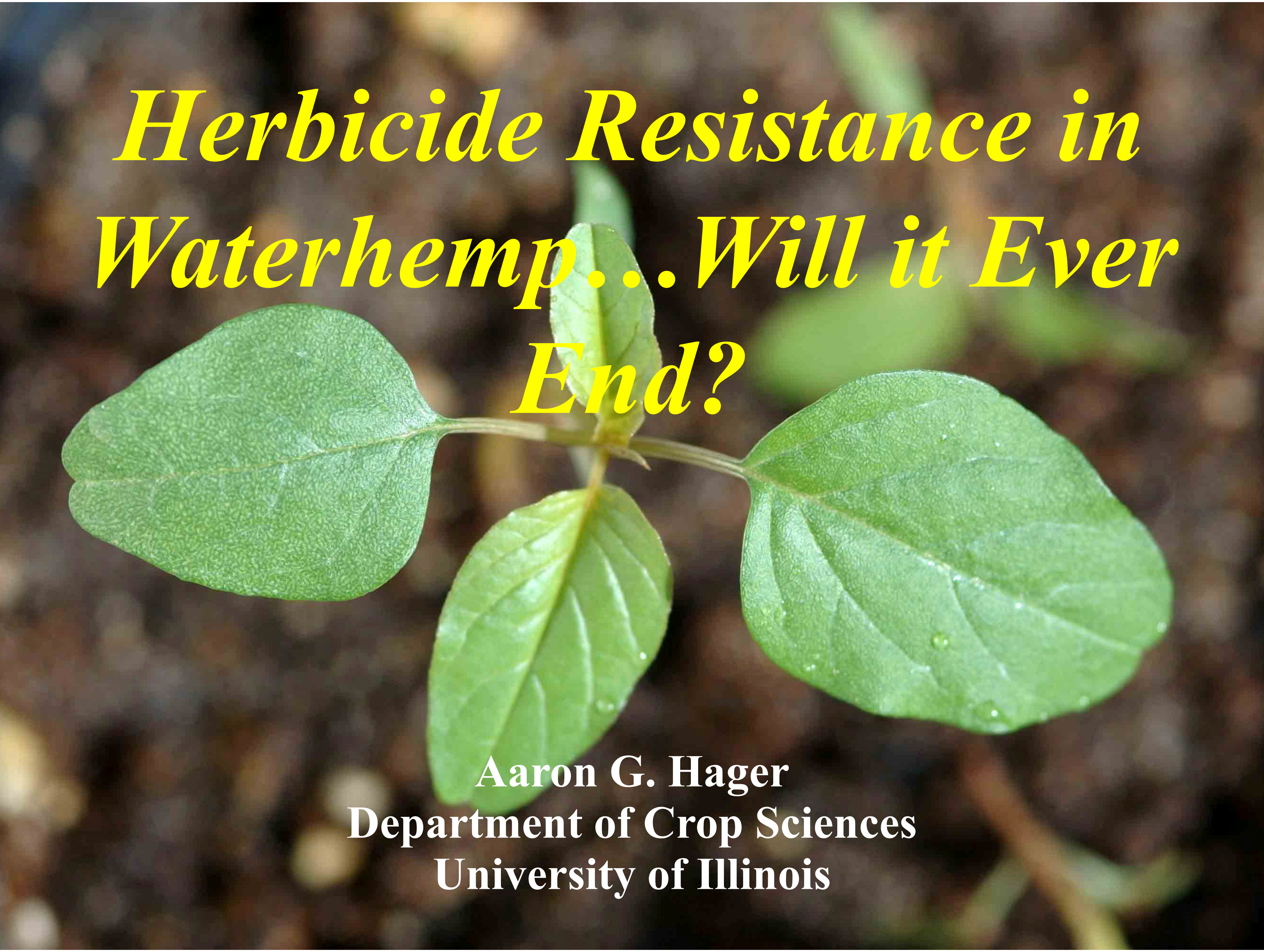
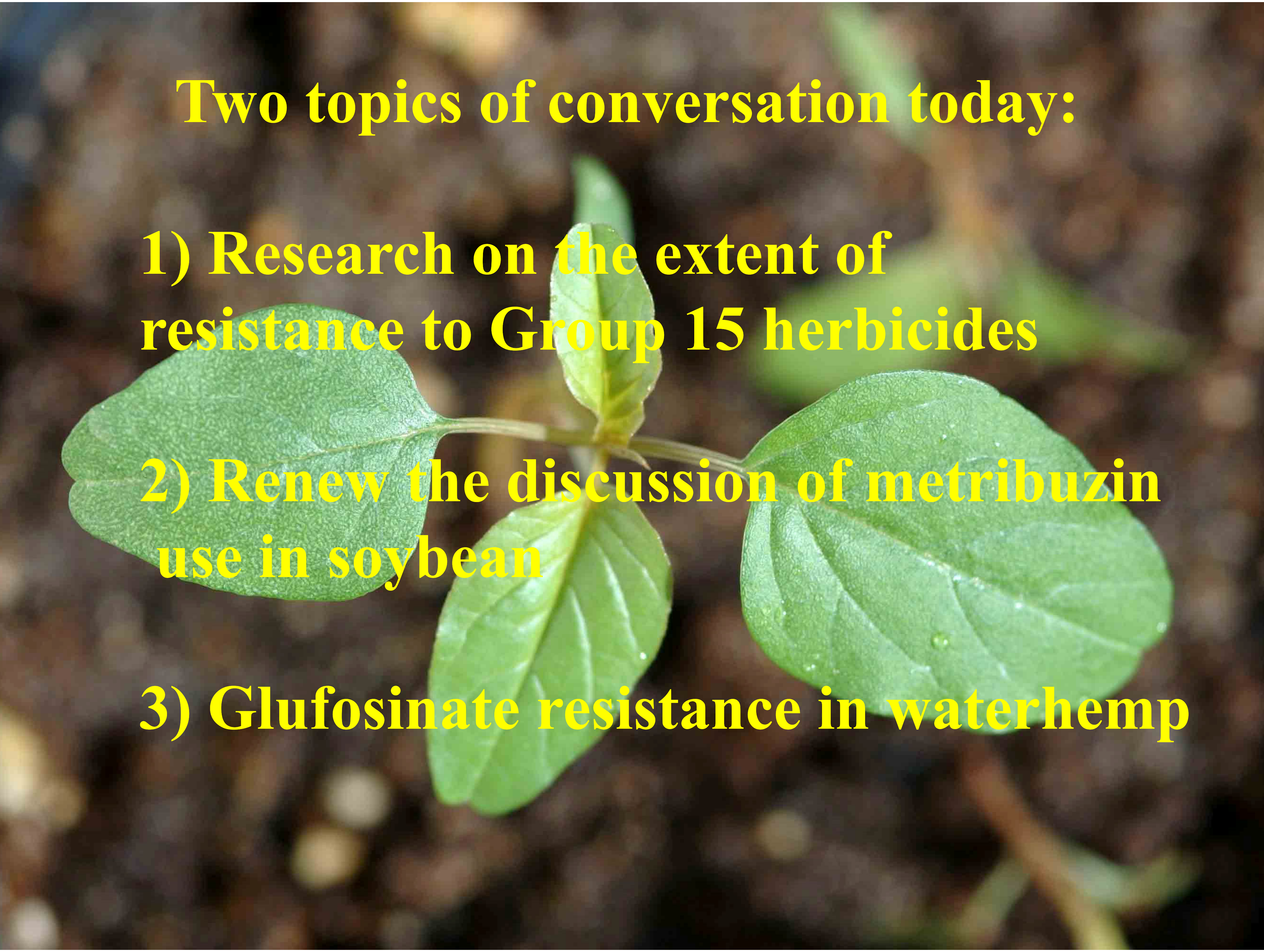


Herbicide Resistance in Waterhemp…Will it Ever End?

Aaron G. Hager
Department of Crop Sciences
University of Illinois

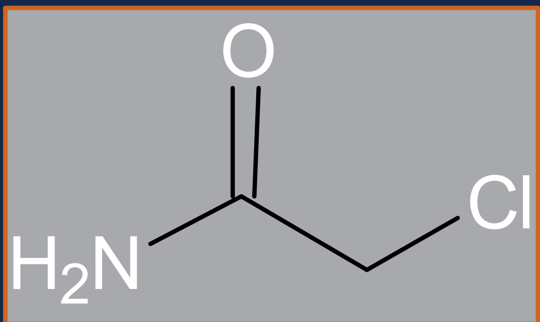


Two topics of conversation today:

1) Research on the extent of resistance to Group 15 herbicides

2) Renew the discussion of metribuzin use in soybean

3) Glufosinate resistance in waterhemp



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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HARNESS®

Herbicide by Monsanto

Outlook®
herbicide

BASF
The Chemical Company

GROUP 15 HERBICIDE

WARRANT®
HERBICIDE

WARRANT® is an encapsulated herbicide for weed control in Field Corn, Production Seed Corn, Cotton, Forage or Grain Sorghum (Milo), and Soybeans.

Dual II Magnum®

Zidua®
Herbicide

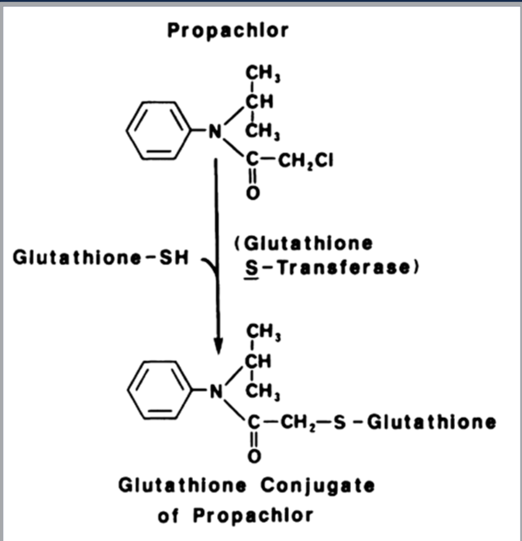

Figure 1. Metabolism of propachlor to the glutathione conjugate

(Fuerst 1987)

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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Callisto 12 fl oz/A
14 DAT
103
06.22.2010 14:3

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

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

		2010				2011			
		Control		Density		Control		Density	
Herbicide	Rate	30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT
	g ai ha^{-1}	%		plants m^{-2}		%		plants m^{-2}	
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[b]	105	68 cd	60 bc	263 def	69 def	62 c	27 de	263 a	145 a
Isoxaflutole + safener[b]	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
Nontreated	—	—	—	1067 a	363 a	—	—	260 a	145 a

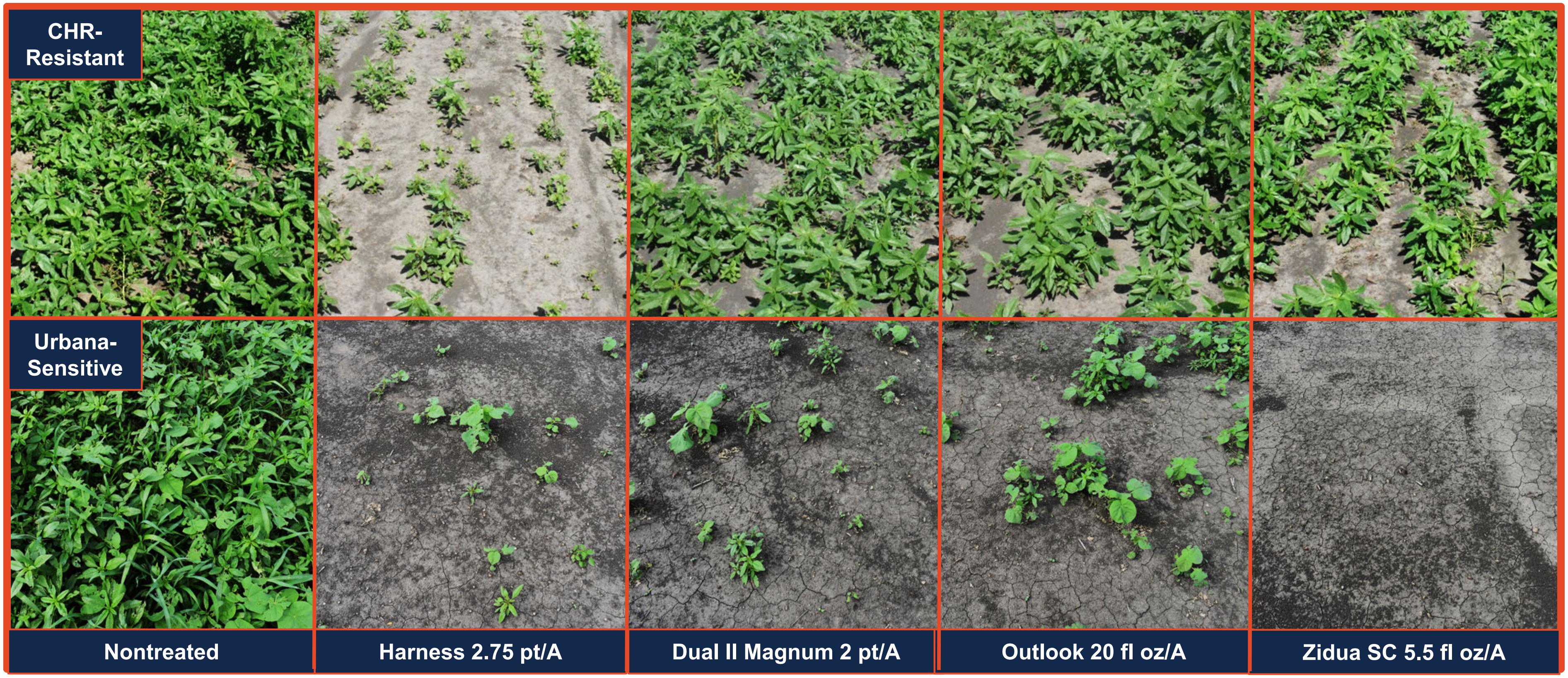
[a] Means with the same letter within a column are not significantly different at $\alpha = 0.05$ (separated by the SAS macro *%pdmix800*).

[b] Cyprosulfamide.

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

Field Results 28 DAT 2020



Field Results 2018 – 2020

28 DAT

Active Ingredient	Trade Name	Waterhemp Control	
		Resistant (CHR)	Sensitive (Urbana)
		%	
acetochlor	Harness 7EC	93 A	98 A
alachlor	Intrro 4EC	91 A	98 A
dimethenamid-*P*	Outlook 6EC	61 B	94 B
pyroxasulfone	Zidua SC	57 B	98 A
acetochlor	Warrant 3L	56 B	96 B
S-metolachlor	Dual Magnum 7.62EC	37 C	95 B
S-metolachlor	Dual II Magnum 7.64EC	30 CD	93 B
metolachlor	Stalwart 8L	20 D	88 C

Values with the same letter not significantly different α=0.05

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

Idealized Dose-Response Curves

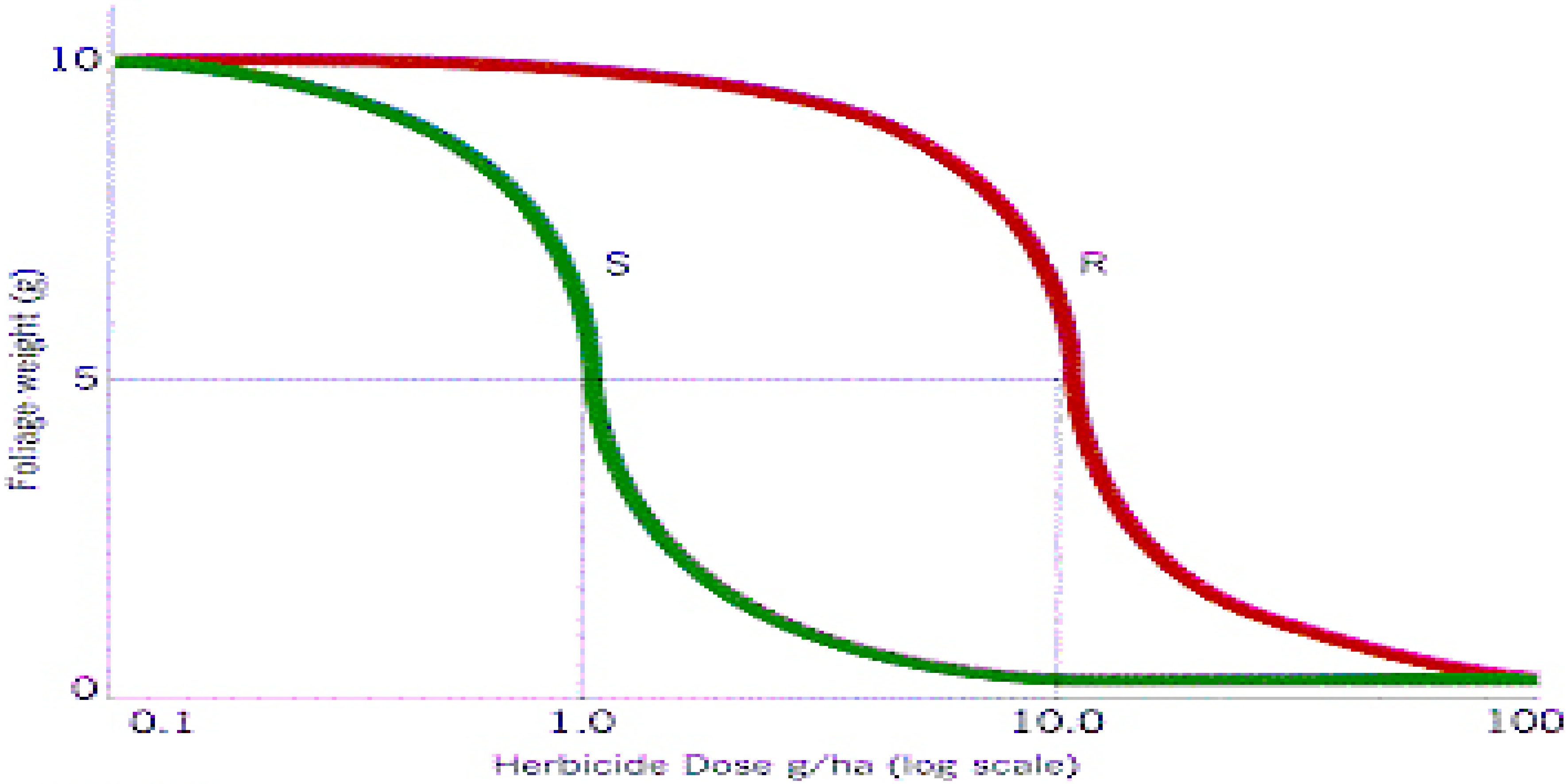


Figure 1.
Dose response curves for a Susceptible (S) and a Resistant (R) population

ED_{50} (susceptible) = 1.0 ED_{50} (resistant) = 10.0

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

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

Results 21 DAT: Dual II Magnum

CHR-M6

MCR-NH40

WUS

ACR

Nontreated

8.4 g ha^{-1}

27 g ha^{-1}

84 g ha^{-1}

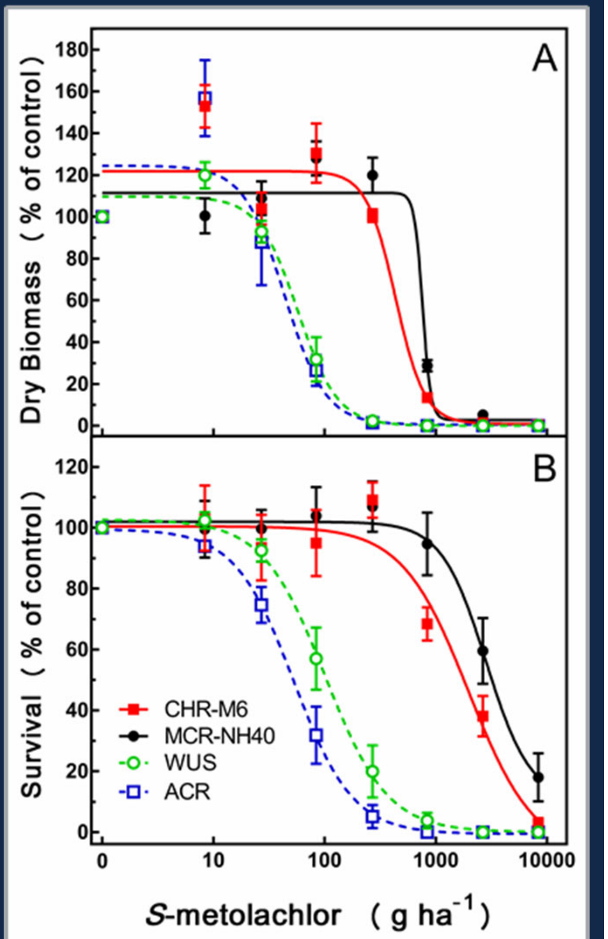
270 g ha^{-1}

840 g ha^{-1}

2.5 pts

8.4 kg ha^{-1}

Results 21 DAT: Dual II Magnum



Population	LD_{50}	R:S	GR_{50}	R:S
CHR-M6	1808	18	431	7.5
		34		9.9
MCR-NH40	3360	33	742	13
		64		17
WUS	101		57	
ACR	53		44	

Results 21 DAT: Harness

CHR-M6

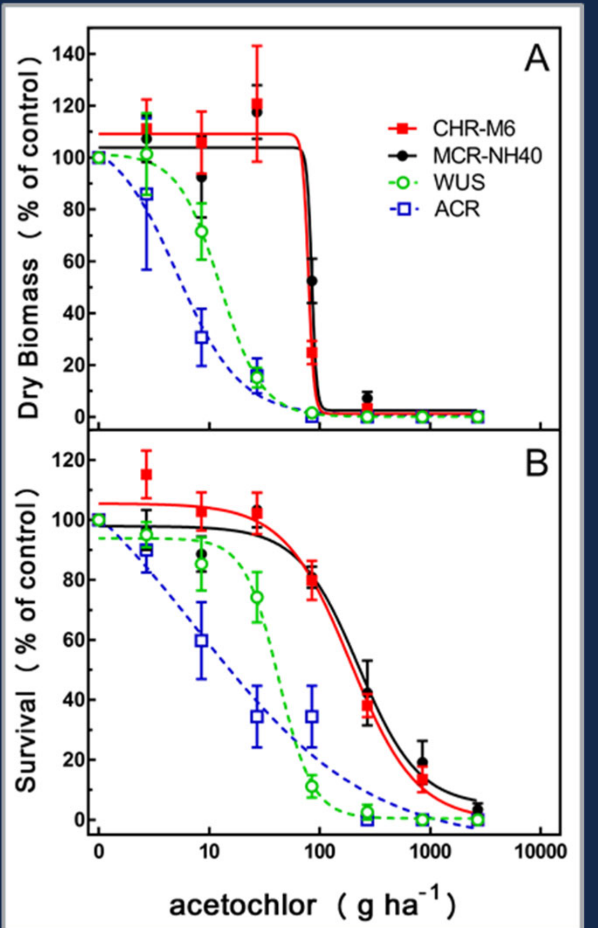
MCR-NH40

WUS

ACR

Nontreated | 2.5 g ha^{-1} | 8 g ha^{-1} | 25 g ha^{-1} | 80 g ha^{-1} | 250 g ha^{-1} | 800 g ha^{-1} | 2.5 pts

Results 21 DAT: Harness



Population	*LD_{50}	R:S	*GR_{50}	R:S
CHR-M6	178	4.5 14	72	6.1 13
MCR-NH40	226	5.7 18	80	6.7 15
WUS	40		12	
ACR	13		5	

*Expressed as g ha^{-1}

Results 21 DAT: Outlook

CHR-M6

MCR-NH40

WUS

ACR

Nontreated

3.5 g ha^{-1}

11 g ha^{-1}

35 g ha^{-1}

110 g ha^{-1}

350 g ha^{-1}

2.5 pts

Results 21 DAT: Zidua SC

CHR-M6

MCR-NH40

WUS

ACR

Nontreated

0.8 g ha^{-1}

2.4 g ha^{-1}

7.8 g ha^{-1}

24 g ha^{-1}

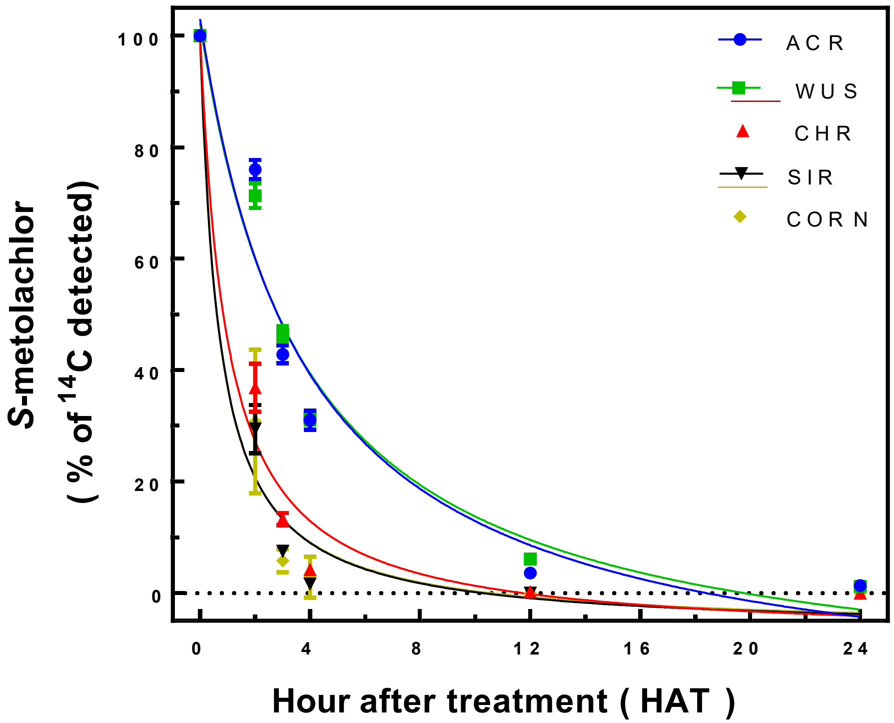
78 g ha^{-1}

6.5 fl oz

Resistance ratios for two Illinois waterhemp populations resistant to Group 15 herbicides. LD_{50} 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_{50} (g ai ha^{-1})……………		
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

HPLC Results



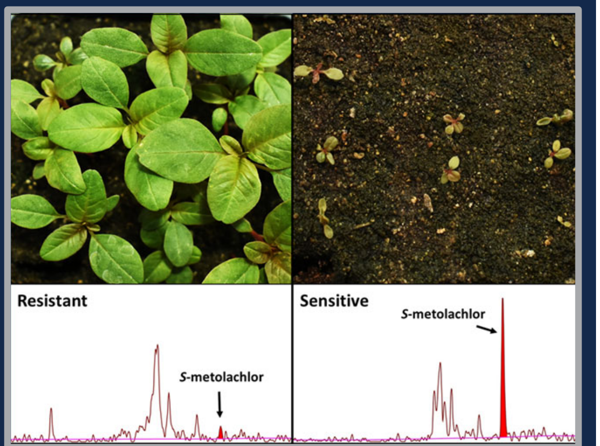
Population	*DT_{50}	*DT_{90}
	Hours after treatment	
ACR	**2.9** (2.7–3.0)	**6.3** (5.7–7.0)
WUS	**2.9** (2.7–3.0)	**7.4** (6.4–8.3)
CHR	**1.7** (1.6–1.8)	**3.2** (3.0–3.5)
SIR	**1.6** (1.5–1.8)	**2.7** (2.5–3.0)
CORN	**1.7** (1.6–1.8)	**2.7** (2.5–3.0)

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

Summary

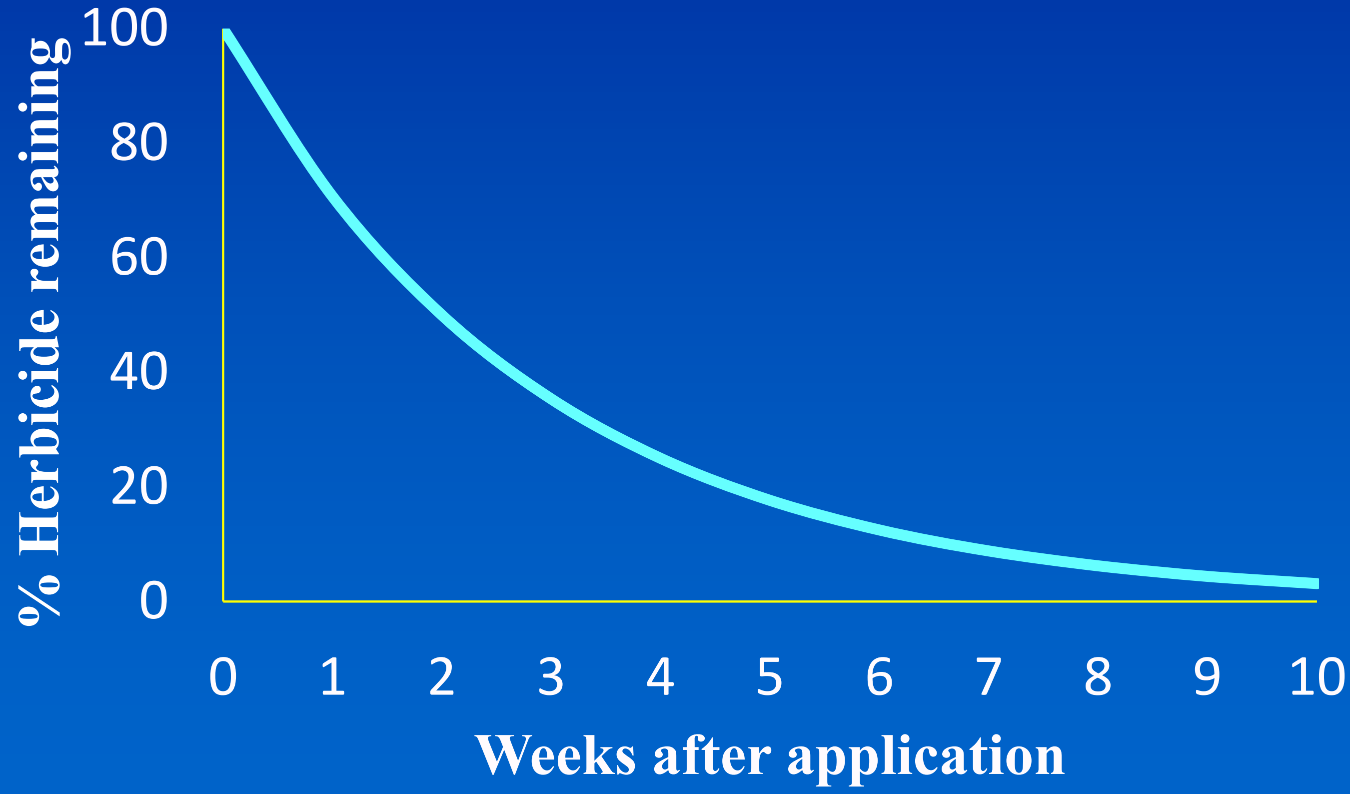
- CHR and SIR are resistant to *S*-metolachlor due to enhanced metabolism relative to sensitive populations
- Resistant waterhemp metabolizes *S*-metolachlor as rapidly as corn
- Resistant waterhemp possess increased GST-activity in comparison to sensitive waterhemp, but much less than corn
- Metabolomics 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

Implications of Resistance

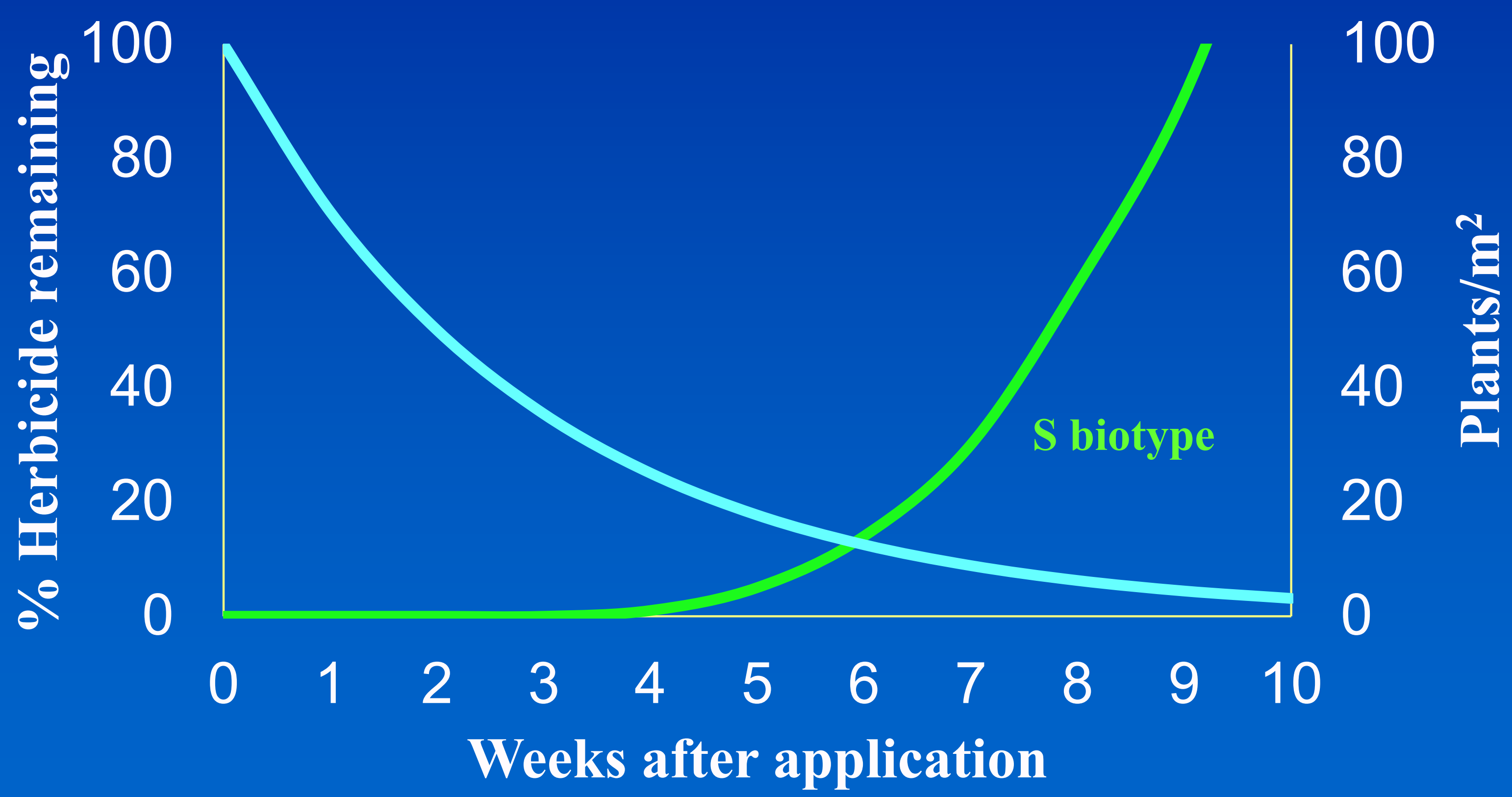


- Two Illinois waterhemp populations are resistant to VLCFA-inhibiting herbicides
- VLCFA-inhibitor efficacy and residual activity can be drastically reduced
- Grower may need to implement earlier postemergence applications
- Overlapping residual herbicide applications
- Apply multiple effective SOAs 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

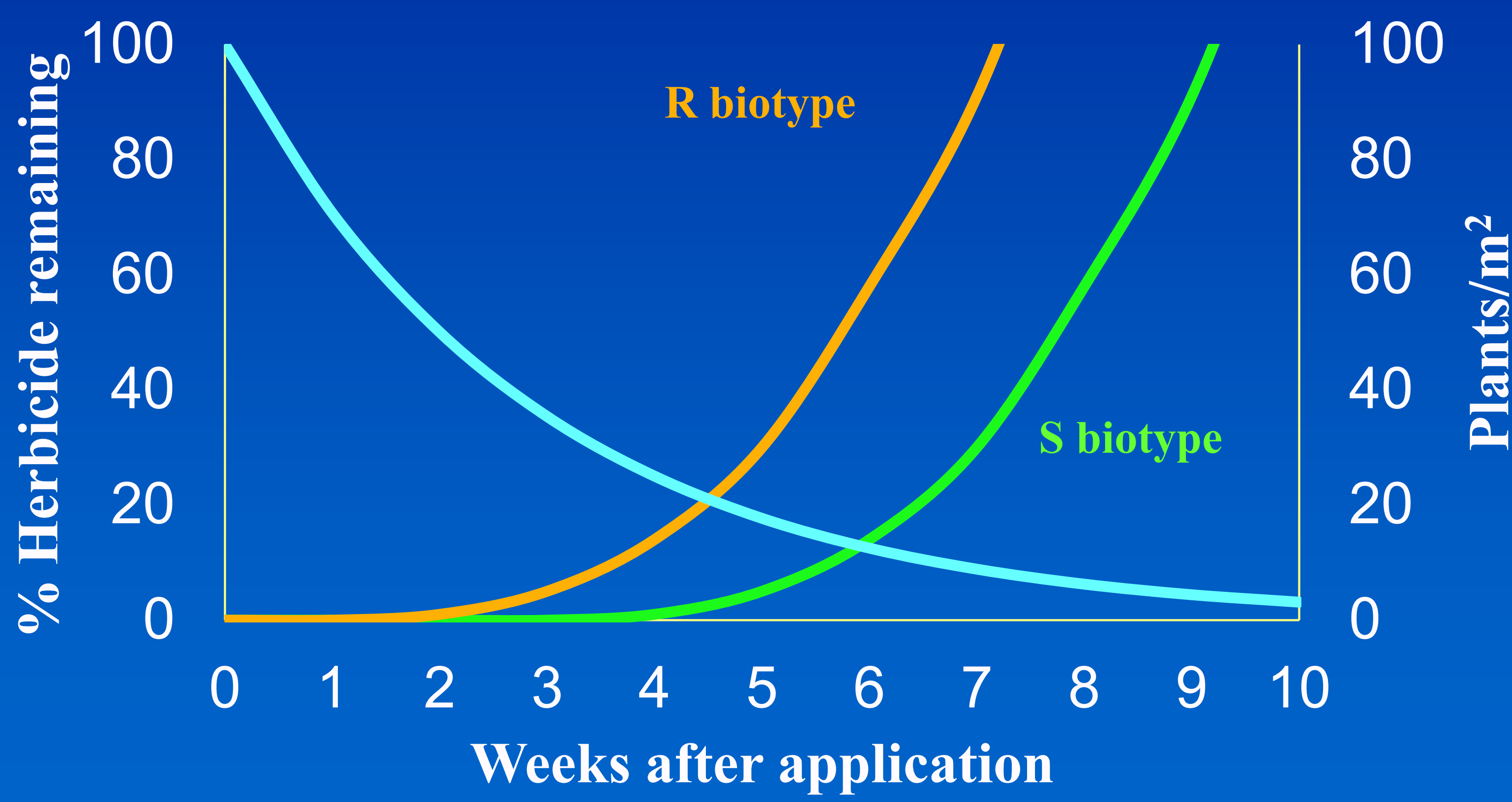
Resistance: What happens to soil-applied herbicides?



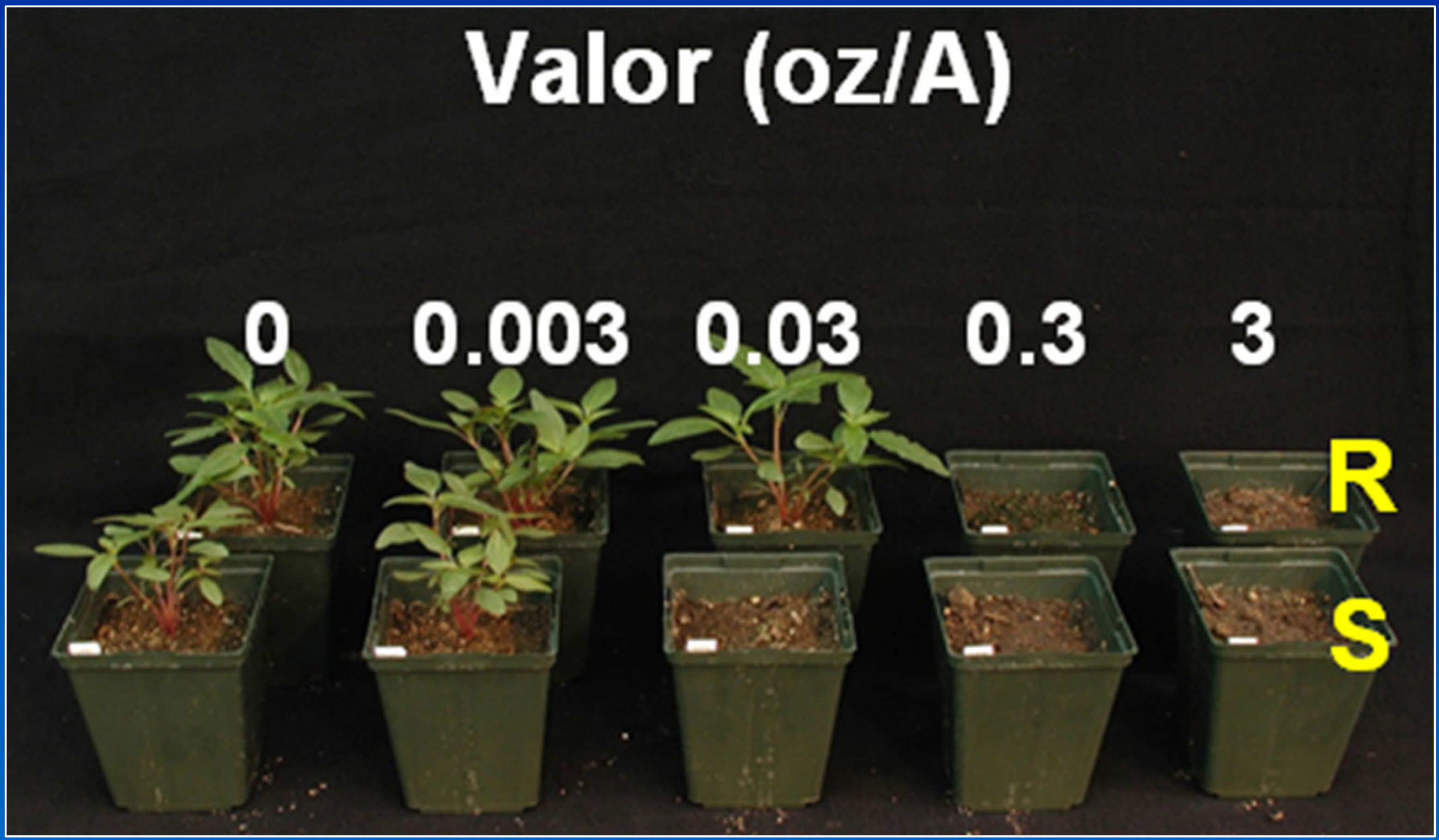
Resistance: What happens to soil-applied herbicides?



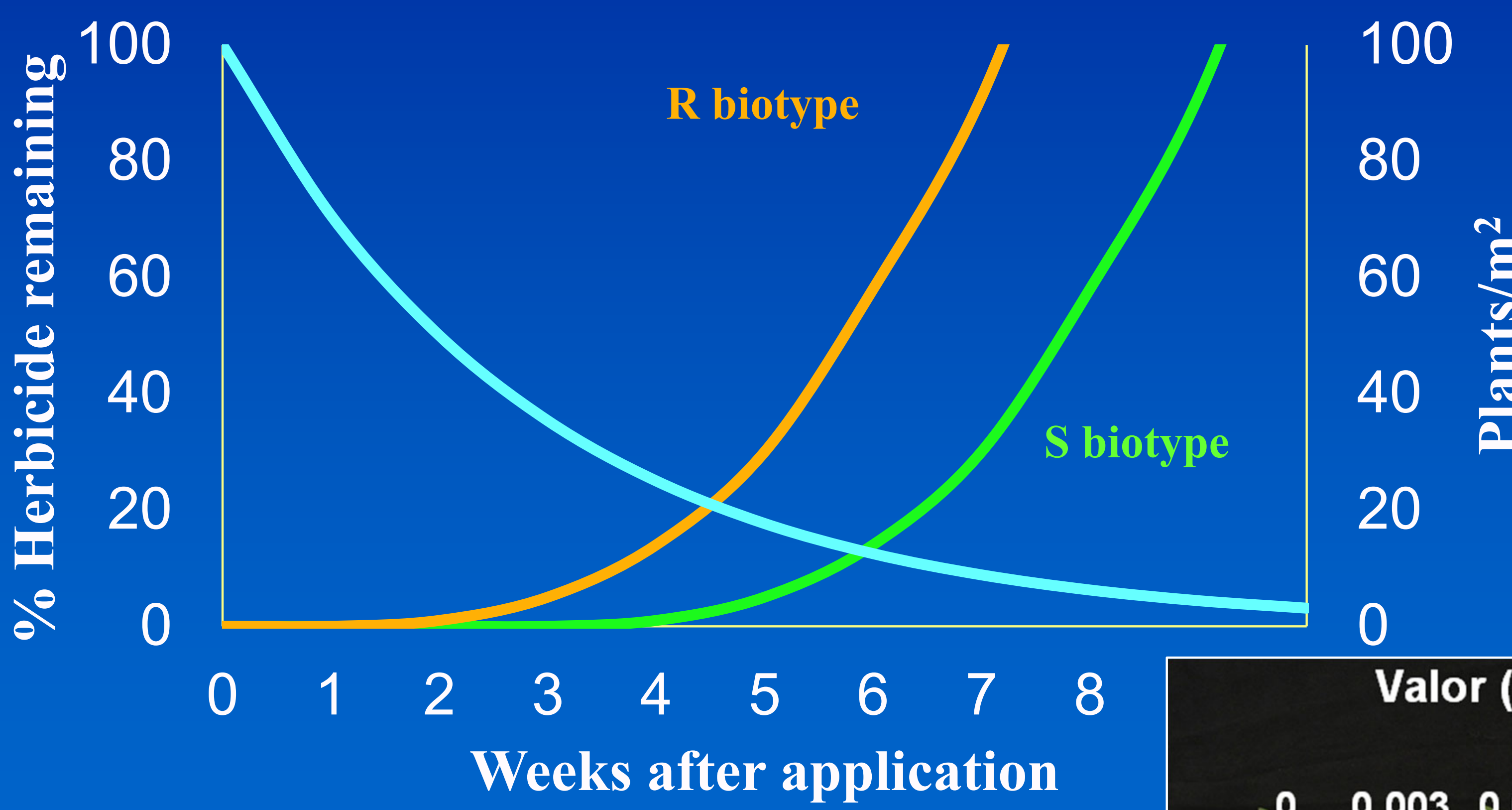
Resistance: What happens to soil-applied herbicides?

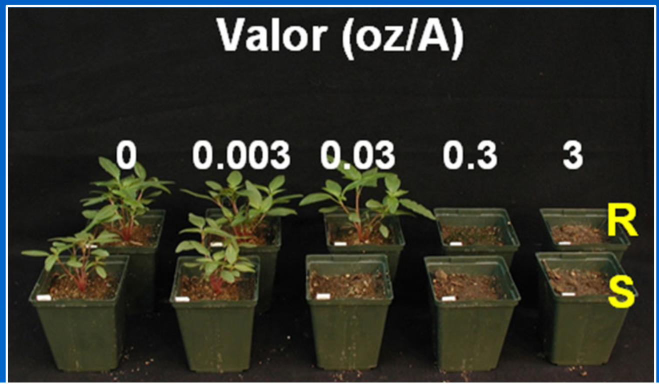


Differentiating R and S biotypes after flumioxazin (Valor) PRE application



Resistance to soil-applied herbicides





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

Travis Wilke[1], Patrick Tranel[1], Martin Williams[2], Aaron Hager[1]

79th Annual NCWSS Meeting

[1]University of Illinois at Urbana–Champaign, [2]USDA Agricultural Research Service

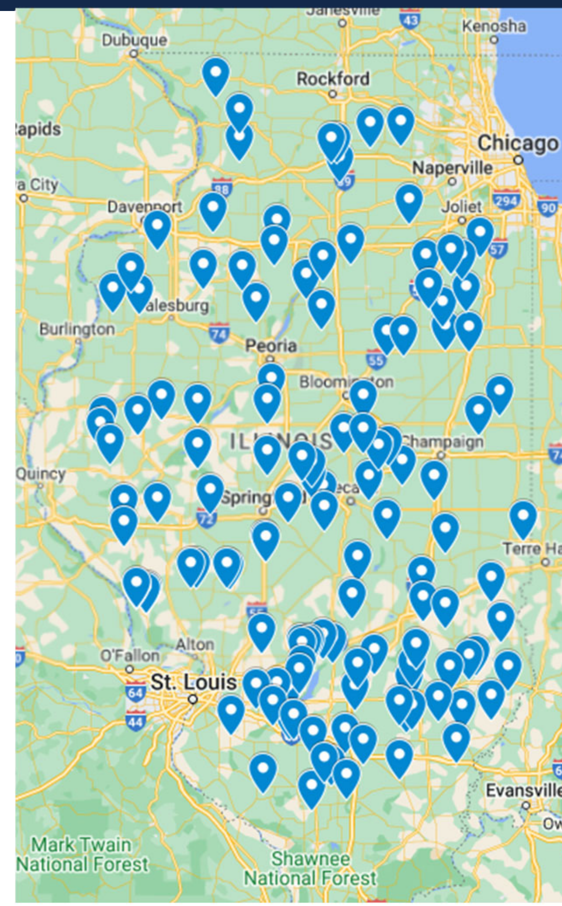
Objectives

- 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

Materials and Methods

Seed Collections – Fall 2023

- Two female inflorescences ≥ 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[1]



[1]Bell (2011)

Materials and Methods

Experimental Design and Data Analysis

- Screening
  - Two Treatments (0 and 0.4 pt Dual II Magnum A^{-1})
  - Two replications
  - Live seedlings counted at 10 DAA
  - Survival percentage at 0.4 pt Dual II Magnum A^{-1}

$$\frac{\#\ Live\ Seedlings\ (Treated) Average}{\#\ Live\ Seedlings\ (Untreated) Average} x\ 100$$

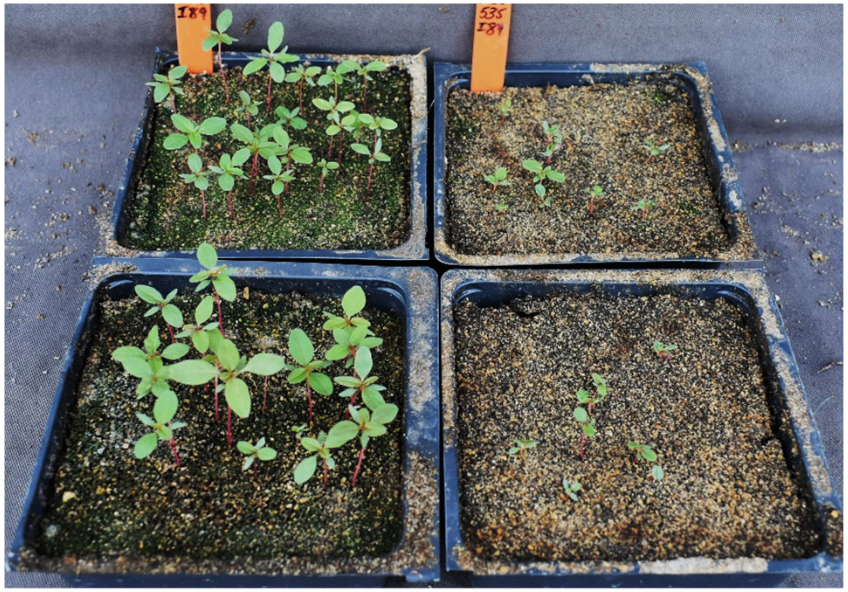
  - Visual assessment of growth reduction in live seedlings in treated replications (data not shown)

Results

Screenings

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

CHR F2-89			
Rate (pt Dual II Magnum A^{-1})	Replicate	Live Seedlings	% Stunt
0	1	21	-
0	2	17	-
0.4	1	10	75
0.4	2	7	80
Survival Percentage = 45%			



0 0.4

Rate Dual II Magnum (pt A^{-1})

Results

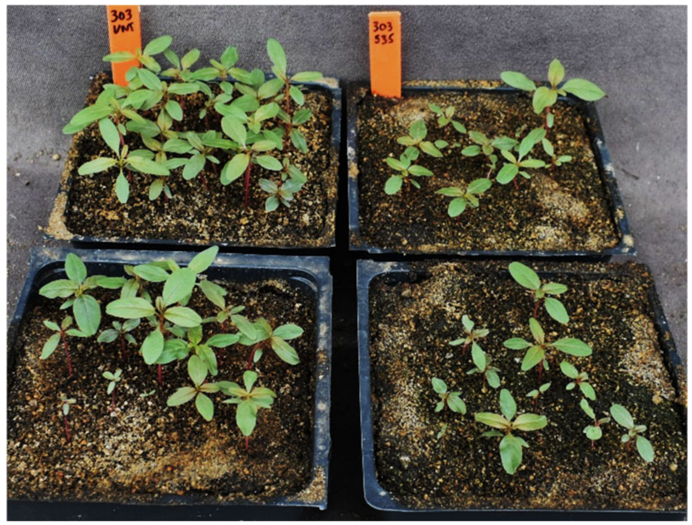
Screenings

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

Rate Dual II Magnum (pt A^{-1})

0	0.4	0	0.4	0	0.4

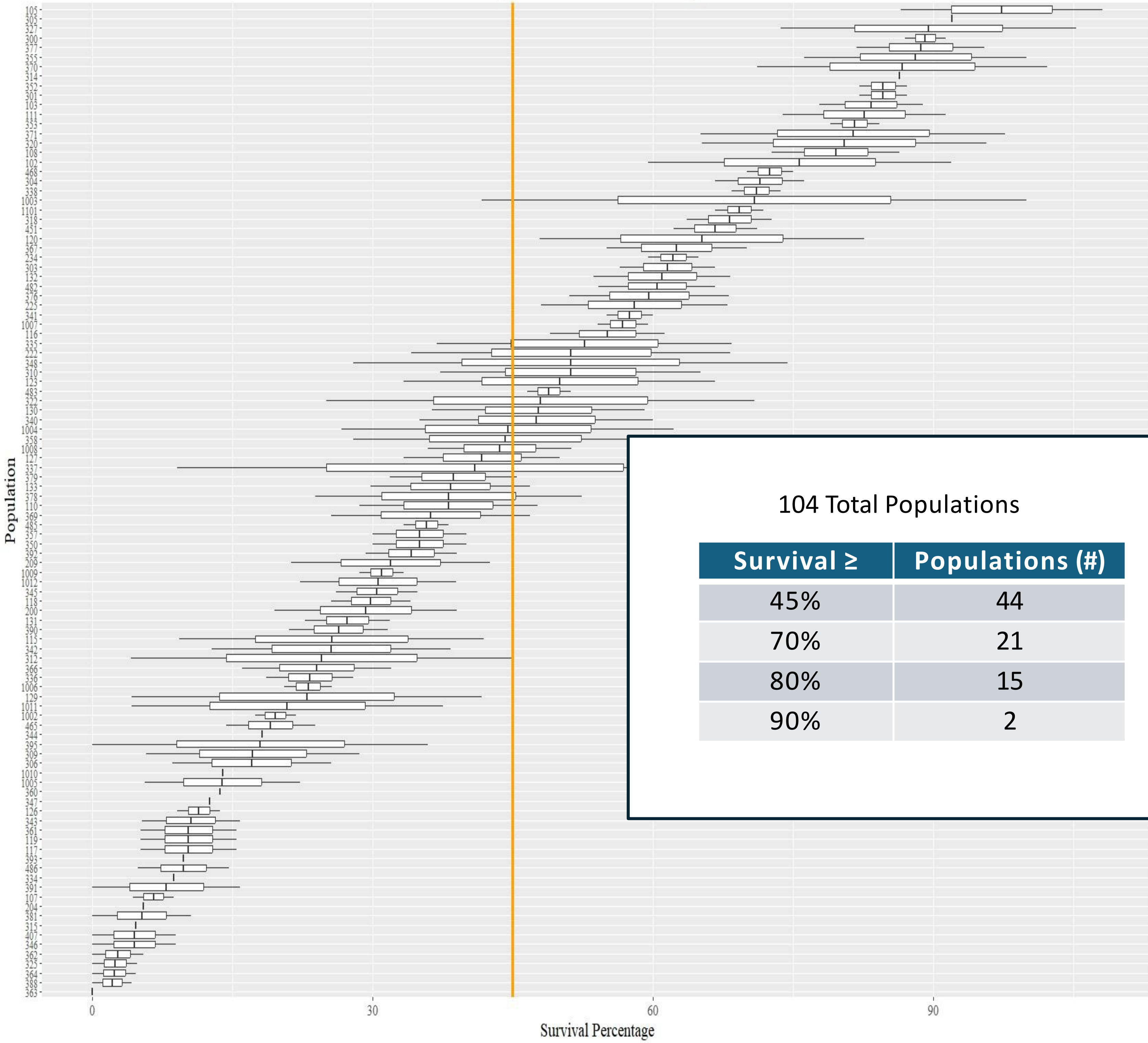
Sample 117
10% Survival



Sample 303
62% Survival

Sample 305
92% Survival

Screening Survival Across Populations



104 Total Populations

Survival ≥	Populations (#)
45%	44
70%	21
80%	15
90%	2

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	-

Conclusions

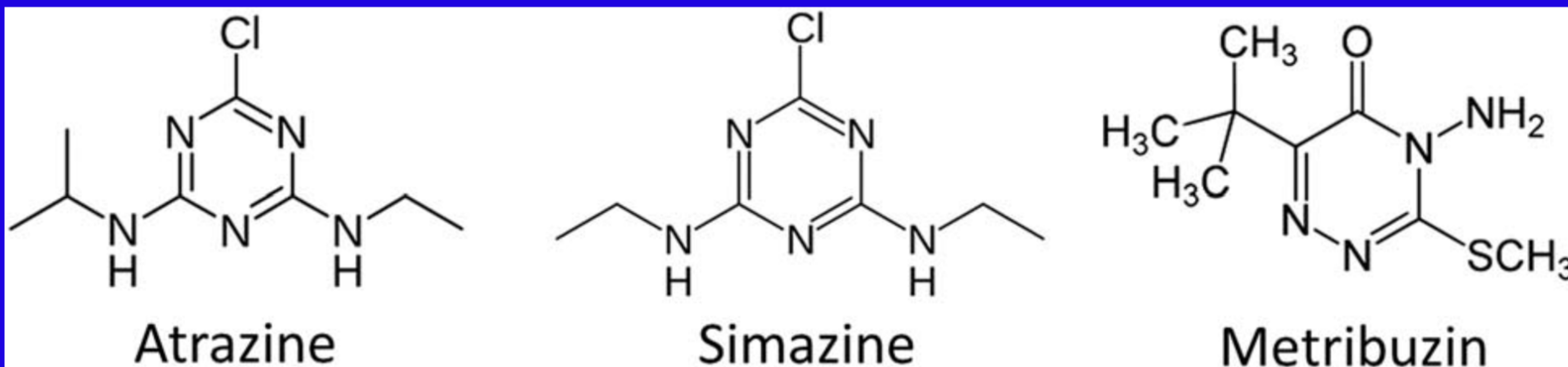
- Waterhemp resistance to Group 15 herbicides is suspected in more populations than originally confirmed
- Large-scale residual herbicide research can be done with the methods described
- Frequency of resistance may be impacted in a short time frame by a lack of utilization of Group 15 herbicides in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

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

Two types of triazine herbicides used in Illinois

Symmetrical **Asymmetrical**



Parker et al. 2018

Symmetrical: nitrogen atoms symmetrically distributed in the phenyl ring

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 [1]
D1 protein	atrazine	1983 [6]
acetolactate synthase	chlorimuron	1992 [8]
tubulin	trifluralin	1998 [9]
acetyl CoA carboxylase	clethodim	2001 [10]
5-enolypyruvylshikimate-3-phosphate synthase	glyphosate	2002 [11]
phytoene desaturase	fluridone	2004 [12]
protoporphyrinogen oxidase	lactofen	2006 [13]
glutamine synthetase	glufosinate	2012 [14]
auxin receptor	2,4-D	2018 [15]

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

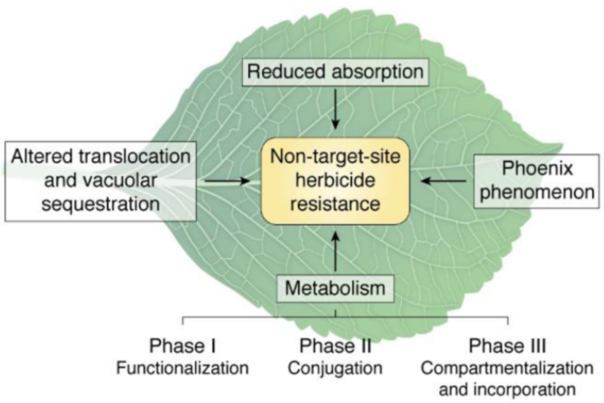
Murphy and Tranel 2019

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

Two types of triazine herbicide resistance mechanisms

Non-target site resistance (Low level)

Figure 5

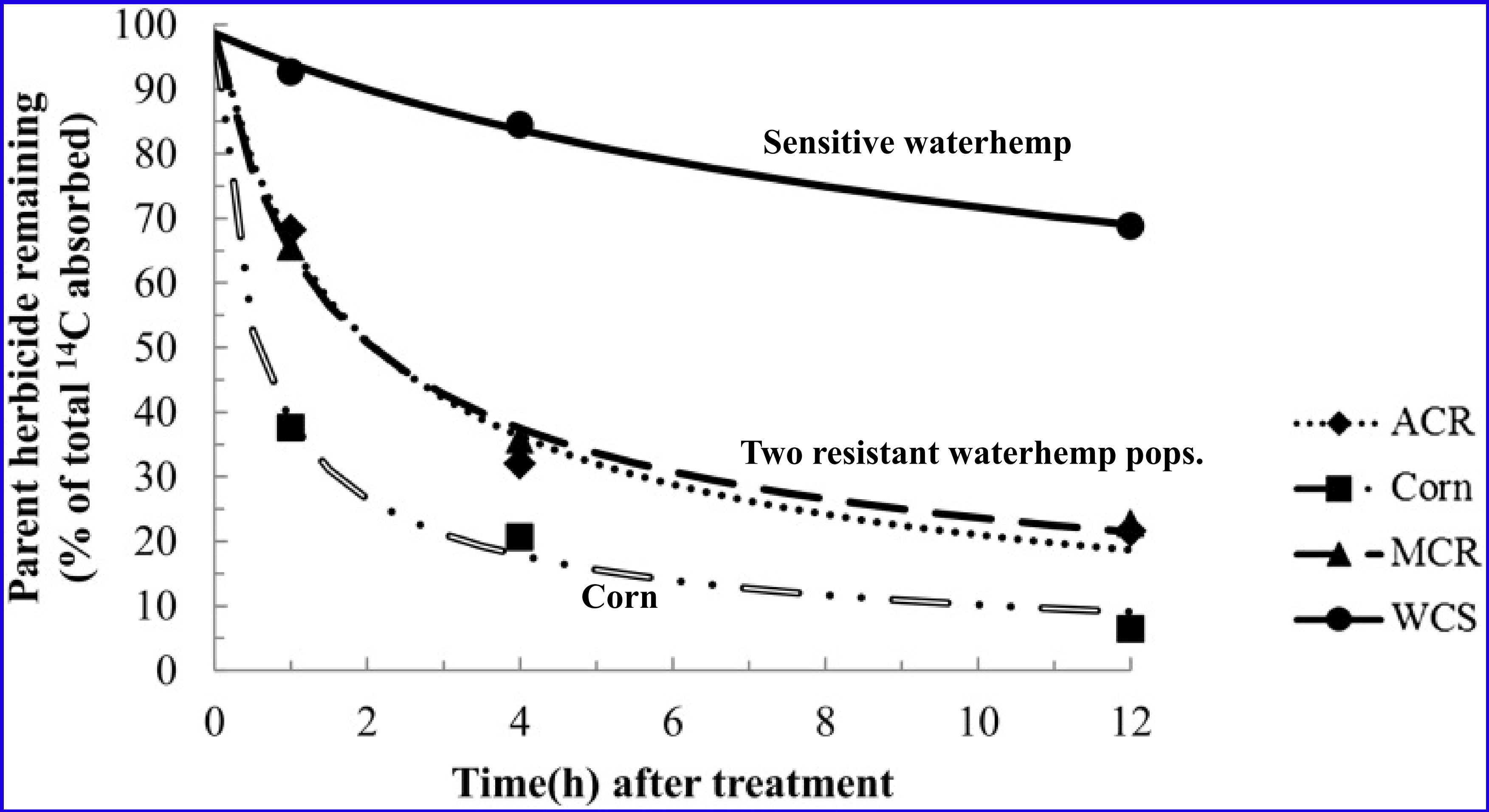


Gaines et al. 2020

Figure 5. Summary of non-target-site resistance (NTSR). Plants can evolve resistance to a herbicide by reducing its absorption, altering its translocation and/or sequestration, developing a rapid necrosis of the foliage (phoenix phenomenon), or via degradation of the active ingredient through the phases I, II and III of metabolism.

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

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 µm [U-^{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 FOMC model (Gustafson and Holden, 1990) to estimate a DT_{50} separately for each waterhemp population and corn. The DT_{50} 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

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?

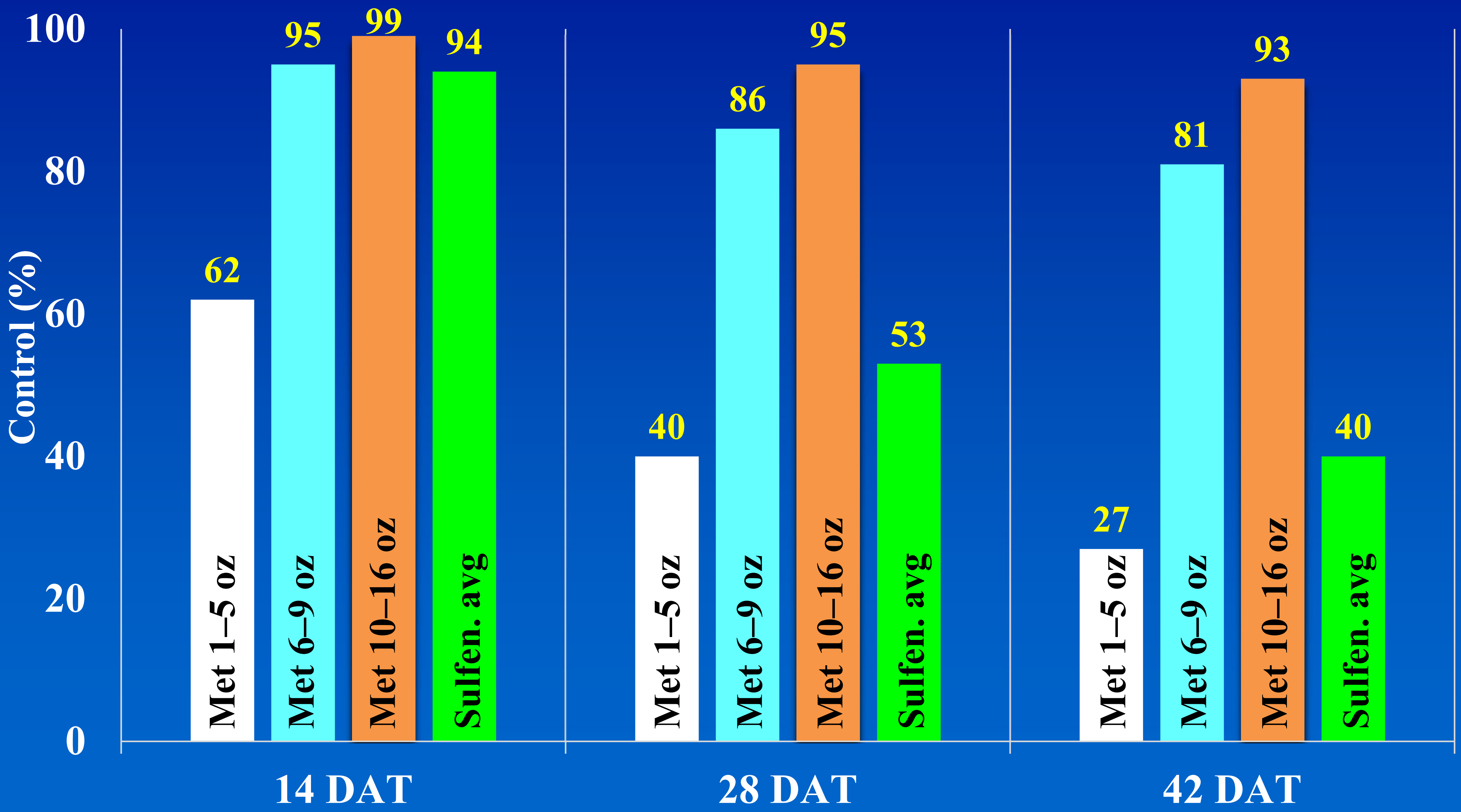
Metribuzin vs Sulfentrazone

- 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)

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

Results

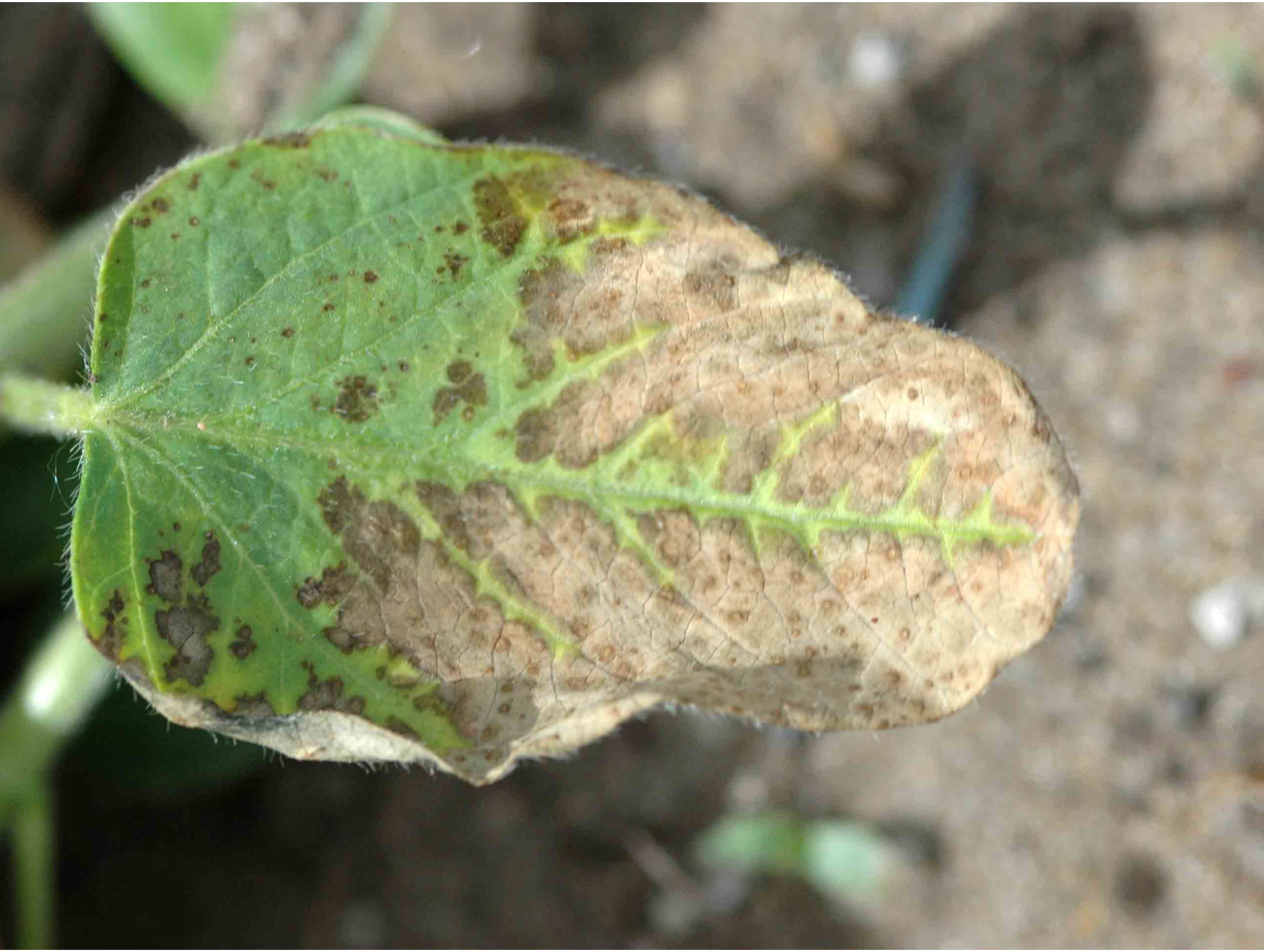


Control (%)
100
80
60
40
20
0
62
95
99
94
40
86
95
53
27
81
93
40
Met 1–5 oz
Met 6–9 oz
Met 10–16 oz
Sulfen. avg
14 DAT
28 DAT
42 DAT


2020 Field Research
42 days after planting
0.313 lb sulfentrazone
1 lb metribuzin

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



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

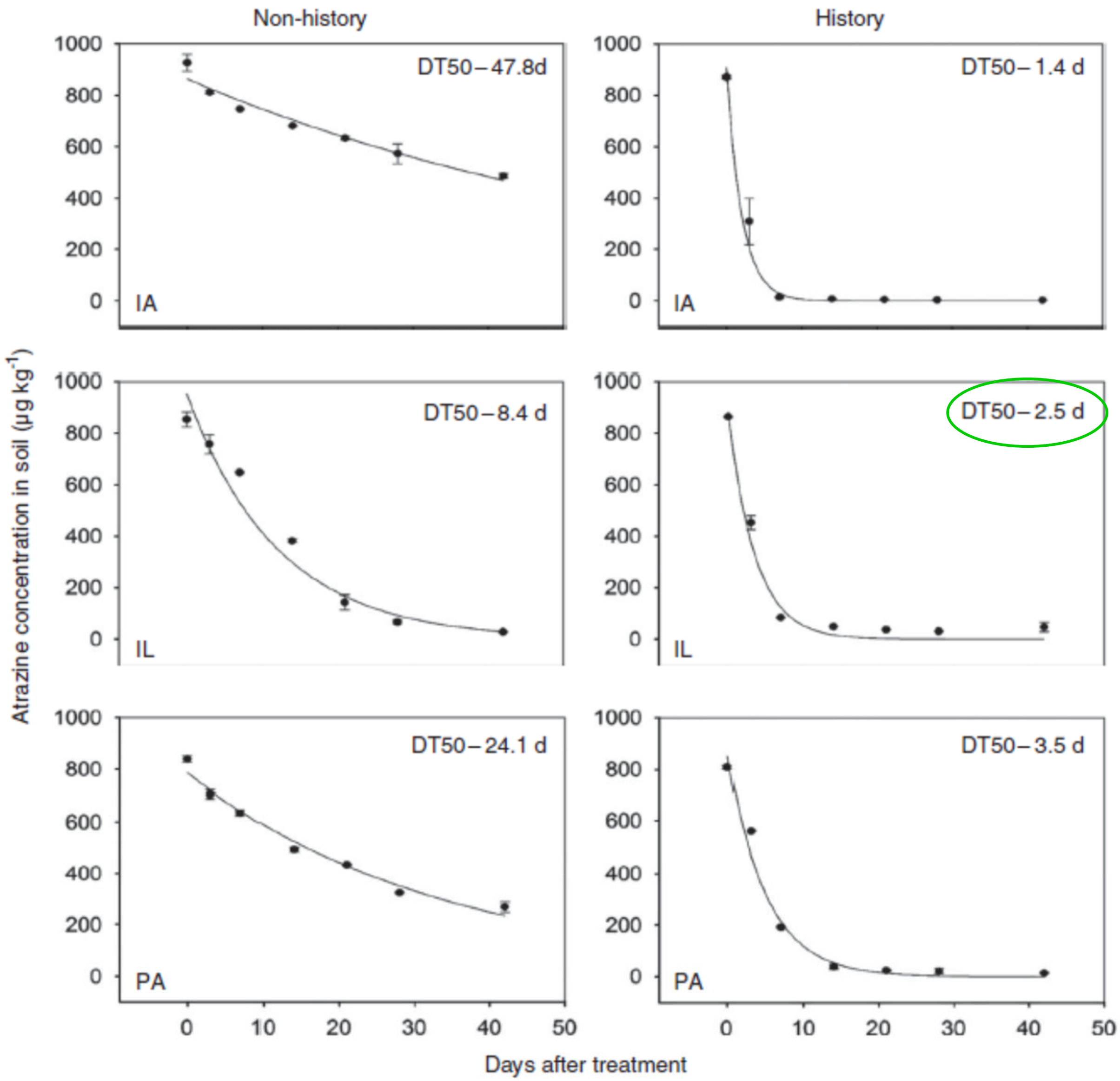


Figure 2. Exponential decay of atrazine in Iowa, Illinois, and Pennsylvania soils as a function of atrazine history and days after atrazine fortification. Error bars indicate 1 SD, and all r^2 values were >0.94. DT50 = half life in days.

"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)**

"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):**

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

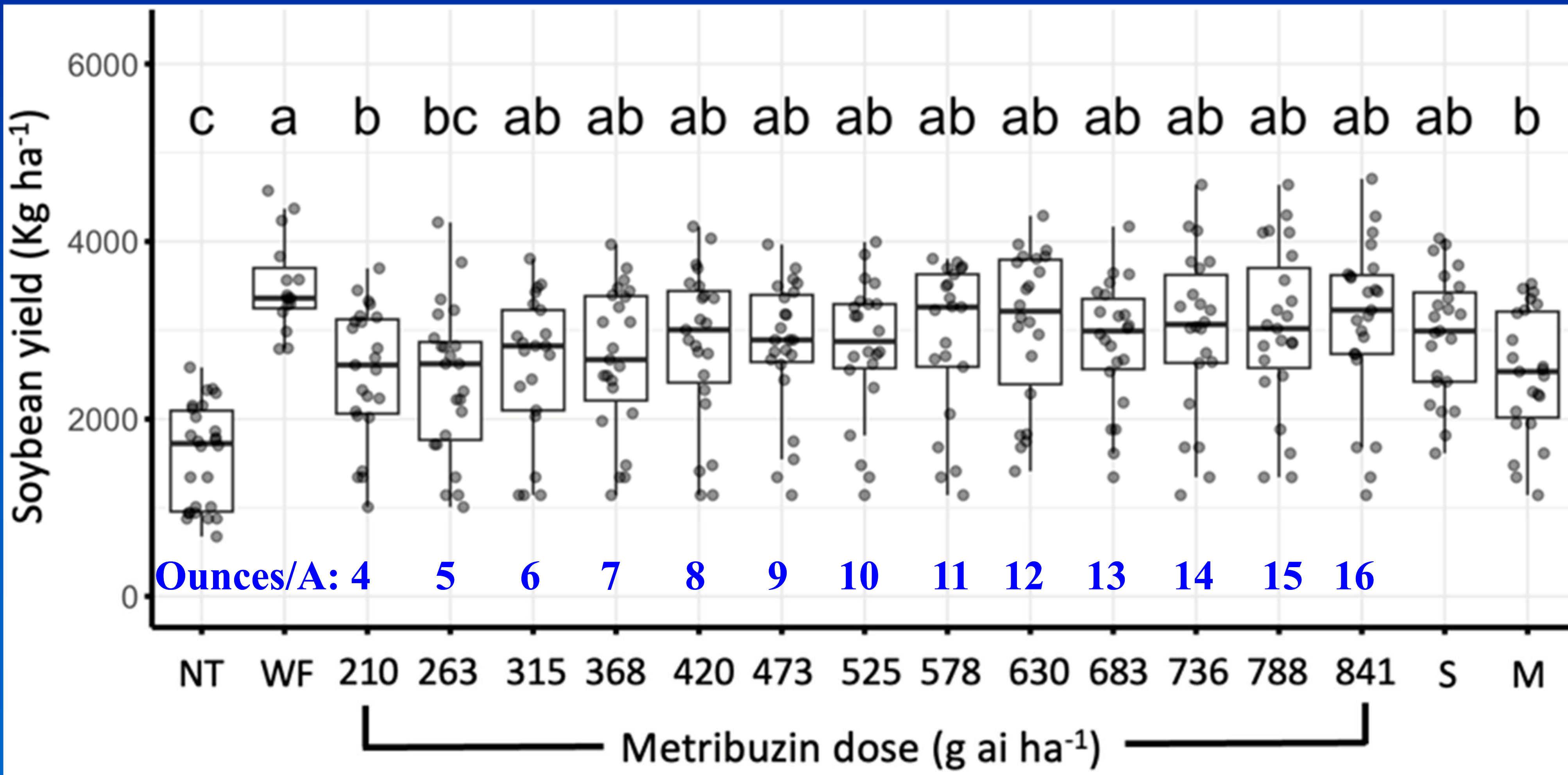
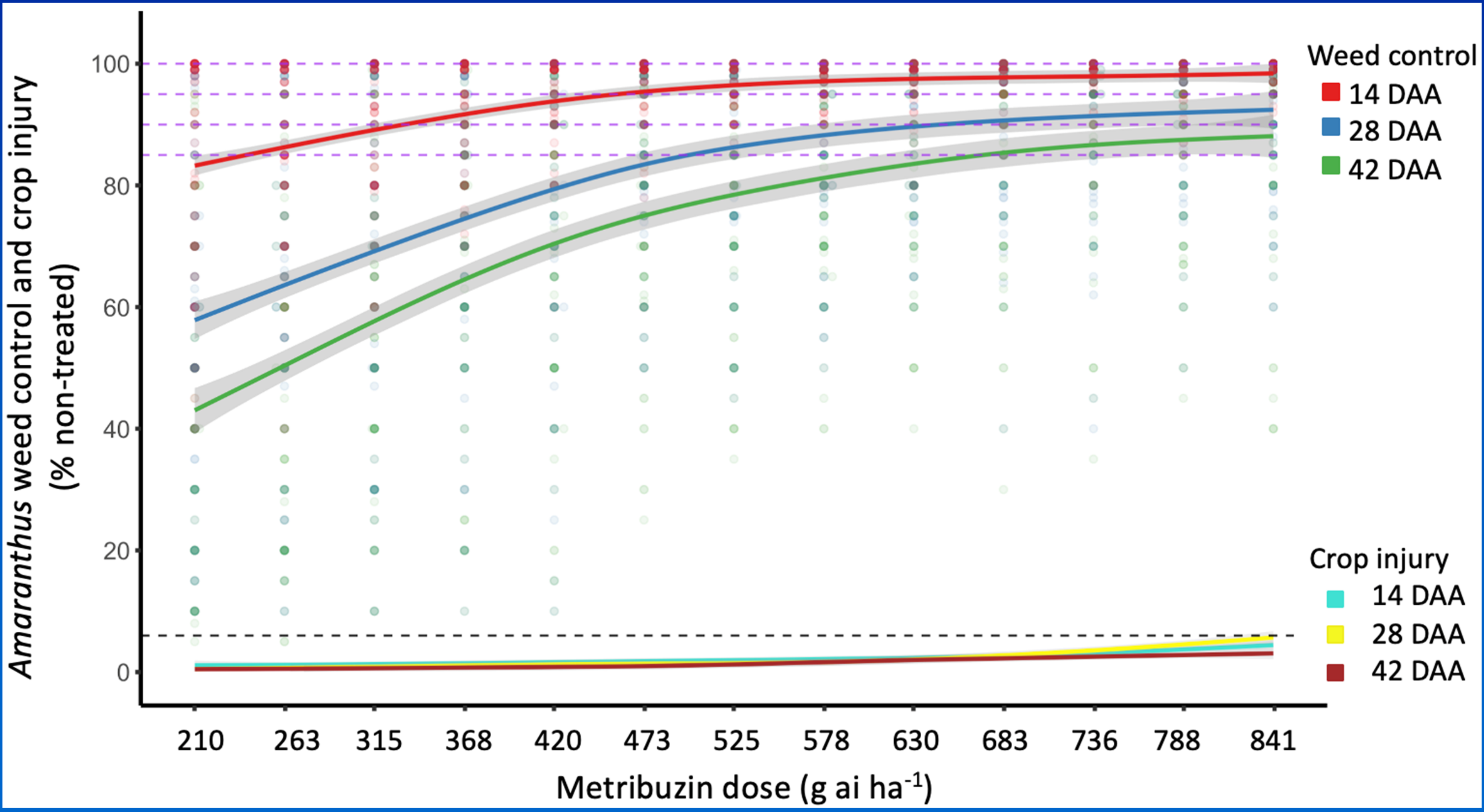


Figure 3. Soybean injury and *Amaranthus* weed control across metribuzin doses at 14, 28 and 42 days after application (DAA) for all site-years except Illinois 2023 and Michigan 2023.



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."

Southern Illinois University CARBONDALE

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Confirmation and Transcriptomic Characterization of Glufosinate-ammonium Resistance in Waterhemp (*Amaranthus tuberculatus*) Populations from Illinois

Cristiana Bernardi Rankrape[1], Isabel Werle Noe[2], Logan Miller[2], Eduardo Lago[1], Rishabh Singh[2], Alexander Lopez[2], Aaron Hager[2], Karla Gage[1], Patrick Tranel[2]

[1] Southern Illinois University Carbondale

[2] University of Illinois at Urbana-Champaign

Material and Methods

❑Greenhouse studies - overview

- CAR, SDY, and M01
  - University of Illinois Plant Care Facility (PCF).
- FRA
  - Southern Illinois University Horticultural Research Center (HRC).
- WUS and BRC
  - Susceptible control populations.

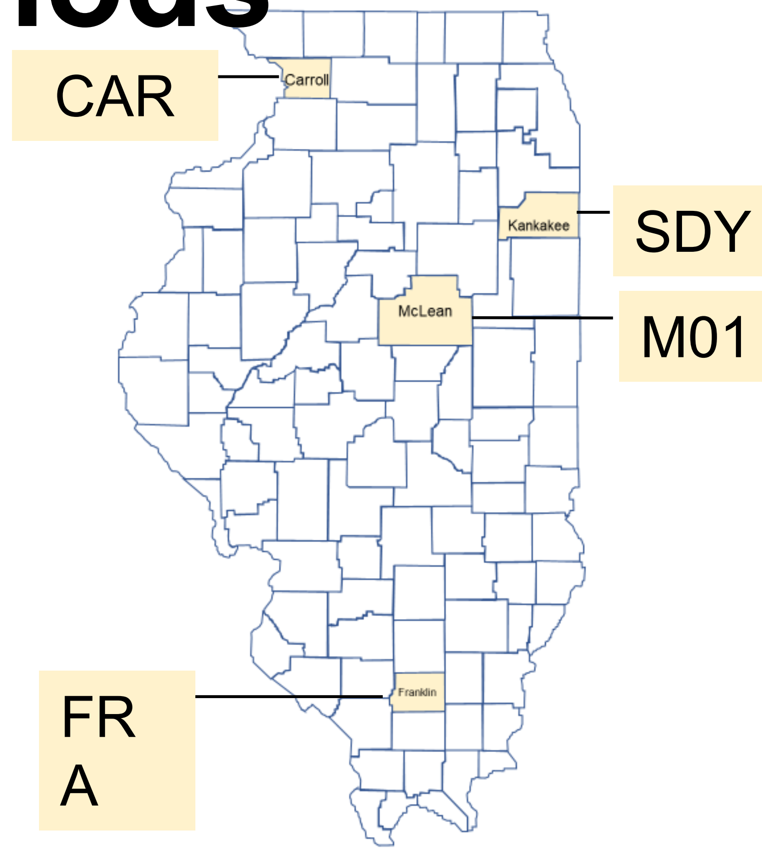


Figure 4. Map showing the geographic distribution of waterhemp populations used in this study. Suspected-resistant populations were collected from Carroll (CAR), Kankakee (SDY), McLean (M01), and Franklin (FRA) counties in Illinois.

Material and Methods

❑Exp. 2. Field experiment

Figure 6. Field experiment setup showing manually laid-down corn plants and tagged waterhemp plants.

- Plants per Plot: 10-15 tagged plants (7.5 – 12.5 cm in height).
- Weather Conditions at Application: temperature 31°C, sunny, humidity 71%, wind 4.9 m/s.
- Control was visually assessed on each marked plant in each plot at 6, 12, and 24 DAA on a scale from:
  - 0 (no control) to 100 (complete control).

Results and Discussion

❑Exp. 1. Greenhouse (GH) dose-response

- CAR, SYD, FRA compared to WSU
  - 2.1- to 3.4-fold based on survival
  - 1.3- to 2.8-fold based on dry biomass

- Palmer amaranth population from North Carolina, LD_{50} values ranging from 1.5- to 2.3-fold (Jones et al. 2024).

Table 3. Parameter estimates from log-logistic regression models describing the responses of suspected-resistant and susceptible *Amaranthus tuberculatus* populations to glufosinate-ammonium in a greenhouse-based dose-response study 21 days after application.

Population	Log-logistic regression model	Whole plant dose-response (g ai ha^{-1})				
		Parameter estimates				
		b[a] (± SE)	c[a] (± SE)	d[a] (± SE)	e[a] (± SE)	LD_{50}/GR_{50}[b]
		Plant survival				
Carroll	3-parameter	1.59 (0.33)	-	0.98 (0.09)	225.22 (42.62)	3.4
WUS	log-logistic	1.16 (0.45)	-	1.00 (0.09)	66.30 (35.53)	
Sidney	3-parameter	4.02 (0.94)	-	1.00 (0.06)	360.07 (27.81)	2.1
WUS	log-logistic	2.03 (0.43)	-	0.99 (0.08)	170.18 (24.94)	
Franklin	3-parameter	4.21 (0.40)	-	1.00 (0.02)	167.32 (4.05)	2.2
WUS	log-logistic	2.82 (1.01)	-	1.00 (0.02)	76.90 (19.00)	
		Dry biomass				
Carroll	4-parameter	2.76 (1.38)	0.27 (0.07)	2.23 (0.09)	115.08 (15.53)	2.8
WUS	log-logistic	1.7 (1.51)	0.21 (0.07)	2.77 (0.09)	41.45 (44.37)	
Sidney	4-parameter	3.43 (0.90)	0.27 (0.09)	2.57 (0.15)	178.09 (14.20)	1.9
WUS	log-logistic	3.17 (1.92)	0.28 (0.08)	3.40 (0.15)	95.73 (24.19)	
Franklin	4-parameter	8.36 (0.35)	0.21 (0.01)	2.21 (0.01)	150.72 (0.81)	1.3
WUS	log-logistic	9.55 (0.63)	0.20 (0.01)	2.02 (0.01)	115.94 (13.76)	

[a] b is the slope around the effective rate, c is the lower asymptote, d is the upper asymptote, and e is the effective rate causing 50% reduction in response.
[b] LD_{50} is the herbicide rate causing 50% mortality; GR_{50} herbicide rate causing 50% biomass reduction relative to the susceptible population.

❑Exp. 2. Field experiment

- Glufosinate provided less than 90% control 24 DAA when applied at one-half the labeled rate.
- 20% of plants survived at the full labeled rate.
- Complete control was only achieved with applications at twice the labeled rate.
- These results corroborate with greenhouse dose-response.

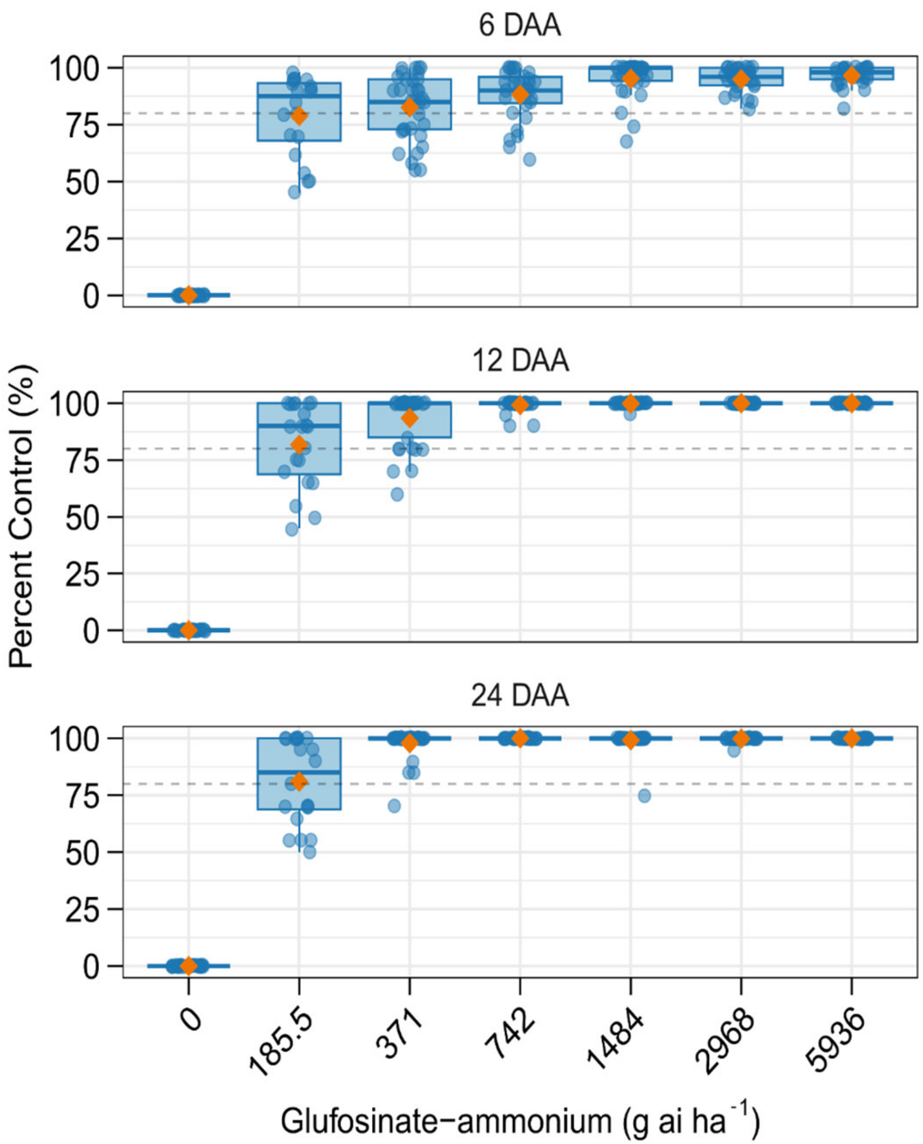


Figure 10. Boxplots showing percent control of the suspected-resistant waterhemp population from Carroll County, Illinois, in response to increasing rates of glufosinate-ammonium in a field dose-response study at 6, 12, and 24 days after application. The vertical dashed line indicates the 80% control threshold. Blue points represent individual plants, and orange triangles denote the mean percentage of control at each herbicide rate.

Tillage, Cropping System, and Soil Depth Effects on Common Waterhemp (*Amaranthus rudis*) Seed-Bank Persistence

Lawrence E. Steckel, Christy L. Sprague, Edward W. Stoller, Loyd M. Wax, and F. William Simmons

Weed Science 55(3):235-239. 2007

A field experiment was conducted in Urbana, IL, from 1997 to 2000 to evaluate the effect that crop tillage, and soil depth have on common waterhemp seed-bank persistence. A heavy field infestation of common waterhemp (approximately 410 plants m^{-2}) was allowed to set seed in 1996 and was not allowed to go to seed after 1996. In 1997, 1998, 1999, and 2000, the percentage of the original common waterhemp seed bank that remained was 39, 28, 10, and 0.004%, respectively, averaged over tillage treatments. Initially, germination and emergence of common waterhemp was greater in no-till systems. Consequently, the number of remaining seeds was greater in the till treatments compared with no-till in the top 0 to 6 cm of the soil profile. This reduction was in part explained by the higher germination and emergence of common waterhemp in the no-tillage treatments. Tillage increased the seed-bank persistence of common waterhemp in the top 0 to 2 cm of the soil profile in 1997 and the top 0 to 6 cm in 1998. Crop had no effect on common waterhemp emergence or seed-bank persistence


Best wishes for a safe and
prosperous 2026