Roundup Resistant Weeds
Changing Weedscapes of Minnesota

2014 MFVGA Cnf.

Roger Becker

University of Minnesota
Historically, Species Shift

- **Burning**
  - Tall grass prairies
    - Non-woody, warm season species
- **Tilling the prairies**
  - Field bindweed
  - Annual Bdlfs.
Historically, Species Shift

- Herb. and fertilizer
  - 2,4-D / N Bdlfs, -> grasses 50’s 60’s
  - Triazine, acetanilides, DNAs - grasses
    • Simazine, Atrazine, Randox
- Periodicity
  - Phenology, Seed Maturation
    • Wild Proso Millet matures before sweet corn
  - Earlier planting dates -> cool species
    - e.g. Giant foxtail, mustards, kochia
  - Non-residual herbicides -> warm species
    - e.g. Crabgrass, Eragrostis, purslane, carpetweed

Photo: Wolf, KState
Historically, Species Shift

- Rainy or droughty periods
- Reduced or no tillage
  - small seeded species and increased perennials
- Treflan + Sencor t.m. 70’s and 80’s
  - Eastern Black Nightshade
- Imidazolinones 90’s
  - Waterhemp
- Glyphosate 2000’s
  - Mare’s Tail (not MN)
  - Waterhemp
  - Ragweeds
Perennial Weeds, 14 Year Study, Nashua IA

Shoot Density / 0.1 A

It Takes a Village for Weeds Too!

What your neighbors do
*DOES impact you*

- Roundup Ready world will shift the species you face in the non-GMO world
Herbicide Resistant Weed-History

• The first identified herbicide-resistant weed—spreading dayflower (*Commelina diffusa*) resistant to 2,4-D—was identified in 1957 in a sugarcane field in Hawaii.

• Since then, more than 200 weeds resistant to one or more herbicides have been identified worldwide.
### Glyphosate resistant marestail
(3” rosette at treatment)

<table>
<thead>
<tr>
<th>Resistant</th>
<th>Susceptible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Glyphosate rates in lbs. acid equivalent per acre. 24 DAT.</th>
<th>Source: Univ. of Tennessee</th>
</tr>
</thead>
<tbody>
<tr>
<td>.28</td>
<td>.38</td>
</tr>
</tbody>
</table>

*Resistant  Susceptible*
Waterhemp 2007
Rochester, MN

Two applications of Roundup Ultra: 34 oz/A and 40 oz/A
Numerous survivors
Initial burndown
Loss of tap root
Prolific re-growth just above and below soil level

Gunsolus, U Mn Weed Sci.
Photo: Duane Rathmann
Waterhemp 2007  Swift County, MN

“Many waterhemp were killed but a few still survived”

One application of Roundup WeatherMax at 22 oz/A

Gunsolus, U Mn Weed Sci.
Photo: Jim Boersma
Quackgrass Resistance or Tolerance?

Phil Westra’s Ph.D. work at MN 70’s

• 2 of 10 biotypes of quackgrass naturally tolerant to glyphosate
• Evolution of glyphosate tolerant lines over the past 30 years
Variation of Phenotype in Untreated Biotypes

104 oz, 2X, Morrow Co.

Sandusky Co.

Madison Co.

Sensitive

J. Stachler, 2004 – Ohio State University
Common lambsquarters and glyphosate

Two applications of glyphosate

Is it resistance or environment?

Chris Boerboom, Univ. of WI
What factors significantly influenced glyphosate and glufosinate activity across several weed species in the U of M Time of Day Study by K. B. Martinson et al.?

**Glyphosate**
Rate > Temp > Weed Height > Adjuvant > Relative Humidity > Time of Day > Dew

**Glufosinate**
Rate > Temp > Time of Day > Weed Height
Lambsquarters Population, Size, and Rate - Control with Glyphosate (Roundup Ultra Max)

- Untreated
- 13 oz (0.5X)
- 26 oz (1X)
- 52 oz (2X)

2 leaves 0.5-0.75”
8-9 leaves 1.0-1.5”
11-13 leaves 2.75-5.0”

Suscept. Resist.
Suscept. Resist.
Suscept. Resist.

19 DAT

J. Stachler, 2004 – Ohio State University
Evolution of Species Shift in Response to Continuous Practices

Adapted from Gunsolus, U Mn Weed Sci.
Weeds To Watch

Weed communities continually shift in response to management practices.

Failure to properly identify new weeds when they first enter a field may result in the plant becoming permanently established and increase weed management costs.

This poster was a six state effort funded by NC Region Pest Mgmt. Center
We all want to eat a balanced, healthful diet. We seek to serve our families high-quality fruits and vegetables that are nutritious, fresh and flavorful.

High-quality produce starts in the fields where our food is grown. America’s farmers are proud to provide families with sweet corn that is delicious and wholesome.

Biotech sweet corn hybrids for the fresh market help farmers produce safe, nutritious and flavorful food, while reducing the number of insecticide applications.
Performance Series™ Sweet Corn

Bacillus thuringiensis (B.t.)
  • Cry1A.105, Cry2Ab2 and Cry3Bb1

Roundup Ready® Technology
  • Roundup PowerMAX®
  • Roundup WeatherMAX®

• Can not retain seed
• Crop destruct w/in 30 days after harvest
• Identity preserved production
  • Market only in U.S., Canada, Mexico
Minnesota’s Herbicide Resistant Weeds-1.

- **Lambsquarters** *(Chenopodium album)* corn C1/5 - Photosystem II inhibitors (atrazine) 1982
- **Velvetleaf** *(Abutilon theophrasti)* corn C1/5 - Photosystem II inhibitors (atrazine)
- **Redroot Pigweed** *(Amaranthus retroflexus)* corn C1/5 - Photosystem II inhibitors (atrazine) 1991
- **Wild Oat** *(Avena fatua)* sugarbeet, wheat A/1 - ACCase inhibitors (diclofop-methyl) 1991
- **Kochia** *(Kochia scoparia)* cropland, wheat B/2 - ALS inhibitors (imazethapyr, thifensulfuron-methyl, tribenuronmethyl) 1994
- **Common cocklebur** *(Xanthium strumarium)* soybean B/2 - ALS inhibitors (imazethapyr) 1994
Minnesota’s Herbicide Resistant Weeds-2.

- **Giant Foxtail**  
  *(Setaria faberi)*corn, soybean B/2 - ALS inhibitors  
  (imazethapyr, nicosulfuron, primisulfuron-methyl) 1996

- **Robust White Foxtail**  
  *(Setaria viridis var. robusta-alba Schreiber)*soybean A/1 - ACCase inhibitors  
  (fenoxaprop-p-ethyl, fluazifop-P-butyl) 1999

- **Purple Robust Foxtail**  
  *(Setaria viridis var. robusta-purpurea)*soybean A/1 - ACCase inhibitors  
  (fenoxaprop-p-ethyl, fluazifop-P-butyl, sethoxydim) 1999

- **Giant Ragweed**  
  *(Ambrosia trifida)*soybean G/9 - Glycines  
  (glyphosate) 2006

- **Common Waterhemp**  
  *(Amaranthus rudis)*soybean G/9 - Glycines  
  (glyphosate) 2007
HERBICIDE RESISTANT WEEDS - MINNESOTA

According to the International Survey of Herbicide Resistant Weeds, there 418 unique cases of herbicide resistant weeds globally with 228 species (131 dicots and 97 monocots). Weeds have evolved resistance to 21 of the 25 known herbicide sites of action and to 150 different herbicides. In Minnesota, 13 weed species have been recorded as having shown resistance to 6 herbicide sites of action and to 13 herbicides. Four species – Common and Giant ragweeds, Robust White Foxtail, and common waterhemp have shown multiple resistance for two sites of action. The most common resistance occurs in corn and soybean systems with two occurrences in wheat and one in sugar beets.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>First Reported Occurrence</th>
<th>Cropping System</th>
<th>Herbicide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Lambsquarters</td>
<td>Chenopodium album</td>
<td>1982</td>
<td>Corn</td>
<td>atrazine</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>Abutilon theophrasti</td>
<td>1991</td>
<td>Corn</td>
<td>atrazine</td>
</tr>
<tr>
<td>Redroot Pigweed</td>
<td>Amaranthus retroflexus</td>
<td>1991</td>
<td>Corn</td>
<td>atrazine</td>
</tr>
<tr>
<td>Common Waterhemp</td>
<td>Amaranthus tuberculatus (syn. Rudis)</td>
<td>1994, 2007</td>
<td>Soybean</td>
<td>imazethapyr, thifensulfuron-methyl, glyphosate</td>
</tr>
<tr>
<td>Wild Oat</td>
<td>Avena fatua</td>
<td>1991</td>
<td>Sugar beets and wheat</td>
<td>diclofop-methyl</td>
</tr>
<tr>
<td>Kochia</td>
<td>Kochia scoparia</td>
<td>1994</td>
<td>Cropland, wheat</td>
<td>imazethapyr, thifensulfuron-methyl, tribenuron-methyl</td>
</tr>
<tr>
<td>Common Cocklebur</td>
<td>Xanthium strumarium</td>
<td>1994</td>
<td>Soybean</td>
<td>imazethapyr</td>
</tr>
<tr>
<td>Giant Foxtail</td>
<td>Setaria faberi</td>
<td>1996</td>
<td>Corn and soybean</td>
<td>imazethapyr, nicosulfuron, primisulfuron-methyl</td>
</tr>
<tr>
<td>Robust White Foxtail</td>
<td>Setaria viridis var.</td>
<td>1996, 1999</td>
<td>Corn and soybean</td>
<td>imazethapyr, nicosulfuron, primisulfuron-methyl, fenoxaprop-P-ethyl; fluazifop –P-buty</td>
</tr>
<tr>
<td>Yellow Foxtail</td>
<td>Setaria lutescens</td>
<td>1997</td>
<td>Soybean</td>
<td>imazethapyr</td>
</tr>
<tr>
<td>Purple Robust Foxtail</td>
<td>Setaria viridis var.</td>
<td>1999</td>
<td>Soybean</td>
<td>fenoxaprop-P-ethyl; fluazifop –P-buty; sethoxydim</td>
</tr>
<tr>
<td>Common Ragweed</td>
<td>Ambrosia artemisiifolia</td>
<td>1998, 2008</td>
<td>Soybean</td>
<td>cloransulam-methyl, imazapyr, glyphosate</td>
</tr>
<tr>
<td>Giant Ragweed</td>
<td>Ambrosia trifida</td>
<td>2006, 2008</td>
<td>Soybean</td>
<td>cloransulam-methyl, glyphosate</td>
</tr>
</tbody>
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01/07/2014
<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Reported Occurrence</th>
<th>Site of Action</th>
<th>Actives</th>
<th>Trade Names (examples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Lambsquarters</td>
<td>Chenopodium album</td>
<td>1982</td>
<td>Photosystem 2 inhibitors (C1/5)</td>
<td>atrazine</td>
<td>Aatrex, Fenatrol, Atranex; etc.</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>Abutilon theophrasti</td>
<td>1991</td>
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<td>Common Waterhemp</td>
<td>Amaranthus tuberculatus (syn. Rudis)</td>
<td>1994, 2007</td>
<td>ALS inhibitors (B/2) AND Glycines (G/9)</td>
<td>(ALS) imazethapyr; imazapyr; thifensulfuron-methyl AND (Glycine) glyphosate</td>
<td>(ALS) Pursuit, Arsenal, Harmony - (Glycine) RoundUp</td>
</tr>
<tr>
<td>Wild Oat</td>
<td>Avena fatua</td>
<td>1991</td>
<td>ACCase inhibitors (A/1)</td>
<td>diclofop-methyl</td>
<td>Pursuit, Harmony, Express</td>
</tr>
<tr>
<td>Kochia</td>
<td>Kochia scoparia</td>
<td>1994</td>
<td>ALS inhibitors (B/2)</td>
<td>imazethapyr; thifensulfuron-methyl; tribenuron-methyl</td>
<td>Pursuit, Harmony, Express</td>
</tr>
<tr>
<td>Common Cocklebur</td>
<td>Xanthium strumarium</td>
<td>1994</td>
<td>ALS inhibitors (B/2)</td>
<td>imazethapyr</td>
<td>Pursuit</td>
</tr>
<tr>
<td>Giant Foxtail</td>
<td>Setaria faberi</td>
<td>1996</td>
<td>ALS inhibitors (B/2)</td>
<td>(ALS) imazethapyr; nicosulfuron; primisulfuron-methyl</td>
<td>Pursuit, Accent, Beacon</td>
</tr>
<tr>
<td>Robust White Foxtail</td>
<td>Setaria viridis var. robusta-alba</td>
<td>1996, 1999</td>
<td>ALS inhibitors (B/2) AND ACCase inhibitors (A/1)</td>
<td>(ALS) imazethapyr; nicosulfuron; primisulfuron-methyl AND (ACCcase) fenoxaprop-P-ethyl; fluazifop –P-buty</td>
<td>(ALS) Pursuit, Accent, Beacon (ACCcase) Puma, Acclaim, Fusilade</td>
</tr>
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<td>Yellow Foxtail</td>
<td>Setaria lutescens</td>
<td>1997</td>
<td>ALS inhibitors (B/2)</td>
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<td>(ALS) Pursuit, Arsenal, Telar, Beacon (Glycine) RoundUp</td>
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<td>Giant Ragweed</td>
<td>Ambrosia trifida</td>
<td>2006, 2008</td>
<td>ALS inhibitors (B/2) AND Glycines (G/9)</td>
<td>(ALS) cloransulam-methyl AND (Glycine) glyphosate</td>
<td>(ALS) Beacon (Glycine) RoundUp</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>#</th>
<th>Year</th>
<th>Species</th>
<th>Site of Action</th>
<th>Actives</th>
<th>Contacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1982</td>
<td>Chenopodium album</td>
<td>Photosystem II inhibitors (G1/15)</td>
<td>atrazine</td>
<td>Jeffrey Gunsonus</td>
</tr>
<tr>
<td>2</td>
<td>1991</td>
<td>Avena fatua</td>
<td>ACCase inhibitors (A/1')</td>
<td>diclofop-methyl</td>
<td>Jeffrey Gunsonus</td>
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<td>3</td>
<td>1991</td>
<td>Atriplex hortensis</td>
<td>Photosystem II inhibitors (G1/15)</td>
<td>atrazine</td>
<td>Jeffrey Gunsonus</td>
</tr>
<tr>
<td>4</td>
<td>1991</td>
<td>Amaranthus retroflexus</td>
<td>Photosystem II inhibitors (G1/15)</td>
<td>atrazine</td>
<td>Jeffrey Gunsonus</td>
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<td>5</td>
<td>1994</td>
<td>Atriplex pumila var. major</td>
<td>ALS inhibitors (B/2)</td>
<td>imazethapyr; thifensulfuron-methyl</td>
<td>Jeffrey Gunsonus</td>
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<td>6</td>
<td>1994</td>
<td>Kochia scoparia</td>
<td>ALS inhibitors (B/2)</td>
<td>imazethapyr; thifensulfuron-methyl; tribenuron-methyl</td>
<td>Jeffrey Gunsonus</td>
</tr>
<tr>
<td>7</td>
<td>1994</td>
<td>Xanthium strumarium</td>
<td>ALS inhibitors (B/2)</td>
<td>imazethapyr</td>
<td>Jeffrey Gunsonus</td>
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<td>8</td>
<td>1996</td>
<td>Salsola kali var. major</td>
<td>ALS inhibitors (B/2)</td>
<td>imazethapyr; nicosulfuron; primisulfuron-methyl</td>
<td>Jeffrey Gunsonus</td>
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<td>9</td>
<td>1997</td>
<td>Salsola pumila</td>
<td>ALS inhibitors (B/2)</td>
<td>imazethapyr</td>
<td>Jeffrey Gunsonus</td>
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<td>10</td>
<td>1999</td>
<td>Amaranthus retroflexus (AS, glauca)</td>
<td>ALS inhibitors (B/2)</td>
<td>cloransulfuron-methyl; imazethapyr; primisulfuron-methyl</td>
<td>Jeffrey Gunsonus</td>
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<tr>
<td>11</td>
<td>2001</td>
<td>Amaranthus retroflexus (AS, glauca)</td>
<td>ALS inhibitors (B/2)</td>
<td>cloransulfuron-methyl; imazethapyr; primisulfuron-methyl</td>
<td>Jeffrey Gunsonus</td>
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<tr>
<td>12</td>
<td>2001</td>
<td>Amaranthus retroflexus (AS, glauca)</td>
<td>ALS inhibitors (B/2)</td>
<td>cloransulfuron-methyl; imazethapyr; primisulfuron-methyl</td>
<td>Jeffrey Gunsonus</td>
</tr>
<tr>
<td>13</td>
<td>2006</td>
<td>Amaranthus tuberculatus</td>
<td>Multiple Resistance: 2 Sites of Action</td>
<td>glyphosate</td>
<td>Jeffrey Gunsonus, Jeff Stachler</td>
</tr>
<tr>
<td>14</td>
<td>2007</td>
<td>Amaranthus tuberculatus</td>
<td>Glyphosate (G/8)</td>
<td>glyphosate</td>
<td>Jeffrey Gunsonus, Jeff Stachler</td>
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<tr>
<td>15</td>
<td>2007</td>
<td>Amaranthus tuberculatus</td>
<td>Glyphosate (G/8)</td>
<td>glyphosate</td>
<td>Jeffrey Gunsonus, Jeff Stachler</td>
</tr>
<tr>
<td>16</td>
<td>2008</td>
<td>Amaranthus tuberculatus</td>
<td>Glyphosate (G/8)</td>
<td>glyphosate</td>
<td>Jeffrey Gunsonus, Jeff Stachler</td>
</tr>
<tr>
<td>17</td>
<td>2008</td>
<td>Amaranthus retroflexus</td>
<td>Glyphosate (G/8)</td>
<td>glyphosate</td>
<td>Jeffrey Gunsonus, Jeff Stachler</td>
</tr>
<tr>
<td>18</td>
<td>2008</td>
<td>Amaranthus retroflexus</td>
<td>Glyphosate (G/8)</td>
<td>glyphosate</td>
<td>Jeffrey Gunsonus, Jeff Stachler</td>
</tr>
<tr>
<td>19</td>
<td>2010</td>
<td>Amaranthus retroflexus</td>
<td>Glyphosate (G/8)</td>
<td>glyphosate</td>
<td>Jeffrey Gunsonus, Jeff Stachler</td>
</tr>
</tbody>
</table>

## Recent Developments of Resistant Weeds Globally

### Most Recent Cases of Herbicide Resistant Weeds Entered into the Database

<table>
<thead>
<tr>
<th>#</th>
<th>Date Last Updated</th>
<th>Species</th>
<th>Country</th>
<th>First Year</th>
<th>Site of Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>January 8, 2014</td>
<td><em>Coryza canadensis</em></td>
<td>United States (Wisconsin)</td>
<td>2013</td>
<td>Glycines (G/9)</td>
</tr>
<tr>
<td>2</td>
<td>January 8, 2014</td>
<td><em>Ambrosia trifida</em></td>
<td>United States (Wisconsin)</td>
<td>2013</td>
<td>ALS inhibitors (B/2)</td>
</tr>
<tr>
<td>3</td>
<td>January 8, 2014</td>
<td><em>Apera spica-venti</em></td>
<td>Lithuania</td>
<td>2013</td>
<td>ALS inhibitors (B/2)</td>
</tr>
<tr>
<td>4</td>
<td>January 8, 2014</td>
<td><em>Echinocloa crus-galli</em></td>
<td>China</td>
<td>2013</td>
<td>Synthetic Auxins (O/4)</td>
</tr>
<tr>
<td>5</td>
<td>January 7, 2014</td>
<td><em>Phalaris minor</em></td>
<td>India</td>
<td>2013</td>
<td>ALS inhibitors (B/2)</td>
</tr>
<tr>
<td>6</td>
<td>January 7, 2014</td>
<td><em>Echinocloa crus-galli</em></td>
<td>Uruguay</td>
<td>2013</td>
<td>ALS inhibitors (B/2)</td>
</tr>
<tr>
<td>7</td>
<td>January 3, 2014</td>
<td><em>Echinocloa crus-galli</em></td>
<td>Uruguay</td>
<td>2013</td>
<td>Synthetic Auxins (O/4)</td>
</tr>
</tbody>
</table>
| 8   | January 2, 2014   | *Kochia scoparia*        | United States (Montana)      | 2013       | Multiple Resistance: 2 Sites of Action:  
|     |                   |                          |                              |            | Glycines (G/9)                      |
| 9   | January 2, 2014   | *Lolium perenne ssp.*    | United States (Missouri)     | 2013       | Multiple Resistance: 2 Sites of Action:  
|     | *multiflorum*     |                          |                              |            | ACCase inhibitors (A/1)             |
|     |                   |                          |                              |            | ALS inhibitors (B/2)                |
| 10  | January 3, 2014   | *Poa annua*              | United States (California)   | 2013       | Glycines (G/9)                      |
| 11  | January 3, 2014   | *Lolium perenne ssp.*    | United States (North Carolina)| 2012      | Glycines (G/9)                      |
| 12  | January 2, 2014   | *Ambrosia trifida*       | United States (Missouri)     | 2011       | Multiple Resistance: 2 Sites of Action:  
|     |                   |                          |                              |            | ALS inhibitors (B/2)                |
| 13  | January 2, 2014   | *Coryza canadensis*      | United States (Kansas)       | 2011       | Multiple Resistance: 2 Sites of Action:  
|     |                   |                          |                              |            | ALS inhibitors (B/2)                |
| 14  | December 29, 2013 | *Ambrosia artemisiifolia*| United States (Minnesota)    | 2010       | Multiple Resistance: 2 Sites of Action:  
|     |                   |                          |                              |            | ALS inhibitors (B/2)                |
| 15  | January 2, 2014   | *Amaranthus tuberculatus*| United States (Missouri)     | 2009       | Multiple Resistance: 2 Sites of Action:  
|     | (*A. rudis*)      |                          |                              |            | ALS inhibitors (B/2)                |
| 16  | January 5, 2014   | *Galium aparine*         | Turkey                       | 2008       | ALS inhibitors (B/2)                |
| 17  | December 29, 2013 | *Amaranthus tuberculatus*| United States (Minnesota)    | 2007       | Multiple Resistance: 2 Sites of Action:  
|     | (*A. rudis*)      |                          |                              |            | ALS inhibitors (B/2)                |
| 18  | December 30, 2013 | *Setaria viridis*        | United States (Montana)      | 2005       | ACCase inhibitors (A/1)             |
| 19  | January 7, 2014   | *Phalaris minor*         | India                        | 1994       | ACCase inhibitors (A/1)             |
| 20  | December 29, 2013 | *Amaranthus tuberculatus*| United States (Minnesota)    | 1994       | ALS inhibitors (B/2)                |
The following two pie charts show the lifecycle duration for all of the herbicide-resistant weeds in the database in comparison to the lifecycle duration of 3,272 known weeds. It is clear that herbicide-resistant weeds are more likely to be annuals or biennials than perennials in comparison to weeds in general.
Please note: The graph does not necessarily plot multiple resistance in the same individual plant. Resistance to different SOA's may be found in separate populations, even in separate countries, this chart presents the cumulative number of SOA's recorded globally for a species. No Species Graph.
Palmer and Waterhemp

**Palmer**
- Dioecious
- Tremendous seed producer
- Herbicide resistant
  - ALS (#2), PSII (#5), glycines (#9), DNA (#3)

**Waterhemp**
- Dioecious
- Tremendous seed producer
- Herbicide resistant
  - ALS (#2), PSII (#5), glycines (#9), HPPD (#27), PPO (#14), 2,4-D (#4)
**Palmer and Waterhemp**

**Palmer**

- Native to the desert Southwest
- Most competitive of the Amaranth sp.
- Growth rate as fast as ~2.5”/day

**Waterhemp**

- Native to the Midwest
- 2nd most competitive of the Amaranth sp.
- Growth rate as fast as ~1.75”/day

[http://www.extension.iastate.edu/CropNews/2013/0820hartzlerpope.htm](http://www.extension.iastate.edu/CropNews/2013/0820hartzlerpope.htm)  
Hand Weeding
Hand Weeding
Herbicide Resistance
(wssa.net/weeds/resistance)

How Herbicides Work

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Herbicide Resistance Types

Single Herbicide Resistance
• Resistant to only **one** herbicide

Cross Herbicide Resistance
• Resistant to **two or more** herbicide families with *same mechanism of action*
• Single resistance mechanism

Multiple Herbicide Resistance
• Resistant to **two or more** herbicides with *different mechanisms of action*
• May be the result of two or more different resistance mechanisms
Herbicide Resistance Types: Cross Resistance

Example:

Revolver, a sulfonylurea, and Velocity, a pyrimidinyloxybenzoic acid, both belong to the ALS-inhibitors, or group 2 herbicides. Both herbicide products have the same mechanism of action.

CAUTION: Weeds that are herbicide-resistant to one member of a herbicide mechanism of action group may or may not be cross-resistant to all herbicides within that group. Consult your local extension specialist for more information.
Herbicide Resistance Types: Multiple Resistance

Example

Apply atrazine

Years 1-5

Select for weeds resistant to group 5 herbicides (shown in black)

The population with resistance to group 5 herbicides increases

Years 5-8

Switch to and apply Barricade®

Years 8-13

Select for weeds resistant to group 3 herbicides (shown in pink) from a population that is resistant to group 5

The population with multiple resistance to group 3 and 5 increases

Years 14 +

Multiple resistance can occur following repeated applications of a single herbicide and selection for herbicide-resistant biotypes followed by repeated applications of another herbicide and selection for herbicide-resistant biotypes.
Conclusions

Repeated use of a herbicide selects for herbicide-resistant biotypes. Over time, the number of resistant individuals in the weed population increases until the majority of the population is herbicide-resistant.

Several factors in the field can affect the selection of herbicide-resistant weeds.

Once a weed is resistant to a single herbicide, it is possible for it to be resistant to another herbicide, with either the same or a different mechanism of action.
Herbicide Resistance Characteristics

**Low-Level Resistance**
- A continuum of plant responses from slightly injured to nearly dead
- The majority of plants display an intermediate response
- Susceptible plants will be present in the population, especially when herbicide resistance is determined early

**Examples**
- Roundup, etc.: GROUP 9 HERBICIDE
- Ronstar, Dismiss, etc.: GROUP 14 HERBICIDE
- Banvel, 2,4 D, etc.: GROUP 4 HERBICIDE
- Gramoxone, etc.: GROUP 22 HERBICIDE

**High-Level Resistance**
- Plants are slightly injured to uninjured
- Few plants have an intermediate response
- Susceptible plants can be present in the population

**Examples**
- Atrazine, Princep, Sencor, etc.: GROUP 5 HERBICIDE
- Revolver, Monument, Velocity, etc.: GROUP 2 HERBICIDE
- Acclaim, Fusilade, Segment, etc.: GROUP 1 HERBICIDE

– A continuum of plant responses from slightly injured to nearly dead
– The majority of plants display an intermediate response
– Susceptible plants will be present in the population, especially when herbicide resistance is determined early
Classification Hierarchy

Example

Mode of Action

Mechanism of Action

Herbicide Family

Herbicide Name

Lipid Synthesis Inhibitors

Group 1 ACCase Inhibitors

One MOA

“Dims”

“Fops”

“Dens”

Sethoxydim “Segment” etc.

Fluazifop-P-butyl “Fusilade” etc.

Pinoxaden “Axial” etc.
Integrated Management

The best strategies to manage herbicide resistance in weeds are established on the concept of diversity of management practices.

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

A combination of tactics reduces the selection pressure imposed by any single practice.

Mechanism of action (MOA) is the biochemical site within a plant with which a herbicide directly interacts. Herbicides with different MOAs are identified by different group numbers. For example, 2,4-D is a group 4 herbicide, and glyphosate is a group 9 herbicide.
Proactive Management Tactics

Strategies to proactively delay herbicide resistance can include one or more of the following tactics:

**Herbicide**
- Multiple herbicides with different mechanisms of action
  - Mixes
  - Sequence
  - Across seasons

**Mechanical**
- Cultivation
  - Timing (pre-plant, in-crop, post-harvest)
  - Frequency

**Cultural**
- Species and cultivar selection
- Plant population
- Fertilization
- Row spacing
- Crop Rotations
- Crop Phenology/planting harvest dates
- Fallow periods / hay or cover crops

*Photo credits: Jim Brosnan, University of Tennessee.*

[Photo credits](http://masonkings.jd-dealer.co.uk/Services/Health-Safety/Cultivator-Safety).

[Photo credits](http://seasonsinthevalley.blogspot.com/2013/06/grey-county-farming-hay-harvest.html).

[Photo credits](http://seasonsinthevalley.blogspot.com/2013/06/grey-county-farming-hay-harvest.html).
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.

**SUSTAINABLE**

- Season 3: Group 5 plus 2
- Season 1: Group 21 plus 2
- Season 2: Group 14 plus 3

**NOT SUSTAINABLE**

Season 3: Group 2
Season 1: Group 2
Season 2: Group 2

*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 mechanisms of action (MOA) to manage herbicide resistance are:

1. Mixture application
2. Sequentially throughout season
3. Across multiple seasons

These options can provide the flexibility to choose the best fit or combinations of fit for local agronomic operations.

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.
Midwest Vegetable Production Guide for Commercial Growers

U of M contributions
Roger Becker, Vince Fritz
Bill Hutchison, Eric Burkness
Carl Rosen, Jerry Wright

http://btny.purdue.edu/Pubs/ID/ID-56/
New Herbicides In Sweet Corn

- Future?
  - Distinct (difuflenzopyr & dicamba)
  - Liberty (glufosinate)
  - Capreno?
New Herbicides In Sweet Corn

Zidua soil applied (pyroxasulfone, BASF)

• Many grass and broadleaf weeds
• PPI, PRE
• E. POST at spiking up to V4 (4 leaf collars visible)
  • Will not control emerged weeds
  • Do not use adjuvants
• Seed at least 1 inch deep
• Do not exceed 2.75 oz. per acre per season on coarse soils, 5 oz. per acre per season on other soils
• 37-day PHI.
### New Herbicides In Sweet Corn

Zidua (pyroxasulfone, BASF)

<table>
<thead>
<tr>
<th>Application Timing</th>
<th>Use Rate by Soil Texture (ozs/A)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coarse</td>
</tr>
<tr>
<td>Preplant surface</td>
<td>1.5 to 2.75</td>
</tr>
<tr>
<td>Preplant incorporated</td>
<td>1.5 to 2.75</td>
</tr>
<tr>
<td>Preemergence</td>
<td>1.5 to 2.75</td>
</tr>
<tr>
<td>Early postemergence</td>
<td>1.0 to 2.75</td>
</tr>
</tbody>
</table>
New Herbicides In Sweet Corn

Cadet POST (processing only?) (fluthiacet-methyl, FMC)
- 0.6-0.9 fl. oz. per acre
- from 2 collars to tasseling
- Broadleaf weeds
  - e.g. pigweed/waterehemp, vele, pesw, wibw, ebns, Kochia
  - Improves many others in T. M.
- Add COC or NIS
- Do not exceed 1.25 fl. oz. per acre per year
- 40-day PHI
New Herbicides In Sweet Corn

Anthem soil applied (pyroxasulfone + fluthiacet-methyl, FMC)

- Rates vary with texture, O.M.
- Controls many broadleaf and grass weeds
- 1 application per season to sweet corn
- 18-month replant restriction for all crops except corn
- 40-day PHI
New Herbicides In Sweet Corn

Anthem POST (pyroxasulfone + fluthiacet-methyl, FMC)

POST is also soil texture O.M. dependent

<table>
<thead>
<tr>
<th>ANTHEM fl oz/A (lb a.i./A)</th>
<th>COARSE</th>
<th>MEDIUM</th>
<th>FINE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 - 8</td>
<td>6 - 9</td>
<td>7 - 12</td>
</tr>
<tr>
<td></td>
<td>(0.084-0.135)</td>
<td>(0.101-0.152)</td>
<td>(0.118-0.202)</td>
</tr>
</tbody>
</table>

- NIS or a silicone-based SU @ 8 fl. oz. / 25 gals. solution
- COC or MSO at 1-2 pts. /A
- may add UAN at 1-2 qts. /A or AMS

•Controls some broadleaf weeds < 2in. in height
New Herbicides In Sweet Corn

Anthem POST

• May temporarily injure sweet corn
  • If foliage is wet at application
  • Do not irrigate w/in 4 hr. of application
  • Some varieties sensitive

• 1 application per season

• 18-month replant restriction all crops except corn

• 40-day PHI
Soil Applied Herbicide Options

Preemergence options
• Annual grasses:
  • Metolachlor products, Outlook, Micro-Tech, Prowl, Define, Acetochlor products (Harness, Surpass), Eradicane, Zidua, Anthem
• Annual broadleaves:
  • Atrazine, Princep, Callisto, Zidua, Anthem

Premixes
• G-Max Lite (Outlook + atrazine)
• Bicep Lite II Magnum (Dual II Magnum + atrazine)
• Bullet or Lariat (Micro-Tech + atrazine)
• Camix, Lumax, Lexar
• Anthem ATZ
Postemergence Herbicide Options

Annual grasses
• Accent*, Accent Q*
• Poast, Poast Plus (Poast Protected varieties)
• Option*

Annual broadleaves
• Aim
• Anthem, (early, ATZ)
• Atrazine*
• Basagran
• Cadet
• Callisto
• Impact*

• Laudis*
• Permit/Sandea
• Starane
• Stinger
• 2,4-D

* Activity on grasses and broadleaves
Postemergence Herbicide Options (Cont.)

POST Package Mixtures

• Laddok (atrazine + Basagran)
• Priority (Aim + Permit / Sandea)

Roundup Tolerant Lines

• Roundup New as of 2012
The Underlying Cause of Weed Species Shifts

- A lack of diversification of weed management and other primary agronomic practices such as tillage and crop rotation

- Economics and time / labor management are often the primary reasons behind this lack of diversification
Recommendations Specific to glyphosate

• Consider sequential herbicide programs using a soil-applied herbicide with a different site of action.

• Spray weeds at the proper time and with the proper rate.

• Avoid continuous glyphosate-resistant crops.

• Consider the advantages and disadvantages of the continued use of one herbicide versus rotation of herbicides.
Weed Management in a Glyphosate Dominated World

Weed species shift potential
• The potential exists but which species?

Durable weed management strategies
• Diversification increases durability

Economics of corn and soybean weed management strategies
• You can pay now ($) or pay later (weed shifts)
• Factor time and labor management into your economic equation
Species Shifts

Change in weed infestation
- Species
- Biotypes

Why?
- No control tactic is equally effective against all weeds
What Does Glyphosate Resistance Look Like?

Photo Credits to Dave Nicolai & Jeff Stachler

Glyphosate Injury

Dying?

Not Dying

Glyphosate Injury

Single Species

Patchy Distribution
Weed Management in a Glyphosate Dominated World

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