Integrated Weed Management: Rationale and Strategies

Sarah Lancaster
Assistant Professor and Weed Science Extension Specialist
Kansas State University

Integrated weed management

Using multiple, complementary weed control practices

Which of the following IWM practices do you use most?

A. Cover crops
B. Cultivating
C. Shading from crop canopy
D. Spraying herbicides
E. All of these

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Cultural</th>
<th>Physical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sequential</td>
<td>Good agronomic practices</td>
<td>Tillage</td>
</tr>
<tr>
<td>Residual</td>
<td>Crop rotation</td>
<td></td>
</tr>
<tr>
<td>Multiple sites of action</td>
<td>Seeding date</td>
<td></td>
</tr>
<tr>
<td>Well-timed</td>
<td>Row spacing</td>
<td>Cover crops</td>
</tr>
<tr>
<td></td>
<td>Plant populations</td>
<td></td>
</tr>
</tbody>
</table>
Which of the following IWM practices do you use most?

A. Cover crops
B. Cultivating
C. Shading from crop canopy
D. All of these

Why integrated weed management?
- Herbicide resistance
- Sustainability
- Herbicide resistance

Herbicide tolerance
The inherited ability of a species to survive and reproduce following herbicide application
- Naturally occurring trait
- Expected result due to herbicide selectivity

Herbicide selectivity
- Application rate
- Placement
- Absorption and translocation
- Metabolism or altered metabolism
- Altered site of action
Herbicide resistance

The ability of a formerly susceptible plant population to survive herbicide doses greater than those that were once used to control the original plant population.

- Herbicide resistance is a heritable trait.

Herbicide resistant weeds in Kansas

<table>
<thead>
<tr>
<th>ALS inhibitors</th>
<th>Palmar amaranth</th>
<th>Waterhemp</th>
<th>Kochia</th>
<th>Marestail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 2 (Classic, Harmony, Pursuit)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Plant growth regulators</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Group 4 (2,4-D, dicamba, Starane Ultra)</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSII inhibitors</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Group 5 (atrazine)</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EPSPS inhibitor</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 9 (glyphosate)</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>PPO inhibitors</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Group 14 (Cobra, Blazer)</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HPPD inhibitors</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 27 (Armezon, Callisto, Laudis)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Herbicide options for pigweed control

**Preplant**
- Soybean
  - Chloransulam
  - Firstrate
  - Flumioxizan
  - Valor
  - Imazosul
  - Imazethapyr
  - Pyroxsulfuron
  - Zidua
  - Saflufenacil
  - Sharp X
  - Sulfentrazone
  - Spartan

- Corn
  - Atrazine
  - Flumioxizan
  - Valor
  - Imazaquin
  - Scepter
  - Imazethapyr
  - Pursuit
  - Pyroxsulfuron
  - Zidua
  - Saflufenacil
  - Sharp X
  - Sulfentrazone
  - Spartan

**Postemergence**
- Soybean
  - Atrazine
  - Dicamba
  - Distinct
  - Mesotrione
  - Callisto
  - Tembotrione
  - Lactil
  - Tolpyralate
  - FlameX
  - Topramazon
  - Impact

- Corn
  - Atrazine
  - Blazer
  - Fomesafen
  - TreBlast
  - Lactil
  - Tembotrione
  - Callisto
  - Tembotrione
  - Lactil
  - Tolpyralate
  - FlameX
  - Topramazon
  - Impact

Herbicide options for pigweed control

**Preplant**
- Soybean
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  - Callisto
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  - Tolpyralate
  - FlameX
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  - Impact

- Corn
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  - Fomesafen
  - TreBlast
  - Lactil
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  - Topramazon
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**Postemergence**
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  - Tembotrione
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  - FlameX
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  - TreBlast
  - Lactil
  - Tembotrione
  - Callisto
  - Tembotrione
  - Lactil
  - Tolpyralate
  - FlameX
  - Topramazon
  - Impact

- 2,4-D (Enlist)
Do you think you have weeds resistant to ALS-inhibitors?

A. True
B. False

Do you think you have weeds resistant to plant growth regulators?

A. True
B. False

Do you think you have weeds resistant to triazines?

A. True
B. False

Do you think you have weeds resistant to PPO inhibitors?

A. True
B. False
Do you think you have weeds resistant to HPPD inhibitors?

A. True
B. False

**CROSS RESISTANCE**

*Single* mechanism confers resistance to multiple herbicides

**MULTIPLE RESISTANCE**

*Multiple* mechanisms confer resistance to multiple herbicides

Negative cross resistance – genetic change that causes resistance to one herbicide causes ‘hypersusceptibility’ to another

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**Cross resistant common cocklebur**

**Multiple resistant Palmer amaranth**

- Nontreated
- Chlorsulfuron (Glean)
- Glyphosate
- Atrazine
- Lactofen (Cobra)
- Mesotrione (Callisto)
- 2,4-D
- Pyrasulfotole + bromoxynil (Huskie)
Causes of resistance

TARGET-SITE MUTATION

One gene

Develops faster

Most cases observed in
- ACCase inhibitors (G1)
- ALS inhibitors (G2)
- PSII inhibitors (G5)

NON-TARGET-SITE MUTATION

> 1 gene

Develops slower
- Begins with low degree of resistance
- Cross resistance more likely

Most frequent form observed in
- ACCase inhibitors
- ALS inhibitors
- EPSPS inhibitor

Altered Site of Action

Plant changes target site

Increased Protein Expression

Plant produce more copies of the target site

TARGET-SITE MUTATION

One gene

Develops faster

Most cases observed in
- ACCase inhibitors (G1)
- ALS inhibitors (G2)
- PSII inhibitors (G5)

NON-TARGET-SITE MUTATION

> 1 gene

Develops slower
- Begins with low degree of resistance
- Cross resistance more likely

Most frequent form observed in
- ACCase inhibitors
- ALS inhibitors
- EPSPS inhibitor
Enhanced Herbicide Metabolism
Plant alters &/or sequesters herbicide, making it ineffective

<table>
<thead>
<tr>
<th>Susceptible</th>
<th>Resistant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbicide</td>
<td>Herbicide gets sequestered</td>
</tr>
<tr>
<td>Site of Action</td>
<td>Site of Action</td>
</tr>
</tbody>
</table>

Reduced Absorption or Translocation
Herbicide transport altered

<table>
<thead>
<tr>
<th>Susceptible</th>
<th>Resistant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbicide</td>
<td>Herbicide</td>
</tr>
<tr>
<td>Site of Action</td>
<td>Site of Action</td>
</tr>
</tbody>
</table>

Best Management Practices for Herbicide Resistance

Scouting
Get a representation of the whole field
- 5-10 stops, spread throughout
- At each stop, walk 10 paces and record the following:
  - Weed species present – ID is critical
  - Life stage or height of weeds
  - Lifecycle (summer annual, winter annual, perennial)
  - Severity of the infestation based on number of plants (Low, medium, high)

Before planting, before herbicide, after herbicide
What weed is shown below?

A. Kochia  
B. Marestail  
C. Palmer amaranth  
D. Waterhemp

Best Management Practices for Herbicide Resistance

Germination characteristics of weeds interacts with management practices

Kochia emergence in Kansas

<table>
<thead>
<tr>
<th>Site</th>
<th>Year</th>
<th>Field</th>
<th>Date 10%</th>
<th>10%</th>
<th>50%</th>
<th>90%</th>
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<tbody>
<tr>
<td>Garden City</td>
<td>2010</td>
<td>NT</td>
<td>3/30</td>
<td>245</td>
<td>425</td>
<td>2369</td>
</tr>
<tr>
<td>Garden City</td>
<td>2011</td>
<td>NT</td>
<td>3/21</td>
<td>266</td>
<td>436</td>
<td>2400</td>
</tr>
<tr>
<td>Garden City</td>
<td>2011</td>
<td>T</td>
<td>3/21</td>
<td>279</td>
<td>443</td>
<td>1473</td>
</tr>
<tr>
<td>Hays</td>
<td>2010</td>
<td>T</td>
<td>3/10</td>
<td>173</td>
<td>300</td>
<td>590</td>
</tr>
<tr>
<td>Hays</td>
<td>2010</td>
<td>NC</td>
<td>3/24</td>
<td>23</td>
<td>148</td>
<td>430</td>
</tr>
<tr>
<td>Hays</td>
<td>2011</td>
<td>T</td>
<td>1/28</td>
<td>43</td>
<td>168</td>
<td>444</td>
</tr>
<tr>
<td>Hays</td>
<td>2011</td>
<td>NC</td>
<td>2/6</td>
<td>96</td>
<td>223</td>
<td>511</td>
</tr>
<tr>
<td>Manhattan</td>
<td>2011</td>
<td>NC</td>
<td>3/3</td>
<td>115</td>
<td>237</td>
<td>500</td>
</tr>
</tbody>
</table>

Werle et al., 2014

Dille et al., 2017
Effect of temperature on Palmer amaranth germination

<table>
<thead>
<tr>
<th>Temperature (F)</th>
<th>Total germination (%)</th>
<th>Days to maximum germination rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>8</td>
<td>--</td>
</tr>
<tr>
<td>50</td>
<td>20</td>
<td>5.3</td>
</tr>
<tr>
<td>59</td>
<td>49</td>
<td>2.3</td>
</tr>
<tr>
<td>68</td>
<td>57</td>
<td>1.9</td>
</tr>
<tr>
<td>77</td>
<td>66</td>
<td>1.1</td>
</tr>
<tr>
<td>86</td>
<td>83</td>
<td>1.5</td>
</tr>
<tr>
<td>95</td>
<td>73</td>
<td>2.2</td>
</tr>
<tr>
<td>LSD_0.05</td>
<td>12</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Steckel et al., 2004

Which weed would be more likely to be suppressed by crop canopy?
A. Kochia
B. Palmer amaranth

Which weed would be more likely to be suppressed by a fall cover crop?
A. Kochia
B. Palmer amaranth

Best Management Practices for Herbicide Resistance
Integrated pigweed management in Kansas

2 crops, 2 years, 3 locations
Cover crop, row-width, cultivation, herbicides

Herbicide program provided ≥ 97% weed control
Row width reduced pigweed growth in some environments
Cover crop generally suppressed pigweeds

Row width effects on pigweed density 8 WAP
No herbicide, no tillage

Cover crop effects on pigweed density 8 WAP
No herbicide, no tillage

Means within a site-year followed by the same letter are similar.
Cover crop effects on pigweed height 8 WAP

<table>
<thead>
<tr>
<th>Location</th>
<th>Years</th>
<th>Treatment</th>
<th>Height (cm)</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manhattan</td>
<td>2</td>
<td>No cover crop</td>
<td>10</td>
<td>0.01</td>
</tr>
<tr>
<td>Manhattan</td>
<td>2</td>
<td>Cover crop</td>
<td>20</td>
<td>0.05</td>
</tr>
<tr>
<td>Hutchinson</td>
<td>2018</td>
<td>No cover crop</td>
<td>30</td>
<td>0.05</td>
</tr>
<tr>
<td>Hutchinson</td>
<td>2018</td>
<td>Cover crop</td>
<td>40</td>
<td>0.001</td>
</tr>
<tr>
<td>Ottawa</td>
<td>2017</td>
<td>No cover crop</td>
<td>50</td>
<td>0.001</td>
</tr>
<tr>
<td>Ottawa</td>
<td>2017</td>
<td>Cover crop</td>
<td>60</td>
<td></td>
</tr>
</tbody>
</table>

Means within a site-year followed by the same letter are similar (α=0.1).

Understanding sites of action

Mode of action
- How the herbicide affects the plant
  - Amino acid synthesis inhibitor

Site of action
- Specific binding site the herbicide interferes with
  - EPSPS inhibition
  - Group 9

Chemical family
- Elements in the molecule
  - Glycine

Herbicide sites of action

<table>
<thead>
<tr>
<th>Group</th>
<th>Site of Action (Mode of Action)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ACCase inhibitors (Lipid synthesis inhibitors)</td>
</tr>
<tr>
<td>2, 9</td>
<td>ALS inhibitors, EPSP Synthase inhibitor (Amino acid synthesis inhibitors)</td>
</tr>
<tr>
<td>3</td>
<td>Microtubule inhibitors (Seedling root growth inhibitors)</td>
</tr>
<tr>
<td>4, 19</td>
<td>Synthetic auxins, Auxin transport inhibitors (Growth regulators)</td>
</tr>
<tr>
<td>5, 6, 7</td>
<td>PS II inhibitors-3 unique sites of action (Photosynthesis inhibitors)</td>
</tr>
<tr>
<td>8, 15, 16</td>
<td>Lipid synthesis inhibitors, Long-chain fatty acid inhibitors, Site unknown (Seedling shoot growth inhibitors)</td>
</tr>
<tr>
<td>10</td>
<td>Glutamine synthetase inhibitor (Nitrogen metabolism inhibitor)</td>
</tr>
<tr>
<td>12, 13, 27</td>
<td>PDS inhibitor, DOXP inhibitor, HPPD inhibitors (Pigment inhibitors)</td>
</tr>
<tr>
<td>14, 22</td>
<td>PPO inhibitors, PSI electron diverter (Cell membrane disruptors)</td>
</tr>
<tr>
<td>17</td>
<td>Nucleic acid inhibitor (Undefined)</td>
</tr>
</tbody>
</table>
ALS Inhibitors (2)

Inhibit acetolactate synthase (aka acetohydroxy acid synthase)
- Necessary to produce branched chain amino acids (valine, leucine, isoleucine)

ALS-inhibitor injury to soybean

Symptoms in 3-14 d
- Shoots stop growing and turn yellow,
- Purple veins – dicots
- “Bottlebrush” roots

Synthetic auxins (4)

Activate auxin response genes (bind to auxin receptor protein)
- Regulate plant growth

Auxin transport inhibitor (diflufenzopyr, group 19) used as a synergist with dicamba

Synthetic auxin injury to corn and soybean

Symptoms appear in 7-14 days
- Bent/twisted stems and petioles
- Misshapen leaves
- Short/thickened roots
Photosynthesis Inhibitors (5)

Bind to D1 protein in PSII
- Blocks electron transport
- Stops CO2 fixation, ATP & NADPH production
- Reactive oxygen and chlorophyll form, chlorophyll lost, reactive species cause lipid peroxidization, which causes leaky membranes (with 5-10 h)

26 species with resistance

Triazine injury to soybean
Symptoms appear first on older leaves, death in 5-10 days
- Leaf tip & margin necrosis
- Interveinal chlorosis

Pigment Inhibitors (Group 27)
Carotenoids are necessary to dissipate reactive oxygen
- Without carotenoids, reactive oxygen peroxidizes lipids, destroying membranes

2 species with resistance

Callisto injury to grain sorghum
Symptoms include white/creamy colored leaves
- AKA “bleachers”
**PPO inhibitors (14)**

Inhibit protoporphyrinogen oxidase
- Necessary to produce chlorophyll
- Accumulated protoporphyrin IX results in formation of reactive oxygen and lipid peroxidation

**Cobra and Reflex injury on soybeans**

Symptoms appear in 3 days
- Bronzing, necrosis
- Drawstring leaves

**Long-chain Fatty acid Inhibitors (15)**

Interfere with very long chain fatty acid synthesis

**Chloroacetamide injury to grain sorghum and soybean**

Grasses that emerge may have buggy-whipping; broadleaf plants stunted, ‘drawstring’ leaves, dark green
- Plants will germinate
Multiple effective sites of action
glyphosate + ALS-resistant Palmer amaranth

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Timing</th>
<th>Effective sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authority XL (2 + 14)</td>
<td>PRE</td>
<td>2</td>
</tr>
<tr>
<td>Glyphosate (9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,4-D (4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tavium (4 + 15)</td>
<td>EPOST</td>
<td>2</td>
</tr>
<tr>
<td>Glyphosate (9)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If you have glyphosate and atrazine-resistant kochia, how many effective modes of action are you using?

A. 0  
B. 1  
C. 2  
D. 3

Which of the following do you practice in your herbicide program?

A. Rotating herbicide groups from year to year 
B. Rotating herbicide groups within a year 
C. Mixing groups within an application 
D. More than one of these

Table 3: Years until resistance occurs (the year that crop yield is below 70% of maximum, which is equivalent to seed density exceeding 20000/ha) for 5 different rotation and mixture (10 strategies) over 4, 8, and 12 times the baseline frequencies shown in Table 1 (A) and these different genetic variants (B); G1: these variants and resistance cross-resistance; G2: these variants and resistance cross-resistance; G3: these variants and resistance cross-resistance. Results for other initial allele frequencies are shown for clarity, but below the same.

<table>
<thead>
<tr>
<th>Herbicide use pattern</th>
<th>G1 Frequency</th>
<th>G2 Frequency</th>
<th>G3 Frequency</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0 0.0 0.0</td>
<td>1.0 0.0 0.0</td>
<td>1.0 0.0 0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>0</td>
<td>0.0 1.0 0.0</td>
<td>0.0 1.0 0.0</td>
<td>0.0 1.0 0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>2.0 0.0 0.0</td>
<td>2.0 0.0 0.0</td>
<td>2.0 0.0 0.0</td>
<td>2.0</td>
</tr>
<tr>
<td>3</td>
<td>3.0 0.0 0.0</td>
<td>3.0 0.0 0.0</td>
<td>3.0 0.0 0.0</td>
<td>3.0</td>
</tr>
<tr>
<td>4</td>
<td>4.0 0.0 0.0</td>
<td>4.0 0.0 0.0</td>
<td>4.0 0.0 0.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

1, trifluralin (dinitroaniline, G3); 2, prosulfocarb + S-metolachlor (thiocarbamate + chloroacetamide, G8 + 15); 3, pyroxasulfone (pyrazole, G15); 4, propyzamide (benzamide, G3).
Modeling the effects of herbicide rotation on trifluralin-resistant annual ryegrass

- 2 shoot inhibitor fb shoot inhibitor
- 2 shoot inhibitor fb shoot inhibitor fb root inhibitor
- 2 shoot inhib fb root inhib fb shoot inhib fb root inhib
- 2 shoot inhib+shoot inhib fb 2 shoot inhib+shoot inhib fb root inhib
- Tri+2 shoot inhib fb tri+shoot inhib fb root inhib
- (2 shoot inhib fb shoot inhib fb root inhib)x3

then tri fb tri fb root inhib fb 2 shoot inhib fb shoot inhib fb root inhib

Best Management Practices for Herbicide Resistance

Pigweed seed retention at soybean maturity

<table>
<thead>
<tr>
<th>State</th>
<th>Seed Retention (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR</td>
<td>99.98 ± 0.00</td>
</tr>
<tr>
<td>IL</td>
<td>99.95 ± 0.03</td>
</tr>
<tr>
<td>NE</td>
<td>98.89 ± 0.23</td>
</tr>
<tr>
<td>MO</td>
<td>99.96 ± 0.00</td>
</tr>
<tr>
<td>TN</td>
<td>99.96 ± 0.01</td>
</tr>
</tbody>
</table>

Palmer amaranth

- AR 99.98 ± 0.00 99.85 ± 0.05
- IL 99.95 ± 0.03 --
- NE 98.89 ± 0.23 99.93 ± 0.02
- MO 99.96 ± 0.00 99.67 ± 0.20
- TN 99.96 ± 0.01 --

Waterhemp

- IL 99.98 ± 0.01 94.98 ± 0.94
- NE 99.99 ± 0.00 99.63 ± 0.10
- MO 100.00 ± 0.00 99.84 ± 0.04
- WI 99.96 ± 0.01 98.80 ± 0.30

HWSC effects on Palmer amaranth seedbank at soybean harvest

Seeds/sq ft

- No fall
- No fall + residual
- Windrow + burn
- Windrow + burn + residual
- Rye cover crop
- Rye cover crop + residual

Seed bank decreased over time
3-pass herbicide program
By year 3, all treatments reduced seedbank compared to no fall treatment
"Rescue" option?
Grower adoption of HWSC in Australia

<table>
<thead>
<tr>
<th>Cropping region and zone</th>
<th>Narrow-window burning</th>
<th>Chaff tamlining</th>
<th>Chaff cast</th>
<th>Bale-direct system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern</td>
<td>4 23 13 77 1 78 1 15 19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QLD Central</td>
<td>- - 18 88 4 78 - - 22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NSW NE/Qld SE</td>
<td>11 23 4 75 - - 2 15 17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NSW NW/Qld SW</td>
<td>28 28 6 70 1 63 4 27 39</td>
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<tr>
<td>NSW Central</td>
<td>12 30 2 100 - - 2 10 16</td>
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<td>NSW Vic. N.</td>
<td>33 29 12 63 - - 12 14 57</td>
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<tr>
<td>SA Midnorth-Lower</td>
<td>31 15 - - 4 50 - - 35</td>
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<tr>
<td>Yorkie Irr.</td>
<td>38 13 2 100 - - 2 10 16</td>
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<tr>
<td>SA Vic Bindertown-Winnem</td>
<td>38 13 2 100 - - 2 10 16</td>
<td></td>
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</tr>
<tr>
<td>Vic. High Rainfall &amp; Tas.</td>
<td>33 34 12 82 2 90 2 60 49</td>
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<tr>
<td>Western</td>
<td>51 30 4 86 7 59 1 43 63</td>
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</tr>
<tr>
<td>WA Central</td>
<td>56 27 7 70 13 57 2 3 78</td>
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<tr>
<td>WA Eastern</td>
<td>45 33 4 90 - - 2 20 49</td>
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<tr>
<td>WA Sandplain-Mallee</td>
<td>33 25 4 100 9 73 2 20 48</td>
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<tr>
<td>WA Northern</td>
<td>35 36 3 100 8 47 - - 36</td>
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<tr>
<td>National average</td>
<td>30 26 7 76 3 64 3 25 43</td>
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Wrap up

Various forms of herbicide resistance are common in Kansas in multiple species

Using cultural or mechanical weed management can improve activity of herbicides and reduce selection pressure leading to herbicide resistant weed populations

Mixing multiple herbicide groups is more effective than rotating herbicide groups

Consider practices to reduce deposits to weed seedbank

ACCase Inhibitors (1)

Inhibit acetyl Coenzyme A carboxylase in grasses
- Required for lipid synthesis within the plant
- Prevents cell membrane development

15 species with resistance
ACCase inhibitor injury to corn

Symptoms start in 2-4 days, plant death takes up to 7 days

- Susceptible plants stop growing, leaves turn purplish then necrotic, leaf sheaths fall away
- Whorl easily removed from plant

Modeling the effects of herbicide rotation on trifluralin-resistant annual ryegrass

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2 G15 fb G15
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2 G15 fb G15 fb G3 fb G15 fb G3
```

![Graph showing the effects of herbicide rotation on trifluralin-resistant annual ryegrass](image-url)