Herbicide Resistance

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Glyphosate Resistant Palmer amaranth in Soybeans
Herbicide Resistant Kochia in Wheat Stubble
Herbicide Resistance

Weed Science Society of America

- 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. Resistant biotypes are genetically different from susceptible biotypes.
Herbicide Resistance Landmarks in Kansas

- 1976: Kochia resistance to atrazine.
- 1987: Kochia resistance to Glean.
- 2005: Marestail resistance to glyphosate.
- 2007: Kochia resistance to glyphosate.
Herbicide Resistance in Kansas

- Photosystem II: 4 species
- ALS inhibitors: 12 species
- PPO: Waterhemp, Palmer amaranth?
- Glyphosate: 6 species
- HPPD: Palmer amaranth
- Auxins: Kochia, Palmer amaranth?

>25 different species * herbicide cases in Kansas
Weed Resistance
A Nationwide Problem

Everyone acknowledges that herbicide-resistant weeds are one of the most pressing challenges currently facing the agricultural market. In fact, in a recent survey of growers conducted by DuPont Crop Protection, 87% of respondents indicated that they were doing everything in their power to prevent the spread of weed resistance on their farms. This was up almost 20% from the percentage reported in an earlier DuPont Crop Protection survey conducted in 2011.

“Growers are aware of the increasing populations of resistant weeds and diseases up and down the country and are doing what they can to protect profitability and sustainability of their operations by taking action against resistance,” said James Hay, business director, North America for DuPont.

Across the country, the problem of resistant weeds continues to grow. In fact, in a few states such as California and Kansas, weed scientists have documented more than 25 species of weeds that show varying levels of resistance to popular herbicides such as glyphosate.

And solving the problem will take time, predicts Susan Cuney, technical development manager for the ICNatra Co. “These weeds in the fields did not all get out of control in just one year, and we are not going to be able to take care of them in just one year either,” says Cuney. “But if growers and retailers work together to develop a good rotational approach to managing them, we can definitely see the process going in the right direction.”

“Our research shows there are no genetic or environmental factors to keep Palmer amaranth from competing with crops and reducing yields in Northern geographies.”
— Adam Davis, USDA

“We have lost the ability to control Palmer amaranth with Roundup in these fields.”
— Stanley Culpepper, University of Georgia

“Many weed scientists consider herbicide resistance to be the most serious immediate challenge to our agricultural system.”
— Michael Barrett, University of Kentucky
How does herbicide resistance develop?

- 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
- Enhanced metabolism/detoxification
- Enzyme Overexpression (increased gene copy #)
- Sequestration
- Reduced absorption & translocation
Altered Site of Action (Gunsolus et al)
Herbicide Cross Resistance

- Weed resistance to different herbicides that have the same mechanism of resistance.

- ALS herbicides
  - Sulfonylureas: Glean, Accent, Permit, Maverick, Peak, etc.
  - Imidazolinones: Pursuit, Raptor, Cadre
  - Triazolopyrimidines: Python, FirstRate
CLASSIC SCEPTER 1X SUSCEPTIBLE
CLASSIC SCEPTER UNTREATED
4X RESISTANT
Herbicide Multiple Resistance

- Weed biotypes with resistance to herbicides with multiple resistant genes and different mechanisms of resistance.

- Examples:
  - Kochia that are resistant to atrazine, ALS herbicides, glyphosate, and dicamba.
  - Palmer amaranth that are resistant to atrazine, ALS herbicides, and hppd herbicides.
Mechanisms of Herbicide Resistance

- Altered target site of action
  - Often a high degree of resistance
- Overexpression (Increased gene copy #)
- Enhanced metabolism/detoxification
- Sequestration
- Reduced absorption & translocation

Often a lower degree of resistance and more rate responsive
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
Palmer Amaranth

- Dioecious
- May produce a million seeds per plant
- Can hybridize with other pigweeds
- Tremendous growth rate
- Resistance to 4 herbicide sites of action
Kochia

- Primarily cross pollinated
- Short seed life
- Early germination (Feb/Mar)
- Highly pubescent
- Drought tolerant
- Tumbleweed seed dispersal
- Resistance to 4 herbicide sites of action
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

- **Sub-lethal herbicide application rates**
Do I have resistant weeds?

- Surviving plants (escapes) in middle of a group of dead plants?
- Have used same herbicide or “site 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
Differential Response of Palmer Amaranth
Differential Palmer Amaranth Response to Glyphosate
Marestail Escapes from Glyphosate
Differential Kochia Response to Herbicides
BMP’s for Herbicide Resistance = BMP’s for Weed Management

- Diversified Weed Management Program:
  - Cultural Practices
  - Knowledge of Weed Biology
  - Crop Rotation
  - Tillage?
  - Multiple Herbicide Sites of Action
  - Residual Herbicides
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, cover crops, cultural practices)
  - “Use the proper rate at the proper time”
WSSA Site of Action Classification

- Number system assigned to different Herbicide Sites of Action
  1. ACCase inhibitors: Assure, Select, Poast, Fusion, etc
  2. ALS inhibitors: Sulfonylureas, Imidazoliones, etc
  4. Auxin receptors: 2,4-D, dicamba, Tordon, etc
  5. Photosystem II inhibitors: atrazine, metribuzin, etc
  9. EPSP inhibitor: glyphosate
  10. Glutamine Synthetase inhibitor: Liberty
  14. PPO inhibitors: Valor, Spartan, Sharpen, Cobra, Cadet, etc
  15. Long Chain Fatty Acid Inhibitors: Dual, Harness, Outlook, Zidua, etc
  22. Photosystem I Inhibitor: Paraquat, Gramoxone, Parazine
  27. HPPD inhibitors: Balance, Callisto, Laudis, Armezon, Huskie, etc
GROUP 14 HERBICIDE

VALOR® HERBICIDE

FOR CONTROL AND/OR SUPPRESSION OF CERTAIN WEEDS IN COTTON, DRY BEANS, FIELD CORN, PEANUT, SOYBEAN, SUGARCANE, SWEET POTATO, FALLOW LAND AND TO MAINTAIN BARE GROUND ON NON-CROP AREAS OF FARMS.

Active Ingredient By Wt.
Flumioxazin* 51%
Other Ingredients 49%
Total 100%

*2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl)-2H-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1H-isouindole-1,3(2H)-dione

Valor® SX Herbicide is a water dispersible granule containing 51% active ingredient.

EPA Reg. No. 59639-99   EPA Est. 11773-IA-01

FIRST AID (continued)

If in eyes: Hold eye open and rinse slowly and gently with water for 15-20 minutes. Remove contact lenses, if present, after the first 5 minutes, then continue rinsing eye. Call a poison control center or doctor for treatment advice.

If swallowed: Call a poison control center or doctor immediately for treatment advice. Have person sip a glass of water if able to swallow. Do not induce vomiting unless told to do so by the poison control center or doctor. Do not give anything by mouth to an unconscious person.

HOT LINE NUMBER
Have the product container or label with you when calling a poison control center or doctor or going for treatment. You may also contact 800-892-0099 for emergency medical treatment information.

PERSONAL PROTECTIVE EQUIPMENT (PPE):

Some of the materials that are chemical-resistant to this product are listed below. If you want more options, follow the instructions for category A on an
Table of Contents (continued)

Directions for use in fall and spring
Preplant burndown prior to field corn
- Fall and Spring Preplant Burndown Programs for Field Corn ..... Table 2
- Weeds Controlled by Fall and Spring Preplant Burndown Programs ..... Table 3
- Tank Mix
  - Tank Mix Partners for Control of Emerged Weeds ..... Table 4

Fallow land
Directions for use to maintain bare ground non-crop areas of farms, orchards and vineyards
- Use Restrictions and Precautions
- Preemergence Application
- Postemergence Application
- Tank Mix Combinations to Maintain Bare Ground on Non-Crops Areas ..... Table 5

Crop rotational interval
Application information
- Crop Rotation Considerations
PERSONAL PROTECTIVE EQUIPMENT (PPE):
Applicators and other handlers must wear: long-sleeved shirt and long pants, chemical-resistant gloves made of waterproof material such as polyethylene or polyvinyl chloride, socks and shoes.

For aerial application to soybeans, mixers and loaders must also wear: PF 5 respirator.

Follow the manufacturer's instructions for cleaning/maintaining PPE. If no such instructions for washables exist, use detergent and hot water. Keep and wash PPE separately from other laundry.

USER SAFETY RECOMMENDATIONS
Users should:
- Wash hands before eating, drinking, chewing gum, using tobacco or using the toilet.
- Remove clothing immediately if pesticide gets inside. Then wash thoroughly and put on clean clothing.
- Remove PPE immediately after handling this product. Wash the outside of gloves before removing. As soon as possible, wash thoroughly and change into clean clothing.

ENVIRONMENTAL HAZARDS
This product is toxic to non-target plants and aquatic invertebrates. Do not apply when weather conditions favoring spray drift or pollution of groundwater occur.
Note: It is illegal to sell, use or distribute this product within, or into, Nassau County or Suffolk County, New York.

Herbicide
A Postemergence Herbicide for Weed Control in Glyphosate Tolerant (GT) Corn

Active Ingredients:
S-metolachlor* .............................................................. 20.50%
Glyphosate, N-(phosphonomethyl) glycine .................................. 20.50%
Mesotrione** ................................................................. 2.05%

Total: 56.95%

Active ingredients per U.S. gallon: S-metolachlor 2.09 pounds, glyphosate acid 2.09 pounds and mesotrione 0.209 pounds.
**Herbicide Site of Action Designation**

<table>
<thead>
<tr>
<th>Herbicide Combination</th>
<th>Rate (oz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorimuron (2) +</td>
<td>6 to 10 oz</td>
</tr>
<tr>
<td>Flumioxazin (14) +</td>
<td></td>
</tr>
<tr>
<td>Metribuzin (5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.015 to 0.024 + 0.048 to 0.08 + 0.17 to 0.28</td>
</tr>
</tbody>
</table>

Trivence is a premix containing 3.9% chlorimuron (Classic), 12.8% flumioxazin (Valor), and 44.6% metribuzin for burndown and residual control of broadleaf weeds. Recommended mainly for eastern Kansas; can be applied preplant in the fall or spring or preemergence until 3 days after planting. Do not apply more than 6 oz/acre if soil pH is greater than 7.0. Apply with oil concentrate or nonionic surfactant for control of emerged weeds. Often applied as a tank-mix with 2,4-D, glyphosate, or other herbicides for enhanced control of certain weed species. Do not apply in fields also treated preemergence with products containing flufenacet, alachlor, metolachlor, or dimethenamid. Do not rotate to wheat for 4 months; alfalfa or field corn for 10 months; sunflower, cotton, sorghum, or oats for 18 months; or canola for 30 months after application. Refer to label for crop rotation guidelines.

*Numbers in parentheses indicate herbicide mode of action; see p. 3 for more information. Products often are available in several formulations or brand names, and label information may vary. Refer to the Names, Toxicities, and Persistence table, p. 12.*
### Herbicide Classification

**Repeated Use of Herbicides with the Same Site of Action Can Result in the Development of Herbicide-Resistant Weed Populations.**

**Mode of Action**
- **Effect on Plant Growth**

**Site of Action**
- **Lipid Synthesis Inhibitors**
  - Aryloxyphenoxypropionate (AOPP)
  - Cyclohexanedione (CHD)
  - Phenylurea

**Amino Acid Synthesis Inhibitors**
- Imidazolone
- Pyrimidinylthiazolone
- Sulfonamides

**Number of Resistant Weed Species in U.S.**
- 15

**Chemical Family**
- Analog
- Cyanuric
- Glyphosate
- Thiocarbamate
- Allyl

**Active Ingredient**
- Chlorimuron
- Clopyralid
- Cyhalofop
- Fenoxaprop
- Fluazifop
- Glufosinate
- Sulfometuron

**Product Examples (Trade Names)**
- Bencar
- Axial
- Assure
- Apollo
- Atrazine

**PreMix**
- **Site of Action Group**
- **Active Ingredient**
- **Trade Name**

**PreMix**
- Agility SG
- Ally Extra
- Antelio
- Authority Assist
- Authority First

**PreMix**
- H Jason Complete
- Instinct
- Keystone (Kesten LA)
- Lexar EZ
- Markman
- Marvel
- Northern Star

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

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 Site of Action chart on the left for more information.
Glyphosate Resistant Pigweed Control

- Utilize an integrated approach incorporating residual and postemergence herbicides with different MOA

- Timing: Waterhemp and Palmer amaranth generally are warm season weeds that don’t germinate until later in the spring and into the summer, but have rapid growth in the summer.
  - Fall and early spring treatments probably will not provide season-long residual control
  - Postemergence treatments need to be timely
Preemergence Palmer Amaranth Control in Soybeans
10 DAP
Preemergence Palmer Amaranth Control in Soybeans
14 DAP
Valor XLT fb Liberty in Liberty Link Soybeans
Managing Marestail

- Timing, Timing, Timing!
- Utilize dicamba, 2,4-D, Sharpen and/or residual herbicides in fall and early spring burndown in no-till.
- Atrazine + 2,4-D in corn or sorghum
- Liberty for late burndown control.
- Utilize fall planted cover crops.
- Don’t skimp on rate or appropriate spray additives.
- Use appropriate treatments.
Management Effect on Marestail in Soybeans
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
  - Soybeans: Authority, Valor, Sharpen, OpTill (Pro), Boundary, metribuzin (Beware of soil limitations)

- Postemergence herbicide options
  - Soybean – Extreme*, Raptor*, Synchrony*
    * Unless also ALS resistant
Glyphosate Resistant Ragweed Management

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

- **Alternative/Tank Mix herbicides:**
  - Soybeans: 2,4-D (preplant)
    - Sharpen (preplant to preemergence)
    - Paraquat (burndown)
    - FirstRate (postemergence, unless ALS Res)
Glyphosate (PP)/Glyphosate (P)
Glyphosate + 2,4-D (PP) / Glyphosate (P)
Future Technologies in Soybeans

- No new novel herbicide modes of action or active ingredients on the horizon
- Crops stacked with multiple traits
- Dicamba resistant soybeans (Xtend) from Monsanto
- 2,4-D resistant soybeans (Enlist) from Dow
- HPPD resistant soybeans from Bayer and Syngenta
Herbicide Resistant Technologies

Summary

- New herbicide resistant crop technologies will provide new options to help with weed control, but need to be part of an integrated weed management program that utilizes residual herbicides and different herbicide modes of action to optimize weed control and crop production, while sustaining the technology.

- Stewardship will be critical to long-term success.
Impacts of Herbicide Resistant Weeds

- Increased weed control costs.
- Decreased yields.
- More reliance on tillage.
- Changes in cropping systems.
- Lower profits.
- Lower land values.
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