The global picture: 350 biotypes (Canada = 51)
>20 Gp 2-HR biotypes

>10 Triazine (gp 5)-HR biotypes:
  ON/QC
Crop types: 1976-2006

percentage of total field crop area

Source: Statistics Canada, Census of Agriculture, 1976 to 2006
Competing for acres: wheat vs. canola 1971-2006

Source: Statistics Canada, Census of Agriculture, 1971 to 2006
Crop diversification: western Canada

Crop types: 2005

Crop types: 2009
Aging farmers

Average age: 52

- Half have off-farm employment
Top 10 weeds in the Prairies

- Green foxtail (millet)
- Wild oats
- Wild buckwheat
- Canada thistle
- Lamb’s-quarters
- Chickweed
- Stinkweed
- Redroot pigweed
- Cleavers
- Kochia
Top 10 weeds in Alberta (2010)

- Wild buckwheat
- Wild oats
- Cleavers
- Canada thistle
- Dandelion
- Volunteer canola
- Chickweed
- Lamb’s-quarters
- Stinkweed
- Hemp-nettle
Cleavers, *Galium spp.*

**Frequency**
- Species not surveyed
- Absent
- 0.1 to 10.0%
- 10.1 to 20.0%
- 20.1 to 50.0%
- More than 50.0%
2007 Alberta survey: 300 fields

2007: 39% of fields
2001: 11% of fields
2007: 12% of fields
2001: 12% of fields
2007: 8% of fields
2001: 3% of fields
Gp 1+2-resistant wild oat in field pea
2007: 15% of fields
2001: not tested
2007: 85% of fields (spring survey)
2001: not tested
2007: 40% fields
2001: 17% fields
Gp 2-resistant spiny annual sow-thistle

Resistant ○ Not resistant •

Sonchus asper

2007: 100%
2001: 67%
Increasing rapidly in Parkland region: selection in pulses

2007: 17%
2001: 0%
Field area with weed resistance in Alberta:
40% of annually-cropped land

<table>
<thead>
<tr>
<th></th>
<th>2001</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gp 1-HR wild oat</td>
<td>1.5</td>
<td>3.6</td>
</tr>
<tr>
<td>Gp 2-HR wild oat</td>
<td>1.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Gp 8-HR wild oat</td>
<td>-</td>
<td>0.8</td>
</tr>
<tr>
<td>Gp 1-HR green foxtail</td>
<td>0</td>
<td>0.1</td>
</tr>
<tr>
<td>Gp 2-HR broadleafs</td>
<td>0.5</td>
<td>1.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3.6</strong></td>
<td><strong>7.8</strong></td>
</tr>
</tbody>
</table>

--- millions acres---

(+117%)
2008 Manitoba survey: 300 fields

Gp 1-resistant wild oat
Resistant ○ Not resistant •

2008: 55%
2002: 40%
Gp 2-resistant wild oat

Resistant ○ Not resistant ●

2008: 18%
2002: 13%
2008: 11%
2002: not tested
Gp 1- and 2-resistant wild oat

2008: 13%
2002: 8%
Gp 1- and 2- and 8-resistant wild oat

2008: 4%
2002: not tested
Gp 1-resistant green foxtail

2008: 44%
2002: 22%
## SMA-AAFC Herbicide Resistance Testing

<table>
<thead>
<tr>
<th></th>
<th>2009 crop year</th>
<th>2008 crop year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gp 2 chickweed</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Gp 2 cleavers</td>
<td>5 (AB: 2)</td>
<td>11</td>
</tr>
<tr>
<td>Gp 2 wild mustard</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Gp 1 green foxtail</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Gp 1 Persian darnel</td>
<td>3 (AB: 2)</td>
<td>(1 in 2004)</td>
</tr>
<tr>
<td>HR wild oat</td>
<td>189</td>
<td>197</td>
</tr>
<tr>
<td>Gp 1</td>
<td>150 (AB: 45)</td>
<td>133</td>
</tr>
<tr>
<td>Gp 2</td>
<td>14 (AB: 6)</td>
<td>16</td>
</tr>
<tr>
<td>Gp 1+2</td>
<td>23 (AB: 17)</td>
<td>45</td>
</tr>
</tbody>
</table>
Resistance Management

Herbicide-Resistant Weeds: Management Tactics and Practices

Hugh J. Beckie²

Chapter 20

Strategies for Managing Herbicide-Resistant Weeds

Hugh J. Beckie
Gurjeet S. Gill

Beneficial Management Practices to Combat Herbicide-Resistant Grass Weeds in the Northern Great Plains

Hugh J. Beckie*
Herbicide selection pressure

Implication of Reduced Herbicide Rates on Resistance Enrichment in Wild Oat (*Avena fatua*)

HUGH J. BECKIE and KEN J. KIRKLAND

Response of wild oat (*Avena fatua*) to residual and non-residual herbicides in canola (*Brassica napus*) in western Canada

H. J. Beckie and F. A. Holm

*SHORT COMMUNICATION*

Selecting for triallate resistance in wild oat
Risk of selection for resistance by herbicide group

Number of applications:
- High: ≤ 10
- Moderate: 11 - 20
- Low: > 20

Herbicide-Resistant Weeds: Management Tactics and Practices

Hugh J. Beckie
Why resistance commonly develops: herbicide target site mutations

1. Substrate binds to Enzyme, Plant Lives
2. Substrate cannot bind to Enzyme, Plant Dies
3. Herbicide cannot bind to Enzyme, Plant Dies
4. Herbicide binds to Enzyme, Substrate cannot bind, Plant Lives
## ACCase mutations in grass weeds

<table>
<thead>
<tr>
<th>Year</th>
<th>Fop</th>
<th>Dim</th>
<th>Clethodim</th>
<th>Den</th>
</tr>
</thead>
<tbody>
<tr>
<td>1781*</td>
<td>R</td>
<td>R</td>
<td>S</td>
<td>R</td>
</tr>
<tr>
<td>1999</td>
<td>Fenox.</td>
<td>S</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>2027</td>
<td>R</td>
<td>S-r</td>
<td>S</td>
<td>R</td>
</tr>
<tr>
<td>2041</td>
<td>R</td>
<td>S-r</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>2078</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>2088</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>2096</td>
<td>R</td>
<td>S-r</td>
<td>S</td>
<td>S</td>
</tr>
</tbody>
</table>
### ALS mutations in weeds

<table>
<thead>
<tr>
<th></th>
<th>SU</th>
<th>IMI</th>
<th>TP</th>
<th>PTB</th>
<th>SCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>122</td>
<td>S-r</td>
<td>R</td>
<td>S</td>
<td>S</td>
<td>nd</td>
</tr>
<tr>
<td>197*</td>
<td>R</td>
<td>S-R</td>
<td>S-R</td>
<td>S-R</td>
<td>S-R</td>
</tr>
<tr>
<td>205</td>
<td>S-r</td>
<td>r-R</td>
<td>r</td>
<td>r</td>
<td>nd</td>
</tr>
<tr>
<td>376</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>574*</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>653</td>
<td>S-R</td>
<td>R</td>
<td>r</td>
<td>r-R</td>
<td>r</td>
</tr>
</tbody>
</table>
Herbicide rotation: propensity for metabolic resistance 
(usually only grass weeds)

<table>
<thead>
<tr>
<th>Example</th>
<th>Chemical class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fenoxaprop</td>
<td>fop - gp 1</td>
</tr>
<tr>
<td>Clodinafop</td>
<td>fop - gp 1</td>
</tr>
<tr>
<td>Tralkoxydim</td>
<td>dim - gp 1</td>
</tr>
<tr>
<td>Chlorsulfuron</td>
<td>SU – gp 2</td>
</tr>
<tr>
<td>Imazethapyr</td>
<td>IMI – gp 2</td>
</tr>
<tr>
<td>Atrazine</td>
<td>triazine – gp 5</td>
</tr>
</tbody>
</table>

- Rotate to herbicides not selective in wheat and nonselective herbicides
Intergroup-HR wild oat

- Resistance to groups
  \[1 + 2 + 8 + 25\]

Symposium

Nature, Occurrence, and Cost of Herbicide-Resistant Wild Oat (Avena fatua) in Small-Grain Production Areas\(^1\)

HUGH J. BECKIE, A. GORDON THOMAS, ANNE LÉGÈRE, DAVID J. KELNER, RENE C. VAN ACKER, and SCOTT MEERS\(^2\)
Cropping system: case study

glyphosate

trifluralin

glyphosate

barley

alfalfa

HR canola

w. wheat or rye

alfalfa

glyphosate (2x)

Chapter 20

Strategies for Managing Herbicide-Resistant Weeds

Hugh J. Beckie
Gurjeet S. Gill
Predicted increase of HR individuals over time

- Herbicide A or B used alone
- Rotation of herbicide A and B
- Mixture of herbicide A and B
Herbicide mixtures

- For a mixture to be effective in delaying resistance, the less resistance-prone component should have the following traits compared to the vulnerable herbicide:
  a) control similar spectrum of weeds; similar efficacy
  b) have similar persistence (component of selection pressure) to control the same flushes of weeds
  c) have a different target site (mode of action)
4-year field expt: two sites in Saskatchewan

-Nontreated (weedy) control
-Weed-free control

16 ALS inhibitor (A: ethametsulfuron) rotation treatments:
-0% frequency (B each year: bromoxynil/MCPA)
-25% frequency (B in 3 off-years)
-50% frequency (B in 2 off-years)
-75% frequency (B in 1 off-year)
-100% frequency (no B)

Mixture treatment:
-A+B each year
Experimental site in Saskatchewan
Herbicide rotations vs. mixtures

Weed control (%) vs. Gp. 2 herbicide applications

Resistant seeds (%) vs. Gp. 2 herbicide applications

Selecting for Weed Resistance: Herbicide Rotation and Mixture

Hugh J. Beckie and Xavier Reboud

*
## Weed response

<table>
<thead>
<tr>
<th>Seedling density (% control)</th>
<th>Biomass at maturity (g/m²)</th>
<th>Seed production (no./m²)</th>
<th>Resistant seed (%)</th>
<th>Resistant seed bank (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0% A</td>
<td>96</td>
<td>0.3</td>
<td>155</td>
<td>2</td>
</tr>
<tr>
<td>25% A</td>
<td>92</td>
<td>11.0</td>
<td>1210</td>
<td>59</td>
</tr>
<tr>
<td>Mix (A+B)</td>
<td>97</td>
<td>0.6</td>
<td>178</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>0% vs Mix</th>
<th>NS</th>
<th>NS</th>
<th>NS</th>
<th>NS</th>
<th>NS</th>
</tr>
</thead>
<tbody>
<tr>
<td>25% vs Mix</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

*NS* indicates no significant difference.
Top management practices to delay resistance

--- % of respondents---

<table>
<thead>
<tr>
<th>Practice</th>
<th>AB</th>
<th>MB</th>
<th>SK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop rotation</td>
<td>29</td>
<td>30</td>
<td>33</td>
</tr>
<tr>
<td>Tillage</td>
<td>18</td>
<td>11</td>
<td>19</td>
</tr>
<tr>
<td>Fallow</td>
<td>17</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>14</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Perennial/forage crops</td>
<td>8</td>
<td>11</td>
<td>1</td>
</tr>
</tbody>
</table>
Competitive ability of hybrid and open-pollinated canola (Brassica napus) with wild oat (Avena fatua)

E. Zand¹ and H. J. Beckie²
Top management practices when HR weeds cover a large area of the field:

- Change herbicides: AB 56, MB 59, SK 43
- Patch management: AB 23, MB 26, SK 29
- Crop rotation: AB 17, MB 38, SK 49
- HR canola: AB 16, MB 22, SK 31
- Silage: AB 13, MB 8, SK 1
Cereal crop seeding rate:

50% increase = 50% weed biomass reduction
Nontreated

Treated

Patch Management of Herbicide-Resistant Wild Oat (Avena fatua)

HUGH J. BECKIE, LINDA M. HALL, and BARCLAY SCHUBA
Risk Assessment of Weed Resistance in the Canadian Prairies

Hugh J. Beckie, Julia Y. Leeson, A. Gordon Thomas, Linda M. Hall, and Clark A. Brenzil*
How are Australian farmers managing herbicide resistance?
Resistance management

Any herbicides that still work

Herbicide rotation/sequences

Any non-herbicide tools that make economic sense
Harrington Seed Destructor
# Top 10 weeds in western Canada

<table>
<thead>
<tr>
<th>Species</th>
<th>Seed shatter index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green foxtail (Setaria viridis)</td>
<td>Good</td>
</tr>
<tr>
<td>Wild oat (Avena fatua)</td>
<td>Poor *</td>
</tr>
<tr>
<td>Wild buckwheat (Polygonum convolvulus)</td>
<td>Good</td>
</tr>
<tr>
<td>Canada thistle (Cirsium arvense)</td>
<td>Fair</td>
</tr>
<tr>
<td>Lamb’s-quarters (Chenopodium album)</td>
<td>Good</td>
</tr>
<tr>
<td>Chickweed (Stellaria media)</td>
<td>Fair</td>
</tr>
<tr>
<td>Stinkweed (Thlaspi arvense)</td>
<td>Fair</td>
</tr>
<tr>
<td>Redroot pigweed (Amaranthus retroflexus)</td>
<td>Good</td>
</tr>
<tr>
<td>Cleavers (Galium aparine)</td>
<td>Good</td>
</tr>
<tr>
<td>Kochia (Kochia scoparia)</td>
<td>Good</td>
</tr>
</tbody>
</table>

Poor – shatters out quickly
Fair – some seed is lost
Good – retains seed very well
Predicting weeds at risk for glyphosate resistance

• Currently 21 glyphosate-resistant weed species worldwide, but only one in Canada – giant ragweed in soybean in Ontario (www.weedscience.org)

• Glyphosate selection pressure is greatest at in-crop herbicide application for top 10 annual weed species except kochia

• In the Grassland region, the top three weeds predicted at greatest potential risk of glyphosate resistance are kochia, wild oat, then green foxtail

• In the Parkland region, wild oat, green foxtail, and cleavers are the top three species
Kochia distribution and abundance in North America
Objectives:

1. Tool for producers to assess their risk of glyphosate resistance on a field-by-field basis;
2. Raise awareness for proactive resistance management in western Canada

Producer answers 10 questions related to crop production system, tillage system, and glyphosate usage (each question with four possible answers)

Tool indicates relative risk of glyphosate resistance based on the 10 responses
Crops with stacked herbicide-resistance traits

- Combinations of traits including glyphosate, glufosinate, HPPD inhibitors, and synthetic auxins
- *Commercialized examples:*
  - glyphosate+dicamba-resistant soybean
  - glyphosate+glufosinate-resistant corn
- Strategy is generally viewed as giving enhanced flexibility to growers to manage resistance
Conclusions

• Insufficient herbicide MOA diversity for many of our major crops in western Canada
• Increasing frequency of resistance has resulted in a resurgence in use of older PRE soil residual products such as triallate or DNAs, and greater use of herbicides in sequences or mixtures to control HR weed species
• Recent research indicates that herbicide mixtures are more effective than rotations in delaying herbicide resistance evolution in weeds –but many implementation challenges!
• Solution: cropping system diversity + herbicide diversity BOTH. Easy, right?!
• Crops with stacked HR traits, with proper stewardship, will facilitate proactive and reactive HR weed management
Thank you!