Herbicide Resistant Weeds

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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 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

SELECTION PRESSURE

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?

• 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
- Late Emergence
- Wrong Stage
- 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

Delye et al. 2013.
<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
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University of Manitoba
Corn and Soybean Herbicide Chart

Repeated use of herbicides with the same site of action can result in the development of herbicide-resistant weed populations.

By Mode of Action (effect on plant growth)

This chart groups herbicides by their modes of action to assist you in selecting herbicides 1) to maintain greater diversity in herbicide use and 2) to rotate among herbicides with different sites of action to delay the development of herbicide resistance.

The Site of Action Group is a classification system developed by the Weed Science Society of America.

<table>
<thead>
<tr>
<th>Site of Action Group</th>
<th>Number of resistant weed species in U.S.</th>
<th>Site of Action</th>
<th>Chemical Family</th>
<th>Active Ingredient</th>
<th>Product Examples (Trade Name)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>ACCase Inhibitors (acetolactate synthase)</td>
<td>Aryloxyphenoxynpropionate</td>
<td>fenoxaprop + fluazifop + quizalofop</td>
<td>component of Fusion + Fusilade BX + Assure II, Targa</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>ALS Inhibitors (acetolactate synthase)</td>
<td>Sulfonylurea</td>
<td>chlorimuron + chlorsulfuron + haloxyfop</td>
<td>Classic + Option + Permit</td>
</tr>
</tbody>
</table>

By Premix

This chart lists premix herbicides alphabetically by their trade names so you can identify the premix’s component herbicides and their respective site of action groups. Refer to the Mode of Action chart on the left for more information.

<table>
<thead>
<tr>
<th>Premix Trade Name</th>
<th>Component</th>
<th>Site of Action Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthem</td>
<td>Zidua, Codex</td>
<td>15</td>
</tr>
<tr>
<td>Authority Assist</td>
<td>Spartan</td>
<td>14</td>
</tr>
<tr>
<td>Authority First</td>
<td>Spartan</td>
<td>14</td>
</tr>
<tr>
<td>Authority MTZ</td>
<td>Spartan</td>
<td>14</td>
</tr>
<tr>
<td>Authority XL</td>
<td>Spartan</td>
<td>14</td>
</tr>
<tr>
<td>Autumn Super</td>
<td>Autumnia</td>
<td>2</td>
</tr>
<tr>
<td>Basis Blend</td>
<td>Resolve</td>
<td>2</td>
</tr>
<tr>
<td>Bicop II Magnum</td>
<td>Dual II Magnum</td>
<td>15</td>
</tr>
<tr>
<td>Boundary</td>
<td>Dual Magnum</td>
<td>15</td>
</tr>
<tr>
<td>Buctifree ATZ</td>
<td>AAttrax</td>
<td>5</td>
</tr>
<tr>
<td>Buil Tetra</td>
<td>Micro-Tech</td>
<td>15</td>
</tr>
<tr>
<td>Gallisto Xtra</td>
<td>Gallisto</td>
<td>27</td>
</tr>
<tr>
<td>Canopy</td>
<td>Classic</td>
<td>2</td>
</tr>
<tr>
<td>Canopy EX</td>
<td>Classic</td>
<td>2</td>
</tr>
<tr>
<td>Capreto</td>
<td>Classic</td>
<td>2</td>
</tr>
<tr>
<td>Cinch ATZ</td>
<td>Lodsil</td>
<td>27</td>
</tr>
<tr>
<td>Cinch ATZ Lite</td>
<td>AAttrax</td>
<td>5</td>
</tr>
<tr>
<td>Corvara</td>
<td>Balance Flexx</td>
<td>27</td>
</tr>
<tr>
<td>Degree Xtra</td>
<td>Degree</td>
<td>15</td>
</tr>
</tbody>
</table>
Current Status of Herbicide Resistant Weeds Globally
International Survey of Herbicide-Resistant Weeds
Current Status of Survey – January 2020

• 510 Unique Resistant Biotypes (Species x SOA)
• 262 Species (152 Dicots and 110 Grass Weeds)
• 93 crops in 70 countries
• over 1,800,000 fields/sites
• Approximately 11 new biotypes discovered per year
• WWW.WEEDSCIENCE.ORG
• 2855 registered users, 618 weed scientists have contributed new cases.
Global Increase in Unique Resistant Cases

- 1st report of triazine resistance - 1968
- RR™ introduced US in 1996
- 1st reports of ALS & ACCase resistance 1980’s
- Roundup resistance
- 1st report of 2,4D resistance - 1956
# Resistant Species for Several Herbicide Sites of Action (WSSA Codes)

- ACCase Inhibitors (1)
- EPSP Syntgase Inhibitors (9)
- PSI Electron Diverter (22)
- HPPD Inhibitors (27)
- PPO inhibitors (14)
- ALS Inhibitors (2)
- Synthetic Auxins (4)
- Microtubule Inhibitors (3)
- PSII Inhibitors (5, 6, 7)

Number of Species

Year

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

- Wheat: 75
- 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
- Railways: 15
- Peas: 13
- Fallow: 12
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**
Acetolactate Synthase Inhibitors (WSSA G2)

- Inhibit the enzyme acetolactate synthase (ALS) preventing the formation of branched chain amino acids - Leucine, isoleucine, and valine
- **IMI = Imidazolinones (6 actives)**
  - Imazapyr, imazaquin, imazethapyr, imazapic, imazamox.
- **PTB = Pyrimidinylthiobenzoates (5 actives)**
  - bispyribac-sodium, pyrithiobac-sodium.
- **SCT = Sulfonylaminocarbonylthiazolinones (2 actives)**
  - flucarbazone-sodium, propoxycarbazone-sodium.
- **SU = Sulfonylureas (32 actives)**
  - Chlorsulfuron, halosulfuron, metsulfuron, nicosulfuron.
- **TP = Triazolopyrimidines (7 actives)**
  - Flumetsulam, diclosulam, penoxsulam.
Acetolactate Synthase Inhibitors

*(Imidazolinone)*

*(Sulfonylurea)*

*(Sulfonylamino carbonyl triazolinone)*

*(Pyrimidinyl thiobenzoate)*

*(Triazolopyrimidinide)*
Chlorimuron (SU) Imazaquin (IMI)

Acetolactate Synthase Enzyme Binding Site being blocked by a Sulfonylurea (chlorimuron) and an Imidazolinoneone (Imazaquin) herbicide
Herbicide groups vary in the frequency of initial resistant individuals.

**High Frequency**
- ALS inhibitors
- ACCase 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*
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

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

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

Here it is

SIMPLICITY
The simplest solutions are often the cleverest
They are also usually wrong
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>20,000,000</td>
</tr>
<tr>
<td>Palmer Amaranth</td>
<td>15,000,000</td>
</tr>
<tr>
<td>Tall Waterhemp</td>
<td>4,000,000</td>
</tr>
<tr>
<td>Sourgrass</td>
<td>3,000,000</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>500,000</td>
</tr>
<tr>
<td>Johnsongrass</td>
<td>250,000</td>
</tr>
<tr>
<td>Rigid Ryegrass</td>
<td>300,000</td>
</tr>
</tbody>
</table>
Glyphosate-Resistant “Giant” Ragweed in Roundup Ready Maize

Ambrosia trifida
Palmer Amaranth (*Amaranthus palmeri*) in Cotton

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
# Resistant Weeds in Oregon - Monocots

<table>
<thead>
<tr>
<th>Plant Name</th>
<th>Groups and Inhibitors</th>
<th>Year</th>
</tr>
</thead>
</table>
| **Italian Ryegrass** *(Lolium perenne ssp. multiflorum)* | Group 1: ACCase inhibitors  
Group 9: EPSP synthase inhibitors  
Group 9: EPSP synthase inhibitors  
Group 10: Glutamine synthase inhibitors  
Group 15: Long chain fatty acid inhibitors | 1987  
2004  
2010  
2010  
2018 |
| **Annual Bluegrass** *(Poa annua)* | Group 16: Lipid Inhibitors  
Group 7: PSII inhibitor (Ureas and amides)  
Group 5: Photosystem II inhibitors  
Group 5: Photosystem II inhibitors  
Group 7: PSII inhibitor (Ureas and amides) | 1994  
1994  
1994  
2000  
2000 |
| **Wild Oat** *(Avena fatua)* | Group 1: ACCase inhibitors  
Group 3: Microtubule inhibitors | 1990  
1990 |
<p>| <strong>Downy Brome</strong> <em>(Cheatgrass)</em> <em>(Bromus tectorum)</em> | Group 2: ALS inhibitors | 1997 |</p>
<table>
<thead>
<tr>
<th>Resistant Weeds in Oregon - Dicots</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Redroot Pigweed</strong> (<em>Amaranthus retroflexus</em>) Group 5 : Photosystem II inhibitors</td>
</tr>
<tr>
<td><strong>Smallseed Flaxfalse</strong> (<em>Camelina microcarpa</em>) Group 2 : ALS inhibitors</td>
</tr>
<tr>
<td><strong>Shepherd's-purse</strong> (<em>Capsella bursa-pastoris</em>) Group 5 : Photosystem II inhibitors</td>
</tr>
<tr>
<td><strong>Kochia</strong> (<em>Kochia scoparia</em>)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Prickly Lettuce</strong> (<em>Lactuca serriola</em>)</td>
</tr>
<tr>
<td><strong>Russian-thistle</strong> (<em>Salsola tragus</em>)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Common Groundsel</strong> (<em>Senecio vulgaris</em>)</td>
</tr>
</tbody>
</table>
Spread of glyphosate-resistant Kochia

Photo: Westra, CSU, 2011
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
Introduction Time of New Herbicide Sites of Action (WSSA codes)

No New Site of Action Introduced in 30 Years!


Year

No New Site of Action Introduced in 30 Years!

Dr. Ian Heap, WeedScience.org 2018
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 2020
- 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?

2020 to 2030?

- 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

2030 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