Wild Oat Resistance Management

K. Neil Harker
AAFC, Lacombe, AB
Kochia Scoparia
Nuisance of Growers

Put to rest by a Group 14 mode of action and up to eight weeks of residual control. Lambs-quarters, redroot pigweed, wild buckwheat and others met the same fate.
Overview

• **Herbicide Resistance Situation**

• **Differential Resistance Risks:**
  – Weeds & Herbicides (some are higher risks than others)

• **Wild Oat Resistance Management Keys**
  – Crop and Crop Stand Health
  – Diverse Cropping Systems
  – IWM

• **Alternative Weed Control Methods**
  – Will they work?
First, let’s not be surprised when resistance happens.

*Any* repeated and consistent weed control practice will lead to resistance.

Unique Herbicide Resistance Cases
- Top 5 Countries

Ian Heap: weedscience.org – Jan 12, 2016
Glyphosate Resistance Cases
- Top 5 Countries (32 Unique GR Weed Species Globally)
And, "Resistance is Spreading"
Early microscopes

It's a mammoth.

Why?
GR Palmer Amaranth Southern USA - Let’s talk “Selection Pressure”

• 4 fields of continuous cotton for ≥ 6 yr
• Herbicide regime
  – Preseed Burn-off: Gly (0.84 kg/ha) + dicamba
  – 1st In-crop herbicide: Gly (0.84 kg/ha) – early POST
  – 2nd In-crop herbicide: Gly (0.84 kg/ha) – prior to 5 leaves
  – 3rd In-crop herbicide: Gly (0.84 kg/ha) + diuron – POST-direct
  – Some years – 4th In-crop: Gly (0.84 kg/ha) + diuron – POST-direct

RESULT:
• By 2004, 4 Tennessee fields with GR Palmer amaranth - 2x to 4x rates
• GR Palmer amaranth in Georgia resistant to 12x rates of glyphosate
  – Culpepper et al. 2006. Weed Sci. 54:620-626
US Acres with GR Weeds (x 1,000,000)

- Nearly half (49%) of surveyed U.S. farmers had glyphosate-resistant weeds in 2012.

Dr. Jason Norsworthy, Univ. Arkansas
HR Palmer Amaranth - 2014

www.weedscience.org

© Dr. Kevin Bradley, University of Missouri
Many Years Ago?
“New” Weed Tool in Arkansas (Hoe)

52% of all hectares handweeded
US$72.69/ha (max = US$370/ha)

2011 Photo: Jason Norsworthy
University of Arkansas
Tillage is now a common scene

2004: 13% of cotton acres cultivated
2010: 32% of cotton acres cultivated

Photo Courtesy Stanley Culpepper
Where are the most GR Weeds?

- Where are the most GR Crops?
  - US, Brazil & Argentina have > 80% of world GR crop acres
  - 330 million acres in 2009
  - Worldwide, there are 112 known instances of GR Weeds

www.plosone.org
Ontario Roundup Ready Corn
- Market Share (%)
Acres of Active Ingredient Applied (x1,000)
- Western Canada (2012 - Summer & Chem Fallow only)

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Acres (x1,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>glyphosate</td>
<td>9,589</td>
</tr>
<tr>
<td>2,4-D ester</td>
<td>1,336</td>
</tr>
<tr>
<td>dicamba</td>
<td>998</td>
</tr>
<tr>
<td>tribenuron</td>
<td>663</td>
</tr>
<tr>
<td>saflufenacil</td>
<td>586</td>
</tr>
<tr>
<td>florasulam</td>
<td>257</td>
</tr>
<tr>
<td>metsulfuron</td>
<td>185</td>
</tr>
<tr>
<td>MCPA ester</td>
<td>132</td>
</tr>
<tr>
<td>carfentrazone</td>
<td>69</td>
</tr>
<tr>
<td>2,4-D amine</td>
<td>59</td>
</tr>
<tr>
<td>clopyralid</td>
<td>41</td>
</tr>
<tr>
<td>bromoxynil</td>
<td>29</td>
</tr>
<tr>
<td>MCPA amine</td>
<td>21</td>
</tr>
<tr>
<td>pyrasulfotole</td>
<td>6</td>
</tr>
<tr>
<td>2,4-DB</td>
<td>6</td>
</tr>
</tbody>
</table>

Source: AGDATA
(# acres receiving a full rate)

> 2X Next Top 14
Where is GR Kochia found?

- Kansas (2007)
- South Dakota (2009)
- Nebraska (2011)
- Alberta (2012)
- Colorado (2012)
- Montana (2012)
- North Dakota (2012)
- Saskatchewan (2012)
- Oklahoma (2013)
- Manitoba (2013)
Elsewhere, in Malaysia...

Multiple resistance across glufosinate, glyphosate, paraquat and ACCCase-inhibiting herbicides in an *Eleusine indica* population

A JALALUDIN, Q YU & S B POWLES
*Australian Herbicide Resistance Initiative, School of Plant Biology, University of Western Australia, Crawley, WA, Australia*

Received 7 January 2014
Revised version accepted 16 July 2014

The Herbicide Sales Team

...the IWM Team

“I’ve got it, too, Omar ... a strange feeling like we’ve just been going in circles.”
Risk of Selection for Resistance - Herbicide Groups

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

But, what happens if 100’s of millions of acres are treated repeatedly with a single “low risk” herbicide?

# Weed Species Resistant to Individual Herbicides (Top 15)

## Factors to Consider
- Resistance susceptibility
- Date of 1st use
- Area of use

<table>
<thead>
<tr>
<th>Herbicide Actives</th>
<th>Number of Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>atrazine</td>
<td>64 (5)</td>
</tr>
<tr>
<td>imazethapyr</td>
<td>39 (2)</td>
</tr>
<tr>
<td>tribenuron-methyl</td>
<td>35 (2)</td>
</tr>
<tr>
<td>imazamox</td>
<td>33 (2)</td>
</tr>
<tr>
<td>chlorsulfuron</td>
<td>31 (2)</td>
</tr>
<tr>
<td>simazine</td>
<td>31 (5)</td>
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<tr>
<td>fenoxaprop-P-ethyl</td>
<td>28 (1)</td>
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<tr>
<td>metsulfuron-methyl</td>
<td>26 (2)</td>
</tr>
<tr>
<td>paraquat</td>
<td>26 (22)</td>
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<tr>
<td>bensulfuron-methyl</td>
<td>24 (2)</td>
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<tr>
<td>fluazifop-P-butyl</td>
<td>24 (1)</td>
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<tr>
<td>glyphosate</td>
<td>24 (9)</td>
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<tr>
<td>iodosulfuron-methyl-sodium</td>
<td>24 (2)</td>
</tr>
<tr>
<td>thifensulfuron-methyl</td>
<td>22 (2)</td>
</tr>
<tr>
<td>sethoxydim</td>
<td>18 (1)</td>
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</table>

©2013 WeedScience.org, Dr. Ian Heap 09/23/2013
# Weed Species Resistant to Individual Herbicides (Top 15)

- atrazine
- imazethapyr
- tribenuron-methyl
- imazamox
- chlorsulfuron
- metsulfuron-methyl
- iodosulfuron-methyl-sodium
- glyphosate
- fenoxaprop-P-ethyl
- simazine
- paraquat
- bensulfuron-methyl
- thifensulfuron-methyl
- fluazifop-P-butyl
- pyrazosulfuron-ethyl

Number of Species

©2016 WeedScience.org, Dr. Ian Heap 01/12/2016
Risk of Resistance
- Weed Species Traits

- **High Weed numbers:**
  - High density
  - Broad distribution

- **High Genetic diversity:**
  - High frequency of resistance mutations

- **High Seed production:**
  - Rapid increase in resistant biotype relative to susceptible population after herbicide application

- **High Out-crossing (gene spread):**
  - Rigid ryegrass, kochia, ...

- **High Seed Bank Turnover (low seed dormancy)**
  - Rigid ryegrass, kochia, ...

- **High proportion of Herbicide Escapes:**
  - Wild oat, cleavers, kochia,
Other Reasons for Resistance

The real reason dinosaurs became extinct
Most Popular Western Canada Crop Rotations

<table>
<thead>
<tr>
<th>#</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
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<tr>
<td>1</td>
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<td>Canola</td>
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<tr>
<td>2</td>
<td>Canola</td>
<td>Wheat</td>
<td>Wheat or Barley or Peas</td>
<td>Canola</td>
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<tr>
<td>3</td>
<td>Canola</td>
<td>Canola</td>
<td>Canola</td>
<td>Canola</td>
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## In-crop herbicides in field crops (2006-2010)

<table>
<thead>
<tr>
<th>Site of Action</th>
<th>Wheat</th>
<th>Barley</th>
<th>Canola</th>
<th>Flax</th>
<th>Field Pea</th>
<th>Lentil</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>% of fields</td>
<td>% of fields</td>
<td>% of fields</td>
<td>% of fields</td>
<td>% of fields</td>
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<td>1</td>
<td>76</td>
<td>86</td>
<td>100</td>
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<tr>
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<td>76</td>
<td>48</td>
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<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>(n)</td>
<td>775</td>
<td>280</td>
<td>49</td>
<td>129</td>
<td>49</td>
<td></td>
</tr>
</tbody>
</table>

Adapted from: Beckie et al. 2013 Weed Technol. 27:171-183
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<td>1</td>
<td>76</td>
<td>86</td>
<td>6</td>
<td>100</td>
<td>24</td>
<td>44</td>
</tr>
<tr>
<td>2</td>
<td>23</td>
<td>12</td>
<td>15</td>
<td>0</td>
<td>76</td>
<td>48</td>
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<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
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<td>0</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>0</td>
<td>42</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>10</td>
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<td>0</td>
<td>37</td>
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<td>0</td>
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<tr>
<td>(n)</td>
<td>775</td>
<td>280</td>
<td>345</td>
<td>49</td>
<td>129</td>
<td>49</td>
</tr>
</tbody>
</table>

Adapted from: Beckie et al. 2013 Weed Technol. 27:171-183
New Herbicide Modes of Action

“No new major herbicide mode of action has been introduced in a commercial herbicide active ingredient in the last 20 years.

There goes another herbicide...

“This is a minor setback. The hunter-gatherer economy is still good.”
A lack of new herbicides, coupled with the over-prescription of existing ones, is making many formerly routine diseases untreatable, according to a new report published by the US Centers for Disease Control and Prevention (CDC).

“We are approaching a cliff. If we don’t take steps to slow or stop drug resistance, we will fall back to a time when simple infections killed people,”

“Every time antibiotics are used in any setting, bacteria evolve by developing resistance and that process can happen with alarming speed. These drugs are a precious, limited resource—the more we use antibiotics today, the less likely we are to have effective antibiotics tomorrow,”

"We're facing a catastrophe,"

“U.S. farmers are heading for a crisis,” Stephen Powles (Sep 2013 – Amer. Chem. Soc.)
Back to Wild Oat...
Top 10 Herbicide Targets
- Western Canada

Estimated Cost of Herbicide Products Applied
($ million)

- Wild oat
- Wild buckwheat
- Canada thistle
- Green foxtail
- Stinkweed
- Kochia
- Wild mustard
- Cleavers
- Sowthistle
- Redroot pigweed

Available: http://weedscience.ca/resources/annual-meeting-archived-files/
Group 1 (ACCase) Resistant Wild Oat

Alberta

2001: 11% of fields
2007: 39% of fields
2014: > 50%

Provincial Resistance Maps
By Hugh Beckie
Post Management Patches – 3 Fields
- Central AB, Black Soil Zone

Dale Fedoruk,  B.Sc. Ag., P.Ag., C.C.A.
Elite Environmental Ltd.
Red Deer, Alberta
elite.enviro@shaw.ca

2-3 L of seed, collected, air-dried & sent for resistance testing

B. Tidemann

D. Fedoruk
# Patches from Field 1 (Fall 2014)

<table>
<thead>
<tr>
<th>Year</th>
<th>Crop</th>
<th>WO Herbicides</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>RR Canola</td>
<td>glyphosate</td>
</tr>
<tr>
<td>2011</td>
<td>Barley</td>
<td>pinoxaden</td>
</tr>
<tr>
<td>2012</td>
<td>Peas</td>
<td>imazamox/imazethapyr</td>
</tr>
<tr>
<td>2013</td>
<td>Barley</td>
<td>pinoxaden</td>
</tr>
<tr>
<td>2014</td>
<td>Barley</td>
<td>triallate + fenoxaprop</td>
</tr>
</tbody>
</table>

Cropping history & data: D. Fedoruk
# Patches from Field 2 (Fall 2014)

<table>
<thead>
<tr>
<th>Year</th>
<th>Crop</th>
<th>WO Herbicides</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>RR Canola</td>
<td>glyphosate</td>
</tr>
<tr>
<td>2011</td>
<td>Barley</td>
<td>pinoxaden</td>
</tr>
<tr>
<td>2012</td>
<td>Barley</td>
<td>pinoxaden</td>
</tr>
<tr>
<td>2013</td>
<td>LL Canola</td>
<td>quizalofop/glufosinate + glufosinate</td>
</tr>
<tr>
<td>2014</td>
<td>Barley</td>
<td>pinoxaden + pinoxaden</td>
</tr>
</tbody>
</table>

Cropping history & data: D. Fedoruk

### Herbicide Resistance

- **flucarbazone (2)**: 68%
- **imazamethabenz (2)**: 74%
- **pyroxsulam (2)**: 36%
- **pinoxaden (1)**: 70%
- **clodinafop (1)**: 86%
- **tralkoxydim (1)**: 97%

% Resistant Seeds
# Patches from Field 3 (Fall 2014)

<table>
<thead>
<tr>
<th>Year</th>
<th>Crop</th>
<th>WO Herbicides</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>Wheat</td>
<td>clodinafop</td>
</tr>
<tr>
<td>2005</td>
<td>Wheat</td>
<td>fenoxaprop</td>
</tr>
<tr>
<td>2006</td>
<td>LL Canola</td>
<td>glufosinate/clethodim + clethodim</td>
</tr>
<tr>
<td>2007</td>
<td>Barley</td>
<td>pinoxaden + tralkoxydim</td>
</tr>
<tr>
<td>2008</td>
<td>Barley</td>
<td>imazamethabenz</td>
</tr>
<tr>
<td>2009</td>
<td>RR Canola</td>
<td>glyphosate + glyphosate</td>
</tr>
<tr>
<td>2010</td>
<td>Wheat</td>
<td>triallate/trifluralin + clodinafop</td>
</tr>
<tr>
<td>2011</td>
<td>Peas</td>
<td>quizalofop</td>
</tr>
<tr>
<td>2012</td>
<td>Wheat</td>
<td>pyroxsulam</td>
</tr>
<tr>
<td>2013</td>
<td>LL Canola</td>
<td>Glufosinate/clethodim</td>
</tr>
<tr>
<td>2014</td>
<td>Wheat</td>
<td>pyroxsulam + pinoxaden</td>
</tr>
</tbody>
</table>

**% Resistant Seeds:**
- flucarbazone (2): 88%
- imazamethabenz (2): 95%
- pyroxsulam (2): 66%
- pinoxaden (1): 85%
- clodinafop (1): 98%
- tralkoxydim (1): 86%

Cropping history & data: D. Fedoruk
Has anyone heard of resistance to barban (Carbyne)?

Perhaps we should not push 100% herbicide efficacy so aggressively...

D. Fedoruk
Seeding Depth & Weeds?

<table>
<thead>
<tr>
<th>Hybrid</th>
<th>June 7 Photo</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 mph</td>
<td>April seeded</td>
</tr>
<tr>
<td>1 cm</td>
<td></td>
</tr>
</tbody>
</table>

Fertilizer Placement & Weeds?

Barley Cover - June 20, 2002

90 kg/ha N in seed row: 22%

90 kg/ha N pre plant band: 78%
Less Crop Canopy $\rightarrow$ More Weeds

22% vs. 78% Cover $\rightarrow$ WO Bio: 967 vs. 192 kg/ha

See Figure 1 - O’Donovan et al. 2008. Crop Sci. 48:1569–1574
Crop Health
- Rotating Varieties & Species
- continuous silage cropping

PRINCIPLE
Rotating Varieties & Species →
• $\uparrow$ Crop Health
• $\uparrow$ Productivity
• $\downarrow$ Diseases
• $\uparrow$ Crop Competition
• $\downarrow$ Weeds
Materials and Methods


- Barley cv. ‘Seebe’ / ‘Seebe’ / ‘Seebe’
- Barley cv. ‘CDC Helgason’ / ‘AC Harper’ / ‘Seebe’
- ‘CDC Helgason’ / Triticale ‘Pronghorn’ / ‘Seebe’
- ‘CDC Helgason’ / Oat ‘AC Mustang’ / ‘Seebe’
- ‘Pronghorn’ / ‘AC Mustang’ / ‘Seebe’
% Leaf Area Diseased (PLAD)

Rotation
Seebe/Seebe/Seebe Helgason/Harper/Seebe Helgason/Pronghorn/Seebe Helgason/Mustang/Seebe Pronghorn/Mustang/Seebe

PLAD

13.8
11.7
9.6
8.2
5.9

LSD_{0.05} = 2.1
Root biomass (2004)

LSD$_{0.05} = 8.2$

Seebe/Seebe/Seebe
Helgason/Harper/Seebe
Helgason/Pronghorn/Seebe
Helgason/Mustang/Seebe
Pronghorn/Mustang/Seebe

Grams

Rotation

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Seebe/Seebe/Seebe</th>
<th>Helgason/Harper/Seebe</th>
<th>Helgason/Pronghorn/Seebe</th>
<th>Helgason/Mustang/Seebe</th>
<th>Pronghorn/Mustang/Seebe</th>
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<tr>
<td>45</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Crop Health - Rotating Species

- Wheat – Canola
- Wheat – Canola – Peas
- Canola – Canola
- Wheat - Wheat
- Wheat – Lentils/Chickpeas – Wheat – Canola
- Wheat – Fallow
- Barley silage
- Barley silage - Winter Wheat – Canola
- Wheat – Alfalfa – Alfalfa – Alfalfa – Canola

Weeds fortunate enough to grow in simple, repeated cropping systems will continue to have little difficulty adapting and thriving.
Cropping - Rotations & Cycles

Winter - Spring - Summer - Fall - Winter

J F M A M J J A S O N D
Cropping - Rotations & Cycles
- Summer Annual Crops

Wild Oat Adaptation

Crop Growth

J F M A M J J A S O N D
Cropping - Rotations & Cycles - Later Seeding

Wild Oat Adaptation
Cropping - Rotations & Cycles
- Earlier Seeding

Wild Oat Adaptation

J F M A M J J A S O N D
Cropping - Rotations & Cycles
- Winter Annual Crops

Wild Oat Adaptation
Downy Brome & Winter Wheat – Weed Density

Adapted from Blackshaw, Weed Technol. 1994. 8:728-732
Cropping - Rotations & Cycles
- Perennial Forages

Wild Oat Adaptation
Silage Harvest Timing & Wild Oats?
Treatments

1. Barley grain - no herbicide
2. Early-cut barley silage - no herbicide
3. Normal-cut barley silage - no herbicide
4. Barley grain - Assert (1/2)
5. Barley grain - Assert (1)
6. Barley grain - Achieve (1/2)
7. Barley grain - Achieve (1)
8. Early-cut barley silage - Assert (1/2)
9. Early-cut barley silage - Achieve (1/2)
10. Normal-cut barley silage - Assert (1/2)
11. Normal-cut barley silage - Achieve (1/2)
Treatments w/o Herbicides:
- wild oat/m²
Early Silage vs. Grain + Herb.: - wild oat/m²

Integrated Weed Management
Treatments

- Rotation – Continuous Barley vs. Bar-Can-Bar-Pea
- Varieties/Cultivars – Short versus Tall
- Seeding Rate – 1X or 2X (200 or 400 seeds/m²)
- Herbicide Rate – ¼, ½, or 1X (ACCase or ALS)
- Treatments applied to same plots year after year – cumulative treatment effects
Year 5
Wild Oat BM – Maturity – ¼ X Rate – 2005 (3-site means after 5 years)

LSD (0.05) = 614

<table>
<thead>
<tr>
<th>Continuous</th>
<th>Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short 200</td>
<td>1092</td>
</tr>
<tr>
<td>Tall 200</td>
<td>687</td>
</tr>
<tr>
<td>Short 400</td>
<td>288</td>
</tr>
<tr>
<td>Tall 400</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>259</td>
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<td></td>
<td>82</td>
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</table>
## Combining Optimal Factor Synergy - Wild oat biomass Reduction

<table>
<thead>
<tr>
<th># Factors</th>
<th>Description</th>
<th>(x)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1x to 2x</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Short to Tall</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cont to Rot</td>
<td>2.7</td>
<td>2-3</td>
</tr>
<tr>
<td>2</td>
<td>1x-Short to 2x-Tall</td>
<td>6.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1x-Cont to 2x-Rot</td>
<td>7.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Short-Cont to Tall-Rot</td>
<td>7.3</td>
<td>6-8</td>
</tr>
<tr>
<td>3</td>
<td>1x-Short-Cont to 2x-Tall-Rot</td>
<td>18.7</td>
<td>19</td>
</tr>
</tbody>
</table>

Is a B-C-B-P-B rotation really diverse?

What would be better?
Materials and Methods

• Supplement natural wild oat infestation in fall and spring of the 1st year
• Combine optimal cultural wild oat management tactics with truly diverse rotations (not just summer-annuals) under no-till regime
• 14 Treatments
  – 100% herbicide, Chem Fallow and Alfalfa checks
• All plots receive a full rate of dicot herbicides
• 4 x 15 m plots in RCBD with 4 replications
• 8 locations
Lacombe, AB (AAFC)
- K. Neil Harker
- John O’Donovan
- Kelly Turkington

Edmonton, AB (U of A)
- Linda Hall

Lethbridge, AB (AAFC)
- Bob Blackshaw
- Newton Lupwayi
- Elwin Smith

Saskatoon, SK (U of S)
- Steve Shirtliffe
- Chris Willenborg

Scott, SK (AAFC)
- Eric Johnson

Winnipeg, MB (U of M)
- Rob Gulden

New Liskeard, ON (U of G)
- John Rowsell

Normandin, QC (AAFC)
- Denis Pageau

8 Sites

Map of Canada highlighting locations and personnel where sites are located.
Data Collection

• Crop stand density - Spring
• Crop biomass - Summer
• Crop yield
• Wild oat density counts - Spring
• Wild oat biomass - Summer
• Wild oat seed bank determination
## Treatments – I

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Checks</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canola-Wheat</td>
<td>C 100H</td>
<td>W 100H</td>
<td>C 100H</td>
<td>W 100H</td>
</tr>
<tr>
<td>Chem Fallow</td>
<td>C 50H</td>
<td>CF 100H</td>
<td>2xFR 0H</td>
<td>CF 100H</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>C 50H</td>
<td>Alf 0H</td>
<td>Alf 0H</td>
<td>Alf 0H</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Summer Annuals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canola-Barley</td>
<td>C 50H</td>
<td>2xB 0H</td>
<td>C 100H</td>
<td>2xB 0H</td>
</tr>
<tr>
<td>Canola-Barley</td>
<td>C 50H</td>
<td>2xB 50H</td>
<td>C 100H</td>
<td>2xB 50H</td>
</tr>
<tr>
<td>Can-Bar-Pea-Wht</td>
<td>C 50H</td>
<td>2xB 0H</td>
<td>P 100H</td>
<td>2xW 0H</td>
</tr>
<tr>
<td>Can-Bar-Pea-Wht</td>
<td>C 50H</td>
<td>2xB 50H</td>
<td>P 100H</td>
<td>2xW 50H</td>
</tr>
</tbody>
</table>

0, 50, & 100% Herbicide rates are for wild oat herbicides only, dicot herbicide rates were 100%
# Treatments – II

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Early-Cut Silage &amp; Winter Annuals</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Can-ES-Pea-WT</td>
<td>C 50H</td>
<td>2xES 0H</td>
<td>P 100H</td>
<td>2xWT 0H</td>
</tr>
<tr>
<td>Can-FR-Pea-WT</td>
<td>C 50H</td>
<td>2xFR 0H</td>
<td>P 100H</td>
<td>2xWT 0H</td>
</tr>
<tr>
<td>Can-ES-ES-WW</td>
<td>C 50H</td>
<td>2xES 0H</td>
<td>2xES 0H</td>
<td>2xWW 0H</td>
</tr>
<tr>
<td>Can-ES-ES-Wht</td>
<td>C 50H</td>
<td>2xES 0H</td>
<td>2xES 0H</td>
<td>2xW 0H</td>
</tr>
<tr>
<td>Can-ES-WW-WT</td>
<td>C 50H</td>
<td>2xES 0H</td>
<td>2xWW 0H</td>
<td>2xWT 0H</td>
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<tr>
<td>Can-ES-WW-ES</td>
<td>C 50H</td>
<td>2xES 0H</td>
<td>2xWW 0H</td>
<td>2xES 0H</td>
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<tr>
<td>Can-ES-WT-ES</td>
<td>C 50H</td>
<td>2xES 0H</td>
<td>2xWT 0H</td>
<td>2xES 0H</td>
</tr>
</tbody>
</table>

0, 50, & 100% Herbicide rates are for wild oat herbicides only, dicot herbicide rates were 100%
Wild Oats Cut with Silage
Cutting Alfalfa
2013 Plots

2011 – Early-cut silage – no wild oat herbicide
2012 – Early-cut silage – no wild oat herbicide
2X Winter Triticale – 0 WO Herbicide

2013 Plots

2011 – Early-cut silage – no wild oat herbicide
2012 – 2X Winter wheat – no wild oat herbicide
<table>
<thead>
<tr>
<th>Treatments</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
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<tbody>
<tr>
<td>C 50H Al 0H Al 0H Al 0H C 100H</td>
<td>18</td>
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<tr>
<td>C 50H ChemF 2xFR 0H C 100H</td>
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<td>8</td>
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<td>C 50H 2xES 0H P 100H 2xWT 0H C 100H</td>
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<td>23</td>
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<tr>
<td>C 50H 2xFR 0H P 100H 2xWT 0H C 100H</td>
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<td>59</td>
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<tr>
<td>C 50H 2xES 0H 2xWT 0H 2xES 0H C 100H</td>
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<td>28</td>
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<td>C 50H 2xES 0H 2xWW 0H 2xES 0H C 100H</td>
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<tr>
<td>C 50H 2xES 0H 2xWW 0H 2xWT 0H C 100H</td>
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<tr>
<td>C 50H 2xES 0H 2xES 0H 2xW 0H C 100H</td>
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<td>107</td>
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<tr>
<td>C 50H 2xES 0H 2xWW 0H 2xWT 0H C 100H</td>
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<td>51</td>
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<td></td>
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<tr>
<td>C 50H 2xB 50H P 100H 2xW 50H C 100H</td>
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<td>21</td>
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<td></td>
<td></td>
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<tr>
<td>C 50H 2xB 0H P 100H 2xW 0H C 100H</td>
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<td></td>
<td></td>
<td></td>
<td>117</td>
</tr>
<tr>
<td>C 50H 2xB 50H C 100H 2xB 50H C 100H</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>C 50H 2xB 0H C 100H 2xB 0H C 100H</td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C 100H W 100H C 100H W 100H C 100H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>74</td>
</tr>
</tbody>
</table>

Blue bars are significantly greater than the bottom 100% herbicide treatment (P < 0.05)
Wild Oat Biomass (2014) – 4 Sites

Blue bars are significantly greater than the bottom 100% herbicide treatment (P < 0.05)
Canola Yield (2014) – 7 Sites

Blue bars are significantly greater than the bottom 100% herbicide treatment (P < 0.05)
### Wild Oat Seedbank (2014) – 7 Sites

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>Wild Oats in Seedbank (# m⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>C 100H</td>
<td>137</td>
</tr>
<tr>
<td>2011</td>
<td>C 100H</td>
<td>105</td>
</tr>
<tr>
<td>2012</td>
<td>C 100H</td>
<td>1172</td>
</tr>
<tr>
<td>2013</td>
<td>C 100H</td>
<td>1887</td>
</tr>
<tr>
<td>2014</td>
<td>C 100H</td>
<td>1045</td>
</tr>
</tbody>
</table>

**Blue bars** are significantly greater than the bottom 100% herbicide treatment (P < 0.05).
Conclusions - I

• Combining 2x seeding rates of early-cut barley silage with 2x seeding rates of winter cereals and excluding wild oat herbicides for 3 of 5 yr often led to similar wild oat density, above-ground wild oat biomass, wild oat seed density in the soil and canola yield as a repeated canola-wheat rotation under a full wild oat herbicide rate regime.

• Wild oat was similarly well-managed after three years of perennial alfalfa without wild oat herbicides.
Conclusions - II

• Forgoing wild oat herbicides in only two of five years from exclusively summer annual crop rotations resulted in higher wild oat density, biomass and seed banks.

• Management systems that effectively combine diverse and optimal cultural practices against weeds, and limit herbicide use, reduce selection pressure for weed resistance to herbicides and prolong the utility of threatened herbicide tools.

Harker et al. 2016. Weed Sci. 64:170-180
Danook shows off his Swiss Army Rock.
Crop Density & Spatial Distribution

Canola 200 seeds m\(^{-2}\)
Wheat: 200 seeds m\(^{-2}\), 5” rows

Canola 200 seeds m\(^{-2}\)
Wheat: 600 seeds m\(^{-2}\), 5” rows

Canola 200 seeds m\(^{-2}\)
Wheat: 600 seeds m\(^{-2}\), uniform

Photo credits: J. Weiner - Denmark
CombCut™
Weed Seed Removal / Destruction

Seed destruction

Baling chaff

Chaff collection

Corrigan, WA, AU
Feb 22, 2013
Chaff Cart
Chaff in Narrow Windrows

Photos: Michael Walsh
Burn Chaff & Weed Seed

- > 90% control of Ryegrass and Wild Radish
- Most Western AU growers use this technique

Photo: Michael Walsh
Chaff Diversion
Weed Seed Retention over Time – 1 site, 1 year

![Graph showing weed seed retention over time for Wild Oat, Cleavers, and Canola across different dates from August 5 to September 29. The graph demonstrates a decrease in retained weed seeds over time for each species.]
Weed Target Suitability

Excellent targets
• Canola, green foxtail

Good targets
• Cleavers, wild mustard

Poor target
• Wild oat
Summary - I

• Some herbicides are being over-used
• Weed Resistance to herbicides continues to increase at a rapid pace
• Many popular wild oat herbicides are already less useful than a few years ago
• Few or no new herbicide mode of actions are being registered
• Low Diversity Rotations are Dominant
Summary - II

• HR Canola → a Resistance Reprieve, but less cropping system diversity → more problems...
• The most-profitable crops drive a lack of rotational diversity
• Harvest Weed Seed Control should be taken seriously
• So far, Weed Resistance has not driven much greater IWM adoption – that could change!
Do We Have To Observe Resistance to Every Last Herbicide and Weed Before We Act Decisively?
Reducing Herbicide Resistance

“The only sustainable solution is for government or end-users of commodities to set herbicide-use reduction targets in our major field crops similar to European Union member states, and include financial incentives or penalties in agricultural programs to support this policy.”

Beckie & Hall. 2014. Crop Protect. 66:40-45
There Are Signs That Serious Trouble is Ahead...

“Say ... what's a mountain goat doing way up here in a cloud bank?”

% of Cropped Land having Resistant Weeds

<table>
<thead>
<tr>
<th>Resistant Group</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wild oat</td>
<td>28.2</td>
</tr>
<tr>
<td>Other Monocots</td>
<td>3.7</td>
</tr>
<tr>
<td>Total Monocots</td>
<td>31.9</td>
</tr>
<tr>
<td>Dicots</td>
<td>5.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>37</strong></td>
</tr>
</tbody>
</table>

Adapted from: Beckie et al. 2013 Weed Technol. 27:171-183
15 million acre rigid ryegrass random resistance survey (West Aus.)

Owen et al. 2014
Weed Research