Herbicide resistance in Canada: Biggest threats, best management, and lessons learnt

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Summary I began my career in weed science dealing with the first case of herbicide resistance in western Canada in 1988: trifluralin-resistant green foxtail (*Setaria viridis* (L.P.) Beauv.). Thirty years later, there are 76 herbicide-resistant (HR) weed biotypes across Canada. The biggest threats to crop production are multiple-resistant wild oat (*Avena fatua* L.) and kochia (*Kochia scoparia* L. Schrad.) in western Canada and Canada fleabane or horseweed (*Conyza canadensis* (L.) Cronq.) in eastern Canada. Management of glyphosate plus ALS inhibitor-resistant Canada fleabane in soybean requires tank-mixing three herbicide modes of action, with significantly increased cost. Alternatively, Roundup Ready (RR) 2 Xtend™ (glyphosate + dicamba) soybean cultivars, introduced in 2017, were planted on 13% of crop area as a tool to control these populations. Glyphosate plus ALS inhibitor-resistant kochia in western Canada, similar to Canada fleabane, has spread very rapidly due to HR allele movement via seed and pollen, increasing reliance on auxinic herbicides. Many farmers cannot control wild oat post-emergence in wheat or barley due to resistance to both ACCase and ALS inhibitor herbicides, relying on pre-emergence tank-mixes. I outline best management practices recommended for HR weed management, such as crop diversity, crop competitiveness, and weed sanitation (including harvest weed seed control). Whereas near-monoculture RR soybean in eastern Canada has contributed to increasing occurrence of glyphosate-resistant weeds, genetically-engineered canola (Liberty Link™ (LL) or RR trait) in western Canada has positively impacted HR weed management over the past 20 years. I will share some lessons on HR weed management I have learnt as a weed scientist and as a farmer over the past 30 years.

Keywords Multiple resistance, integrated weed management.

BIGGEST THREATS

There are currently 76 herbicide-resistant (HR) weed biotypes across Canada, a rate of increase of about two new cases per year since 1988 (although the first case was reported in the 1950s). In eastern Canada, specifically the province of Ontario, Canada fleabane (*Conyza canadensis* (L.) Cronq.) resistant to both glyphosate and acetolactate synthase (ALS) inhibitors is the biggest threat to profitable crop production, where a typical three-year rotation is corn-soybean-winter wheat. Since the discovery of glyphosate-resistant Canada fleabane in eight fields in Essex County in 2010, it has now spread across all 30 counties (800 km) in southern Ontario, principally via seed movement by wind (Shields *et al.* 2006). Of those 30 counties, 23 have multiple-resistant (glyphosate + ALS inhibitor) populations. There are good control options in corn; in wheat, pyrasulfotole/bromoxynil provides best control. There are no good options in soybean (78% of crop area planted to Roundup Ready (RR) cultivars). The best treatment is a three-way mixture: glyphosate + metribuzin + saflufenacil, albeit inconsistent control at increased herbicide cost and yield loss (Pearce 2017). In 2017, RR2 Xtend™ (glyphosate + dicamba) soybean was introduced, which provides a new option to control multiple-resistant Canada fleabane. Adoption of these stacked (dual)-trait cultivars in the first year of introduction was 13% of seeded area.

In western Canada, the top five crops are canola (9.3 million ha), wheat (8.6), barley (2.2), lentil (1.8), and field pea (1.7), out of an annually-cropped area of 28 million ha. Of that area, 15 million ha (54%) are infested with HR weeds. The biggest threats to crop production are multiple-resistant wild oat (*Avena fatua* L.) and kochia (*Kochia scoparia* L. Schrad). Populations of wild oat resistant to both acetyl-CoA carboxylase (ACCase) and ALS inhibitors were found in 42% of randomly-surveyed fields in Manitoba in 2016 (up from 13% in 2008 and 8% in 2002); in Saskatchewan in 2014–2015, this biotype was found in 25% of surveyed fields (5% in 2009, 1% in 2003) (Beckie *et al.* 2017a,b). In 2017, five-way resistance in wild oat was reported: ACCase inhibitor, ALS inhibitor, triallate, sulfentrazone, and pyroxasulfone (Mangin *et al.* 2016), despite no history of use of the latter two herbicides. There are no post-emergence herbicide options for multiple-resistant (ACCase + ALS inhibitor)

wild oat in wheat or barley; pre-emergence options include triallate or trifluralin + triallate (suppression by trifluralin or pyroxasulfone). The only options in field pea are pre-emergence trifluralin or triallate; in lentil, the only option is pre-emergence-applied trifluralin. Kochia, resistant to both glyphosate and ALS inhibitors in western Canada, similar to Canada fleabane, has spread very rapidly due to HR allele movement via seed and pollen (Beckie *et al.* 2016), increasing reliance on auxinic herbicides (especially fluroxypyr and dicamba). For example, three counties in southern Alberta had kochia populations resistant to both glyphosate and ALS inhibitors in 2012, or 5% of ca. 300 populations (Hall *et al.* 2014). By 2017, this biotype had spread via tumbleweed across all 16 southern Alberta counties, comprising over 50% of the ca. 300 populations sampled.

BEST MANAGEMENT

Although proactive and reactive HR weed management practices have both been recommended to growers in different agroecoregions globally, there was a need to identify and priorise those having the most impact in mitigating or managing herbicide selection pressure in the Northern Great Plains of North America (Table 1, Beckie and Harker 2017). Our perspective on this issue is based on collaborative research, extension activities and dialogue with growers, or farming experience (cereal, oilseed and pulse crop production) during the past 30 years. The foundation of HR weed management is crop diversity and competitive crops and practices that promote competitiveness. Although the most common crop rotation is not diverse (canola-wheat), canola allows different in-crop herbicide modes-of-action (glufosinate, glyphosate) to manage ACCase or ALS inhibitor resistance. The majority of canola area is planted to Liberty Link (LL) cultivars, with the remainder mainly RR. Hybrid canola is similar to barley in weed suppression ability. Growers who routinely adhere to good weed sanitation practices are less likely to have HR weeds. Harvest weed seed control falls under this category; on-farm research using the Harrington Seed Destructor started in 2017 in Alberta to evaluate its efficacy on key economic weed species (Tidemann *et al.* 2017).

Table 1. Top 10 herbicide resistance weed management practices in western Canada (as reviewed in Beckie and Harker 2017).

10	Maintaining a database
9	Strategic tillage
8	Field- and site-specific weed management
7	Weed sanitation
6	In-crop wheat-selective herbicide rotation
5	Herbicide site-of-action rotation
4	Herbicide mixtures or sequences
3	Pre- and post-herbicide scouting
2	Competitive crops and environment
1	Crop diversity

Growers in western Canada are using a number of recommended practices, based on responses of 600 Saskatchewan growers in 2015; in particular scouting has rapidly increased in adoption since the last grower management questionnaire in 2003 (Beckie *et al.* 2017a). Other top 10 weed management practices used by growers, such as crop rotation, tank-mixing herbicides, and herbicide mode-of-action (group) rotation, are among the top 10 recommended practices. For those growers managing HR weeds, four practices are preferentially used compared with growers without HR weeds (Figure 1): crop rotation, herbicide site-of-action rotation, tank-mixing herbicides, and pre-emergence herbicide treatment. Overall, those with HR weeds rely more on herbicides at all application windows, and have greater adoption of scouting before in-crop herbicide treatment, tank-mixing herbicides, herbicide site-of-action rotation, growing weed-competitive crops, and increasing crop seeding rates vs. those without resistance (G-statistic).

LESSONS LEARNT

A dozen lessons or perhaps perspectives I have gained over the last 30 years as a farmer and weed scientist are the following: (1) the more you look, the more you find (surveillance); (2) lack of weed management diversity (or as Prof. Steve Powles says, 'herbicide-only syndrome'); (3) growers still expect a new mode-of-action herbicide to save them; (4) growers reactively, not proactively, manage HR weeds; (5) integrated weed management is only practised after multiple-HR weeds evolve; (6) short-term profitability and/or cash flow drive crop management decisions and growers greatly discount future potential rewards relative to an immediate gratuity; (7) stewardship is not as important for rented or leased land; (8) grass HR weed management is generally more difficult than broadleaf HR weed management; (9) gene flow, the second part of the HR weed equation, is usually neglected or underappreciated; (10) genetically engineered canola (LL or RR) has been a net benefit in proactively or reactively managing HR weeds in western Canada; (11) there is no silver bullet in managing HR weeds: synergistic 'stacked' cultural weed management practices have

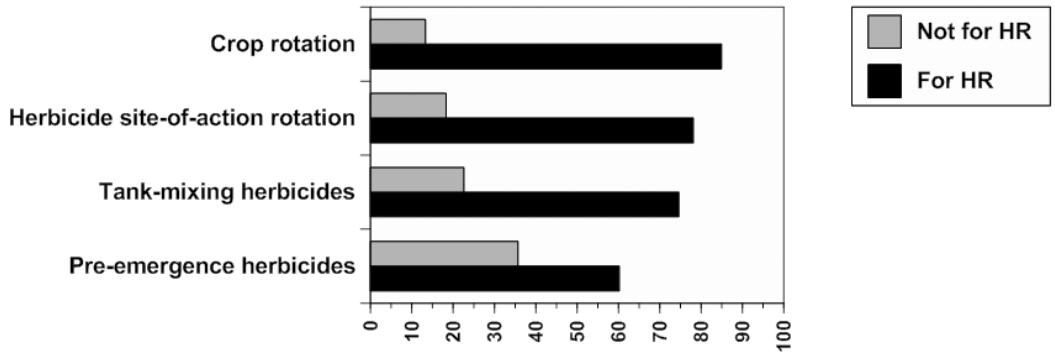

Figure 1. Four practices preferentially used by growers for HR weed management vs. those growers who do not have HR weeds (2015 Saskatchewan survey; n = 250 respondents).

been proven effective; and (12) HR weeds can be managed successfully and profitably if growers are flexible and adaptable.

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