Glyphosate Resistance

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Summary
Glyphosate resistance has been reported in 11 weed species worldwide since 1995. Recent cases have been linked to Roundup Ready (RR) monoculture cropping systems in the Americas. In Canada, glyphosate resistance in weeds through selection pressure has not been reported. Current glyphosate-use patterns in western Canada are okay in terms of weed resistance risk, but that could change quickly in the next few years due to potentially tighter canola rotations (e.g., demand for biodiesel), less tillage (continually rising fuel costs), and managing weed resistance to other herbicide modes of action.

Introduction
Glyphosate has been on the market since the early 1970s. It is our most important herbicide. With increased adoption of conservation tillage and concurrent increased use of glyphosate, including that in glyphosate-tolerant (RR) crops since the mid-1990s, many producers have expressed concerns over the potential for evolution of glyphosate-resistant weeds. In Canada, glyphosate resistance in weeds has not been reported. Glyphosate is considered a low-risk herbicide for selecting for weed resistance (Figure 1). This paper provides a current snapshot of glyphosate resistance in weeds worldwide, outlines the risk of resistance in Canada, and makes recommendations to delay resistance.

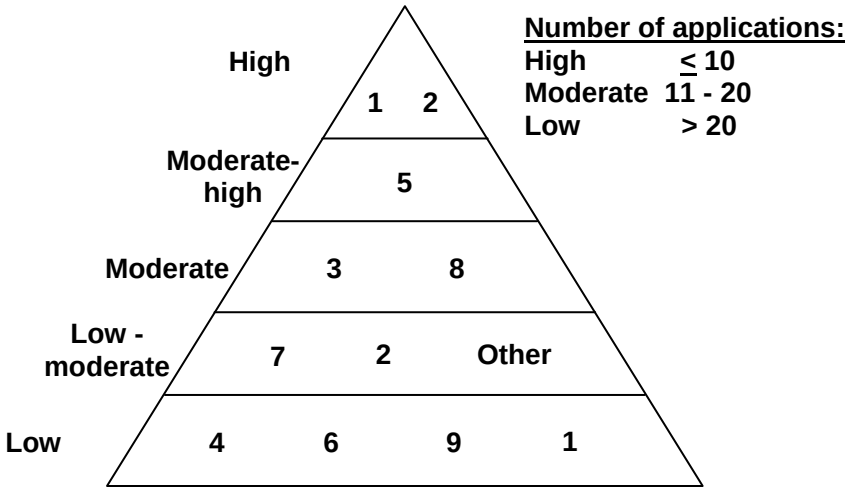

Figure 1. Classification of herbicide groups for risk of selection for weed resistance (glyphosate = Group 9) (Beckie 2006).

Glyphosate Resistance: Worldwide

Since the introduction of RR crops in the mid-1990s, several weed species resistant to the herbicide have been reported elsewhere in the world (Heap 2006). Five glyphosate-resistant weeds, including annual ryegrass, Italian ryegrass, goosegrass, hairy fleabane, and buckhorn plantain, were not a consequence of glyphosate selection pressure in RR crop production systems, but in orchards and vineyards, roadsides, or non-herbicide-tolerant (HT) crops (e.g., preplant, pre- or postharvest). Since 2000, however, evolution of six glyphosate-resistant biotypes have been linked to RR cropping systems in the United States and South America.

In various regions of the United States, sequential in-season applications combined with near RR soybean monoculture (or RR cotton) (e.g., Stachler and Loux 2006) have contributed to the evolution of glyphosate-resistant Canada fleabane (horseweed) across a large area in more than a dozen states since 2000, common ragweed in Arkansas and Missouri (2004), common waterhemp in Missouri (2005), and Palmer amaranth in Georgia (2005) (Heap 2006). Glyphosate-resistant wild poinsettia in Brazil and johnsongrass in Argentina in 2005 were linked to intensive RR soybean systems adopted across vast expanses of cropland. Such practices create an intense selection pressure for weed resistance and jeopardize the future utility of this important herbicide. Glyphosate continues to be used where resistance has occurred. However, addition of a tank-mix partner to control the glyphosate-resistant weeds increases costs to farmers. For example, glyphosate-resistant Canada fleabane in conservation-tillage systems in the North Delta region of the southern United States requires a phenoxy herbicide and one or two residual herbicides. As a consequence of this additional herbicide cost (US $16 to $62/ha), conservation tillage has dropped by about 50% in cotton and 30% overall (Steckel et al. 2005).

Glyphosate Resistance Risk: Canada

Glyphosate resistance through pollen flow

We actually do have glyphosate-resistant weeds in Canada. In addition to evolved weed resistance through herbicide selection pressure, glyphosate resistance in weed species may also occur through gene flow from related RR crops. Evolved weed resistance through selection pressure in HT crops generally poses a greater risk than resistance in related weed species through gene flow. A notable exception is gene flow from HT canola to bird's rape (*Brassica rapa* L.) in eastern Canada or Polish canola volunteers in western Canada (Warwick et al. 2003). Bird's rape has a limited distribution as an agricultural and/or non-crop weed in canola-growing areas in Québec. Hybridization between bird's rape and canola occurred in two field experiments (7% frequency), and in wild populations in commercial fields in Québec (14%). Hybrids with the RR trait were morphologically similar to bird's rape, and had reduced pollen viability (about 55%). Such hybridization was not unexpected as *B. rapa* is an ancestor of *B. napus*. Rarer hybridization with wild radish also occurred. However, studies have indicated that the probability of gene flow from HT canola to wild radish, wild mustard, or dog mustard is very low ($< 2\text{-}5 \times 10^{-5}$).

I have monitored glyphosate resistance in weeds on the prairies since 1998. That year, a survey of 53 zero-till fields (10-24 years of continuous glyphosate use) in the three prairie provinces did not detect resistance. A subsequent survey of 50 RR canola fields in Alberta in 2003 similarly did not detect glyphosate resistance. A Canada fleabane survey at 14 sites in Saskatchewan in

2003 found one suspected population. Subsequent testing, however, did not confirm resistance although some individuals in the population had an elevated tolerance to the herbicide. Weed samples collected in a planned prairie weed resistance survey of 1000 fields from 2007 to 2009 will be screened for glyphosate.

RR crops in Canada

Of the approximately 5.5 million ha of canola grown in 2005 (Statistics Canada 2005), about 50% (>2.5 million ha) is estimated to be resistant to glyphosate (RR cultivars) (Figure 2). In 1997, the number of non-HT canola cultivars commercially available peaked at 46, compared with only one RR canola cultivar (Anonymous 1995-2006). By 2006, there was only one non-HT cultivar and 35 RR cultivars.

Similar to canola, the adoption of HT soybean has been rapid. All registered HT cultivars are RR. It is primarily an eastern crop, with 80% of the nation's soybean area in Ontario (Statistics Canada 2005). RR soybean, first grown in Ontario in 1997, constituted about 60% (565,000 ha) of the total crop area by 2005 (Figure 3). In contrast to soybean, adoption of HT corn has been less rapid. Fifty-seven and 34% of corn in Canada is grown in Ontario and Québec, respectively (Statistics Canada 2005). HT corn cultivars were first grown in 1998. In 2005, Liberty Link (LL) and RR corn comprised 14 and 12%, respectively, of the crop area in Ontario; 23 and 27%, respectively, of the crop area in Québec; and 17 and 18%, respectively, of the total crop area in eastern Canada (M. Gans, pers. comm.). The total area of RR and LL corn in Canada in 2005 was 485,000 ha. Less rapid adoption of HT corn than HT soybean reflects the performance and cost of herbicide treatments in non-HT corn.

Although the majority (54%) of RR canola producers in western Canada apply glyphosate twice in-crop, less than 15% of the area treated annually with herbicides received an in-crop glyphosate application (Thomas et al. 2002; Leeson et al. 2004, 2005). In comparison, total glyphosate usage in a year ranges from 34% (Alberta and Manitoba) to 62% (Saskatchewan) of land cropped to cereals, oilseeds, or pulses, averaging 50% prairie-wide (Leeson and Thomas, unpubl. data). Relatively high glyphosate usage in Saskatchewan is linked to the adoption of zero tillage; 39, 27, and 13% of cropland in Saskatchewan, Alberta, and Manitoba, respectively, is planted using zero-tillage practices (Statistics Canada 2002). Therefore, the contribution of RR canola to overall glyphosate selection pressure in prairie cropping systems is likely relatively low. However, in-crop herbicide application often exerts the greatest selection intensity on weed populations (Beckie 2006). Integrated weed management is not extensively practiced in RR canola. RR canola is often grown in weedy fields, which can reduce weed seed banks in subsequent years. Therefore, RR canola provides an opportunity to reduce herbicide use in subsequent rotational crops.

In contrast to the situation of RR canola, the risk of evolved glyphosate resistance in weeds as a consequence of HT cropping is markedly greater in RR soybean-based production systems in eastern Canada. When glyphosate resistance occurs, it will likely be first reported in Ontario. Herbicide use in soybean in southwestern Ontario has changed dramatically over the past decade. In 1997, more than 75% of the crop in Ontario was treated with at least one Group 2 herbicide (Beckie et al. 2001). In some regions of Ontario, farmers had switched from a traditional corn,

soybean, and winter wheat rotation to near monoculture of soybean, creating a high selection pressure for Group 2-resistant broadleaf weeds such as pigweed species. With the rapid adoption of RR soybean since the late 1990s, use of Group 2 herbicides in soybean has markedly declined. The reduction in Group 2 herbicide selection pressure, however, has been countered by a corresponding increase in glyphosate selection pressure.

Given the importance of glyphosate in reduced-tillage cropping, monoculture RR soybean and multiple in-crop glyphosate applications in soybean or other crops should be dissuaded. The inexpensive cost of glyphosate relative to total variable costs and its lack of soil residual activity are disincentives for a reduction in herbicide-use intensity. Nevertheless, implementation of integrated weed management practices in RR crops, such as an intermediate (38 cm) rather than a wide (76 cm) row spacing in RR soybean, can markedly reduce the real or perceived need for sequential in-crop glyphosate applications. In RR canola, research has shown that a single application at the four-leaf stage is usually sufficient to optimize yield.

Reducing the risk

In Australia where glyphosate resistance was first discovered in 1995 in annual ryegrass, weed scientists recommended rotating preplant glyphosate with a paraquat-based product (e.g., Gramoxone) or preplant glyphosate followed in sequence by tillage or a paraquat-based product. I wouldn't recommend this in Canada, at least not now. However, I would recommend avoiding multiple applications in a field each year (either preplant, in-crop, preharvest, postharvest) – that is, a threshold of 1 application per field per year *on average*. Nothing is certain in life, but setting yourself a reasonable limit should at least delay glyphosate resistance on your farm. Herbicides, including glyphosate, should be viewed as a non-renewable resource. We should learn from the American experience in terms of the wise use of RR crops in rotation and glyphosate stewardship in general.

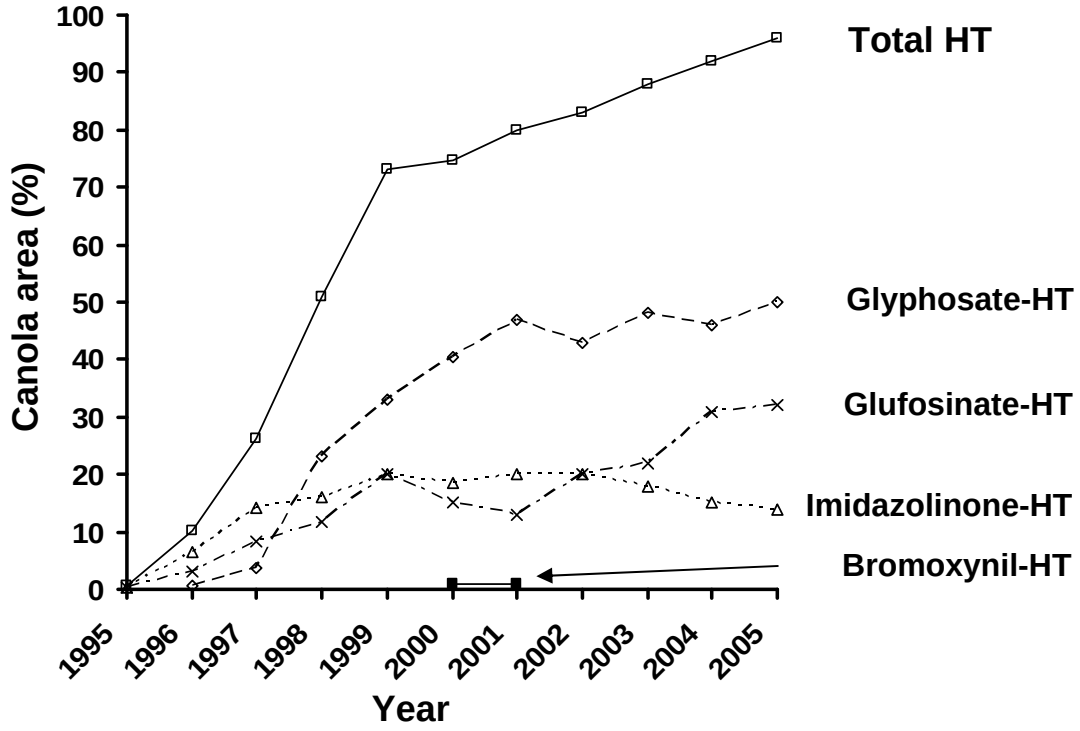

Figure 2. Adoption of HT canola in Canada (Beckie et al. 2006).

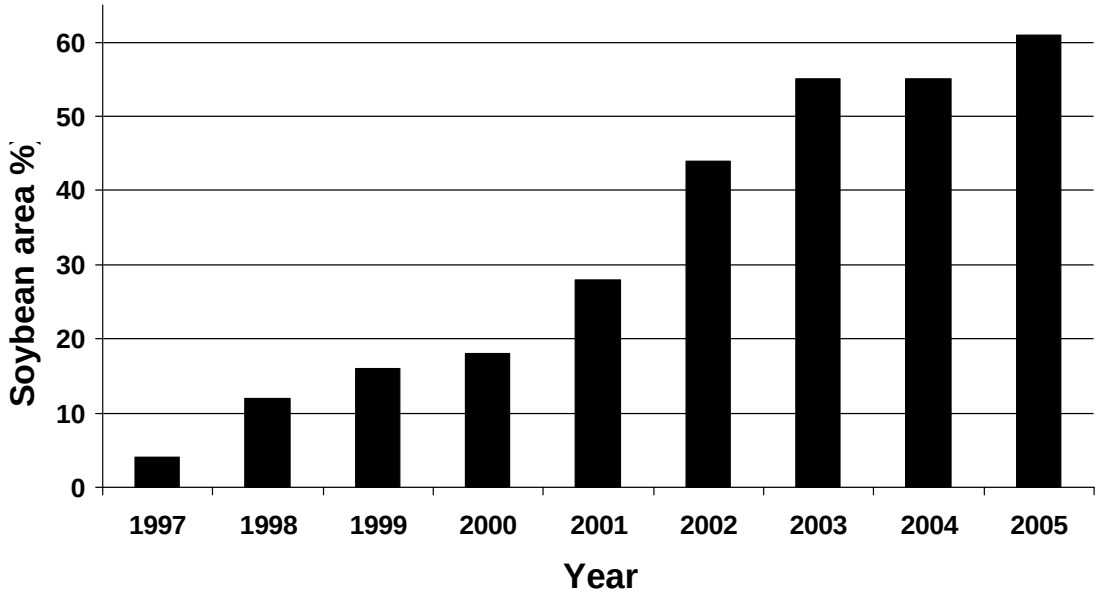

Figure 3. Adoption of RR soybean in Ontario (Beckie et al. 2006).

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