Herbicide Resistance

The ability of a weed biotype to survive treatment with a given herbicide to which the weed species is normally susceptible.

Resistant biotypes are genetically different from susceptible biotypes.
# History of KS confirmed resistant weeds

<table>
<thead>
<tr>
<th>Weed Species</th>
<th>Herb Mode of Action</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Bindweed</td>
<td>Synthetic Auxins (2,4-D)</td>
<td>1964</td>
</tr>
<tr>
<td>Kochia</td>
<td>PSII (atrazine)</td>
<td>1976</td>
</tr>
<tr>
<td>Downy brome</td>
<td>PSII (atrazine)</td>
<td>1977</td>
</tr>
<tr>
<td>Kochia</td>
<td>ALS (chlorsulfuron)</td>
<td>1987</td>
</tr>
<tr>
<td>Russian thistle</td>
<td>ALS (chlorsulfuron)</td>
<td>1988</td>
</tr>
<tr>
<td>Palmer amaranth</td>
<td>PSII (atrazine)</td>
<td>1991</td>
</tr>
<tr>
<td>Palmer amaranth</td>
<td>ALS (imazethapyr)</td>
<td>1995</td>
</tr>
<tr>
<td>Redroot pigweed</td>
<td>PSII (Atrazine)</td>
<td>1995</td>
</tr>
<tr>
<td>Waterhemp</td>
<td>ALS (imazethapyr, thifensulfuron)</td>
<td>1995</td>
</tr>
<tr>
<td>Waterhemp</td>
<td>PSII (atrazine)</td>
<td>1995</td>
</tr>
<tr>
<td>Common sunflower</td>
<td>ALS (imazethapyr)</td>
<td>1996</td>
</tr>
<tr>
<td>Shattercane</td>
<td>ALS (nicosulfuron, primisulfuron)</td>
<td>1996</td>
</tr>
<tr>
<td>Common cocklebur</td>
<td>ALS (chlorimuron, imazaquin)</td>
<td>1997</td>
</tr>
<tr>
<td>Waterhemp</td>
<td>PPO (acifluorfen, fomesafen)</td>
<td>2001</td>
</tr>
<tr>
<td>Horseweed-marestail</td>
<td>EPSPS (glyphosate)</td>
<td>2005</td>
</tr>
<tr>
<td>Bushy Wallflower/Flixweed</td>
<td>ALS (several)</td>
<td>2005/07</td>
</tr>
<tr>
<td>Waterhemp&amp; Giant ragweed</td>
<td>EPSPS (glyphosate)</td>
<td>2006</td>
</tr>
<tr>
<td>Common ragweed &amp; Kochia</td>
<td>EPSPS (glyphosate)</td>
<td>2007</td>
</tr>
<tr>
<td>Cheat &amp; Japanese Brome</td>
<td>ALS (imazamox, propoxycarbazone, pyroxsulam, sulfosulfuron)</td>
<td>2007</td>
</tr>
</tbody>
</table>
How does herbicide resistance develop?

- Mutation occurs in plants in response to exposure to herbicide treatment.
- Selection of individual biotypes within a population that are naturally more tolerant to a herbicide. Repeated exposure results in a shift in the population from one that is initially susceptible to one that is no longer controlled by the herbicide.
How does herbicide resistance develop?

- Mutation occurs in plants in response to exposure to herbicide treatment.
- Selection of individual biotypes within a population that are naturally more tolerant to a herbicide. Repeated exposure results in a shift in the population from one that is initially susceptible to one that is no longer controlled by the herbicide.
The degree of herbicide resistance can vary depending on:

- Mechanism of resistance
- Inheritance of resistance
  - Single vs multiple genes
  - Dominant vs recessive
Mechanisms of Herbicide Resistance

- Altered site of action
  - Often a high degree of resistance
- Enhanced metabolism/detoxification
- Sequestration
- Reduced absorption & translocation

Often a lower degree of resistance and more rate responsive
Altered Site of Action
Herbicide Cross Resistance

Weed resistance to different herbicides due to the same mechanism of resistance.

ALS herbicides

- Sulfonylureas: Glean, Accent, Permit, Maverick, Peak, etc.
- Imidazolinones: Pursuit, Raptor, Cadre
- Triazolopyrimidines: Python, FirstRate
Herbicide Multiple Resistance

- Weed biotypes with resistance to herbicides with multiple resistant genes and different mechanisms of resistance.
- Examples: kochia that are resistant to both triazine and ALS inhibiting herbicides. Waterhemp with resistance to triazine, ALS and PPO inhibitor herbicides.
Waterhemp resistant to triazine and ALS herbicides
Inheritance of Herbicide Resistance

- Single gene resistance
  - Simple
  - Quicker to develop

- Multiple gene resistance
  - Complex
  - Slower to develop
Weed Characteristics that Favor Resistance

❖ Species with broad genetic diversity
  ➢ Species that readily cross pollinate
  ➢ Species that hybridize with related species

❖ Species with rapid turnover rate
  ➢ High seed production
  ➢ Short seed life
Herbicide Characteristics that Favor Resistance

- Herbicides with a very specific site of action.
- Herbicides that have long residual effects in the soil.
- Herbicides with a high degree of selectivity.
Management factors that favor resistance:

_selection Pressure_

- ‘Stand alone’ herbicide weed control program (no other tactics)
- Herbicide applied multiple times during the growing season
- Herbicide used for consecutive seasons; OR repeated application with same site of action to same or different crops
- Limited crop rotation
- Minimum or no-tillage system
Do I have resistant weeds?

- Surviving plants (escapes) in middle of a group of dead plants?
- Have used same herbicide “mode of action” for several years?
- Herbicide failure not a result of:
  - Unfavorable environmental conditions
  - Inadequate spray coverage
  - Oversized weed plants at application
  - Inadequate herbicide rate
Palmer amaranth Biotype Response to Pursuit
Best defense against herbicide resistant weeds

Avoid continuous selection for R-biotypes

- Rotate and/or tankmix herbicides with different sites of action, within and across years
- Crop rotation
- Include other control tactics (cultivation, prevention, crop competition, cultural practices)
- “Use the proper rate at the proper time”
How does herbicide rate affect resistance development?

Higher rates may enhance selection for single gene, highly resistant biotypes.

Lower rates will select for multi-gene, low level rate creep or marginally controlled weeds.
Glyphosate Resistance Update

Dallas Peterson
Kansas State University
Glyphosate Resistant Weeds

- **Annual ryegrass:** 1996 - Australia, California, South America, S. Africa
- **Goosegrass:** 1997 - Malaysia
- **Horseweed/marestail:** 2000 - East, South and Midwest US.
- **Common Ragweed:** 2004 - Missouri, Kansas
- **Giant Ragweed:** 2004 - Ohio, Indiana, Kansas
- **Palmer Amaranth:** 2005 - Georgia, Southeast US
- **Waterhemp:** 2005 - Missouri, Illinois, Kansas
- **Johnsongrass:** 2006 - Argentina, Arkansas
- **Kochia** 2007 - Kansas
- **Lambsquarters?**
Confirmed Glyphosate Resistant Weeds in Kansas

- Marestail
- Common waterhemp
- Giant ragweed and common ragweed
- Kochia
Marestail Escapes from Glyphosate
Glyphosate Resistant Marestail Assay – 2 WAT

Sumner Co. →

Miami Co. →

Check →

Glyphosate Rate: 1 pt 1 qt 1.5 qt 0
Glyphosate Resistant Marestail Assay – 4 WAT

Sumner Co. →

Miami Co. →

Check →

Glyphosate Rate: 1 pt 1 qt 1.5 qt 0
Managing Marestail

- Timing, Timing, Timing!
- Atrazine + 2,4-D in corn or sorghum
- Utilize 2,4-D, dicamba, Sharpen and/or residual herbicides in fall and early spring burndown in no-till.
- Control marestail in the wheat crop.
- Don’t skimp on rate or appropriate spray additives.
- Use appropriate treatments.
Continuous soybeans for many years, RR soybeans with at least one application of glyphosate since 1996

Waterhemp also ALS and PPO resistant, but not triazine resistant
NWMO1 Biotype Glyphosate Dose-Response

None  1 pt  1 qt  2 qt  1 gal  2 gal

(Rate of 3# ae glyphosate/A)

Kevin Bradley,
University of Missouri
Common Waterhemp Biotype Response to 0.75 lb ae Glyphosate/A

Susceptible  Moderately Tolerant  Resistant

Kevin Bradley, University of Missouri
Glyphosate Resistant Waterhemp Management

 Foundation preemergence herbicides
   Corn: Atrazine premixes, Lexar/Lumax, Balance Flexx, Sharpen, Verdict
   Soybeans: Prefix, Authority, Valor, Fierce, Intrro

 Postemergence herbicide options
   Corn – Callisto, Laudis, Impact, Status
   Soybean – Flexstar, Cobra, Ultra Blazer
Glyphosate Resistant Giant Ragweed Assay

Rate: 8X 4X 3X 2.5X 2X 1.5X 1X 1/2X 1/4X 0X
Glyphosate Resistant Ragweed Management

่าย Timing, Timing Timing!
- Both species are early spring germinators.
- Control prior to planting when ragweed less than 4 inches.

Alternative/Tank Mix herbicides:
- Corn&Sorghum - 2,4-D, Sharpen, dicamba, Integrity, and/or atrazine.
- Soybeans - 2,4-D (preplant), Sharpen (preplant to preemergence), or FirstRate in soybeans.
Touchdown + 2,4-D (PP) / Touchdown
One Meandering Row of Uncontrolled Kochia
Glyphosate Resistant Kochia?

Poor control of a wandering row of kochia with glyphosate was observed in a field of Roundup Ready cotton in Stevens county, KS in the summer of 2007.

Kochia seed was collected from the uncontrolled plants in the cotton field in Stevens county and from an uncropped area in Finney county in the fall of 2007.

Greenhouse experiments were conducted to compare the efficacy of glyphosate at various rates on the two kochia populations.
Materials and Methods

- S and R biotypes of kochia were grown in the greenhouse and treated when plants were 1 to 2 inches tall.
- Kochia plants were treated with Roundup Weather Max at 0.38, 0.75, 1.5, and 3 lb ae/a (11, 22, 44, & 88 oz/A).
- Weed control was visually evaluated 2 and 4 weeks after treatment.
Kochia biotype response to glyphosate, 4 WAT.

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Rate ae (lb/a)</th>
<th>Rate Product (oz/a)</th>
<th>Biotype Finney (% control)</th>
<th>Biotype Stevens (% control)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roundup WMax + AMS</td>
<td>0.38</td>
<td>11</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td>&quot;</td>
<td>0.75</td>
<td>22</td>
<td>100</td>
<td>42</td>
</tr>
<tr>
<td>&quot;</td>
<td>1.12</td>
<td>33</td>
<td>100</td>
<td>76</td>
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<tr>
<td>&quot;</td>
<td>1.5</td>
<td>44</td>
<td>100</td>
<td>92</td>
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<td>&quot;</td>
<td>2.25</td>
<td>66</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>&quot;</td>
<td>3</td>
<td>88</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>LSD (5%)</td>
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<td></td>
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</table>
Kochia biotype response to glyphosate, 4 WAT.

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Rate ae (lb/a)</th>
<th>Rate Product (oz/a)</th>
<th>Biotype Finney (% Mortality)</th>
<th>Biotype Stevens (% Mortality)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roundup WMax + AMS</td>
<td>0.38</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&quot;</td>
<td>0.75</td>
<td>22</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>&quot;</td>
<td>1.12</td>
<td>33</td>
<td>100</td>
<td>45</td>
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<tr>
<td>&quot;</td>
<td>1.5</td>
<td>44</td>
<td>100</td>
<td>75</td>
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<td>&quot;</td>
<td>2.25</td>
<td>66</td>
<td>100</td>
<td>100</td>
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<tr>
<td>&quot;</td>
<td>3</td>
<td>88</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>LSD (5%)</td>
<td></td>
<td></td>
<td></td>
<td>13</td>
</tr>
</tbody>
</table>
Glyphosate Resistant Kochia? (9 DAT)

Stevens Co.

Finney Co.

Roundup WMax:

Untreated 0.38 lb (11 oz) 0.75 lb (22 oz) 1.5 lb (44 oz) 2.25 lb (66 oz) 3 lb (88 oz)
Glyphosate Resistant Kochia? (2 WAT)

Stevens Co.

Finney Co.

Roundup WMax:

Untreated 0.38 lb (11 oz) 0.75 lb (22 oz) 1.5 lb (44 oz) 2.25 lb (66 oz) 3 lb (88 oz)
Glyphosate Resistant Kochia?
(5 WAT)

Stevens Co.
Finney Co.

Roundup WMax:

<table>
<thead>
<tr>
<th></th>
<th>Untreated</th>
<th>0.38 lb</th>
<th>0.75 lb</th>
<th>1.13 lb</th>
<th>1.5 lb</th>
<th>2.25 lb</th>
<th>3 lb</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(11 oz)</td>
<td>(22 oz)</td>
<td>(33 oz)</td>
<td>(44 oz)</td>
<td>(66 oz)</td>
<td>(88 oz)</td>
</tr>
</tbody>
</table>
Kochia Population Response to Glyphosate
Jason Waite

Ten kochia populations from diverse cropping systems in KS, ID and WA were evaluated in the greenhouse, including 3 suspicious populations from western Kansas.

Treated with 0X, 1/16X, 1/8X, 1/4X, 1/2X, 1X, 1.5X, 2X, 4X, and 6X the standard rate of 0.75 lb ae glyphosate per acre.

Kochia treated when 5 inches tall.
Dose Response
Materials and Methods

- Visual injury evaluated 7, 14, and 21 days after treatment
  - 0 = no injury, 100 = mortality
- GR$_{50}$ - rate required to cause 50% visual injury
  - Calculated using non-linear regression
- Resistant Index - Resistance relative to the most susceptible population
  - Calculated by dividing GR$_{50}$ of desired population by the GR$_{50}$ of Jerome County
- Randomized complete block design with 14 replications
  - Study was repeated
Dose Response

Visible rating of Ingalls vs Jerome County population as affected by glyphosate 21 DAT

Ingalls $R^2=0.9975$
Jerome County $R^2=0.9943$

Jason Waite
## Dose Response

$GR_{50}$ for kochia populations.

<table>
<thead>
<tr>
<th>Location</th>
<th>$GR_{50}$</th>
<th>Location</th>
<th>$GR_{50}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingalls, KS</td>
<td>2.47</td>
<td>Minidoka County, ID</td>
<td>0.78</td>
</tr>
<tr>
<td>Norton, KS</td>
<td>1.80</td>
<td>Prosser, WA</td>
<td>0.69</td>
</tr>
<tr>
<td>Stevens County, KS</td>
<td>1.52</td>
<td>Eden, ID</td>
<td>0.69</td>
</tr>
<tr>
<td>Syracuse, KS</td>
<td>0.79</td>
<td>Research Center, WA</td>
<td>0.67</td>
</tr>
<tr>
<td>Hays, KS</td>
<td>0.78</td>
<td>Jerome County, ID</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Jason Waite
### Dose-Response

Resistant Index for kochia populations.

<table>
<thead>
<tr>
<th>Location</th>
<th>Resistant Index</th>
<th>Location</th>
<th>Resistance Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingalls, KS</td>
<td>4.57</td>
<td>Minidoka County, ID</td>
<td>1.44</td>
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<tr>
<td>Norton, KS</td>
<td>3.33</td>
<td>Prosser, WA</td>
<td>1.28</td>
</tr>
<tr>
<td>Stevens County, KS</td>
<td>2.81</td>
<td>Eden, ID</td>
<td>1.28</td>
</tr>
<tr>
<td>Syracuse, KS</td>
<td>1.46</td>
<td>IAREC, WA</td>
<td>1.24</td>
</tr>
<tr>
<td>Hays, KS</td>
<td>1.44</td>
<td>Jerome County, ID</td>
<td>1</td>
</tr>
</tbody>
</table>

*Jason Waite*
IAREC, 5 inch kochia, 14 DAT

INKS, 5 inch kochia, 14 DAT
Stage of Growth Influence

Materials and Methods

- INKS, EDID, IAREC and NTKS populations
- Plants were treated at 2.5, 5, and 10 inch heights at rates of glyphosate similar to the dose response study.
- Treatments were replicated 6 times
  - Study was repeated
Response of 2.5 inch Kochia to glyphosate, 21 DAT

- **NTKS**
  - Equation: $y=0.2004+99.8242/[1+(x/0.7784)^{7.5220}]$
  - $R^2=1.00$

- **INKS**
  - Equation: $y=-0.5523+99.9696/[1+(x/0.9409)^{7.0516}]$
  - $R^2=0.99$

- **EDID**
  - Equation: $y=-0.5223+100.7340/[1+(x/0.3978)^{4.0775}]$
  - $R^2=0.99$

- **IAREC**
  - Equation: $y=-0.8001+99.1854/[1+(x/0.2485)^{4.1061}]$
  - $R^2=0.99$
Response of 5 inch Kochia to glyphosate, 21 DAT

\[ \text{NTKS } y = -3.6006 + \frac{104.6668}{1 + \left(\frac{x}{1.4829}\right)^{1.8348}} \]
\[ R^2 = 0.98 \]

\[ \text{INKS } y = -12.0201 + \frac{113.0159}{1 + \left(\frac{x}{1.8137}\right)^{1.7008}} \]
\[ R^2 = 0.98 \]

\[ \text{EDID } y = 0.0837 + \frac{98.7465}{1 + \left(\frac{x}{0.7012}\right)^{3.8765}} \]
\[ R^2 = 0.99 \]

\[ \text{IAREC } y = -0.1415 + \frac{97.0716}{1 + \left(\frac{x}{0.4233}\right)^{5.8014}} \]
\[ R^2 = 0.99 \]
Response of 10 inch Kochia to glyphosate, 21 DAT

NTKS: $y = 9.0092 + \frac{90.3720}{1 + \left(\frac{x}{1.7969}\right)^{7.9137}}$, $R^2 = 0.99$

INKS: $y = 14.4017 + \frac{85.5591}{1 + \left(\frac{x}{2.6199}\right)^{2.9136}}$, $R^2 = 0.99$

EDID: $y = -1.3516 + \frac{101.7606}{1 + \left(\frac{x}{0.8172}\right)^{3.2770}}$, $R^2 = 0.99$

IAREC: $y = -0.5546 + \frac{94.6693}{1 + \left(\frac{x}{1.0409}\right)^{3.5986}}$, $R^2 = 0.99$
Trail of kochia plants in a soybean field near Colby, KS in 2007 after spraying three times with glyphosate (Stahlman).
Greenhouse-Grown Kochia Response to Glyphosate (Stahlman)

Progeny from parental plant 25

Susc. 0X 1X 2X 4X
Response of Kochia Plants Grown Outdoors to Glyphosate (Stahlman)

<table>
<thead>
<tr>
<th>Susc.</th>
<th>Progeny from parental plant 31</th>
</tr>
</thead>
<tbody>
<tr>
<td>0X</td>
<td>0X</td>
</tr>
<tr>
<td></td>
<td>2X</td>
</tr>
<tr>
<td></td>
<td>4X</td>
</tr>
<tr>
<td></td>
<td>8X</td>
</tr>
</tbody>
</table>
Summary

- Glyphosate-resistance in multiple kochia populations in western Kansas is confirmed
- Resistance developed independently
- Currently, mostly 2X to 4X level resistance; but will worsen without change in practice
- GR-kochia may or may not be less fit
- Management strategies
  - herbicide program
  - biology and seed bank
Kochia Problem Sites in 2007; confirmed glyphosate resistant
Prevailing wind direction

Successful GR-Kochia populations sampled fall 2010

Additional suspect populations sampled in 2010 relative to location of sites with confirmed glyphosate resistance

Many additional sites not sampled
Phillip Co. KS – 2010; grower application at 10 gpa
April 21: 42 oz Buccaneer Plus + 9 oz 2,4-D LVE + AMS + NIS
June 2: 49 oz Buccaneer Plus + 1 oz Sharpen + AMS + NIS (1 DPP)
June 24: 31 oz Buccaneer Plus + 0.7 oz Cadet + COC + Guardian (POST)
Lane Co. KS 2010 – No-till 18 years; grower application
- 32 oz Roundup + 10 oz Salvan (5 lb 2,4-D acid) 2 weeks preplant
- 60 oz Roundup + 0.7 oz Cadet + MSO + sticker POST at 10 gpa
- FMC resprayed same mix at 15 gpa
Greeley Co. KS – 2010. Problem started 4 years ago; blew in from neighbors field 1 mile to the north
Source field of the previous picture
Glyphosate Resistant Kochia Management

Timing and Environment.
- The majority of kochia germinates early but will continue into the growing season.
- Apply herbicides before kochia gets too large and with optimal environmental conditions.
- Do not plant into uncontrolled kochia stands.

Foundation preemergence herbicides
- Corn: Lexar/Lumax, Balance Flexx, Corvus, Sharpen, Verdict, atrazine (unless also triazine resistant)
- Soybeans: Authority, Valor, Sharpen, OpTill

Postemergence herbicide options
- Corn – Dicamba, Status, Starane, Callisto, Laudis, Capreno, Impact
- Soybean – Extreme*, Raptor*, Synchrony*
  * Unless also ALS resistant
Glyphosate Resistant Palmer Amaranth in Georgia

Glyphosate Resistant Palmer Amaranth
Stanley Culpepper, University of Georgia

WeatherMax 88 oz at 1 inch
WeatherMax 88 oz at 4 inch
WeatherMax 88 oz at 12 inch
Glyphosate Resistant Palmer Amaranth in Georgia

Sus.

WMax: 0 3 6 12 24 48 oz/A

Res.

Stanley Culpepper,
University of Georgia
Best defense against herbicide resistant weeds

- Avoid continuous selection for R-biotypes
  - Rotate and/or tankmix herbicides with different sites of action, within and across years
  - Crop rotation
  - Include other control tactics (cultivation, prevention, crop competition, cultural practices)
  - “Use the proper rate at the proper time”