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January 2020
Dealing with herbicide resistance:
Where are we at? How did we get here?
And.....
It’s not all about the herbicides!!
Current State of Resistance

• No new herbicide mechanism of action known to be released anytime soon!
• Last mode of action discovered was \(~30\) years ago
  – Group 27
• \(\uparrow\) Number of weeds with herbicide resistance
  • \(\uparrow\) weeds with multiple resistance
  • \(\uparrow\) acres infested
Additional resources available:

Canadian Weed Science Society - CWSS

https://weedscience.ca
CWSS resources online:

Canadian Weed Science Society (CWSS) - [https://weedscience.ca](https://weedscience.ca)

Topics in Canadian Weed Science

- Soil Residual Herbicides: Science and Management
- The first decade of herbicide-resistant crops in Canada
- New Crops and Crops with Second-Generation Traits: Weed Management Challenges

Integrative Weed Management

Physical weeds: Progress and challenges
Number of Resistant Species for Several Herbicide Sites of Action (WSSA Codes)

- ACCase Inhibitors (1)
- ALS Inhibitors (2)
- EPSP Synthase Inhibitors (9)
- Synthetic Auxins (4)
- PSI Electron Diverter (22)
- Microtubule Inhibitors (3)
- HPPD Inhibitors (27)
- PSII Inhibitors (5, 6, 7)

Note: PSII Inhibitors Combined

Year: 1955 to 2020

Dr. Ian Heap, WeedScience.org 2019
Number of Herbicide-Resistant Species by Crop

- Wheat: 77
- Corn (maize): 61
- Rice: 51
- Soybean: 48
- Roadsides: 34
- Winter wheat: 32
- Spring Barley: 30
- Orchards: 27
- Canola: 21
- Cotton: 18
- Pastures: 18
- Vegetables: 16
- Fallow: 15
- Railways: 15
- Peas: 14

Dr. Ian Heap, WeedScience.org 2019
Increase in Unique Resistant Weed Cases for Canada

Number of Unique Resistant Cases

Year


Dr. Ian Heap, WeedScience.org 2019
<table>
<thead>
<tr>
<th>#</th>
<th>Species</th>
<th>Common Name</th>
<th>Location</th>
<th>Year</th>
<th>Other Information</th>
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<td>26</td>
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<td>Manitoba</td>
<td>1988</td>
<td>Microtubule inhibitors (K1/3)</td>
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<td>Antimicrotubule mitotic disrupter (Z/25)</td>
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<td>Photosystem II inhibitors (C1/5)</td>
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<td>37</td>
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<td>ACCase inhibitors (A/1)</td>
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<td>ALS inhibitors (B/2)</td>
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<td>Lipid Inhibitors (N/B)</td>
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<td>Antimicrotubule mitotic disrupter (Z/25)</td>
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<td>40</td>
<td>Amaranthus retroflexus</td>
<td>Redroot Pigweed</td>
<td>Manitoba</td>
<td>2002</td>
<td>ALS inhibitors (B/2)</td>
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<td>41</td>
<td>Thlaspi arvensis</td>
<td>Field Pennycress</td>
<td>Manitoba</td>
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<td>42</td>
<td>Galinsoga spartium</td>
<td>False Cleavers</td>
<td>Manitoba</td>
<td>2008</td>
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<td>Common Chickweed</td>
<td>Manitoba</td>
<td>2008</td>
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<td>44</td>
<td>Amaranthus procumbens</td>
<td>Powell Amaranth</td>
<td>Manitoba</td>
<td>2008</td>
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<td>45</td>
<td>Polygonum lapathifolium</td>
<td>Pale Smartweed</td>
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<td>46</td>
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<td>ALS inhibitors (B/2)</td>
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<td>EPSP synthase inhibitors (G/9)</td>
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<td>ACCase inhibitors (A/1)</td>
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<td>ALS inhibitors (B/2)</td>
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<td>PPDK inhibitors (E/14)</td>
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<td>Long chain fatty acid inhibitors (K3/15)</td>
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<td>Lipid Inhibitors (N/B)</td>
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</tbody>
</table>
There are currently 510 unique cases of herbicide resistant weeds globally, with 262 species (152 broadleafs and 110 grasses). Weeds have evolved resistance to 23 of the 26 known herbicide sites of action and to 167 different herbicides. Herbicide resistant weeds have been reported in 93 crops in 70 countries.

>75 in Canada
Herbicide rotation risk pyramid

- **High**: 1, 2
- **Moderate-high**: 5
- **Moderate**: 3, 8
- **Low-moderate**: 7, 22
- **Low**: 4, 6, 9, 10

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

**Repeated applications**
- Goose grass in Malaysia
- Italian ryegrass in Oregon
Herbicide Resistance.....

• HR issues have been around for years and we’re still using herbicides?

• Have we taken ‘the thinking’ out of weed control?

• Are we heading to a train wreck?

— Without changing weed control practices, YES!!
### Progression of Weed Resistance

Weed resistance progresses logarithmically

<table>
<thead>
<tr>
<th>Treatment</th>
<th>% Resistant Weeds in Population</th>
<th>Weed Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Application</td>
<td>0.0001</td>
<td>Excellent</td>
</tr>
<tr>
<td>1st Application</td>
<td>0.0143</td>
<td>Excellent</td>
</tr>
<tr>
<td>2nd Application</td>
<td>0.0205</td>
<td>Excellent</td>
</tr>
<tr>
<td>3rd Application</td>
<td>0.0294</td>
<td>Excellent</td>
</tr>
<tr>
<td>4th Application</td>
<td>0.122</td>
<td>Excellent</td>
</tr>
<tr>
<td>5th Application</td>
<td>0.686</td>
<td>Failure</td>
</tr>
</tbody>
</table>

Year 0

Credit: Mike DeFelice

Herbicide-resistant biotype

**seed pool or seed bank in soil**

First application of herbicide to the initial population
Progression of Weed Resistance

Weed resistance progresses logarithmically

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<td>0 Application</td>
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<td>Excellent</td>
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<tr>
<td>1st Application</td>
<td>.00143</td>
<td>Excellent</td>
</tr>
<tr>
<td>2nd Application</td>
<td>.0205</td>
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<td>3rd Application</td>
<td>.294</td>
<td>Excellent</td>
</tr>
<tr>
<td>4th Application</td>
<td>4.22</td>
<td>Excellent</td>
</tr>
<tr>
<td>5th Application</td>
<td>60.9</td>
<td>Failure</td>
</tr>
</tbody>
</table>

Year 4

seed pool or seed bank in soil

Control may still appear acceptable, but the seed pool is almost completely composed of the resistant type
### Progression of Weed Resistance

Weed resistance progresses logarithmically.

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<th>Treatment</th>
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<td>4.22</td>
<td>Excellent</td>
</tr>
<tr>
<td>5th Application</td>
<td>60.5</td>
<td>Failure</td>
</tr>
</tbody>
</table>

Herbicide resistance cannot be reversed in a practical time frame. In many cases, the seed pool is unlikely to change back because there is no fitness penalty.

Weed plants and seed pool are now mostly herbicide-resistant.
Dealing with herbicide resistance:

- It’s not all about the herbicides!!

**Integrated weed management practices include:**

- cultural
- mechanical
- herbicide
Diversity of Practices

The best strategies to manage herbicide resistance in weeds are established on the concept of diversity. Diversity can be achieved by:

- Using mechanical, cultural, and biological practices in addition to herbicides
- Applying several herbicides with different mechanisms of action and overlapping control (each herbicide is active on the target weed or weeds)

A combination of tactics reduces the selection pressure imposed by any single practice.
Proactive Management: Cultural Tactics

Crop Management. Agronomic practices, such as choice of hybrid or variety, differences in planting times, fertilizer management, row spacing, plant populations, seed bed preparation, and harvesting techniques can influence the growth cycle of weed species and therefore provide an advantage to the crop. For example, narrow crop row spacing can quickly shade sensitive weed species, while longer periods of weed control are generally required for wider row spacings.

Crop Rotation. Natural differences exist among the abilities of crops to compete with weeds. The greatest benefit in crop rotation comes as a result of the most diverse crop rotations, because they provide the greatest opportunities for exploiting differences in tillage practices, competitiveness, and herbicide choices.
Managing herbicide resistance:

Cultural

- Crop Rotation
- Plant Populations
- Row Spacing
- Planting Date
- Fertilizer Placement
- Cover Crops
• Management methods:
  – Cultural control
    • Crop rotation
    • Crop type (including variety),
      Rye > oat > barley > wheat > canola > field pea > soybean >
      flax > lentil (Blackshaw et al., 2002)
      • Certified seed
      • Seeding date
      • Seeding rate
      • Row width – narrower for more rapid canopy closure
      • Fertilization – side-band & seed placed versus broadcast
Crop Management

- Choice of hybrid/variety
- Different planting times
- Fertilizer management
- Row spacing
- Plant populations
- Seed bed preparation
- Harvest technique

All influence growth cycle of weed species
Solution—Understand impact of weed seed movement

- Means of dispersal:
  - Water
  - Machinery
  - Wind
  - Humans
  - Animals / birds
Crop Rotation

- Diverse crop rotations
  - Provide greatest opportunities to exploit differences in tillage practices, competitiveness and herbicide choices
Managing herbicide resistance

Mechanical

- Tillage
  - Pre-plant
  - In-crop
  - Post harvest
Proactive Management: Mechanical Tactics

Mechanical tactics include techniques such as:

- Pre-plant tillage
- Strip or zone-tillage
- In-crop cultivation
- Post-harvest mowing and/or tillage
- Hand-rogueing before seed set

Equipment sanitation is also important to slow the spread of herbicide-resistant weeds and weed seeds.

Photo: Image number K5197-3 at the USDA-ARS image gallery.
Harrington Seed Destructor
Herbicide

- Multiple herbicides with different mechanisms of action
  - Mixes
  - Sequence
  - Across seasons
Proactive Management: Herbicide Tactics

Herbicide choice requires careful planning so that products with different mechanisms of action (MOA), or unique group numbers, and activity on the same target weeds, are intentionally combined with each other or other weed control practices.

Repeated annual use of a herbicide with the same MOA in the absence of other MOAs or different management strategies can lead to resistance.

Note: For all herbicide applications, it is critical to apply the labeled rate at the correct time. Management strategies based only on a herbicide mechanism of action classification system, or herbicide group number, may not adequately address specific and local needs. Consult product labels and the assistance of your local extension specialist for more information.
Proactive Management: Herbicide Tactics

The main schemes for applying herbicides with different mechanism of action (MOA) to manage herbicide resistance are:

- Mixture application
- Sequentially throughout season
- Across multiple seasons

Note: For all herbicide applications, it is critical to apply the labeled rate at the correct time. Management strategies based only on a herbicide mechanism of action classification system, or herbicide group number, may not adequately address specific and local needs. Consult product labels and the assistance of your local extension specialist for more information.
Benefits of Soil Residual Herbicides

• Time management
• Critical Weed Free Period
• Flushing weed control
• **Alternate modes of action**
  – multiple modes of effective action
  – herbicide layering
The next few slides are examples of the extensive information contained in the Guide. 2020 version available late winter/early spring.
Soil Residual Herbicides

When applied at recommended rates in a crop, most herbicide residues will disappear within a few weeks after application and impose no restriction on cropping options the next year. However, some herbicide residues do not degrade quickly, and can persist in the soil for months or years following application, thereby restricting the crops that can be grown in rotation. Herbicide residues in the soil are deactivated in various ways including:

- Break down by chemical reactions,
- Break down by soil microbes,
- Escape to the atmosphere as a gas (volatilization),
- Break down by light (photodegradation),
- Leaching,
- Binding to soil particles.

Herbicides often disappear from the environment by more than one of these mechanisms. Many herbicides considered to be non-residual are bound temporarily to soil particles while they are broken down gradually by either soil microbes or chemical reactions. The binding action insures that the herbicide is not available to the crop in quantities that will cause damage.

As a general rule, breakdown processes are favoured by warm, moist soil conditions. During the winter, when the ground is frozen, and in the summer when the soil is dry, herbicide degradation is reduced. The residual activity of certain herbicides is also affected by soil organic matter and soil pH. These soil factors are seldom uniform across a field.

Herbicide carryover is aggravated by low levels of organic matter and is more likely to occur on eroded hilltops than in other parts of a field. The risk of herbicide carryover will also be greater in sprayer overlaps which are most common around headlands and slough margins.

Growers should be aware of the residual properties before applying any herbicide if they are to avoid cropping restrictions in following years. Knowledge of the limitations associated with herbicides that leave a soil residue, along with an accurate record of application (i.e. rates, locations) will serve to minimize rotational problems. Each herbicide used in mixes should be considered separately.

Soil tests using chemical extraction cannot always give a good indication of the potential injury risk from herbicide residue because of the influence of organic matter, clay and pH. Because of this, a field bioassay or laboratory bioassay, where plants are grown directly in the treated soil are best for detecting the potential for injury. These tests are not intended to be used to shortcut restrictions on the label, but provide information on rotational crops where none is available.

Injury symptoms from other causes can resemble herbicide carryover injury (i.e. cold weather, flooding, drought, insects, diseases, etc.). Consult with your local agronomist on potential causes before spending money on testing.

Herbicides that leave a soil residue and are of particular concern in Western Canada are found in the following chart.
## Re-cropping Restrictions - Residual Herbicides:

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>Alfalfa</th>
<th>Barley</th>
<th>Canaryseed</th>
<th>Clearfield canola</th>
<th>Non-Clearfield canola</th>
<th>Fababean</th>
<th>Field corn</th>
<th>Dry beans</th>
<th>Field Peas</th>
<th>Flax</th>
<th>Forage grasses</th>
<th>Lentil</th>
<th>Mustard</th>
<th>Oats</th>
<th>Potatoes</th>
<th>Rye</th>
<th>Soybeans</th>
<th>Sunflowers</th>
<th>Wheat (durum)</th>
<th>Wheat (spring)</th>
<th>Wheat (winter)</th>
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</table>
Topramezone

Company:
AmVac Corporation, distributed in Canada by UAP (Impact - PCP#28141)
BASF Canada (Armezon - PCP#30131)

Formulation:
336 g/L topramezone formulated as a suspension.
- Container size:
  - Armezon: 0.6 L
  - Impact: 8 L

Crops and Staging:
Corn (field*, seed, sweet**): From the 1 to 7 leaf stage
* Including both conventional and herbicide tolerant varieties.
** NOTE: Tolerance of sweet corn varieties to topramezone and its mix partners may be variable. When tolerance is unknown, check with the supplier of seed and/or apply to a small area first to assess tolerance.

Weeds and Staging:
The following weeds are controlled with topramezone unless otherwise indicated:
Topramezone MUST BE applied in tank mix with one of the herbicide options indicated in “Tank Mixes:”
- Grass weeds below from the 1 to 4 leaf stage:
  - Barnyard grass*
  - Foxtail (green and yellow)*
- Broadleaf weeds below from the 1 to 8 leaf stage:
  - Chickweed (common)*
  - Kochia (up to 10 cm)**
  - Lamb’s-quarters*
  - Lady’s-thumb*
  - Nightshade (eastern black)
  - Pigweed (redroot, green)
  - Ragweed (common)
  - Velvetleaf*
  - Volunteer canola (up to 8 leaf) including glyphosate-tolerant varieties**
  - Wild mustard

* Armezon only. All types including glyphosate-resistant varieties.
Effects of Growing Conditions:
When weeds are stressed because of drought, flooding, hot or cool temperatures, weeds are not actively growing, control may be reduced.

Tank Mixes:
Herbicides:
Topramezone must be mixed with one of the following:

- **Field and Sweet Corn:**
  - AAtrix (0.42 L per acre) (DO NOT use Merge with this mix in sweet corn)
- **Field corn only:**
  - Frontier Max (0.3 L per acre) + AAtrix (rates above)
- **Glyphosate tolerant corn only:**
  - Glyphosate (360 g ae per acre, no adjuvant required) (see glyphosate page for details)
  - Glyphosate + AAtrix (rates above)
  - Glyphosate + AAtrix (rates above) + Frontier Max (rates above)

Fungicides: None registered.
Fertilizers: None registered.
Insecticides: None registered.

Note: The above mixes are those listed on the topramezone label only.
Adding ingredients in the correct order is critical for optimum performance. Check labels of both products to be mixed for directions. General guidelines can be found on page 11.
Restrictions:

- **Rainfall:** DO NOT apply if heavy rain is forecast. Contact manufacturer for more information.
- **Re-entry Interval:** DO NOT enter treated fields for at least 12 hours.
- **Grazing Restrictions:** DO NOT graze treated fields or cut for feed within 45 days of application.
- **Pre-harvest Interval:** Leave 45 days between application and harvest.
- **Re-cropping Interval:** Field corn only may be seeded to treated areas after a crop failure. Winter wheat may be seeded a minimum four months after application. Spring wheat, canola, field corn, navy (white) bean, soybean, lentils, pea and alfalfa may be seeded the following crop year. Check tank mix options for additional reseeding restrictions. Conduct a field bioassay (a test strip grown to maturity) the year before growing any other crop.
- **Aerial Application:** DO NOT apply by air.
- **Storage:** Store in a cool (above 5°C), dry area. If product is frozen, bring to room temperature and agitate before use.
- **Buffer Zones:**

<table>
<thead>
<tr>
<th>Application method</th>
<th>Buffer Zones (metres) Required for the Protection of:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Aquatic Habitats of Depths</td>
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<tr>
<td></td>
<td>Less than 1 m</td>
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<td></td>
<td>Greater than 1 m</td>
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<tr>
<td>Ground *</td>
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</tbody>
</table>

See page 36 for an explanation of the different habitats.

* Buffer zones can be reduced by 70% when using shrouds and by 30% when using cones mounted less than 12 inches from the crop canopy.
<table>
<thead>
<tr>
<th>Site of Action (Group)</th>
<th>Common Name</th>
<th>Herbicide Tradename</th>
<th>Premix or Co-pack† Tradenames*</th>
</tr>
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<tbody>
<tr>
<td>Sulfonylurea “SU” continued</td>
<td>tribenuron</td>
<td>Express SG=Spike=MPower Extra</td>
<td>Barricade II†, Broadside†=Refine M†,</td>
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<td>=Inferno WDG</td>
<td>Express FX†, Express Pro, Enforcer MSU†,</td>
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<td>Inferno Duo, Ko-Act†=MPower X-Ko,</td>
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<td>Luxxur†, MPower X-Pro†, Predicade†*,</td>
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<td>Refine SG=Nimble=Deploy=MPower R</td>
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<td>=Boost=Draft, Retain SG†, Signal FSU†,</td>
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<td>Travallas, Triton C†, Triton K†*</td>
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<tr>
<td>Triazolopyrimidine “TZP”</td>
<td>florasulam</td>
<td>PrePass Flex=Priority=MPower</td>
<td>Broadband*, Cirpreme XC†, MPower</td>
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<td>Battlefront=Blitz=FirstPass</td>
<td>Battlefront M†=Frontline XL†=Topline†,</td>
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<td>MPower Battlefront+2,4-D†=Frontline</td>
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<td>2,4-D†, HotShot†, Korrex II†, Paradigm†,</td>
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<td>MPower Kickoff†=PrePass XC†,</td>
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<td>MPower Battlefront CM†=Spectrum†*,</td>
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<td>Stellar†=Outshine†, Stellar XL*</td>
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<td>pyroxulam</td>
<td>Simplicity</td>
<td>Rexade†, Tandem†*</td>
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<td>Sulfonylamino-carbonyltriazolinone “SACT”</td>
<td>flucarbazone</td>
<td>Everest/Sierra 2.0, Everest/Sierra 3.0</td>
<td>Inferno Duo</td>
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<td>propoxycarbazone-sodium</td>
<td>Olympus</td>
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<td>thiacarbazon</td>
<td>Varro</td>
<td>Luxxur†, Predicade*, Velocity m3*</td>
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<td>Mitotic Inhibitor (3)</td>
<td>ethalfluralin</td>
<td>Edge</td>
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<td>Dinitroaniline (DNA)</td>
<td>trifluralin</td>
<td>Treflan=Bonanza=Rival</td>
<td>Fortress MicroActiv*</td>
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<td>Benzamide</td>
<td>propyzamide</td>
<td>Kerb (SC, 50WP)</td>
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<td>Growth Regulators (4)</td>
<td>2,4-D amine</td>
<td>2,4-D, others</td>
<td>Dyvel DSp, Restore II</td>
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<td>2,4-D ester</td>
<td>2,4-D Ester, Salvo</td>
<td>Approve*=Leader*=Thrasher*=Thumper*,</td>
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<td>Blackhawk*(† old form), Turboprop,</td>
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<td>Extarane XT, Dicklapax DX, Enforcer Pt*</td>
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<tr>
<td>Site of Action (Group)</td>
<td>Common Name</td>
<td>Herbicide Tradename</td>
<td>Premix or Co-pack Tradenames*</td>
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<td>ACC-ase Inhibitor (1) Aryloxyphenoxy propionic acid “Fop”</td>
<td>clodinafop</td>
<td>Horizon NG=Foothills NG=Nextstep NG, Cadillac One=Ladder All In, Aurora= Cadillac=Foax=Ladder=Signal=Slam-R</td>
<td>Signal FSU*, Traxos, TraxosTwo*</td>
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<td>fenoxaprop</td>
<td>Puma Advance = Wildcat Enhanced, Bengal WB= Cord= MPower HellCat= Vigil WB</td>
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<td>quizalofop</td>
<td>Assure II=Yuma GL</td>
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<td>Cyclohexanedione “Dim”</td>
<td>clethodim</td>
<td>Select=Centurion=Antler=Arrow= Clethodim 250=MPower Independence= Shadow RTM=Patron =Statue, Arrow=All-In</td>
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<td>sethoxydim</td>
<td>Poost Ultra</td>
<td>Odyssey Ultra/Odyssey Ultra NXT*, Solo Ultra*</td>
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<td>tralkoxydim</td>
<td>Achieve= Bison=Marengo=Nufarm Tralkoxydim</td>
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<td>Phenylpyrazolin “Den”</td>
<td>pinoxaden</td>
<td>Axial</td>
<td>Axial iPak**, Axial Xtreme*, BroadBand*, Rezuvant**, Traxos, TraxosTwo*</td>
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<td>imazamethabenz</td>
<td>Assert=Avert</td>
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<td>imazamox</td>
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<td>Ares, Salute*</td>
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<td>imazethapyr</td>
<td>Pursuit=Gladiator=MPower Kamikaze= MultiStar=Phantom</td>
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<td>Odyssey=Duet, Odyssey NXT, Odyssey Ultra/Odyssey Ultra NXT*</td>
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### Common Soil Residual Herbicides

<table>
<thead>
<tr>
<th>WSSA Group</th>
<th>Timing</th>
<th>Site of Action</th>
<th>Example Products</th>
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<tr>
<td>2</td>
<td>POST</td>
<td>ALS Amino Acid synthesis Inhibitor</td>
<td>Davai, Solo, Odyssey, Option</td>
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<tr>
<td>3</td>
<td>PPI (soil active)</td>
<td>Mitosis Inhibitor/ cell division – bind to tubulin</td>
<td>Edge, Treflan, Fortress MicroActiv</td>
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<tr>
<td>5</td>
<td>PPI (soil active)</td>
<td>PSII Inhibitor/ Membrane disruptor</td>
<td>Aatrex, Primextra II Magnum</td>
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<td>8</td>
<td>PPI (soil active)</td>
<td>Lipid Synthesis Inhibitor (Non-ACCase)</td>
<td>Avadex, Fortress MicroActiv</td>
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<td>14</td>
<td>POST (foliar) with slight soil activity</td>
<td>PPG oxidase or Protox Inhibitor</td>
<td>Reflex, Flexstar GT, Authority, Valtera</td>
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<tr>
<td>15</td>
<td>PPI, PRE (surface) with residual soil activity</td>
<td>Very long chain fatty acid inhibitor</td>
<td>Focus, Zidua, Dual II Magnum</td>
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<tr>
<td>27</td>
<td>POST - Somewhat systemic (has soil residues)</td>
<td>HPPD Pigment Inhibitor</td>
<td>Shieldex 400 SC, Impact, Armezon</td>
</tr>
</tbody>
</table>
Factors Affecting Herbicide Persistence

- soil characteristics (texture, organic matter, pH)
- herbicide characteristics
- soil interception/plant residue
- rainfall (total amount and distribution over the year)
- rate of herbicide applied
- application date
- growing conditions following planting in the spring
Soil - Impact on Herbicide Persistence

- temperature
- moisture
  - microbial and chemical degradation
  - reduced moisture causes herbicides to bind more tightly to soil particles (adsorption) – unavailable for degradation or uptake
- OM/Soil Texture (clay content)
  - provides binding sites for herbicide adsorption
- pH (7.0 neutral)
  - determine characteristics of herbicide adsorption
  - can influence microorganism activity
Maximizing Trifluralin Effectiveness

• **High volatility** – must be incorporated very soon after application
• Binds tightly to surface residue, will not wash off with rainfall
  – spray with the direction of the stubble
• trifluralin not highly water soluble, once it is incorporated, not much chance of impacting seed as long as seed is placed below the herbicide layer
Maximizing Pyroxasulfone Effectiveness

- **Non-volatile** – incorporation may be a detriment
- Requires water for activation – delay in rainfall could result in poor weed control
- Will wash off surface residue but will not volatize so is not lost
- Heavy rainfall can leach pyroxasulfone below the weed seed zone and into the crop zone = increased crop injury and less weed control
Primextra II Magnum (atrazine, S-metolachlor)

• WARNING:

Do not plant any crop other than corn in the same year on land treated with PRIMEXTRA II MAGNUM Herbicide as injury may occur. The following year there is virtually no hazard to soybeans, white beans, corn, oats or barley (not underseeded to a legume) in Eastern Canada. Moldboard plough and till soil thoroughly before planting these rotational crops. In the Prairie Provinces, corn must be planted the year following application. However, when the rotational crop is subjected to stress conditions, e.g. abnormally hot, dry weather, preceded by extended periods of dry weather the previous season, injury may occur.
Rapid changes with development of herbicide resistance have resulted in a number of different guidelines, all with valuable points.
10-point “minimum requirement” list for farmers to control the resistance problem in weeds:

- Maintain a weed-free zone field borders, 100% of acres
- Practice zero-tolerance (100% weed control) when herbicides are main tool
- Choose the most effective herbicide(s)
- Apply the most effective soil-applied herbicide(s)
- Rotate herbicide mechanisms of action.
- Plant a different type of herbicide-resistant crop every other year
- Apply post-emergence herbicides to small (1- to 3-inch) weeds
- Include the most effective adjuvant(s) focus on weed control
- Apply herbicides at the appropriate droplet size herbicide type
- Reduce sprayer travel speeds.
Top 10 Herbicide Resistant Weed Management practices

- 10. Keep Records
- 9. Strategic tillage; if, where or when needed
- 8. Field+site-specific weed mgmt (1 size may not fit all)
- 7. Weed sanitation: border control+slowing HR dispersal
- 6. In-crop selective herbicide rotation
- 5. Herbicide grp rotation: avoid back-to-back in-crop Grp 1 or 2
- 4. Herbicide mixtures/sequences: better than rotations
- 3. Scout: know your enemy
- 2. Competitive crops/practices that promote competitiveness
- 1. Crop diversity
A National Summit on Strategies to Manage Herbicide-Resistant Weeds May 2012
National Academy of Science

Herbicide Resistance – Best Management Practices
Herbicide Resistance – Best Management Practices

• Understand the biology of the weeds

• Use a diversified approach toward weed management prevent weed seed production reduce # weed seeds in soil seedbank.

• Plant into weed-free fields. Keep fields as weed free as possible.
Herbicide Resistance – Best Management Practices

• Plant weed-free crop seed

• Scout fields routinely.

• Use multiple herbicide mechanisms of action (MOAs) that are effective against the most troublesome weeds or those most prone to herbicide resistance.
Herbicide Resistance – Best Management Practices

- Crop competition to suppress weeds
- Use other practices – e.g. mechanical
- Prevent field-to-field and within-field movement of weed seed or vegetative propagules.
Herbicide Resistance – Best Management Practices

- Manage weed seed at harvest and after harvest to prevent a buildup of the weed seedbank.

- Manage field borders
Back in the ‘old days’…..personal experience and observations:

As a Red River Valley agronomist:

• Saw customer change in weed management from soil incorporated to post emergent herbicides–ease of application, improved weed control

• Move away from soil incorporated products like trifluralin, ethafluralin, triallate, to newer Group 1 products and others– ease of application, timing.

    Reasons for this complete change in management included:
    • no longer needed incorporation – reduced tillage, less risk of wind and water erosion;
    • Flooding - which limited fall applications, and potentially efficacy;
    • improved level of weed control/cleaner fields
    • Ease of application; and with introduction of HT crops, ease of product choice

Fast forward to today – we’re now paying for that ‘ease’ of choices. Realities to we need to think about include increased diversity in all aspects of growing crops.
Back in the ‘old days’…..personal experience and observations:

To paraphrase a crop input colleague:

• We need to juggle up our herbicide choices – and get some soil incorporated herbicides back in to the rotation

• We need to ratchet down our expectations for degree of weed control with those products

• We have to be better about long term planning – making best use of the management tools we have

• Farming isn’t easy! Complexity is increasing all the time.

• The choices we make now affect the future – what’s the long term cost of a short term decision today?

• NO SILVER BULLETS!!
- Make sure you ask ALL the questions!
  - Both producer and agronomist
    (increased importance with more complex cropping/HR weed/residual herbicide concerns – increased importance for record keeping)

- Importance of local agronomist

- Build relationships; 2\textsuperscript{nd} and 3\textsuperscript{rd} set (or more) of eyes will support the success of your farm
### Key points to include to any list for managing herbicide resistance:

<table>
<thead>
<tr>
<th>Scout!!</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Follow up scout – is your weed control working? What measures to take?</td>
</tr>
<tr>
<td>- Keeping an eye on your crops throughout the growing season becomes more important with these increasing challenges. The need to deal with weed issues immediately and completely has never been more important!!</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Keep Records!!</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Soil applied and soil incorporated herbicides increase the need for good records for ongoing weed management decisions AND to prevent crop injury in future crop seasons.</td>
</tr>
</tbody>
</table>
Take-home......

• Will this happen to me? YES!!!
  → and it likely already has!!

• Is there a magic bullet? NO!!!

• Know what’s coming, and continue with good crop management decisions
Prevent seed production – Zero Tolerance

Year 1

“I Think I Can Get One More Year Out of Glyphosate”
Herbicide Resistance

Sources:

https://weedscience.ca

https://weedscience.ca/topics-in-weed-science/

http://wssa.net/

http://wssa.net/wssa/weed/resistance/
Thanks to:

- **Tammy Jones**, MB Agriculture and Resource Development
- **Dr. Rob Gulden**, University of Manitoba
- **Dr. Hugh Beckie**
- **Dr. Jeff Stachler**
- **Weed Science Society of America**
- **Canadian Weed Science Society**
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