2008, Young, 2006). The amounts of glyphosate usage in the US has increased by 15-fold since 1994, with the period of 1994-2002 being the largest increase in both glyphosate use and herbicide-tolerant crops (FOE, 2008, Young, 2006). Large increases in glyphosate use are also reported in Argentina, one of the four largest GM crop producing countries (Pengue, 2005). There especially its potency and spectrum of activity lends it to recruiting what was previously marginal land for large-scale agriculture using herbicide-tolerant GE crops (Pengue, 2005). While these

Have GE crops reduced herbicide use?

A consuming debate centers on the claim that overall pesticide use has been reduced in the agricultural systems that have adopted GE crops. GE crops that produce their own insecticide appear to modestly reduce the amount of *other kinds of* insecticides that were previously applied, at least until resistance or secondary pests might emerge and reverse this trend (Pretty, 2001). However, on a weight or volume basis, the amount of herbicide used may have dramatically increased in the USA (FOE, 2008, Pretty, 2001). In contrast, Cerderia and Duke cite research that calculates a net replacement of 3.27 million kg of other herbicides with only 2.45 million kg of glyphosate in USA soybean fields, and other research showing a net 17 million kg reduction across all relevant crops in the USA because of GE crops (Cerdeira and Duke, 2006).

Volume and weight comparisons have their value, but also their limitations. An increase in the weight or volume of glyphosate over some replaced herbicides, such as carfentrazone-ethyl, would be expected in any case because the glyphosate formulations can be 100 times the volume of these alternative herbicides (Cerdeira and Duke, 2006). Thus, glyphosate arguably could increase the volume of herbicide use by about a factor of 100 before more herbicide were actually being used, provided that the glyphosate was replacing these kinds of alternative herbicides.

In this analysis, the key point is that it is the absolute amounts of glyphosate being used, the pattern of its application, and the effective loss of herbicide and alternative weed management diversity that cause the environmental harms, rather than a debate about whether there is more or less herbicide use in general, and the comparative environmental and human health effects of various herbicides.

lands may be marginal for agriculture, they are nonetheless important for supplying ecosystem services (GEO-4, 2007). Finally, the use of glyphosate has reduced the diversity of chemical agents used for weed control and this significantly contributes to the selection of glyphosate-tolerant weeds (Powles, 2008, Young, 2006).

Since both crops and some weeds are glyphosate-tolerant, and not fully resistant (despite sometimes being called herbicide resistant), applying more glyphosate can for awhile control the weeds (Pengue, 2005, Young, 2006). However, this strategy creates a vicious cycle whereby using even more glyphosate reinforces the evolutionary drive in weeds to achieve ever higher levels of tolerance, and exposes larger potential weed populations to the herbicide.

Coupled with the large increase in acreage in GE crops and the concentration of this acreage into effectively only four countries (Reddy, 2001, UNEP, 2003), even a rare mutant weed could establish a population of offspring that would persist under the umbrella of repetitive glyphosate applications. Amplification would be fast because each season more glyphosate-tolerant weed seeds would be added to the soil bank. Resistance can spread by weeds hitchhiking on machinery and along with agricultural products that are now globally distributed.

Resistance to glyphosate is a real problem, but the news might get even worse. Herbicides for plants are analogous to antibiotics for bacteria (Service, 2007). Herbicides, like antibiotics, reward resistance by removing susceptible competitors. Many antibiotics work by inhibiting an essential enzymatic activity. Glyphosate does so as well; it inhibits the essential plant enzyme called EPSPS (5-enolpyruvyl-shikimate-3-phosphate synthase) which is required to synthesize certain essential components of proteins. Also like antibiotics, the biochemistry of resistance may simultaneously create resistance to more than one toxic chemical, what is called MDR for multiple drug resistance in the case of antibiotics (Heinemann, 1999). MDR arises when special pumps in the surface of cells selectively remove the toxic chemical and thus prevent it from reaching a lethal concentration inside the cell, wherein the enzyme it targets resides (Heinemann, 1999). MDR pumps are usually mutant versions of already existing pumps that selectively transport a number of different chemicals. Changes in their substrate range can cause them to recognize several new compounds at once, even if those compounds do not share the same general chemical properties. In this way, the use of one toxin, say glyphosate, could select for weeds resistant to glyphosate and possibly other herbicides all at the same time. While this mechanism of resistance has not been confirmed in *Sorghum halepense* arising in Argentina, it has been suggested as a particularly troubling possibility by government advisors (Valverde and Gressel, 2006).

Weed shifts and resistance

A high level of glyphosate-tolerance is intrinsic in some plants making them naturally adapted to cropland in which glyphosate is used. Weeds might have other characteristics that adapt them to glyphosate-dominated agroecosystems even if they are susceptible to glyphosate, for example, weeds that can germinate and seed between applications. Given enough time and use, those plants that are intrinsically glyphosate-tolerant by whatever means can move into the agroecosystem, displacing the glyphosate-susceptible weeds that may have previously kept them out. The technical term for this kind of event is a "weed-shift" (Owen and Zelaya, 2005).

Resistance can also arise through mutation or gene flow, as has happened for example in Canadian canola crops (Heinemann, 2007). Any of these outcomes is unwelcome. For example, HT Canadian canola affects multiple crops because canola volunteers are one of Canada's most serious weeds (Hall et al., 2000). Maize and soybean are weeds in any rotation cropping with one another, and in cotton (Owen and Zelaya, 2005, Reddy, 2001). Volunteers can normally be controlled with other herbicides, but gene flow can create plants simultaneously resistant to several herbicides (Heinemann, 2007). In addition, using other herbicides to control HT volunteers increases the use of these herbicides and thus undermines the claim that glyphosate sustainably replaces other herbicides.

The range and types of resistant weeds are important to note, because they are some of the most important and costly to the cropping systems dominated by GE crops, namely cotton, corn and soybean. Resistant forms of *Sorghum halepense* (or Johnsongrass) are reported in both Argentina (Valverde and Gressel, 2006) and the United States (Monsanto, 2008). Resistant *Ambrosia artemissifolia* and *Ambrosia trifida* (common and giant ragweed, respectively), *Amaranthus palmeri*, *Amaranthus rudis* and *Amaranthus tuberculatus* (waterhemp) have emerged in the US (Powles, 2008). *Lolium* spp (ryegrass) resistance is reported in the US and Australia (Owen and Zelaya, 2005, Powles, 2008). Resistant populations of *Euphorbia heterophylla* are now found in Brazil (Behrens, 2007, Powles, 2008) and populations of *Conyza canadensis* (horseweed) in both Brazil and China (Powles, 2008, Zelaya et al., 2007).

Is GM a pro-poor technology?

The implications of resistance eat away at both claims for long-term benefits from using these kinds of GE crops and indicate that farmers who use glyphosate are the losers, even if they do not use GE crops. First, the claim of net environmental benefit from substituting glyphosate for more toxic or persistent herbicides is unsustainable because glyphosate failure results in the re-introduction of such herbicides (Pengue, 2005). While new herbicides might also become available (Behrens, 2007), these may not completely substitute for glyphosate and, in the meantime, there are fewer options because alternative herbicides have been driven out of the market (Service, 2007). Second, the claim that glyphosate encourages conservation (or no-) till agriculture (Cerdeira et al., 2007, Raney and Pingali, 2007) is lost as farmers return to tilling to control weeds (Valverde and Gressel, 2006). The combination of converting marginal land to glyphosate-controlled crop production and subsequent use of tilling could significantly increase the negative effects of erosion.

With the price of glyphosate herbicides falling (Service, 2007), the utility of this herbicide should be more easily captured by poor farmers, and allow the herbicide to be used in urban settings were other herbicides might be less desirable. However, as resistance spreads, these comparative advantages will be lost. Adoption of other GE crops with tolerance for different herbicides, for example glufosinate or dicamba (Behrens, 2007, Service, 2007), is not an obvious solution to the problem so long as herbicide application patterns remain the same for these crops.

It is possible that stacked plants, with tolerance for more than one kind of herbicide simultaneously, might delay the development of resistance because each herbicide could be used in rotation. This again is not a solution and it potentially introduces a bigger risk because gene flow from these crops will accelerate the development of weeds and volunteers resistant to multiple herbicides.

There is great stress on the planet to produce enough food for everyone now and for as long as humanity might need it; and great stress on nations to maintain indefinitely the capacity to continue to produce nutritious and satisfying food (IAASTD, in press). Current strategies for agriculture were recently criticized in an international review of unprecedented scale (IAASTD, in press). Among the most severe criticisms were reserved for the use of private sector incentives to produce agricultural technologies that were of benefit to the poor and the planet. In the last couple of decades, genetic engineering has been the focus of a large component of private sector modern biotechnology (Atkinson et al., 2003, Kennedy, 2003, UNDP, 1999, WHO, 2005). This just does not work to empower the poor and subsistence farmer (IAASTD, in press). As the World Bank recently said, "the benefits of biotechnology, driven by large, private multinationals interested in commercial agriculture, have yet to be safely harnessed for the needs of the poor" (p.158 World Bank, 2007). This is because "agbiotech, as it currently stands, holds [little] promise for developing countries, where many small-scale, resource-poor farmers rely on the cultivation of minor staple crops on marginal lands for their subsistence" (p.190 Spielman, 2007).

The potential loss of another technology, in this case glyphosate, appears to be but one more example of how genetic engineering designed by large corporations for their profit is appropriating a valuable resource from those with the least ability to pay.

Acknowledgements

The authors thank three reviewers for constructive comments. We are grateful to NORAD for support.

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