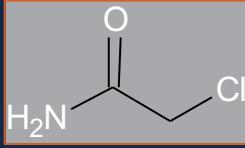


1



2



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## VLCFA-inhibitors

- Group 15 Herbicides
  - Discovered in the 1950s
- Preemergence (PRE) activity
- Target VLCFA elongases
  - Plants starve for very long chain fatty acids (VLCFAs)
  - Essential for the formation of cuticle waxes and cellular membranes
- Sensitive plants either fail to emerge or remain in an arrested state of growth after emergence

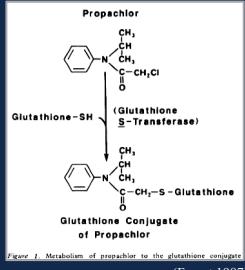
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## Old Chemistries Today



- Important for PRE control of annual monocots and small-seeded dicots
  - Waterhemp and Palmer amaranth
- Residual components in many herbicide premixes
  - Especially in soybean production
- Important components of layered residual herbicide programs in soybean
  - extend soil-residual control after POST application
- Resistance is rare
  - ~13 species worldwide, only three dicot species (two species of *Amaranthus*)

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**Responses of an HPPD Inhibitor-Resistant Waterhemp (*Amaranthus tuberculatus*) Population to Soil-Residual Herbicides (Hausman et al. 2013)**

Table 4. Mean estimates<sup>a</sup> of control and density of McLean Co., IL waterhemp 30 and 60 d after treatment (DAT) of soil-applied herbicides in corn.

Herbicide	Rate	2010				2011			
		Control		Density		Control		Density	
		30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT
		g ai ha <sup>-1</sup>	%	plants m <sup>-2</sup>		plants m <sup>-2</sup>		plants m <sup>-2</sup>	
Isoxaflutole	105	65 cd	57 c	443 cde	103 cde	62 c	25 de	217 ab	120 ab
Isoxaflutole	210	90 a	87 a	48 g	9 fg	83 ab	48 bc	55 cde	55 cd
Isoxaflutole + safener <sup>b</sup>	105	68 cd	60 bc	263 def	69 def	62 c	27 de	263 a	145 a
Isoxaflutole + safener <sup>b</sup>	210	87 ab	85 a	137 fg	32 efg	73 bc	38 cd	105 bc	89 abc
Mesotrione	210	53 d	50 c	417 cde	141 bcd	58 c	38 cd	65 cd	67 bc
Mesotrione	420	73 bc	48 c	191 efg	51 efg	83 ab	62 b	33 de	25 de
Atrazine	1680	8 e	7 d	859 ab	292 ab	58 c	17 e	191 ab	141 a
Atrazine	3360	13 e	8 d	520 bcd	248 abc	78 bc	22 de	115 bc	129 a
Acetochlor	1680	87 ab	82 ab	125 fg	49 defg	83 ab	62 b	19 de	16 e
Acetochlor	3360	93 a	88 a	93 fg	4 g	94 a	85 a	5 e	5 e
S-metolachlor	1600	17 e	7 d	596 abc	215 abc	18 d	17 e	200 ab	120 a
Non-treated	—	—	—	1067 a	363 a	—	—	260 a	145 a

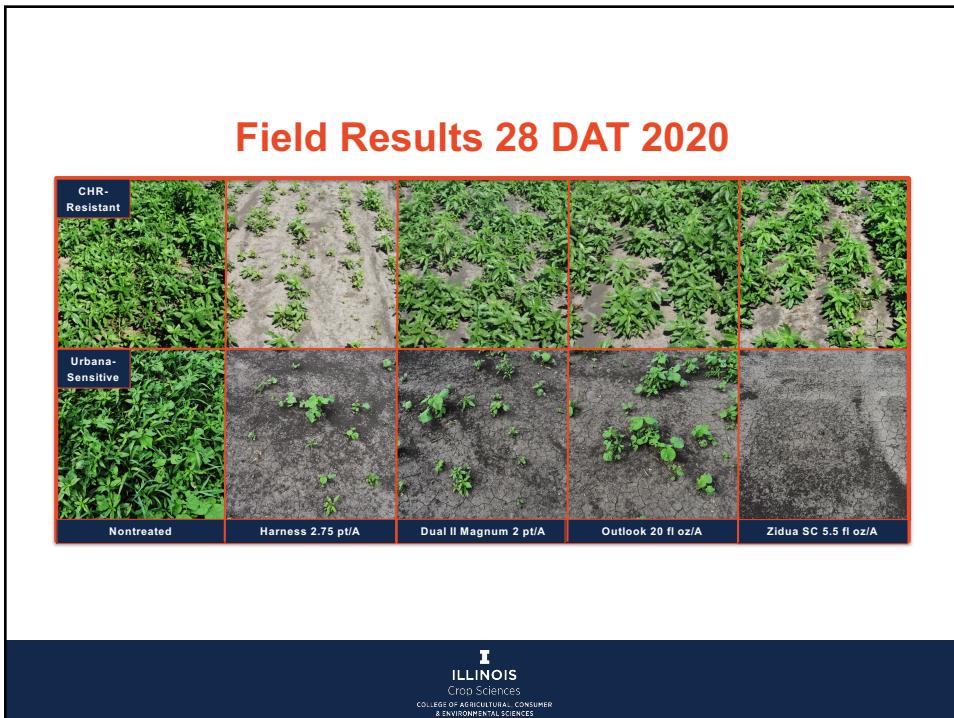
<sup>a</sup> Means with the same letter within a column are not significantly different at  $\alpha = 0.05$  (separated by the SAS macro %pdmix800).

<sup>b</sup> Cyprosulfamide.

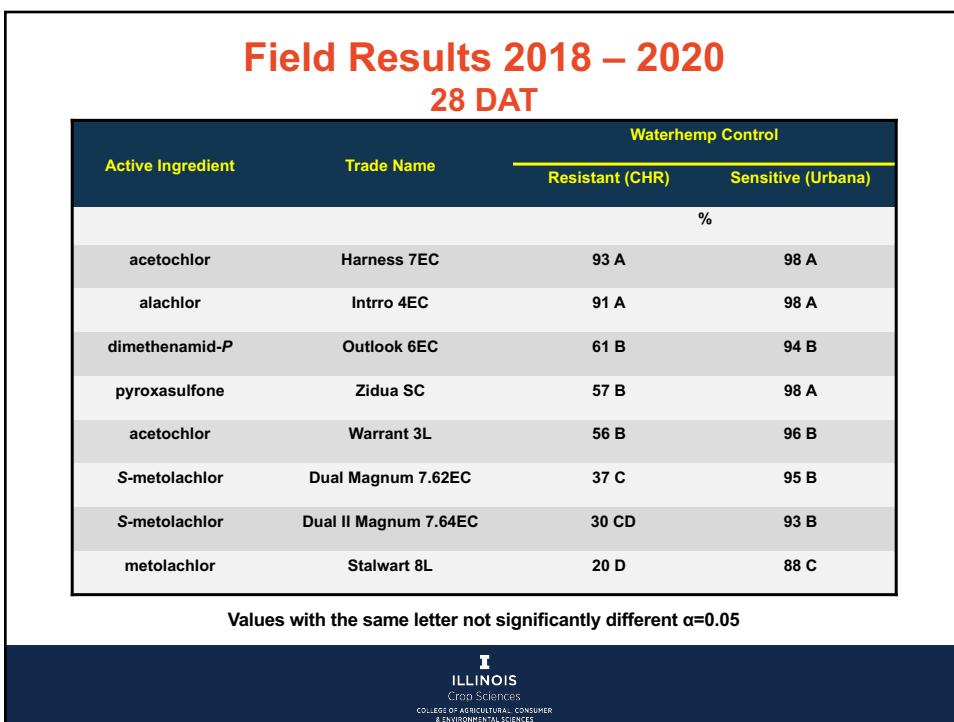
7

## Background

- Less than expected PRE control of the first HPPD-resistant population (MCR) from McLean Co., Illinois with S-metolachlor
- Similar observations on another HPPD-resistant population from Champaign Co., IL (CHR)
- Very few Group 15 products provide acceptable PRE control of CHR
- Previous greenhouse experiments revealed a large difference between progeny of CHR and a known sensitive in response to acetochlor and S-metolachlor



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## Investigating Herbicide Resistance

- **Dose-response experiments**
  - Generate response curves from which you can calculate the dose required to produce the same level of response in each population
    - often the dose required to reduce plant biomass 50%
    - other parameters often reported include differences in plant emergence, enzyme activity
    - apply statistical tests to determine if differences are significant
      - resistance ratio describes the degree of resistance
      - $GR_{50}$  resistant /  $GR_{50}$  susceptible = resistance ratio

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## Idealized Dose-Response Curves

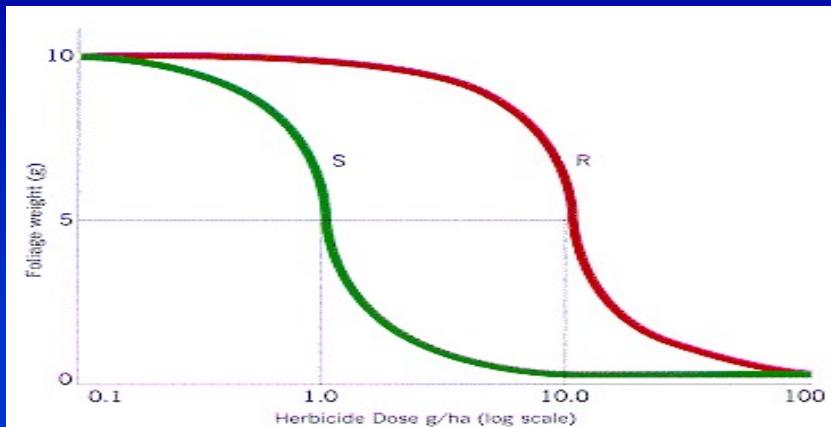


Figure 1.  
Dose response curves for a Susceptible (S) and a Resistant (R) population

$$ED_{50} (\text{susceptible}) = 1.0 \quad ED_{50} (\text{resistant}) = 10.0$$

$$\text{Resistance Index} = \frac{ED_{50} (\text{resistant})}{ED_{50} (\text{susceptible})} = \frac{10}{1} = 10$$

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## Herbicides

- Dual II Magnum  
0.125 fl oz – 1 gallon
- Harness  
0.04 fl oz – 2.6 pts
- Outlook  
0.07 fl oz – 66 fl oz
- Zidua SC  
0.02 fl oz – 21 fl oz
- Rates set on  $\log_{3.16}$  scale
- Survival and biomass recorded 21 DAT
- Analyzed in the *drc* package in R

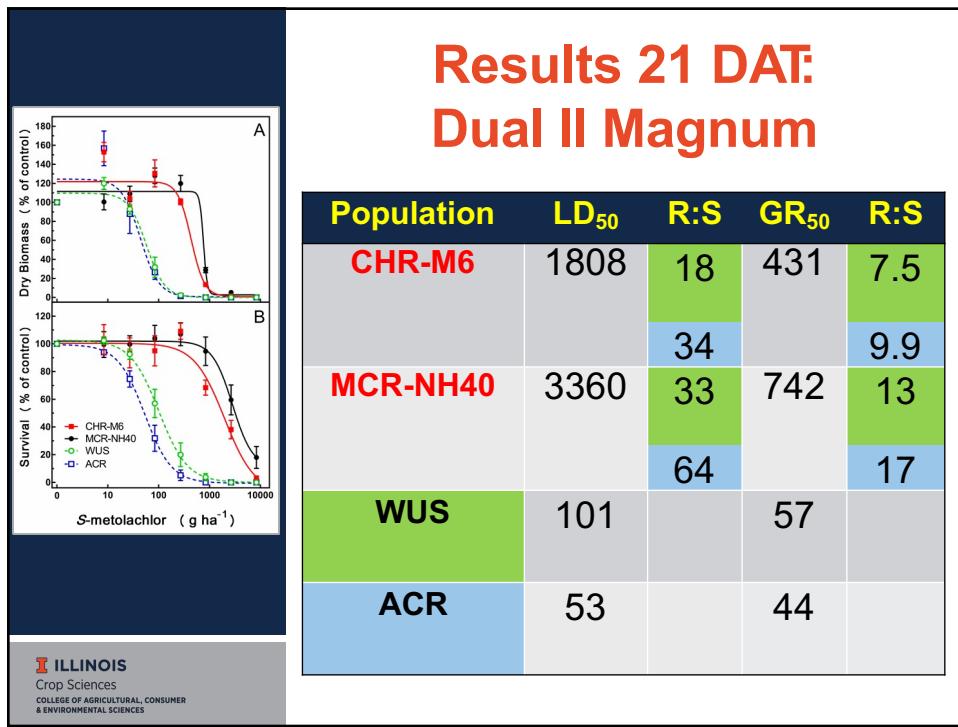


13

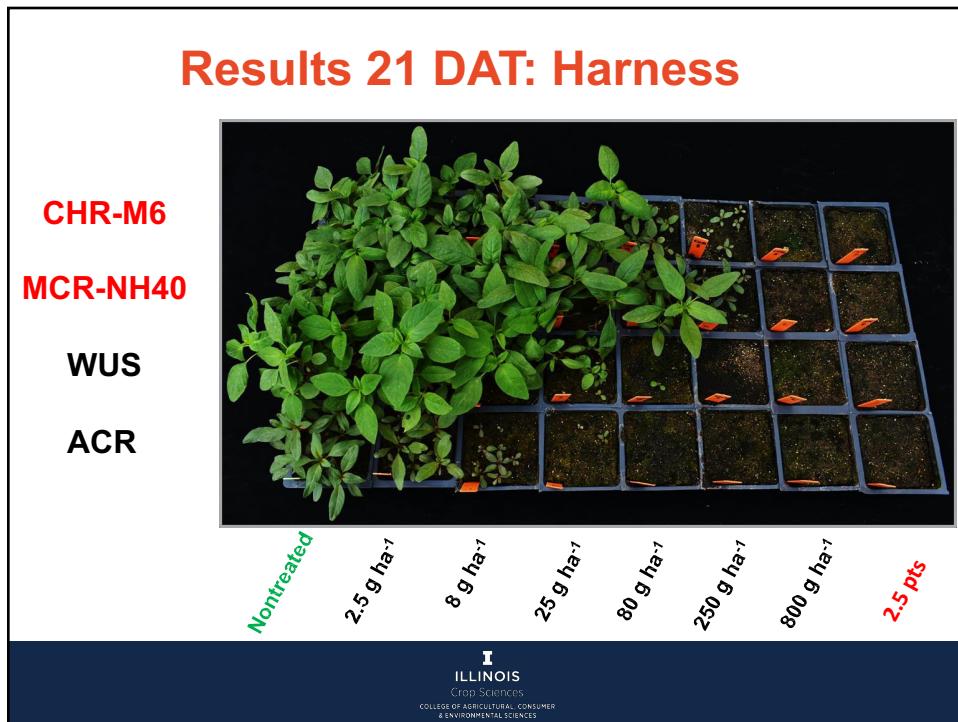
## Results 21 DAT: Dual II Magnum



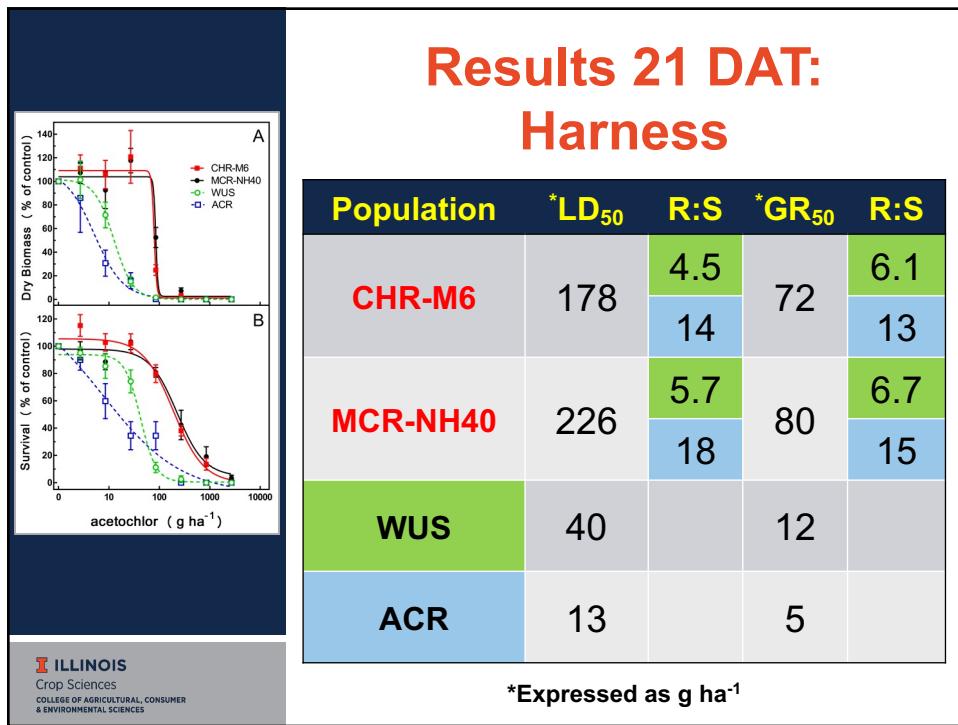
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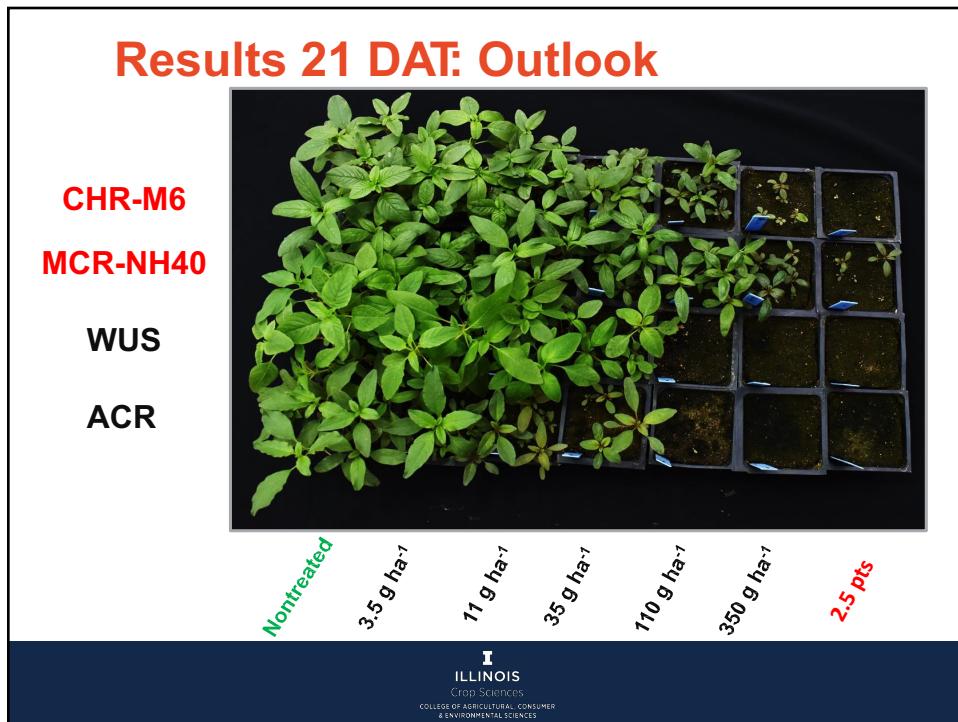
15



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17



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## Results 21 DAT: Zidua SC

CHR-M6

MCR-NH40

WUS

ACR



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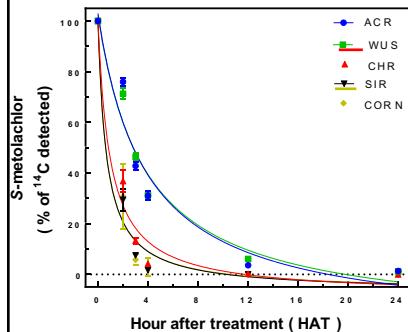
Resistance ratios for two Illinois waterhemp populations resistant to Group 15 herbicides. LD<sub>50</sub> values represent the rates required to reduce waterhemp emergence/survival by 50 percent.

Herbicide	Resistant populations (CHR-M6 and MCR-NH40)	Sensitive populations (ACR and WUS)	R/S ratio
.....LD <sub>50</sub> (g ai ha <sup>-1</sup> ).....			
S-metolachlor	1808–3360	53–101	18–64
dimethenamid	729–1463	26–35	21–56
pyroxasulfone	65–153	9–10	7–17
acetochlor	178–226	13–40	5–18

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## HPLC Results



Population	*DT <sub>50</sub>	*DT <sub>90</sub>
Hours after treatment		
ACR	<b>2.9</b> (2.7–3.0)	<b>6.3</b> (5.7–7.0)
WUS	<b>2.9</b> (2.7–3.0)	<b>7.4</b> (6.4–8.3)
CHR	<b>1.7</b> (1.6–1.8)	<b>3.2</b> (3.0–3.5)
SIR	<b>1.6</b> (1.5–1.8)	<b>2.7</b> (2.5–3.0)
CORN	<b>1.7</b> (1.6–1.8)	<b>2.7</b> (2.5–3.0)

\*Values expressed as hours after treatment (HAT)  
followed by their respective 95% confidence interval of  
the mean



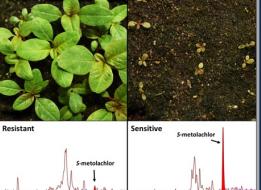
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## Summary

- CHR and SIR are resistant to S-metolachlor due to enhanced metabolism relative to sensitive populations
- Resistant waterhemp metabolizes S-metolachlor as rapidly as corn
- Resistant waterhemp possess increased GST-activity in comparison to sensitive waterhemp, but much less than corn
- Metabolomics revealed that resistant waterhemp have metabolite profiles that differ from sensitive waterhemp
- Results indicate more intricate, coordinated pathway(s) for S-metolachlor metabolism in resistant waterhemp than in sensitive waterhemp or corn



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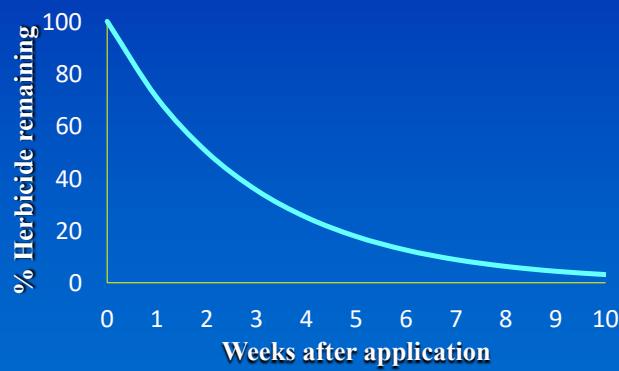
## Implications of Resistance

- Two Illinois waterhemp populations are resistant to VLCFA-inhibiting herbicides
- VLCFA-inhibitor efficacy and residual activity can be drastically reduced
- Grower may need to implement earlier postemergence applications
- Overlapping residual herbicide applications
- Apply multiple effective SOAs each season
- Integrated management practices with nonchemical control methods
- Distribution of Group 15-resistance is poorly understood
- Not all herbicide failures are due to resistance

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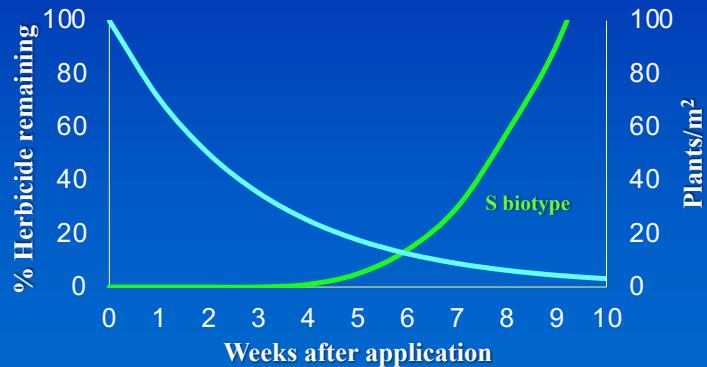
23

## Resistance: What happens to soil-applied herbicides?



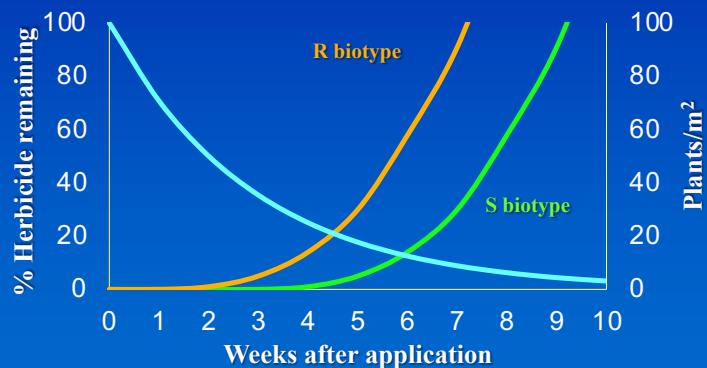
24

## Resistance: What happens to soil-applied herbicides?



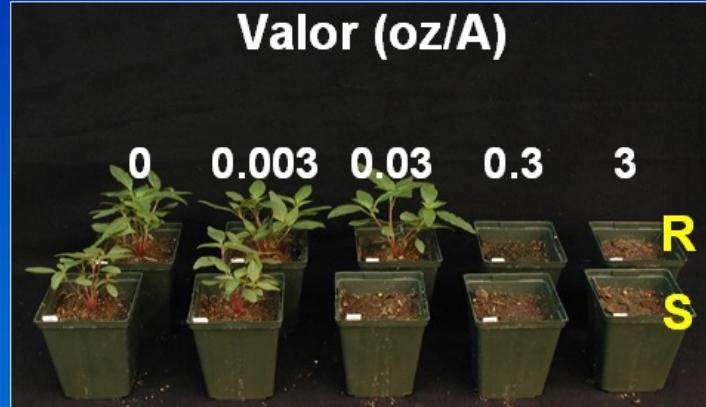
25

## Resistance: What happens to soil-applied herbicides?



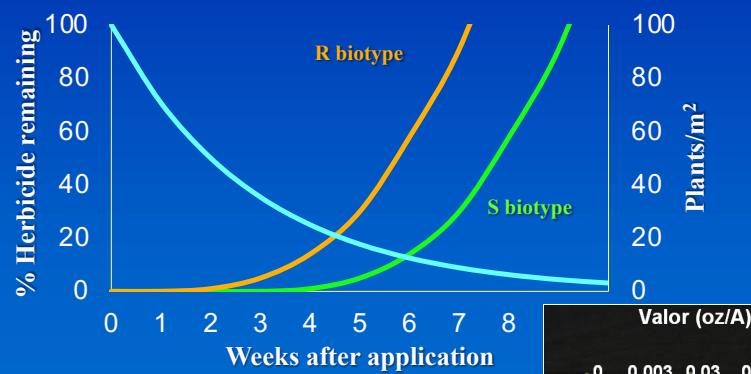
26

## Differentiating R and S biotypes after flumioxazin (Valor) PRE application



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## Resistance to soil-applied herbicides



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# Documenting the Extent of Resistance to Group 15 Herbicides in Illinois Waterhemp (*Amaranthus tuberculatus*)

Travis Wilke<sup>1</sup>, Patrick Tranell<sup>1</sup>, Martin Williams<sup>2</sup>, Aaron Hager<sup>1</sup>

## 79<sup>th</sup> Annual NCWSS

<sup>1</sup>University of Illinois at Urbana-Champaign <sup>2</sup>USDA Agricultural Research Service



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## Illinois Waterhemp

- Resistance confirmed to herbicides from seven unique sites of action (SOA) in Illinois, including populations with resistance to herbicides from multiple SOAs<sup>1</sup>
- Two populations of Illinois waterhemp (CHR and MCR) have confirmed resistance to VLCFA-inhibiting herbicides<sup>2</sup>

Year	Country	MOAs	Year	Country	MOAs
1993	United States (Illinois)	Inhibition of Acetolactate Synthase HRAC Group 2 (Legacy B)	2009	United States (Illinois)	Inhibition of Acetolactate Synthase HRAC Group 2 (Legacy B), Inhibition of Enolpyruvyl Shikimate Phosphate Synthase HRAC Group 9 (Legacy G), Inhibition of Hydroxypyruvyl Pyruvate Oxydoreductase HRAC Group 27 (Legacy F2), PsiI inhibitors - Serine 264 Binders HRAC Group 5 (Legacy C1 C2)
1996	United States (Illinois)	Inhibition of Acetolactate Synthase HRAC Group 2 (Legacy B), PsiI inhibitors - Serine 264 Binders HRAC Group 5 (Legacy C1 C2)	2001	United States (Illinois)	PsiI inhibitors - Serine 264 Binders HRAC Group 5 (Legacy C1 C2)
2001	United States (Illinois)	PsiI inhibitors - Serine 264 Binders HRAC Group 5 (Legacy C1 C2)	2002	United States (Illinois)	Inhibition of Acetolactate Synthase HRAC Group 2 (Legacy B), Inhibition of Propanoyl Enolpyruvyl Oxidase HRAC Group 4 (Legacy E), PsiI inhibitors - Serine 264 Binders HRAC Group 5 (Legacy C1 C2)
2006	United States (Illinois)	Inhibition of Acetolactate Synthase HRAC Group 2 (Legacy B), Inhibition of Enolpyruvyl Shikimate Phosphate Synthase HRAC Group 9 (Legacy G)	2016	United States (Illinois)	Auxin Mimics HRAC Group 4 (Legacy O), Inhibition of Acetolactate Synthase HRAC Group 2 (Legacy B), Inhibition of Hydroxypyruvyl Pyruvate Oxydoreductase HRAC Group 27 (Legacy F2), Inhibition of Propanoyl Enolpyruvyl Oxidase HRAC Group 4 (Legacy E), PsiI inhibitors - Serine 264 Binders HRAC Group 5 (Legacy C1 C2)
2009	United States (Illinois)	Inhibition of Acetolactate Synthase HRAC Group 2 (Legacy B), Inhibition of Hydroxypyruvyl Pyruvate Oxydoreductase HRAC Group 27 (Legacy F2), PsiI inhibitors - Serine 264 Binders HRAC Group 5 (Legacy C1 C2)	2016	United States (Illinois)	Very Long-Chain Fatty Acid Synthesis inhibitors - HRAC Group 15 (Legacy K3 N)
					<sup>1</sup> Heap (2024) <sup>2</sup> Strom et al. (2019)

<sup>1</sup>Heap (2024)

<sup>2</sup>Strom et al. (2019)



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## Illinois Waterhemp

- Resistance confirmed to herbicides from seven unique sites of action (SOA) in Illinois, including populations with resistance to herbicides from multiple SOAs<sup>1</sup>

- Two populations of Illinois waterhemp (CHR and MCR) have confirmed resistance to VLCFA-inhibiting herbicides<sup>2</sup>

- Resistance to soil-applied herbicides is difficult to detect in the field due to the shortened duration of control affected by multiple factors

Year	Country	MOAs
2009	United States (Illinois)	Inhibition of Acetyl-CoA:Shikimate Synthase HRAC Group 2 (Legacy B), Inhibition of Endoxynyl Shikimate:Phosphate Synthase HRAC Group 9 (Legacy G), Inhibition of Protoporphyrinogen Oxidase HRAC Group 14 (Legacy E), PSII inhibitors - Serine 264 Binders HRAC Group 5 (Legacy C1 C2)
2016	United States (Illinois)	<b>Alpha Mimics</b> HRAC Group 4 (Legacy O), Inhibition of Acetyl-CoA:Shikimate Synthase HRAC Group 9 (Legacy B), Inhibition of Hydroxymethyl Pyruvate Dioxygenase HRAC Group 27 (Legacy F2), Inhibition of Protoporphyrinogen Oxidase HRAC Group 14 (Legacy E), PSII inhibitors - Serine 264 Binders HRAC Group 5 (Legacy C1 C2)
	United States (Illinois)	Very Long-Chain Fatty Acid Synthesis Inhibitors HRAC Group 15 (Legacy K3 N)

<sup>1</sup>Heap (2024)

<sup>2</sup>Strom et al. (2019)



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## Objectives

- Determine extent of resistance to Group 15 herbicides in Illinois waterhemp populations
- Develop a scalable method for residual herbicide screenings in a greenhouse setting
- Identify resistant populations for subsequent research related to metabolism-based resistance



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## Materials and Methods

**Seed Collections – Fall 2023**

- Two female inflorescences  $\geq$  30 ft apart per field, bagged separately
- Public submissions from 16 fields with suspected resistance

University of Illinois Waterhemp Resistance Survey  
Submission Form

Thank you for submitting waterhemp seed samples for our new research with resistance to Group 15 herbicides at the University of Illinois Urbana-Champaign. Please complete this form to the best of your ability and attach your seed samples in separate paper bags.

Mail samples to:  
Dr. Aaron Hager  
Department of Crop Sciences  
1302 S Goodwin Ave  
Urbana, IL 61801

OFFICE USE ONLY  
 Population: \_\_\_\_\_

**Guidelines for submission:**

- Please watch a short video on how to collect waterhemp samples at <http://go.illinois.edu/waterhempvideo>
- Please collect two female inflorescences of waterhemp seed from two female plants (one female per bag); at least 30 feet apart from one another.
- Please attach a separate paper bag for each sample.
- Fill out each paper to the best of your knowledge to aid in data comparison.
- Leaving an unknown field blank is unacceptable.

Estimated coordinates of field: Latitude: N 40.8775 Longitude: W 88.2278

Contact Name: \_\_\_\_\_  
Phone Number: \_\_\_\_\_  
Date Collected: \_\_\_\_\_  
Current Crop in Field: \_\_\_\_\_  
Coordinates of Field (dddd.ddd):  
Latitude: \_\_\_\_\_  
Longitude: \_\_\_\_\_  
County: \_\_\_\_\_

Herbicide History:

	PRE	POST
2021		
2022		
2023		

Staple to sample bag.1



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## Materials and Methods

**Seed Collections – Fall 2023**

- Two female inflorescences  $\geq$  30 ft apart per field, bagged separately
- Public submissions from 16 fields with suspected resistance
- Random collections from 127 fields across 84 of 102 counties in Illinois
  - Soybean crops, including 25 fields in a double crop system

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Coordinates of Field (dddd.ddd):  
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County: \_\_\_\_\_

Herbicide History:

	PRE	POST
2021		
2022		
2023		

Staple to sample bag.1



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## Materials and Methods

### Seed Collections – Fall 2023

- Two female inflorescences  $\geq 30$  ft apart per field, bagged separately
- Public submissions from 16 fields with suspected resistance
- Random collections from 127 fields across 84 of 102 counties in Illinois
  - Soybean crops, including 25 fields in a double crop system



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## Materials and Methods

### Seed Collections – Fall 2023

- Two female inflorescences  $\geq 30$  ft apart per field, bagged separately
- Public submissions from 16 fields with suspected resistance
- Random collections from 127 fields across 84 of 102 counties in Illinois
  - Soybean crops, including 25 fields in a double crop system
- Inflorescences dried for minimum of 7 days in greenhouse, seeds cleaned and stratified<sup>1</sup>



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## Materials and Methods

### Herbicide Application

- Immediately following sowing
- Compressed air research sprayer
- TeeJet 80015 Even Flat Spray Nozzle
- $16.33 \text{ gal A}^{-1}$ , 43 psi



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## Materials and Methods

### Herbicide Application

- Immediately following sowing
- Compressed air research sprayer
- TeeJet 80015 Even Flat Spray Nozzle
- $16.33 \text{ gal A}^{-1}$ , 43 psi



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## Materials and Methods

### Developing a Discriminating Dose

- S-metolachlor chosen based on previous R:S ratios
  - Highest recorded R:S ratio of  $LD_{50}$ <sup>1</sup>
- Search for discriminating dose beginning at  $LD_{50}$  of WUS
  - WUS survival reduced to 0% < 0.2 pt Dual II Magnum A<sup>-1</sup>
  - Need for a less “overly sensitive” comparison in future dose-response experiments
- Putative resistance based on herbicide rate with defining level of control to known-resistant sample

<sup>1</sup>Strom et al.  
(2019)



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## Materials and Methods

### Experimental Design and Data Analysis

- Screening
  - Two Treatments (0 and 0.4 pt Dual II Magnum A<sup>-1</sup>)
  - Two replications
  - Live seedlings counted at 10 DAA
  - Survival percentage at 0.4 pt Dual II Magnum A<sup>-1</sup>

$$\frac{\# \text{Live Seedlings (Treated) Average}}{\# \text{Live Seedlings (Untreated) Average}} \times 100$$
- Visual assessment of growth reduction in live seedlings in treated replications (data not shown)



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## Results

### Screenings

- Comparison to known-resistant, CHR F2BC-89
- Search for samples with minimum 45% survival

CHR F2-89			
<u>Rate (pt Dual II Magnum A<sup>-1</sup>)</u>	<u>Replicate</u>	<u>Live Seedlings</u>	<u>% Stunt</u>
0	1	21	-
0	2	17	-
0.4	1	10	75
0.4	2	7	80

Survival Percentage = 45%



Rate Dual II Magnum (pt A<sup>-1</sup>)

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## Results

### Screenings

- Samples have revealed a range of responses to the screening rate in each execution



CHR F2BC-89; 45% Survival

Collection 377; 89% Survival

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## Results

### Screenings

- Samples have revealed a range of responses to the screening rate in each execution

Rate Dual II Magnum (pt A<sup>-1</sup>)

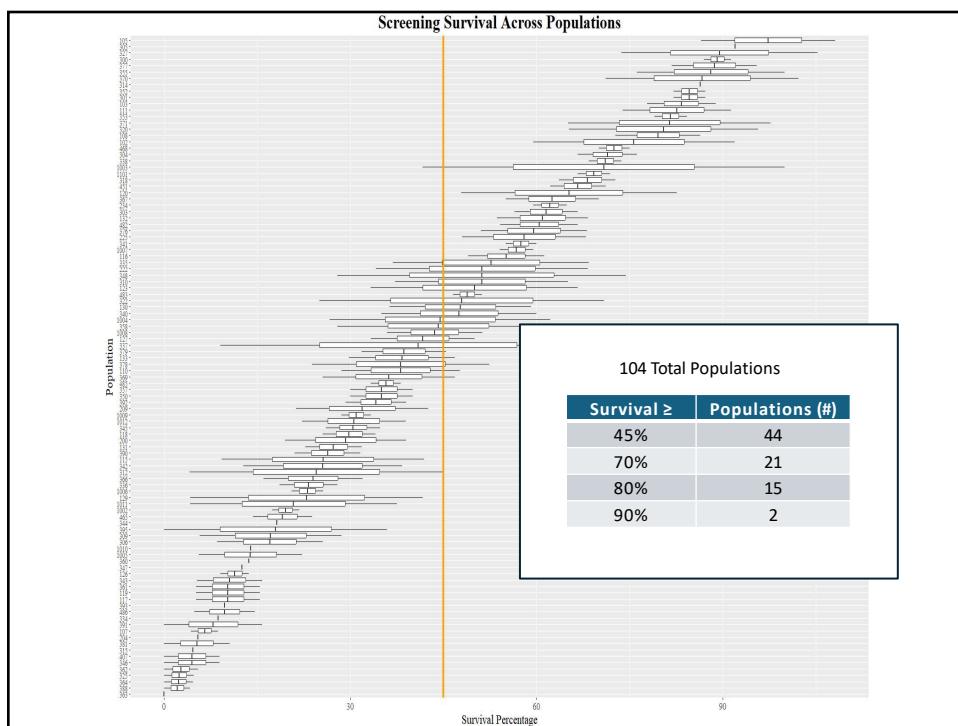
Sample 117  
10% Survival

Sample 303  
62% Survival

Sample 305  
92% Survival

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## S-metolachlor Dose Response

Sample	Screening Survival Percentage	LD50 (g/ha)	St. Error +/-	R/S
305	92	1570	201.2	120
103	83	768	127.0	59
1003	71	998	134.6	77
451	67	580	78.4	45
390	26	760	95.1	58
1010	14	443	117.5	34
204	5	65.66	15.5	5
WUS	0	12.93	4.6	-

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## Conclusions

- Waterhemp resistance to Group 15 herbicides is suspected in more populations than originally confirmed
- Large-scale residual herbicide research can be done with the methods described
- Frequency of resistance may be impacted in a short time frame by a lack of utilization of Group 15 herbicides in practices such as double-cropping

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**Common soybean soil-residual herbicides**

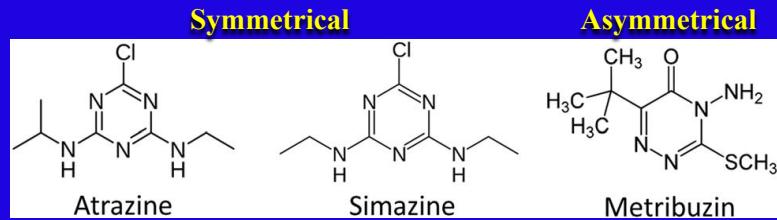
Herbicide group	Resistance in waterhemp
Group 2 (ALS inhibitors)	Yes
Group 14 (PPO inhibitors)	Yes
Group 15 (acetamides, etc.)	Yes
Group 5 (PS II inhibitors)	Yes and No

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## Two types of triazine herbicides used in Illinois



Parker et al. 2018

**Symmetrical: nitrogen atoms symmetrically distributed in the phenyl ring**

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## Two types of triazine herbicide resistance mechanisms

### Target-site resistance (High level)

Table 1. Identification of mutations conferring target-site resistance to herbicides.

Target Site	Representative Herbicide	Year <sup>1</sup>
D1 protein	atrazine	1983 [6]
acetolactate synthase	chlormuron	1992 [8]
tubulin	trifluralin	1998 [9]
acetyl CoA carboxylase	clethodim	2001 [10]
5-enolpyruvylshikimate-3-phosphate synthase	glyphosate	2002 [11]
phytoene desaturase	fluridone	2004 [12]
protochlorophyllogen oxidase	lactofen	2006 [13]
glutamine synthetase	glufosinate	2012 [14]
auxin receptor	2,4-D	2018 [15]

<sup>1</sup> Indicates first year of publication in peer-reviewed literature of a resistance-conferring mutation in the target-site from a field-evolved weed population.

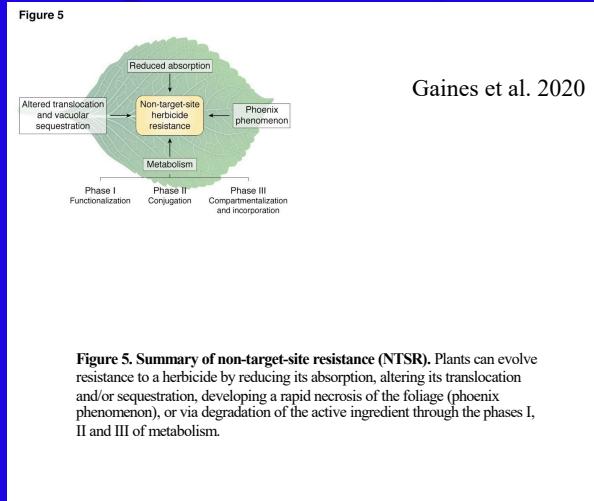
Murphy and Tranell 2019

**First identified resistance-conferring target-site mutation:  
Single nucleotide polymorphism Ser-264-Gly (1983)  
*Amaranthus hybridus***

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## Two types of triazine herbicide resistance mechanisms

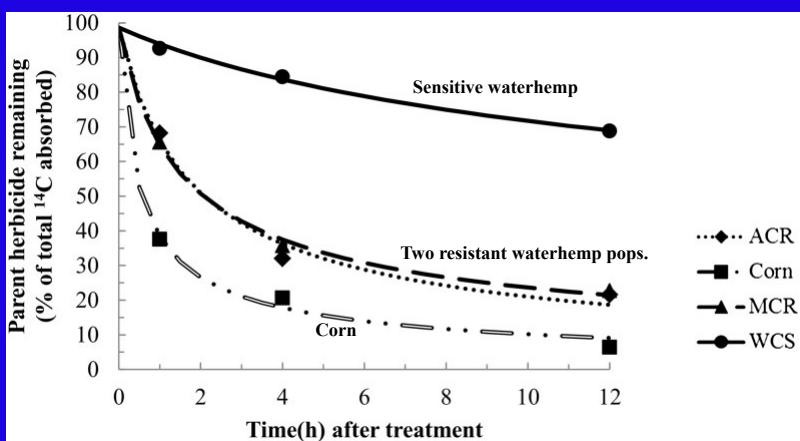
### Non-target site resistance (Low level)



Phase I involves a slight modification of the herbicide molecule which predisposes it to further modification. Phase II involves combining the modified herbicide with another compound (sugar, glutathione, etc.) that facilitates the final step. Phase III uses transport enzymes to move the herbicide into the cell vacuole (often described as a cell's garbage can) or outside of the cell in the intracellular space. Hartzler 2019

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## Atrazine metabolism in waterhemp (sensitive and resistant) and corn



Time course of atrazine metabolism in excised leaves of corn and MCR, ACR, and WCS waterhemp populations. Excised leaves (third youngest leaf; 2-3 cm in length) from waterhemp (10-12 cm) or corn seedlings were placed in 0.1 M Tris-HCl buffer (pH 6.0) for 1 h, followed by 0.1 M Tris-HCl (pH 6.0) plus 150  $\mu$ M [ $^{14}$ C]atrazine for 1 h, then one-quarter-strength Murashige and Skoog salts solution for 0.3, or 11 h. Data were analyzed by nonlinear least-squares regression analysis and fit with a  $\text{Model A}$  model ([www.sas.com/technote/2002/003.html](http://www.sas.com/technote/2002/003.html)) to estimate a  $T_{1/2}$  separately for each waterhemp population and corn. The  $T_{1/2}$  values of atrazine determined by regression analysis were 0.6 h (95% confidence interval of 0.3-0.9) in corn, 2.2 h (95% confidence interval of 1.1-3.2) in MCR, 2.2 h (95% confidence interval of 1.1-3.2) in ACR, and greater than 12 h in WCS.

Ma et al. 2013

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### What's the big deal with symmetrical and asymmetrical triazines and two types of resistance mechanisms?

- Target-site resistance confers resistance to symmetrical and asymmetrical triazines
  - neither atrazine nor metribuzin remain effective
  - however, most instances of triazine resistance in waterhemp is NOT target-site based
- Non-target site resistance (i.e., enhanced herbicide metabolism) currently is specific to symmetrical triazines
  - atrazine is not effective, but metribuzin remains effective
- So, how effective would metribuzin be on a waterhemp population resistant to herbicides from Groups 2 (ALS), 5 (atrazine), 14 (PPO), 15 (VLCFA), and 27 (HPPD)?
  - longer residual control compared with a soil-applied PPO?

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## Metribuzin vs Sulfentrazone

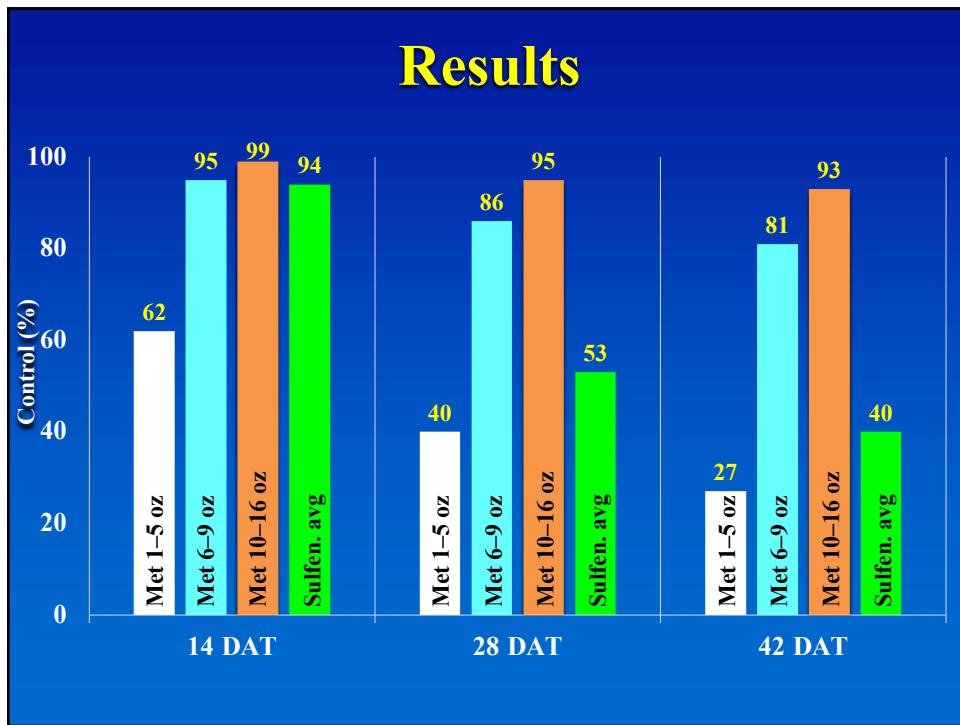
- Field experiments in 2019 and 2020 in Champaign County
  - Flanagan silt loam, pH = 5.5, 4.4% organic matter
- Metribuzin (TriCor 75DF) applied at incremental one-ounce rates
  - 1 to 16 ounces product/acre
- Sulfentrazone (Authority) applied at “common” use rate (0.25 lb ai/acre) and highest rate in any premix (0.313 lb ai/acre)

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## Metribuzin vs Sulfentrazone

- Herbicides applied PRE the day of soybean planting
  - 2019: June 10      2020: June 2
- Soybean planted in 30” rows
  - plot size was 10’ x 30’ and included 4 soybean rows
- Each treatment replicated three times
  - visual estimates of waterhemp control made 14, 28, and 42 days after planting

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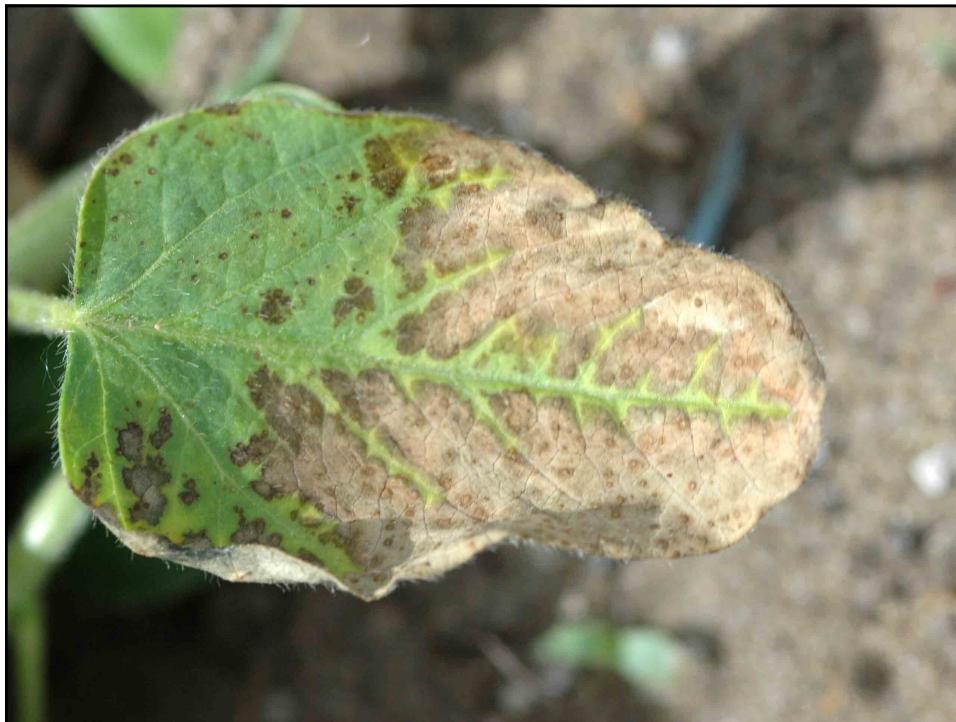


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## Summary

- Metribuzin can be an effective herbicide option for residual waterhemp control
  - even for populations resistant to atrazine
- Appropriate application rates are necessary to provide sufficient residual control
  - 5 oz or less will not be very effective
  - 10 oz or higher control was 90%+ 6 weeks after planting
- PPO resistance greatly diminishes residual control with soil-applied PPO inhibitors
  - 6 weeks after planting: 40% control in 2020 on a resistant population vs 93% control in 1996/97 on sensitive populations

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## Cautions with metribuzin

- Sensitive varieties still exist
  - check with seed company
- Soil pH and organic matter are important
  - availability increases with increasing soil pH
  - high affinity for organic matter
- Injury tended to be more common when higher atrazine rates were used
  - higher atrazine rates = atrazine carryover
  - better application equipment to avoid overlaps
  - accelerated atrazine degradation more common now

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*“Optimizing metribuzin rates for herbicide-resistant Amaranthus weed control in soybean”*

Published Open Access in Weed Technology  
Funded by the United Soybean Board

- Research conducted in 15 states in 2022 – 2023
  - mostly located on PPO-resistant WH and PA populations
- Objectives were to determine length of residual *Amaranthus* control and soybean injury
  - 14, 28, and 42 days after PRE applications
- 17 PRE treatments were evaluated
  - 13 rates of metribuzin (4 – 16 oz Metricor 75DF)
  - 1 rate of Authority (8 oz Authority 75DF or 12 fl oz Spartan 4F)
  - 1 rate of S-metolachlor (1.6 pints Dual Magnum)

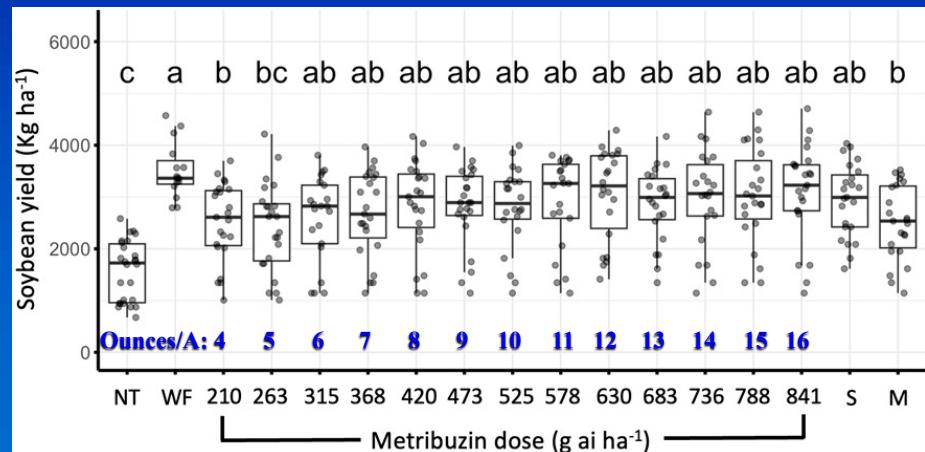
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***“Optimizing metribuzin rates for herbicide-resistant Amaranthus weed control in soybean”***  
**Results of most interest (31 total environments)**

- Soybean injury (visually evaluated, subjective):
  - Model predicted no more than 5% even at highest metribuzin dose (16 oz Metricor 75DF)
  - 10% 14 DAA in 4 environments, <5% by 28 DAA
  - Up to 20% 42 DAA in 2 environments (AR and LA)
  - No injury with sulfentrazone and S-metolachlor
- Soybean height (a non-subjective metric):
  - No significant differences 28 DAA (20 environments)
- Soybean yield (a non-subjective metric):

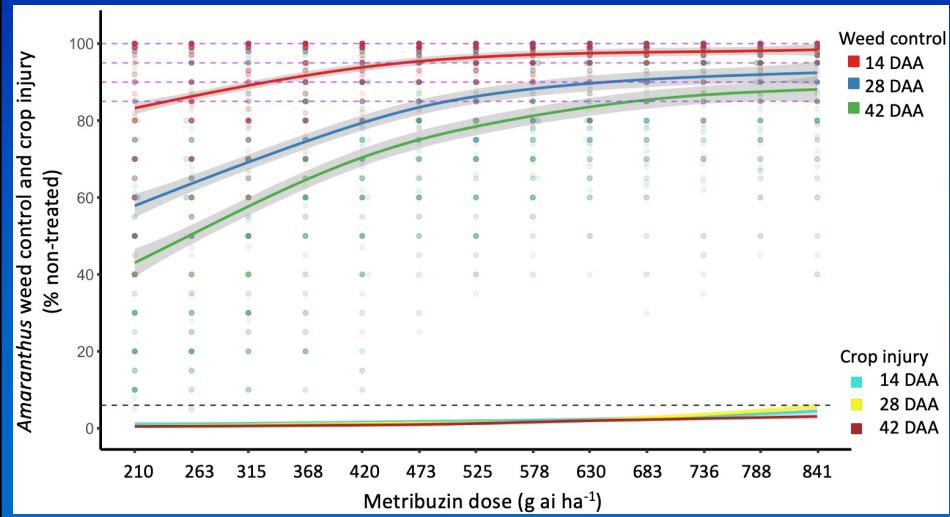
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**Figure 9. Soybean yield from seven site-years across herbicide treatment.**



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**Figure 3. Soybean injury and *Amaranthus* weed control across metribuzin doses at 14, 28 and 42 days after application (DAA) for all site-years except Illinois 2023 and Michigan 2023.**



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## Practical Implications

**“This multi-state study demonstrates that metribuzin, a long-established soil-residual herbicide, remains a viable option for residual control of Palmer amaranth and waterhemp.”**

**“Results suggest that metribuzin can be safely applied at higher rates than those commonly included in commercial premixes, particularly in optimum precipitation conditions.”**

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*Best wishes for a safe and  
prosperous 2026*



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