Institute of Ag Professionals

Proceedings of the 2015 Crop Pest Management Shortcourse & Minnesota Crop Production Retailers Association Trade Show

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Purpose of Survey

The purpose of the International Survey of Herbicide Resistant Weeds is to:

• Document the occurrence and importance of herbicide-resistant weeds worldwide
• Scientifically based reporting
Herbicide Resistance – Simple Definition

Resistance is the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type.

Genetic diversity – rare resistant mutation

+ Selection – the repeated use of the same herbicide, or herbicides with the same site of action

= RESISTANCE
Prerequisites for Resistance Evolution

- Individuals with genes conferring resistance within the population
- Selection pressure on individuals possessing those genes
Resistance is Evolution at Work

Resistance is a naturally occurring evolutionary response to selection pressure by a mortality agent (i.e., a herbicide)
How Does Herbicide Resistance Develop?

- Herbicides do not “create” resistance
- Individual plants naturally resistant are present in very low numbers
- Herbicides select for those resistant individuals
Weed Resistance

Scientific Guesstimates:

- ALS inhibitors - 1 in 100,000?
- ACCase inhibitors - 1 in 1,000,000?
- Many herbicides - 1 in 10,000,000?
- Auxins & Glyphosate - 1 in 100,000,000?

SELECTION PRESSURE

- Weed Seeds in Soil often >100 million seeds/ha
- Weed Seedling Populations often >1 million seedlings/ha
Weed Resistance

SURVIVORS SET SEED

Herbicide Miss

Resistant

Wrong Stage

Late Emergence

Also Seed Bank
Weed Resistance

HERBICIDE FAILURE DUE TO RESISTANCE

Resistance is detected when a high proportion (usually >30%) of the population are resistant to the herbicide.
Resistance Caused by Genetic Mutations that Convey

- Altered site of action
  - change in target enzyme

- Gene Overexpression
  - More enzyme produced endowing resistance

- Enhanced metabolism
  - ability to degrade herbicide

- Decreased translocation
  - Herbicide does not get to its site of action

- Sequestration
  - Herbicide not available to the plant – tied up.
Herbicide application

The consecutive steps of herbicide action

1. Penetration
2. Translocation to the location of the target protein
3. Accumulation at the target protein location
4. Binding to the target protein
5. Ensuing damage, cell and plant death

and the corresponding known resistance mechanisms

A. Reduced penetration
B. Altered translocation, compartmenting
C. Enhanced herbicide metabolism
D. Compensation or protection
E. Target overproduction
F. Target mutation

O·

Peroxidase activity

Delye et al. 2013.
Microtubules

- Fatty acid synthesis
- Photosynthesis
- Amino acid synthesis
- Chloroplast

Microtubule organization

- K1, K2

Hormone transport

- Hormone-based gene regulation

Nucleus

Cell wall synthesis

- B, G, H

Tetrahydrofolate synthesis

- L

Mitochondria

ATP synthesis

- M

A, K3, N

C, D, E, F

Delye et al. 2013.
WHY WORRY ABOUT HERBICIDE-RESISTANT WEEDS?

• ECONOMICS!
  If you do not plan to manage herbicide resistance, then you are likely to lose the utility of effective, inexpensive herbicides.

• ECONOMICS!
  If you are not aware of herbicide resistance, then you may waste your money on re-treatment of resistant weeds.

• ECONOMICS!
  Gr that fail to take the threat of herbicide-resistant weeds seriously may well be left with no herbicide options and skyrocketing weed control costs.
Current Status of Herbicide Resistant Weeds Globally
WEEDSCIENCE.ORG
International Survey of Herbicide-Resistant Weeds
21 Years Online
International Survey of Herbicide-Resistant Weeds
Current Status of Survey – December 2015

• 461 Unique Resistant Biotypes (Species x SOA)

• 247 Species

• 144 Dicots and 103 Grass Weeds

• over 1,200,000 fields/sites

• Approximately 11 new biotypes discovered per year

• WWW.WEEDSCIENCE.ORG
What is Classified as a Unique Case?

• A Unique Species X Site of Action (group or class of herbicide)

• Wild Oat (1, 2, 3, 8, 25)*
  • = 5 Unique cases

• Whilst multiple resistance is recorded separately, they don’t necessarily contribute to unique cases

• Otherwise every combination would contribute to a unique case, and wild oat would potentially account for nearly a hundred combinations

* Letters represent different herbicide sites of action - WSSA Classification of herbicides, this classification system can be found at [http://www.weedscience.org](http://www.weedscience.org).

WSSA number classification system originally developed by Ian Heap in 1990 at University of Manitoba
# Table 3: Herbicide groups based on their mechanism of action

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Group 3</th>
<th>Group 4</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Group 5</th>
<th>Group 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bladex L, Blagal*, Lexone, Sencor</td>
<td>Buctril M*, Hoe-Grass II*, Pardner, Laser*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group 7</th>
<th>Other Herbicides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lorox, Afolan</td>
<td>The herbicides Avadex BW, Assert, Avenge 280C, Carbyne, Eptam Mataven, Stampede, TCA and Basagran are in groups of their own.</td>
</tr>
</tbody>
</table>

* Products contain more than one active ingredient and therefore may appear in more than one group.

** Products not registered of January 1991.

New herbicides do not necessarily have a unique mechanism of action and may fall within the groups listed above.

**Note**: Herbicides that have the same mechanism of action do NOT necessarily control the same weed spectrum or have the same crop safety. For example, Assert and Ally have the same mechanism of action, however, Assert controls wilds oats; Ally does not. Remember to always read and follow label instructions.

Prepared by: Dr. Ian Heap and Dr. Ian Morrison
Department of Plant Sciences
University of Manitoba
How to Delay or Avoid the Development of Resistance

Follow the guidelines below to delay the appearance of resistance.

- **Rotate herbicides**
  Using the same herbicide year after year may cause resistance to develop. To avoid resistance herbicides must be rotated. It is important not only to use a different herbicide but to use one in a different herbicide group with a different mechanism of action. If rotation is not practised, resistant plants escape control and continue to add to the problem. Table 3 lists herbicides in groups with the same mechanism of action. Successive use of products in the same group is not a true herbicide rotation. In planning a herbicide rotation farmers should reserve the use of a group of herbicides for crops where there are few or no alternative classes that could be used.

- **Use herbicides only when needed**
  Herbicides should be used as part of an integrated control program and not as the sole method of weed control. Cultural control practices that favour strong crop competition and timely cultivation can be used effectively to reduce weed populations. Attempting to eradicate a particular weed in a field over 8-10 years with a program using the same herbicide can result in the development of resistance. Weeds should be tolerated in a crop if they are below economic damage levels. Refer to Weed Facts — Knowing When it Pays to Spray Wild Oats — Agdex No. 641, March 1988.

- **Keep records of herbicide applications**
  Records are necessary to make sensible decisions on herbicide rotation and to evaluate the probability of resistance developing. Records should consist of the field location/name, year, crop, herbicides and rates applied, weed infestations present at spraying and the control provided by the herbicide(s). The more detailed the records (e.g. environmental conditions at time of spraying, date and time of spraying, spray volume/acre) the better the chance of accurately interpreting the probable cause of weed control failures.

- **Use of tank mixes**
  In a few special cases, use of a tank mix may delay the appearance of resistance. Use of a tank mix for this purpose is only worthwhile in combating resistance if the components of the tank mix kill the same weed by different mechanisms.

  For instance, either Reline or MCPA will kill lamb's-quarters — each using a different method of killing the plant. Using the tank mix of Reline and MCPA, rather than using one product or the other on its own, means less chance of lamb's-quarters developing herbicide resistance.

  Tank mixing does not delay resistance if the products used in the mix each control different weeds.

How to Tell if You Have Resistance

To date, few instances of poor control by herbicides are due to weed resistance. However, this does not mean the possibility should be ignored. Suspicious situations should be checked out as soon as a problem appears. Before assuming herbicide resistance, rule out all other factors that might have affected herbicide performance including misapplication, spray misses, unfavourable weather conditions, improper leaf staging and weed flushes after application. Having ruled out the above possibilities look for the following:

- Other weeds listed on the product label are controlled satisfactorily,
- Herbicide failure is patchy and there is no reasonable explanation,
In Reality Almost Every Population is a Unique Case

• Each different mutation is a unique case
• Metabolic resistance – levels vary from population to population – each is a unique case
• Gene over expression – number of copies varies from population to population, even differing between individuals – each is a unique case
• Populations can be a mixture of mechanisms, each is a unique case………etc.
Number Resistant Species for Several Herbicide Sites of Action (WSSA Codes)

- ACCase Inhibitors (1)
- ALS Inhibitors (2)
- EPSP Synthase Inhibitors (9)
- Synthetic Auxins (4)
- PSII Inhibitors (5,6,7) [Note: PSII Inhibitors Combined]

Dr. Ian Heap, WeedScience.org 2015
Increase in Unique Herbicide Resistant Weed Cases for Selected Crops

- Corn (maize)
- Wheat
- Soybean
- Rice
- Cotton

Dr. Ian Heap, WeedScience.org 2015
Factors Influencing the Evolution of Resistance

1. Initial resistance gene frequency (for the particular weed/site of action combination)
2. Selection pressure (frequency and efficacy of herbicide use).
3. Number of individuals treated over time
4. Residual activity of the herbicide
5. Genetic basis of resistance (degree of dominance of the resistance trait and the breeding system of the weed)
6. Fitness of the resistance trait
7. Weed Seed Production
8. Seed Dispersal Mechanisms
9. Seed longevity in the soil
Big Drivers of Resistance

• **Number of Individuals Treated**
  • Approximated by area treated x time

• **Species**
  • Some weeds are more prone to resistance than others – *Amaranthus, Lolium, Alopecurus, Echinochloa, and Conyza*

• **Herbicide Chemistry**
  • Number of ways weeds can evolve resistance
    • Resistance Gene Frequency
  • Number of species the herbicide targets
  • Area and time of use
  • These factors account for >90% impact on the outcome of resistance
Area treated by a SOA is very important. Herbicide usage is greatest in:

- **ALS inhibitors**
- ACCase inhibitors
- Glyphosate
- Photosystem II inhibitors
- Synthetic Auxins

### Number of Registered Herbicide Actives

<table>
<thead>
<tr>
<th>Herbicide Sites of Action</th>
<th>Number of Registered Herbicides</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALS inhibitors</td>
<td>56</td>
</tr>
<tr>
<td>PPO inhibitors</td>
<td>28</td>
</tr>
<tr>
<td>Photosystem II inhibitors</td>
<td>26</td>
</tr>
<tr>
<td>Long chain fatty acid inhibitors</td>
<td>26</td>
</tr>
<tr>
<td>Synthetic Auxins</td>
<td>23</td>
</tr>
<tr>
<td>ACCase inhibitors</td>
<td>21</td>
</tr>
<tr>
<td>PSII inhibitor (Ureas and amid)</td>
<td>20</td>
</tr>
<tr>
<td>Microtubule inhibitors</td>
<td>16</td>
</tr>
<tr>
<td>Lipid Inhibitors (thiocarbamat)</td>
<td>14</td>
</tr>
<tr>
<td>Unknown</td>
<td>14</td>
</tr>
<tr>
<td>HPPD inhibitors</td>
<td>10</td>
</tr>
<tr>
<td>Carotenoid biosynthesis inhibitors</td>
<td>7</td>
</tr>
<tr>
<td>PSII inhibitors (Nitriles)</td>
<td>6</td>
</tr>
<tr>
<td>Mitosis inhibitors</td>
<td>3</td>
</tr>
<tr>
<td>Uncouplers</td>
<td>3</td>
</tr>
</tbody>
</table>

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Dr. Ian Heap, WeedScience.org 2015
Herbicide groups vary in the frequency of initial resistant individuals.

**High Frequency**
- ALS inhibitors
- ACCCase inhibitors
- Photosystem II inhibitors

**Low Frequency**
- Glyphosate
- Synthetic Auxins
Weeds vary in their propensity to evolve resistance. Genera very prone to resistance are: *Lolium*, *Echinochloa*, *Amaranthus*, *Conyza*. 

<table>
<thead>
<tr>
<th>Weed Species</th>
<th>Number of Sites of Action</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Lolium rigidum</em></td>
<td>11</td>
</tr>
<tr>
<td><em>Echinochloa crus-galli var. crus-galli</em></td>
<td>10</td>
</tr>
<tr>
<td><em>Poa annua</em></td>
<td>9</td>
</tr>
<tr>
<td><em>Alopecurus myurosoides</em></td>
<td>7</td>
</tr>
<tr>
<td><em>Echinochloa colona</em></td>
<td>7</td>
</tr>
<tr>
<td><em>Eleusine indica</em></td>
<td>7</td>
</tr>
<tr>
<td><em>Amaranthus tuberculatus (=A. rudis)</em></td>
<td>6</td>
</tr>
<tr>
<td><em>Lolium perenne ssp. multiflorum</em></td>
<td>6</td>
</tr>
<tr>
<td><em>Amaranthus palmeri</em></td>
<td>5</td>
</tr>
<tr>
<td><em>Amaranthus hybridus (syn:...</em></td>
<td>5</td>
</tr>
<tr>
<td><em>Ambrosia artemisiifolia</em></td>
<td>5</td>
</tr>
<tr>
<td><em>Avena fatua</em></td>
<td>5</td>
</tr>
<tr>
<td><em>Conyza canadensis</em></td>
<td>5</td>
</tr>
<tr>
<td><em>Kochia scoparia</em></td>
<td>5</td>
</tr>
<tr>
<td><em>Kochia scoparia</em></td>
<td>5</td>
</tr>
<tr>
<td><em>Raphanus raphanistrum</em></td>
<td>5</td>
</tr>
</tbody>
</table>

Source: Dr. Ian Heap, WeedScience.org 2015
North American, South American, and to some extent Australian herbicide-resistance research is focusing on Glyphosate Resistance.

Whilst over reliance of glyphosate in Roundup Ready crops is the main driver of glyphosate resistance it is not the only cause.
Factors Associated with Evolution of Glyphosate Resistant Weeds

• RR Crops (glyphosate use)
  – Glyphosate only
  – Minimum Tillage

• Orchards / Vineyards
  – Glyphosate only
  – Multiple (up to 6) annual app.
  – “Low rates”
  – Minimum Tillage

• Fallow
  – Glyphosate only
  – “Low rates”
  – Minimal Tillage
Glyphosate Resistant Crops Adopted Quickly in North and South America

Glyphosate Resistant Crops saved the corn/soybean farmers from ALS inhibitor, ACCase inhibitor, and Triazine resistant weeds.

- Lower production costs
- Higher yield
- Simplicity
- Convenient
- Flexibility
- Safety (occupational, family, environmental)
- Save time
- Level of control
- Consistency
- Crop safety

Glyphosate Resistant Crops in U.S. (% of planted acres)
3. Find x.

Here it is

SIMPPLICITY

The simplest solutions are often the cleverest
They are also usually wrong
Increase in Glyphosate-Resistant Weeds Worldwide

- Annual Sowthistle
- Tall Windmill Grass
- Red Brome
- Sweet Summer Grass
- Hairy Beggarticks
- Smooth Pigweed
- Spiny Amaranth
- Tropical Sprangletop (Juddsgrass)
- Windmill Grass
- Sumatran Fleabane
- Perennial Ryegrass
- Kochia
- Sourgrass
- Palmer Amaranth
- Woody borerria
- Giant Ragweed
- Hairy Fleabane
- Italian Ryegrass
- Goosegrass
- Rigid Ryegrass
- Horseweed
- Buckhorn Plantain
- Common Ragweed
- Ragweed Parthenium
- Tall Waterhemp
- Johnsongrass
- Junglerice
- Liverseedgrass
- Gramilla mansa
- Wild Radish
- Ripgut Brome
- Annual Bluegrass

Year: 1990 to 2015

Dr. Ian Heap, WeedScience.org 2015
Seven Species account for 99% of the Reported Area Infested with Glyphosate-Resistant Weeds

<table>
<thead>
<tr>
<th>Species</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horseweed</td>
<td>10,000,000</td>
</tr>
<tr>
<td>Palmer Amaranth</td>
<td>6,000,000</td>
</tr>
<tr>
<td>Sourgrass</td>
<td>2,000,000</td>
</tr>
<tr>
<td>Tall Waterhemp</td>
<td>2,000,000</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>200,000</td>
</tr>
<tr>
<td>Johnsongrass</td>
<td>150,000</td>
</tr>
<tr>
<td>Rigid Ryegrass</td>
<td>100,000</td>
</tr>
</tbody>
</table>
Glyphosate-Resistant “Giant” Ragweed in Roundup Ready Maize

Ambrosia trifida
Farmers now using up to 7 herbicide applications plus hand hoeing at a cost up to $360/ha

Glyphosate 4X rate at 3 cm
Glyphosate 4X rate at 10 cm
Glyphosate 4X rate PDIR

Palmer Amaranth (*Amaranthus palmeri*) in Cotton
Spread of glyphosate-resistant Kochia

Photo: Westra, CSU, 2011
## Herbicide Resistant Weeds in Minnesota

<table>
<thead>
<tr>
<th>Weed</th>
<th>Herbicide Resistant Mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common cocklebur</td>
<td>2 (ALS inhibitors)</td>
</tr>
<tr>
<td>Common Lambsquarters</td>
<td>5 (Photosystem II inhibitors)</td>
</tr>
<tr>
<td><strong>Common Ragweed</strong></td>
<td>2 (ALS inhibitors), 9 (EPSP synthase inhibitors)</td>
</tr>
<tr>
<td>Giant Foxtail</td>
<td>2 (ALS inhibitors)</td>
</tr>
<tr>
<td>Giant Green Foxtail</td>
<td>1 (ACCase inhibitors), 2 (ALS inhibitors)</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>2 (ALS inhibitors), 9 (EPSP synthase inhibitors)</td>
</tr>
<tr>
<td>Kochia</td>
<td>2 (ALS inhibitors), 9?</td>
</tr>
<tr>
<td>Redroot Pigweed</td>
<td>5 (Photosystem II inhibitors)</td>
</tr>
<tr>
<td><strong>Tall Waterhemp</strong></td>
<td>2 (ALS inhibitors), 9 (EPSP synthase inhibitors), 14 (PPO inhibitors), 9?</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>5 (Photosystem II inhibitors)</td>
</tr>
<tr>
<td>Wild Oat</td>
<td>1 (ACCase inhibitors), 2 (ALS inhibitors)</td>
</tr>
<tr>
<td>Yellow Foxtail</td>
<td>2 (ALS inhibitors)</td>
</tr>
</tbody>
</table>
Biggest Resistance Challenges

1. Multiple Resistance
2. Non-Target Site Resistance
3. Decline in herbicide discovery
4. Over reliance on a few herbicide resistant crops
5. Farmers not adopting management strategies
Species with Resistance to More than One Site of Action

Year

Number Species with Multiple Resistance

Dr. Ian Heap, WeedScience.org 2014
HOW DID WE (the west) GET HERE?

Up until the 1940’s
- Diversified cropping systems
- Small Farms
- Livestock integrated with cropping
- Tillage
- Hand Weeding
- Significant Losses due to weed control

1940’s to mid 1990’s
- Modern Herbicides
- Larger Farms
- Livestock decoupled from cropping
- Reduced Tillage
- Less Diversity
- Better weed control
- Higher Yields
- Greater Profitability
- Herbicide Resistance
- Diversity in Herbicide SOA’s

1990’s to 2015
- Roundup Ready Crops
- Herbicide Discovery Drops
- Multiple herbicide resistance increases
- Less Tillage and Less Diversity in Weed Control
- Farmers with no clue about conventional weeds and weed control techniques
- Resistance reduces profitability
WHERE ARE WE GOING?

2015 to 2025?

- Re-education of Farmers
- Diversified cropping systems
- Herbicide Resistant Crops (multiple stacked traits)
- A Few New Herbicide Sites of Action
- Adoption of Resistance Management Strategies
- Increased Tillage
- Cover Crops
- Stale Seedbeds
- Integration of Weed Control Systems
- Zero tolerance for weed escapes

2025 into the future?

- Greater Diversity in Cropping Systems
- True Integrated Weed Management Systems
- More New Herbicide Sites of Action (China?)
- Herbicide Resistant Crops
- Cheap Robotic Weeder’s?
- Genetically Engineered Biocontrols
- Blindsided by a New Weed Control Technology
How to Avoid/Delay Resistance

- Rotation of herbicide sites of action.
- **Tank mixing herbicides with different modes of action**
  Both herbicides must be active on the same target species.
- Use pre-emergence herbicides in addition to post-emergence herbicides
- Use full rates
- Use of non-herbicidal weed control where economical

**PRACTICE INTEGRATED WEED MANAGEMENT**
Any consistent practice to control weeds year after year will result in directed evolution towards survival.

The solution is to vary weed control practices and destabilize evolution.

Integrated Weed Management