Herbicide-Resistant Crop Management: A Canadian Perspective

Hugh J. Beckie
Agriculture and Agri-Food Canada Research Centre, Saskatoon

hugh.beckie@agr.gc.ca

Introduction

In 2014, the top five genetically modified (GM) or transgenic crop producers were the United States, Brazil, Argentina, India, and Canada, together accounting for 90% of the global area of these crops (James, 2015). The United States has 40% of the area; Brazil, 23%; Argentina, 13%; India, 6%; and Canada, 6%. Although GM cultivars of 11 crops have been released, 4 crops cover 99% of the GM crop area. Soybean (*Glycine max* L. Merr.), corn (*Zea mays* L.), and cotton (*Gossypium hirsutum* L.) are the main GM field crops grown in the US, whereas soybean dominates the cultivated area in Brazil and Argentina. In Canada, canola (*Brassica napus* L.), soybean, and corn are the main GM crops, while cotton is the only GM crop grown in India.

Herbicide resistance (HR) is still the dominant trait in GM crops (86% of total), 20 years after their introduction. Single-trait HR cultivars account for 58% of GM crop area, single-trait *Bacillus thuringiensis* (*Bt*), for 14%, and stacked traits (HR+*Bt*), for 28%. In Canada, the adoption rates of GMHR canola, corn (grain), and soybean in 2014 were 98, 91, and 80%, for total cultivated areas of 8.08, 1.23, and 2.24 million ha, respectively. Canola is mainly grown in western Canada, in contrast to corn and soybean, which are mainly grown in eastern Canada.

HR Crop Deregulation: Herbicide Resistance Stewardship/ Management Plan Requirements

Since 2004, the Plant Biosafety Office, Canadian Food Inspection Agency, has required applicants for the deregulation of an HR crop to submit an herbicide resistance stewardship or management plan (CFIA, 1994, 2014). Specifically, the applicant needs to address the following: (1) control of volunteers, as well as identification of any potential changes in agronomic practices related to the HR trait that could impact sustainability, e.g., soil conservation; (2) selection of herbicide resistance in weeds resulting from the potential continued application of the same herbicide in subsequent rotations, i.e., guidelines for rotation of crops and herbicides; (3) introgression of the HR trait into related species; (4) management of the HR crop during the growing season, especially where multiple resistance due to cross-pollination could arise in subsequent growing seasons; (5) communication to growers and an efficient mechanism for them for reporting problems; and (6) monitoring the effectiveness of the stewardship plan.

Herbicide Registration: Mitigation via Resistance Management Labeling

Resistance management symbols and statements on product labels have been required since 1999 by the Pest Management Regulatory Agency (PMRA) (Beckie et al., 1999). That directive (PRO99-06) was updated in 2013 (DIR2013-04; PMRA, 2013). The site of action (group) number(s) is located on the front panel of product packaging, with resistance best management practices (BMPs) in the use directions. These BMPs, which are the same for all herbicide products, ask the user to do the following: (1) Where possible, rotate use of the product and other herbicides in its group (as defined by site of action) within a growing season (sequence) or among growing seasons with herbicides from different groups that control the same weeds in a field. (2) Use tank mixtures with herbicides from a different group when such use is permitted; to delay resistance, the less resistance-prone partner should control the target weed(s) as effectively as the more resistance-prone partner. (3) Apply an integrated weed management program that includes scouting and historical information on herbicide use and crop rotation and also considers several other practices. These are tillage (or other mechanical control methods); cultural (for example, higher crop seeding rates, and precision fertilizer application method and timing to favor crop over weeds); biological controls (weed-competitive crops or varieties); and other management practices. (4) Monitor weed populations after herbicide application for signs of resistance development (e.g., a weed species on the herbicide label is not controlled). If resistance is suspected, prevent weed seed production in the affected area, if possible with an alternative herbicide from a different group. Prevent movement of resistant weed seeds to other fields by cleaning harvesting and tillage equipment when moving between fields, and planting clean seed. (5) Have suspected resistant weed seeds tested by a qualified laboratory to confirm resistance and identify alternative herbicide options. (6) Contact a local extension specialist or certified crop advisor for any additional pesticide resistance management and/or integrated weed management recommendations for specific crops and weed biotypes. (7) Contact the producing company for further information or to report suspected resistance. The above points constitute a standard statement for products containing one or more active ingredients from the same group. For products containing two or more active ingredients from different groups, the statement would be modified to reflect the situation.

Monitoring/Surveillance of HR Weeds

A framework for postrelease environmental monitoring of GM crops facilitates this process, and weed surveys are an important element of such a framework (Beckie et al., 2010). My first HR weed survey was conducted 20 years ago! Periodic random field surveys of HR weeds should be led by a public institution, usually within its provincial or state boundary. Grower management questionnaires may accompany field survey data collection; correlation analysis can identify reduced-risk practices (e.g., Beckie et al., 2008). Surveys are supplemented by testing samples of suspected HR weeds submitted by growers to a qualified laboratory and publicizing occurrence via HR weed maps (e.g., Beckie et al., 2013). These combined activities allow close tracking of HR weed occurrence in time and space and facilitate early grower awareness and timely management.

Stacked-HR Trait Soybean and Canola

The seed industry's response to the perfect storm comprising rising incidence of glyphosate-resistant (GR) weed populations and concomitant lack of introduction of new herbicide sites of action (the last introduction occurred in 1982) is commercialization of stacked-HR trait cultivars in our major crops. Currently, there are four GR weed species in Canada—Canada fleabane or horse weed (*Conzya canadensis* L. Cronq.), giant ragweed (*Ambrosia trifida* L.), common ragweed (*Ambrosia artemisiifolia* L.), and waterhemp (*Amaranthus tuberculatus* (=*A. rudis*) L.—all in southwestern Ontario in the GR corn/soybean belt, and GR kochia (*Kochia scoparia* L. Schrad.) in western Canada. GR kochia has been selected primarily in chem-fallow areas, but is also found in cereal, oilseed (e.g., GR canola), and pulse crops (e.g., Beckie et al., 2015). Currently, between 50 and 100 sites with confirmed GR kochia exist in the three prairie provinces. The most recent surveys in Ontario indicate that GR horseweed is most prevalent (155 sites in eight counties), followed by giant ragweed (71 sites in five counties), common ragweed (5 sites in one county), and waterhemp (<5 sites in one county) (Byker et al., 2013; Van Wely et al., 2015).

Therefore, stacked-HR trait crops such as soybean are widely viewed as a necessary, albeit interim, tool for managing GR weeds. Roundup Ready 2 Xtend (glyphosate + dicamba) was approved in 2012 in Canada; it will be available in 2016. Dicamba is applied at 600 g ai/ha (or 300 *fb* 300). The environmental impact (EI) per hectare is 15.8, a moderate rating (Beckie et al., 2014). Adoption will probably be very rapid, as RR2 Extend will be the Monsanto platform for all future soybean cultivars; in addition, Pioneer announced it will be going with RR2 Extend and dropping the development of Enlist (glyphosate + 2,4-D) soybean (P. Sikkema, pers. comm.). Therefore, the adoption of the latter HR system will likely be slow, simply because the two largest soybean seed companies—Pioneer and DeKalb—will not be carrying this trait (P. Sikkema, pers. comm.). Enlist soybean was approved in 2013 in Canada (available in 2016). 2,4-D is applied at 834 g ai/ha, with two sequential applications the maximum. The resultant EI from the two applications would be 25.6 (high) (Beckie et al., 2014).

Stacked-HR trait canola (Roundup Ready 2 Xtend) is expected to be approved and released in the next decade (after corn). Cultivars will likely have a three-way stack, with glufosinate added. Dicamba-HR canola would be susceptible to another auxinic herbicide, 2,4-D, commonly used to control volunteers. What are the management implications? Dicamba is currently applied at 140 g ai/ha to 10–15% of wheat and barley fields (two crops covering 50% of the annually cropped area) in western Canada. Increasing the areas of soybean and corn (including cultivars with this stacked trait) across the Canadian prairies will increase the dicamba selection pressure for HR weeds (300–600 g ai/ha rate structure). Growers will need to tank-mix another herbicide with dicamba or use an alternative to dicamba to control canola volunteers in cereal crops grown the following year.

Auxinic Herbicide Resistance Risk

Currently, there are 31 group 4 or synthetic auxin-HR weed species (Heap, 2015). However, 5 of these are grasses or monocots, resistant only to quinclorac (a quinoline carboxylic acid). The aster (Asteraceae) and mustard (Brassicaceae) families disproportionally account for 40% of remaining HR species. The inheritance of resistance is often attributed to a single, dominant to semidominant gene. The cross-resistance pattern among classes (phenoxy, benzoic acid, carboxylic acid) is generally unpredictable (Beckie & Tardif, 2012). Therefore, given the above characteristics, a significant increase in the intensive (herbicide load) and extensive (regional area) in-crop use of synthetic auxins will undoubtedly parallel or duplicate the scenario of the rise of GR weeds observed from 2000 to the present day. Both site-of-action herbicides are considered inherently low risk relative to other groups, but risk dramatically rises when the application threshold is exceeded.

Technology Stewardship Agreement and Use Guide: Improving Stewardship

Growers do not usually read the technology-use guide after they purchase GM crop seed. Mandatory training sessions for growers would enhance adoption of BMPs. The seed industry's main objective is to regulate planted seed. Contrary to the stipulation in the HR stewardship/management plan, it does not really monitor the effectiveness of these plans. Feedback that growers may volunteer is not publicized. Recommendations are needed on herbicide-use intensity (e.g., multiple applications of glyphosate, dicamba, etc., in a field every year) and HR crop rotation frequency thresholds (e.g., back-to-back canola cultivation). Enhanced industry and federal and provincial/state government incentives (e.g., crop insurance) are needed to increase adoption of BMPs. Perhaps a useful model to emulate is GMHR canola and cotton cultivation in Australia (Werth et al., 2008). For example, glyphosate is not recommended the year following GR canola, and two post-herbicide surveys are stipulated in any season that GR cotton is grown.

Summary and Conclusions

The reality is that proactive HR weed management is rare. Growers, especially when they are renters rather than owners, greatly discount potential future rewards relative to present ones. In Canada, renters farm nearly half of all cultivated land. In a nutshell, that socio-economic factor is the basic reason for the lack of proactive grower attitudes and actions.

Which direction are we going? Likely not "the road less traveled." Cultivars with stacked HR traits (e.g., glyphosate + glufosinate + dicamba) will provide a short-term respite from HR (including GR) weeds, but they will perpetuate the herbicide treadmill and accelerate the selection of multiple-HR weed populations in the longer term. Industry stewardship plans need teeth. To avoid a "tragedy of the commons," recommendations for maximum herbicide-use intensity (within and across growing seasons) and HR crop rotation frequency are needed. Concomitantly, industry and government incentives must expand to improve grower adoption of BMPs for HR crops and HR weeds. The only long-term solution is for government or end users of commodities to set herbicide-use reduction targets in our major field crops similar to those set by European Union states. Government agricultural policy should include financial incentives and/or penalties in agricultural programs to support these targets. The only sustainable solution is herbicide-use reduction, incentivized by government programs.

References

Beckie HJ et al. (1999) The effect of labeling herbicides with their site of action: A Canadian perspective. Weed Technology 13 655–661.

Beckie HJ et al. (2008) Risk assessment of weed resistance in the Canadian prairies. Weed Technology 22 741–746.

Beckie HJ et al. (2010) A framework for post-release environmental monitoring of second-generation crops with novel traits. Crop Science 50 1587–1604.

Beckie HJ et al. (2013) Herbicide-resistant weeds in the Canadian prairies: 2007 to 2011. Weed Technology 27 171–183.

Beckie HJ et al. (2014) Environmental impact of glyphosate-resistant weeds in Canada. Weed Science 62 385–392.

Beckie HJ et al. (2015) Glyphosate-resistant kochia (*Kochia scoparia* L. Schrad.) in Saskatchewan and Manitoba. Canadian Journal of Plant Science 95.

Beckie HJ Tardif FJ (2012) Herbicide cross resistance in weeds. Crop Protection 35 15–28.

Byker HP et al. (2013) Occurrence of glyphosate and cloransulam resistant Canada fleabane (*Conzya canadensis* L. Cronq.) in Ontario. Canadian Journal of Plant Science 93 851–855.

[CFIA] Canadian Food Inspection Agency (1994) Directive 94-08: Assessment Criteria for Determining Environmental Safety of Plants with Novel Traits.

http://www.inspection.gc.ca/plants/plants-with-novel-traits/applicants/directive-94-08/eng/1304475469806/1304475550733.

[CFIA] Canadian Food Inspection Agency (2014) Stewardship of Plants with Novel Traits. http://www.inspection.gc.ca/plants/plants-with-novel-traits/general-public/stewardship/eng/1338182461688/1338183836785.

Heap IM (2015) International Survey of Herbicide Resistant Weeds. http://www.weedscience.org.

James C (2015) ISAAA Brief 49: Executive Summary. Global Status of Commercialized Biotech/GM Crops: 2014. http://www.isaaa.org.

[PMRA] Pest Management Regulatory Agency (2013) DIR2013-04: Pesticide Resistance Management Labelling Based on Target Site/Mode of Action. http://www.hc-sc.gc.ca/cps-spc/pubs/pest/_pol-guide/dir2013-04/index-eng.php.

Van Wely et al. (2015) Glyphosate and acetolactate synthase inhibitor resistant common ragweed (*Ambrosia artemisiifolia* L.) in southwestern Ontario. Canadian Journal of Plant Science 95 335–338.

Werth JA et al. (2008) Managing the risk of glyphosate resistance in Australian glyphosate-resistant cotton production systems. Pest Management Science 64 417–421.

Speaker Profile: http://www.agr.gc.ca/eng/science-and-innovation/research-centres/saskatchewan/saskatoon-research-and-development-centre/scientific-staff-and-expertise/beckie-hugh-phd/?id=1181929515754