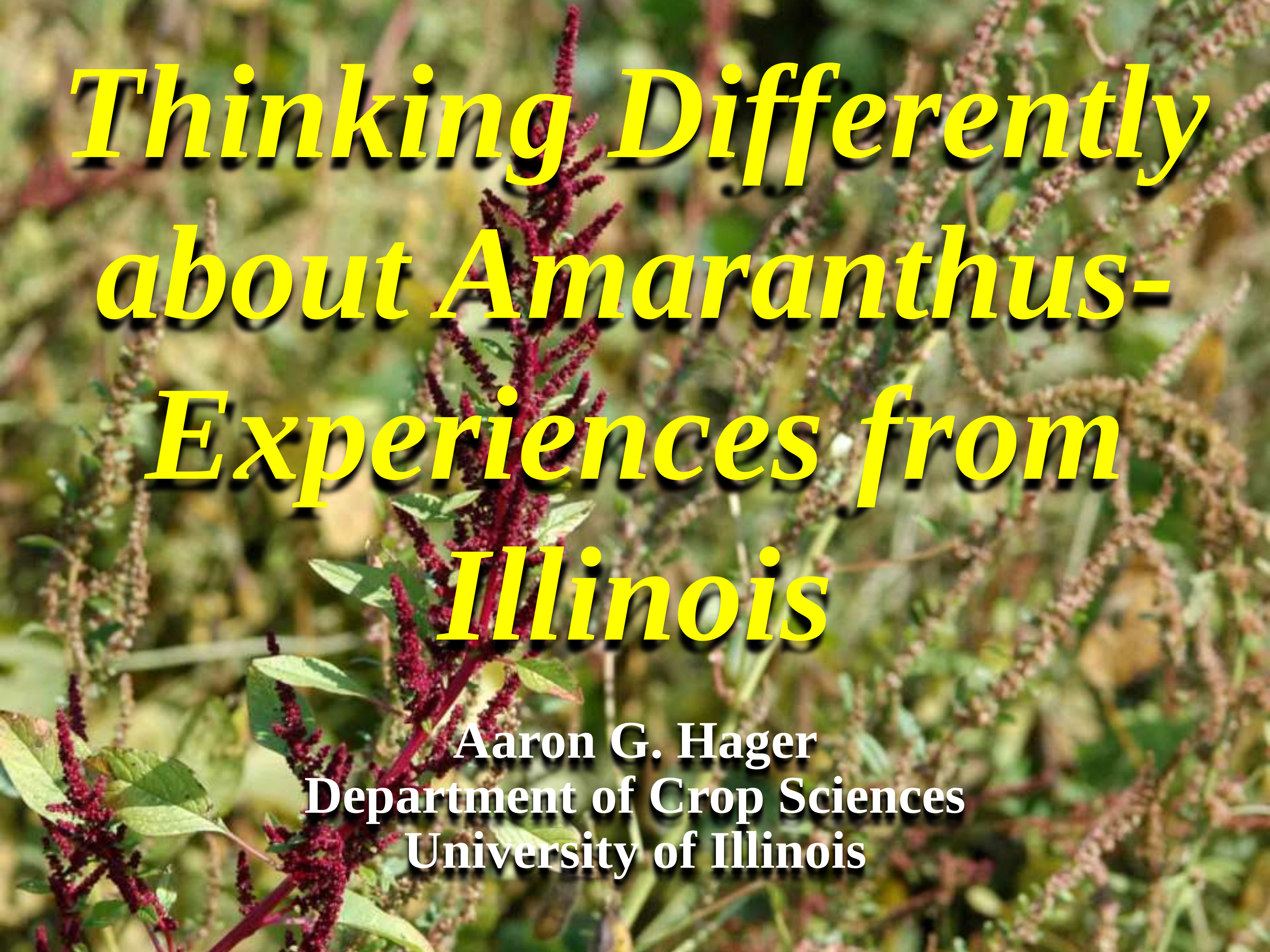


Thinking Differently about Amaranthus- Experiences from Illinois

Aaron G. Hager
Department of Crop Sciences
University of Illinois

What’s so different about *Amaranthus*?

Monoecious species of “yesteryear”

What's so different about *Amaranthus*?

Dioecious species of today

Common cocklebur
ALS inhibitors

Common ragweed
ALS inhibitors

Giant ragweed
ALS inhibitors

Kochia
ALS inhibitors
Triazines
ALS + Triazine

Smooth pigweed
ALS inhibitors
Triazines

Waterhemp
ALS inhibitors
Triazines
PPO
Glyphosate
HPPD inhibitors
2,4-D

Horseweed
Glyphosate
ALS

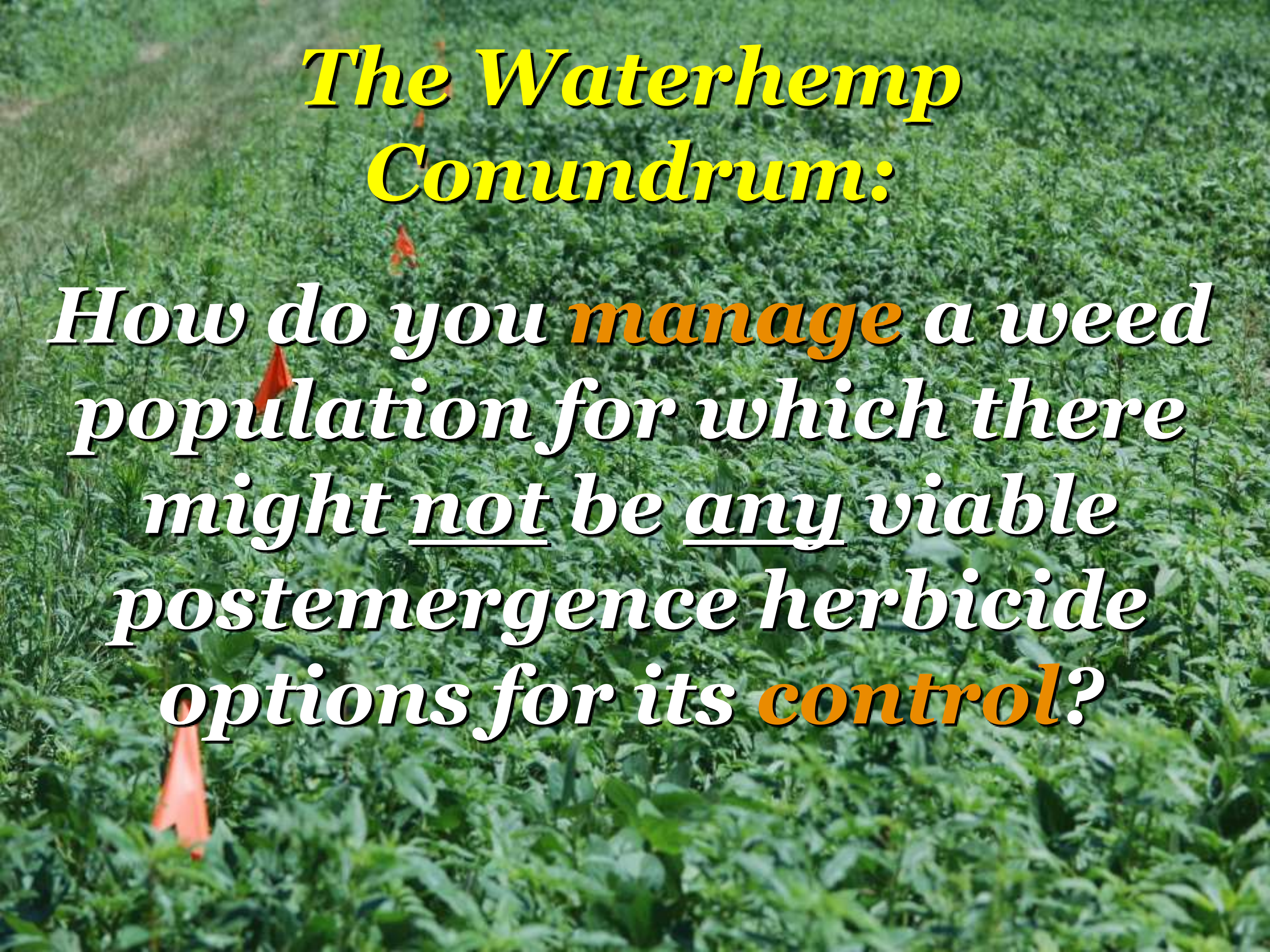
Common lambsquarters
Triazines

E. Black Nightshade
ALS inhibitors

Palmer amaranth
Glyphosate, ALS, PPO

Shattercane
ALS inhibitors

Foxtail
ALS inhibitors
ACCase inhibitors


The Waterhemp Conundrum:
How do you manage a weed population for which there might not be any viable postemergence herbicide options for its control?

Herbicide Resistance in waterhemp

- Several biological characteristics of waterhemp help facilitate selection of herbicide resistant biotypes
  - dioecious species, so cross pollination must occur to make seed
  - female plants capable of producing large amounts of seed

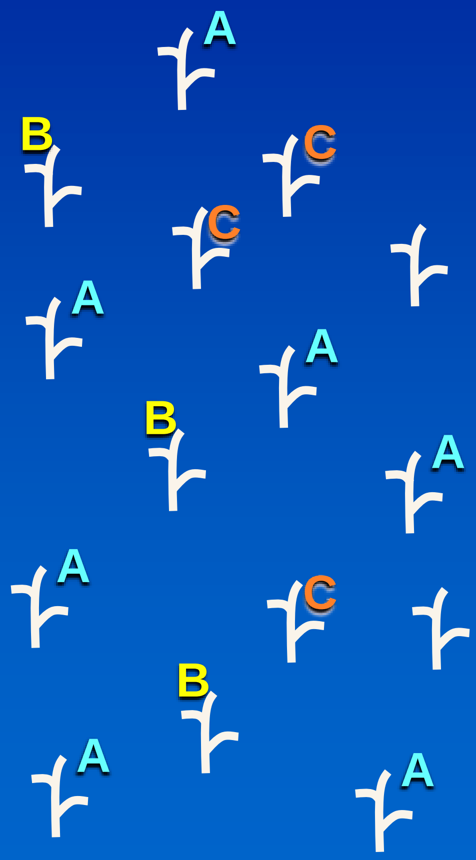
- Resistance in Illinois waterhemp has been documented to herbicides from six site-of-action classes
  - ALS inhibitors, triazines, PPO inhibitors, glyphosate, HPPD inhibitors, and auxinic herbicides (2,4-D)


10.5 pints/acre
2,4-D
8 pints/acre
2,4-D

Waterhemp has now evolved resistance to herbicides from 6 site-of-action families, but even more challenging than this is………

Multiple herbicide resistance in waterhemp

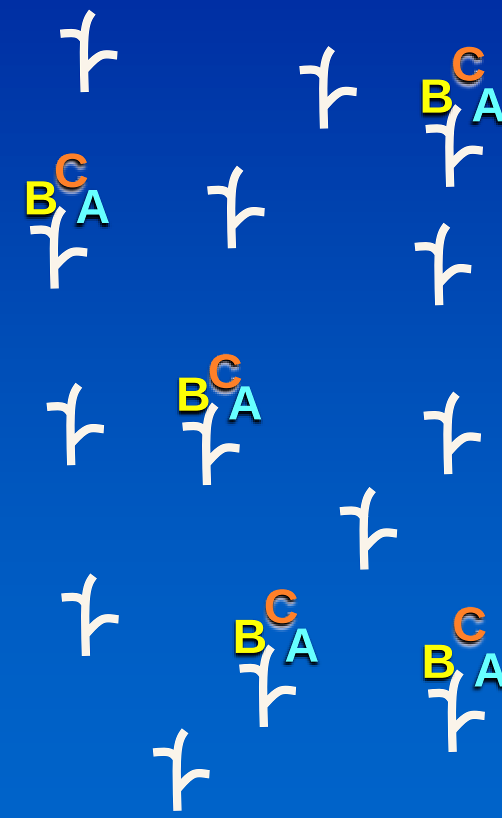
Multi-resistance at population vs. individual level



Herbicide A

Herbicide B

Herbicide C



Population level

Individual level

Multiple resistant waterhemp in Illinois

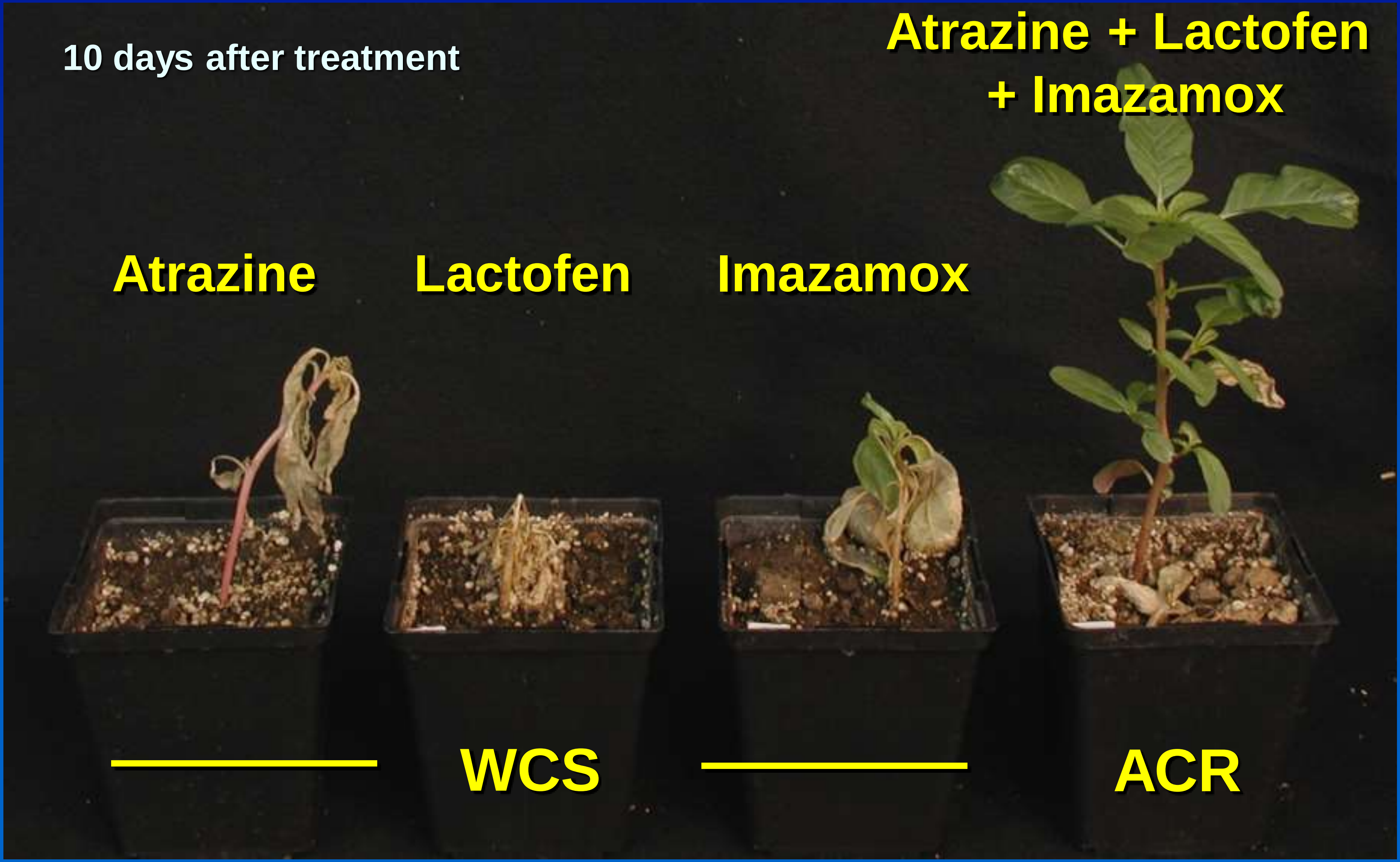
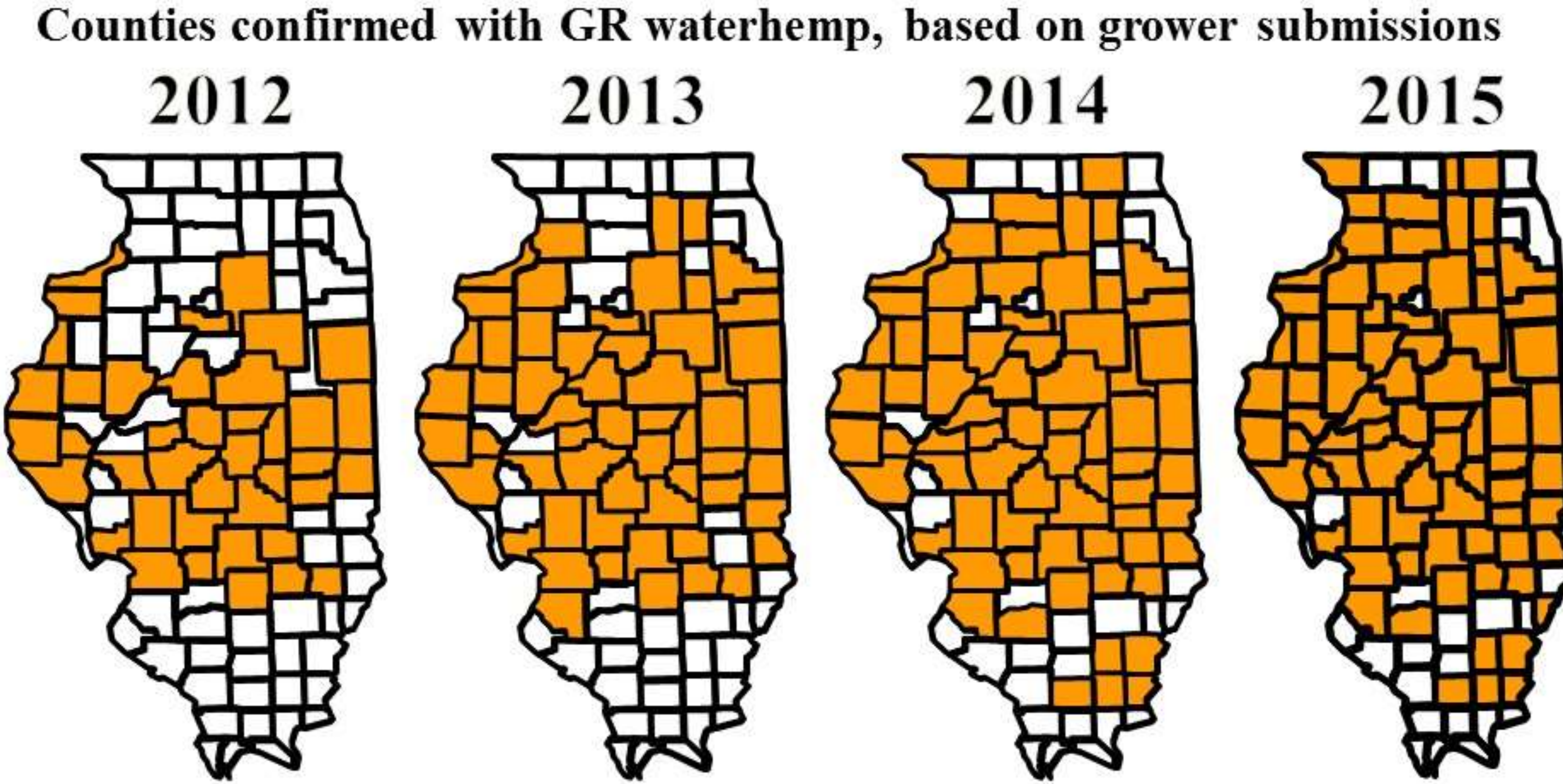
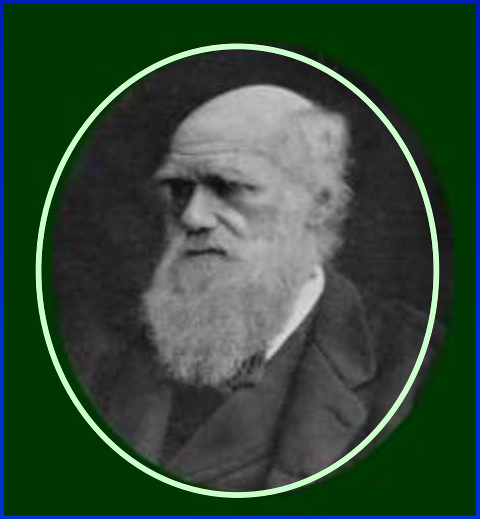


Figure 1. Range expansion of glyphosate-resistant waterhemp



Herbicide resistance is the outcome of evolution



Charles Darwin
1809 - 1882

Resistance management strategies have to play by the rules of evolution

Herbicide resistance defined evolutionarily:

An increase in frequency of resistance alleles in a population after exposure to herbicide selection.

Genetics 101

- **Selection acts on phenotypes, but the unit of inheritance is the gene**
- **Alleles are different versions of the same gene**
- **Typically, an individual has two different alleles for each gene**

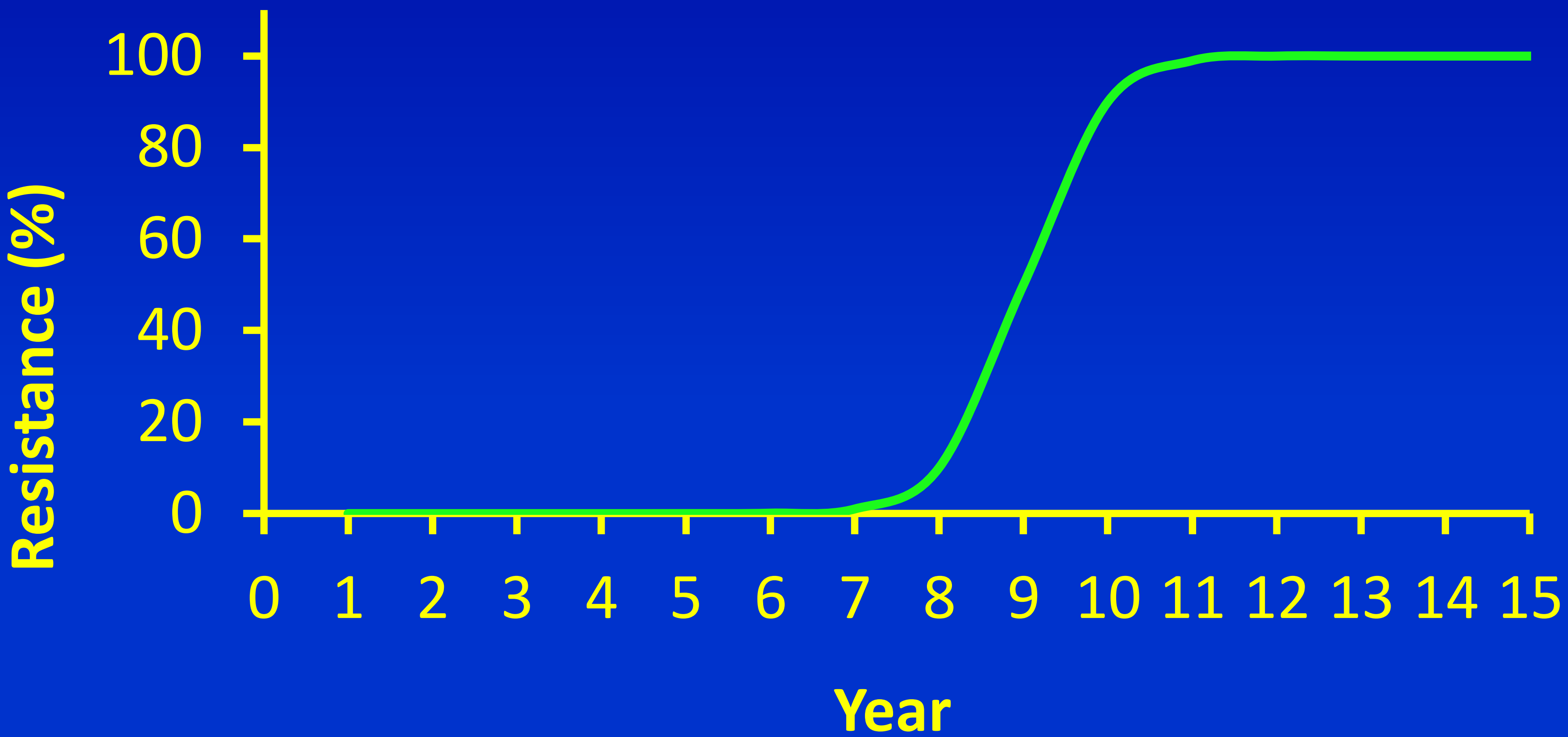
Example: blood type alleles A, B, and O

Take-home message thus far:

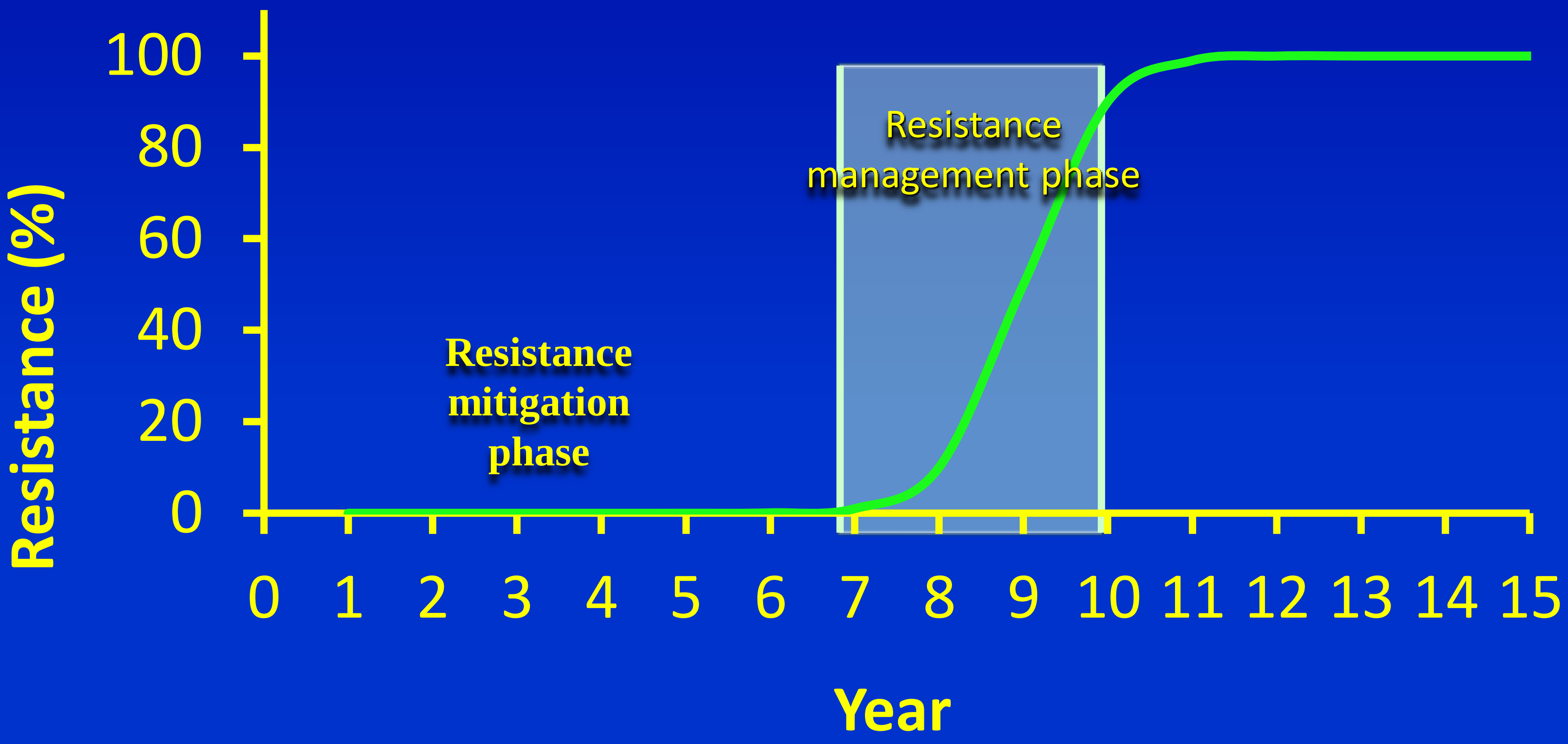
- Because of its evolutionary nature, herbicide resistance is a mathematical and, hence, rather predictable process

- Given “x” weed density, “x” mutation rate, “x” years of herbicide applications, etc., the percentage of resistant weeds will be “y”

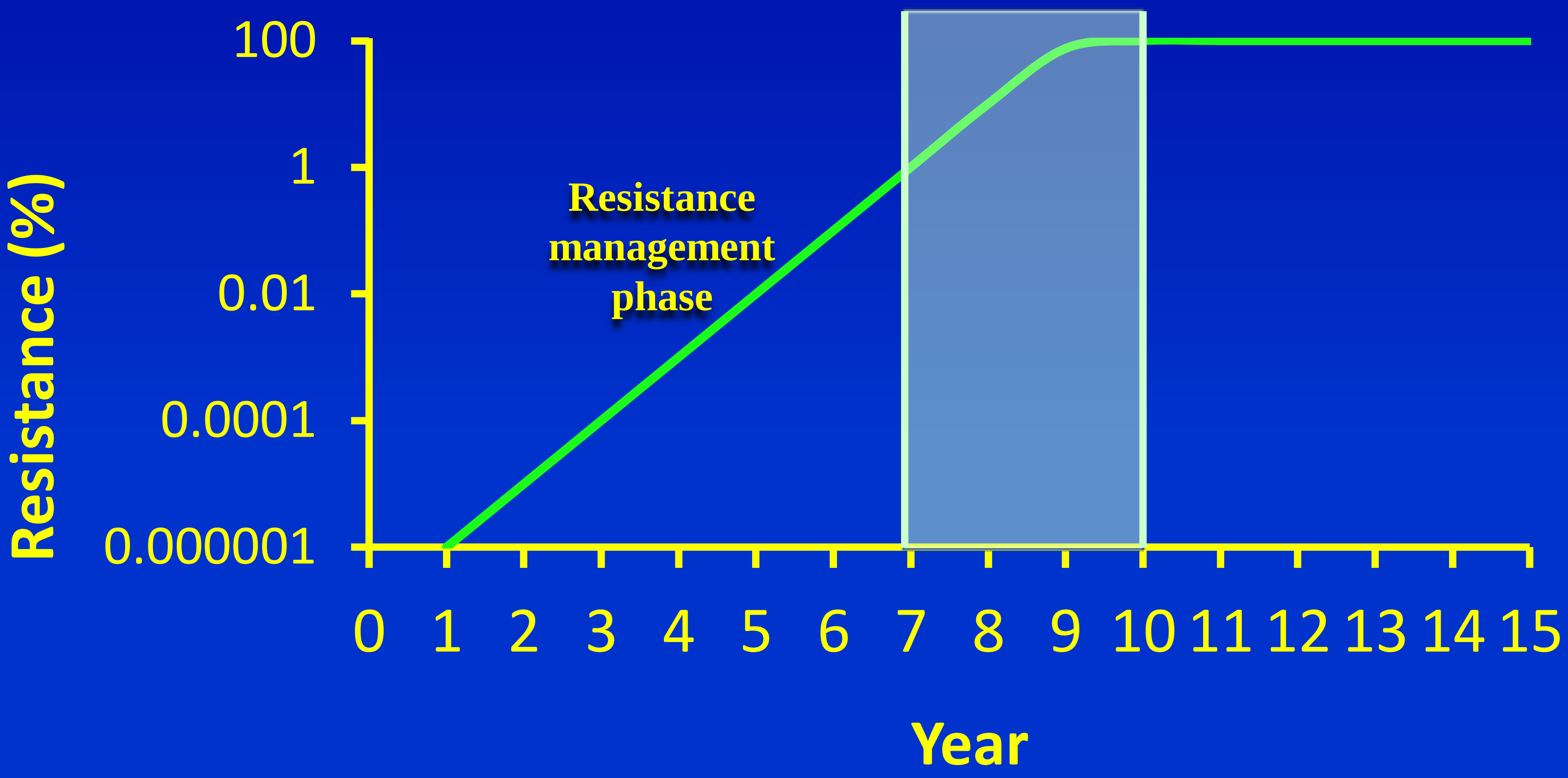
Graph of resistance evolution



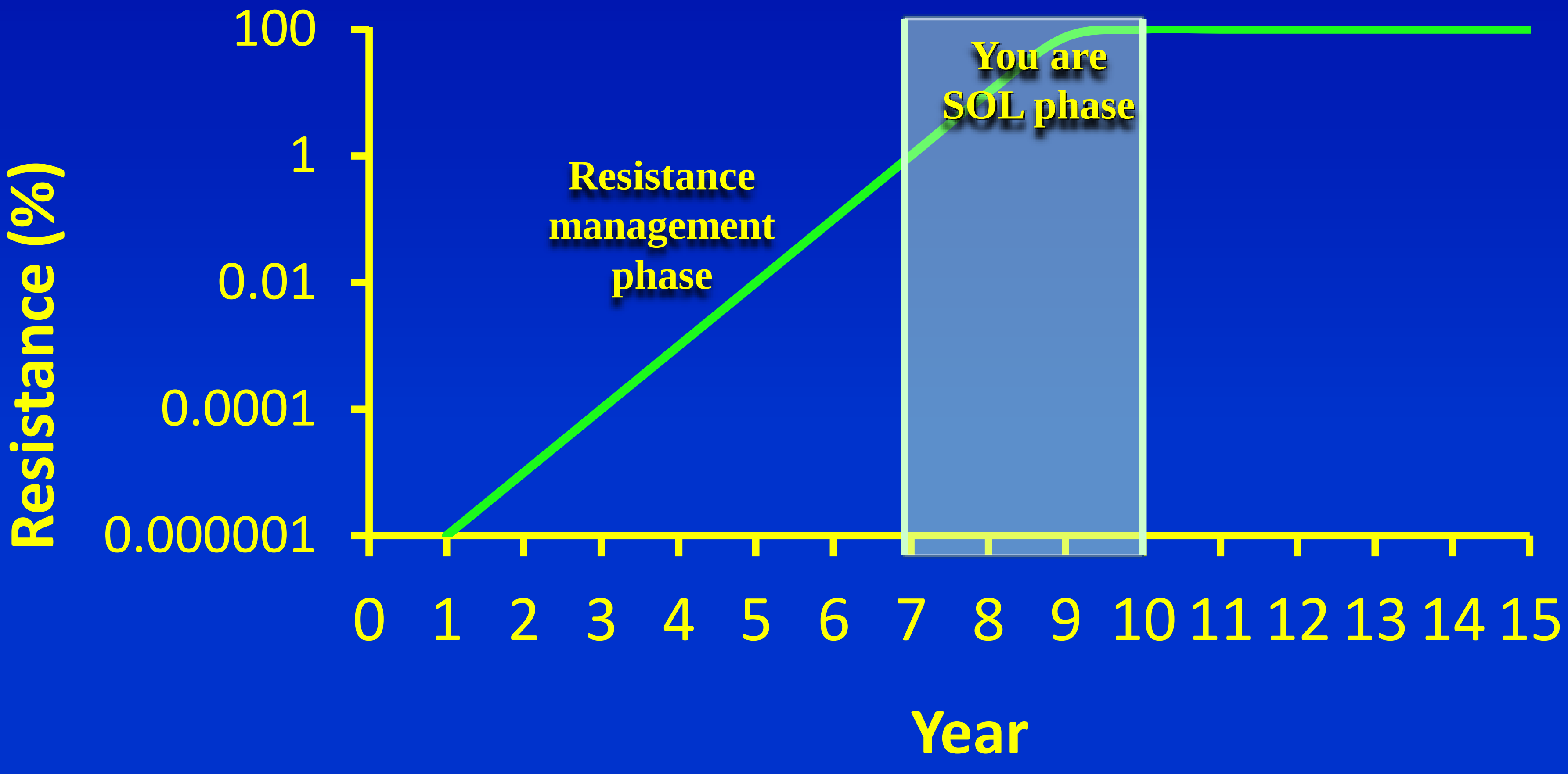
Graph of resistance evolution



Graph of resistance evolution



Graph of resistance evolution



A landscape-scale approach to understand glyphosate-resistant waterhemp

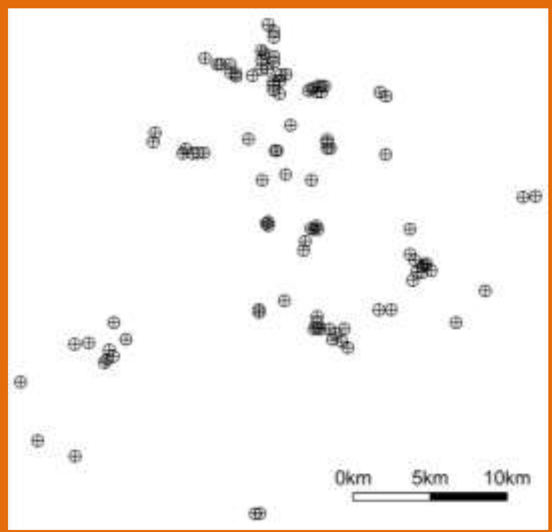
Jeff Evans
Patrick Tranel
Aaron Hager
Adam Davis

Managing the Evolution of Herbicide Resistance

JA Evans, PJ Tranel, AG Hager, B Schutte, C Wu, LA Chatham, AS Davis
University of Illinois and USDA-ARS

What factors contribute to the occurrence of herbicide-resistant weeds?

Address using an epidemiological approach.



» **Management**
- Mean(MOA/yr)
- Max(MOA/yr)
- % years PRE used
- % years Gly used
- Mean(Gly apps./yr)
- Herbicide turnover index
- % corn years
- Manure

» **Soil**
- Concentrations of each of 12 nutrients
- pH
- C:N ratio
- OM
- Inorganic N
- Bulk density
- Sand %
- Silt %
- Clay %
- Texture
- Water holding capacity

» **Weeds**
- Waterhemp seed bank density
- 3 descriptions of waterhemp density/distribution in field
- Presence of other *Amaranthus* weeds
- Presence of grass weeds and each of 8 other broadleaf weeds

» **Landscape**
- Elevation
- Max slope
- Dist. to forest
- Dist. to stream
- No. and area of bare patches
- Presence and length of grass waterways
- Field area
- Presence of watercourse on margin
- Perimeter length
- Edge:interior ratio
- Dist. to resistant pop.
- % field border with trees

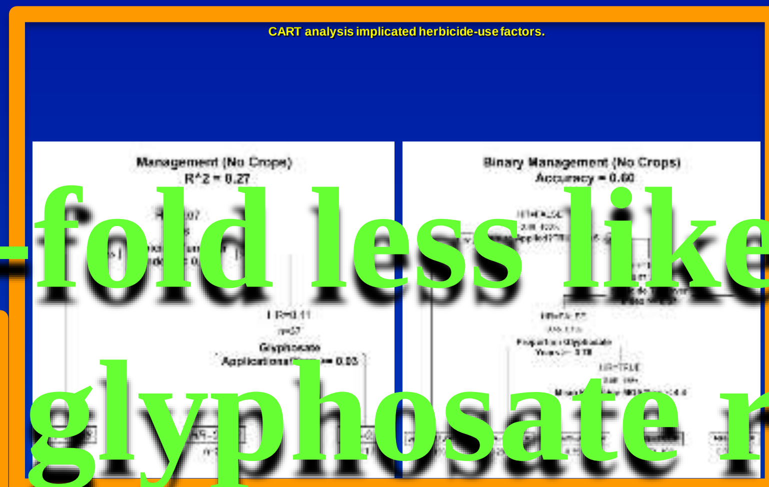
Test association of factors with occurrence of glyphosate-resistant *A. tuberculatus*.

Managing the Evolution of Herbicide Resistance

Major Findings

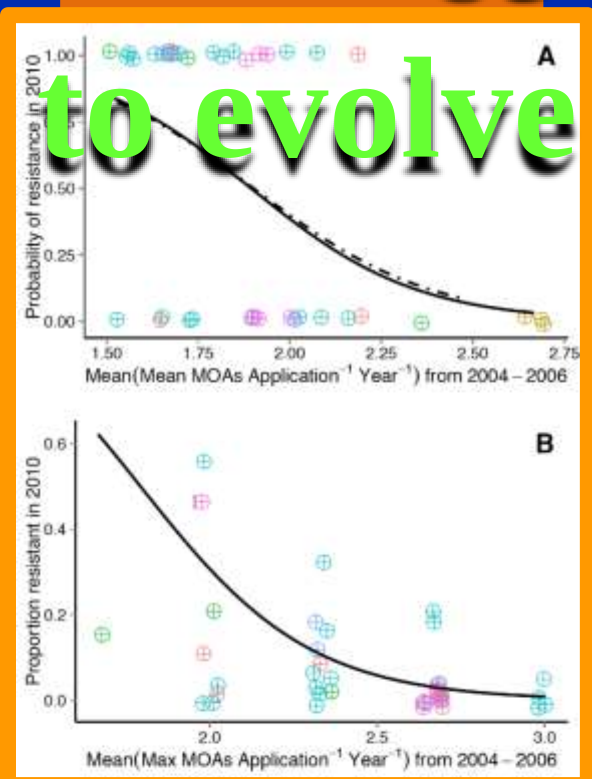
Dependent var.	Model	R^2
% Resistance	Management	0.27
	Soil	0.18
	Landscape	0.18
	Weeds	0.09
	M + S + L + W	0.26
	S + L + W	0.18
Presence/absence of resistance	Management	0.53
	Soil	0.29
	Landscape	0.44
	Weeds	[illegible]
	M + S + L + W	[illegible]
	S + L + W	[illegible]

1) Management factors are most important.



But… did management influence resistance, or did resistance influence management?

83-fold less likely to evolve glyphosate resistance



2) Herbicide mixing, and not herbicide rotation, mitigates resistance.

3) Proximity to neighbor's GR waterhemp was not a good predictor.

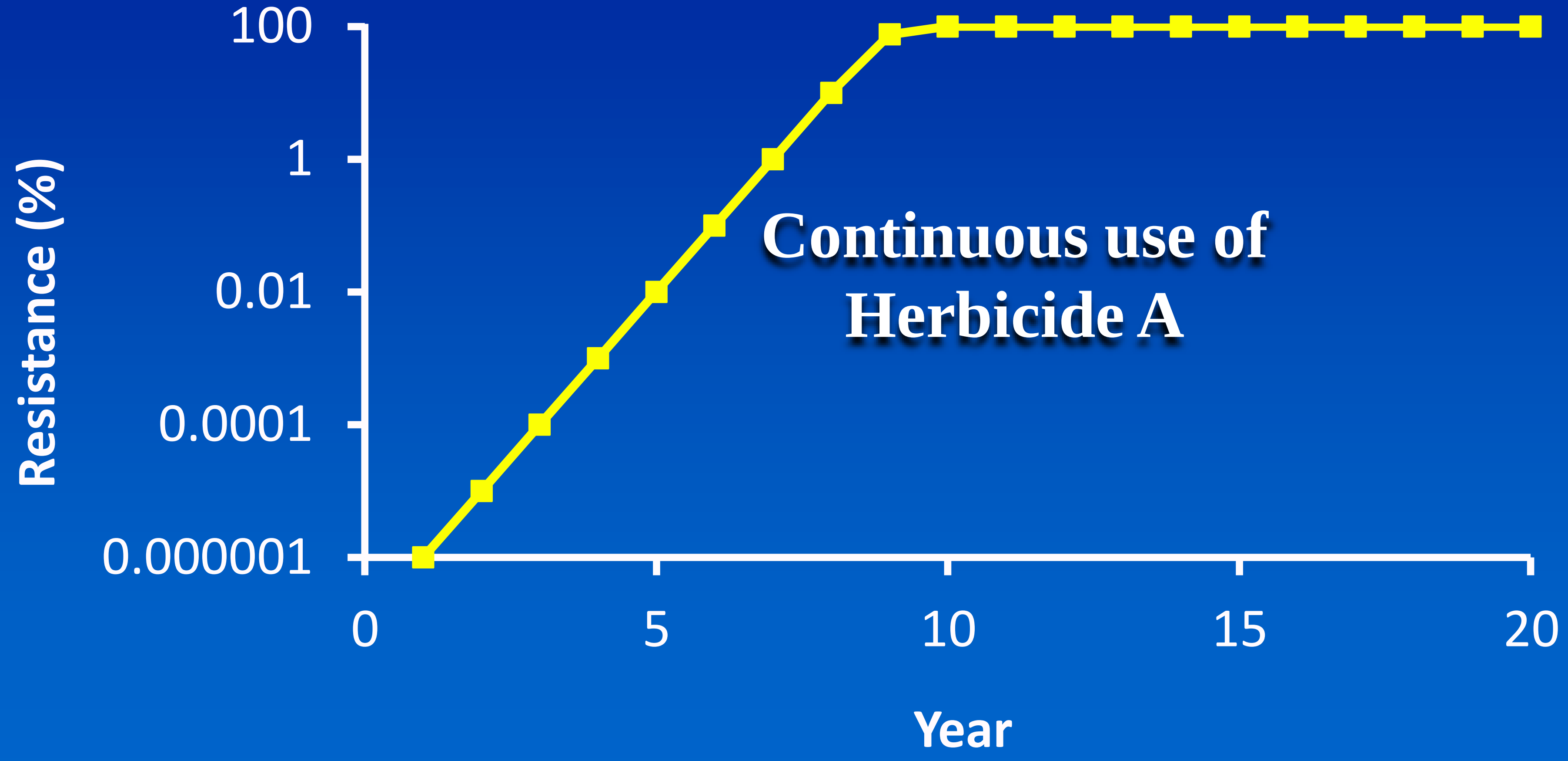
Funding: USDA AFRI, Monsanto Co., ISA

Why herbicide rotation is not particularly effective

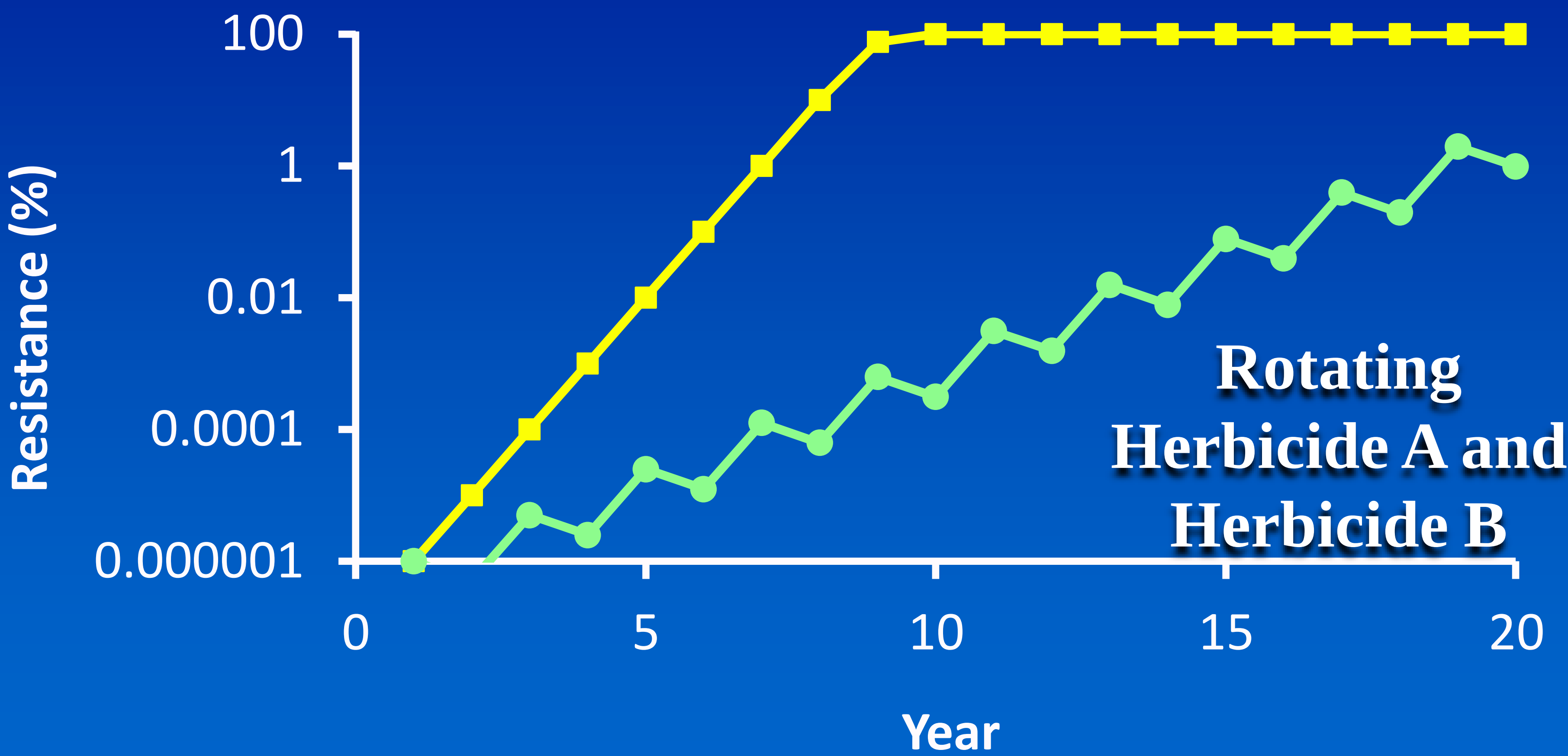
The basis for rotation is fitness costs of HR traits

- A plant with resistance to Herbicide A is at an advantage when Herbicide A is applied
- It was generally assumed (and demonstrated with triazine resistance) that a plant with resistance to Herbicide A is at a *disadvantage* if Herbicide A is not applied
  - this is referred to as the fitness cost of herbicide resistance

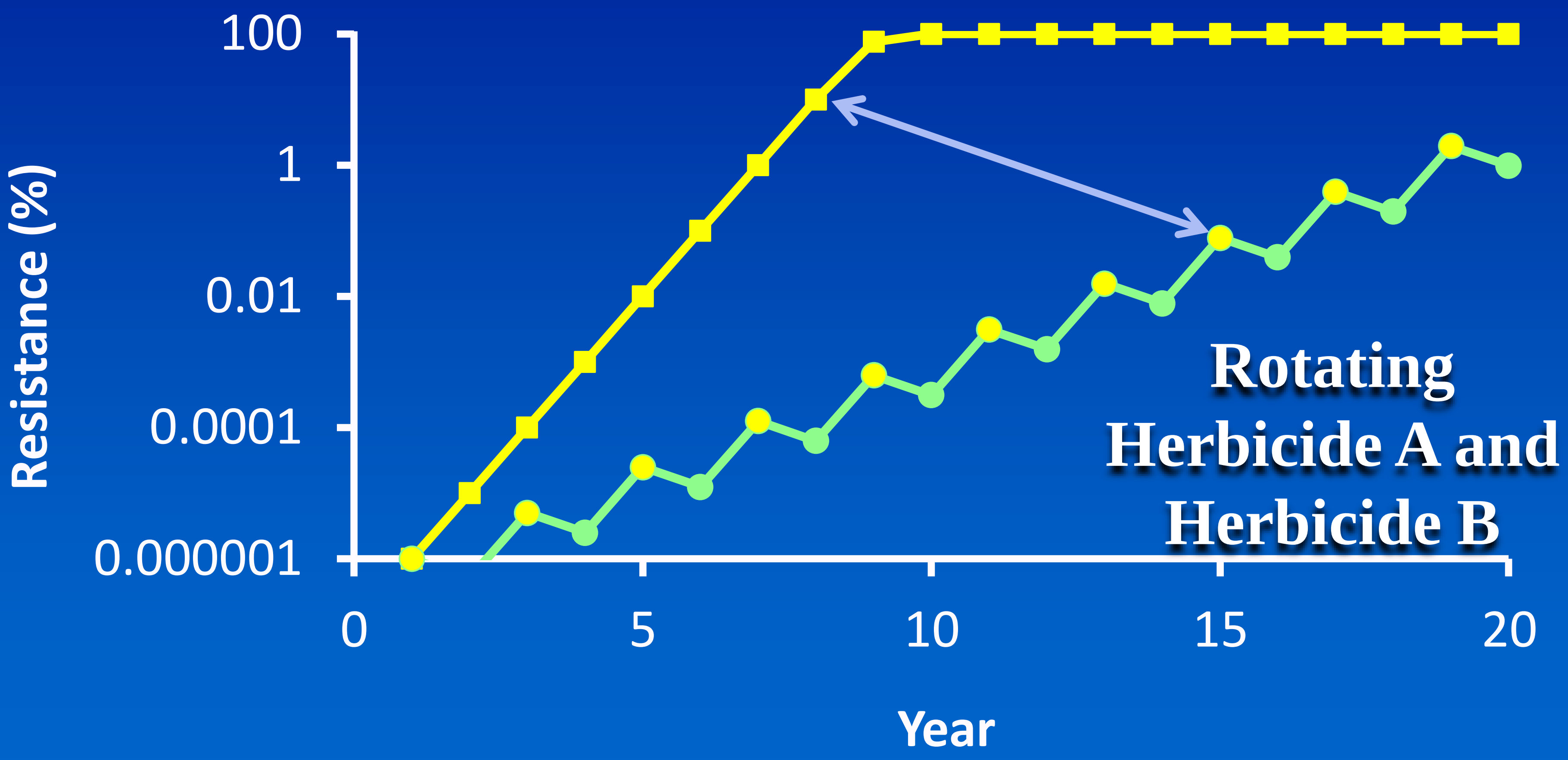
Effectiveness of herbicide rotation depends on fitness cost



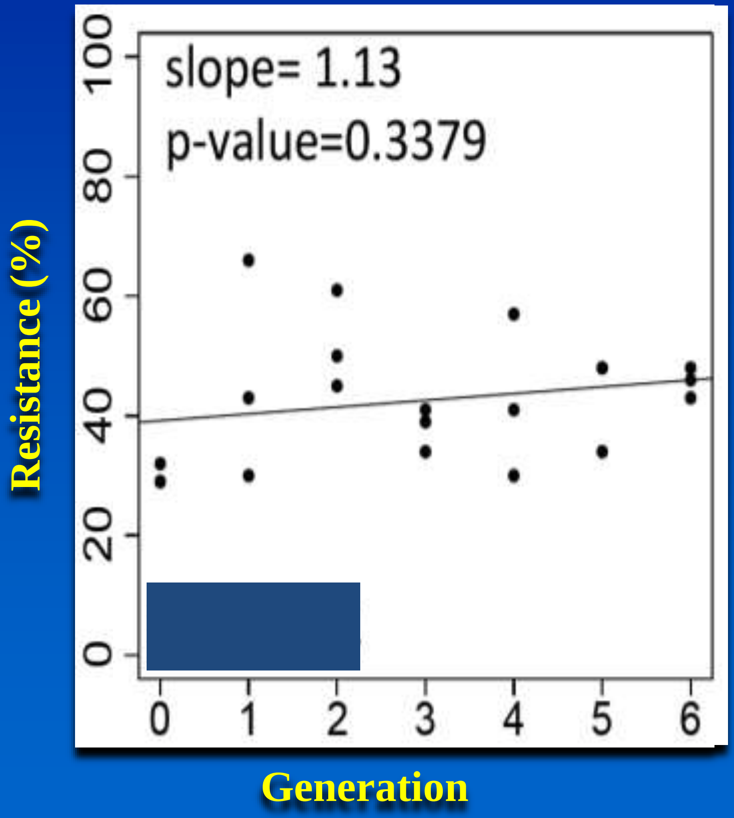
Effectiveness of herbicide rotation depends on fitness cost



Effectiveness of herbicide rotation depends on fitness cost

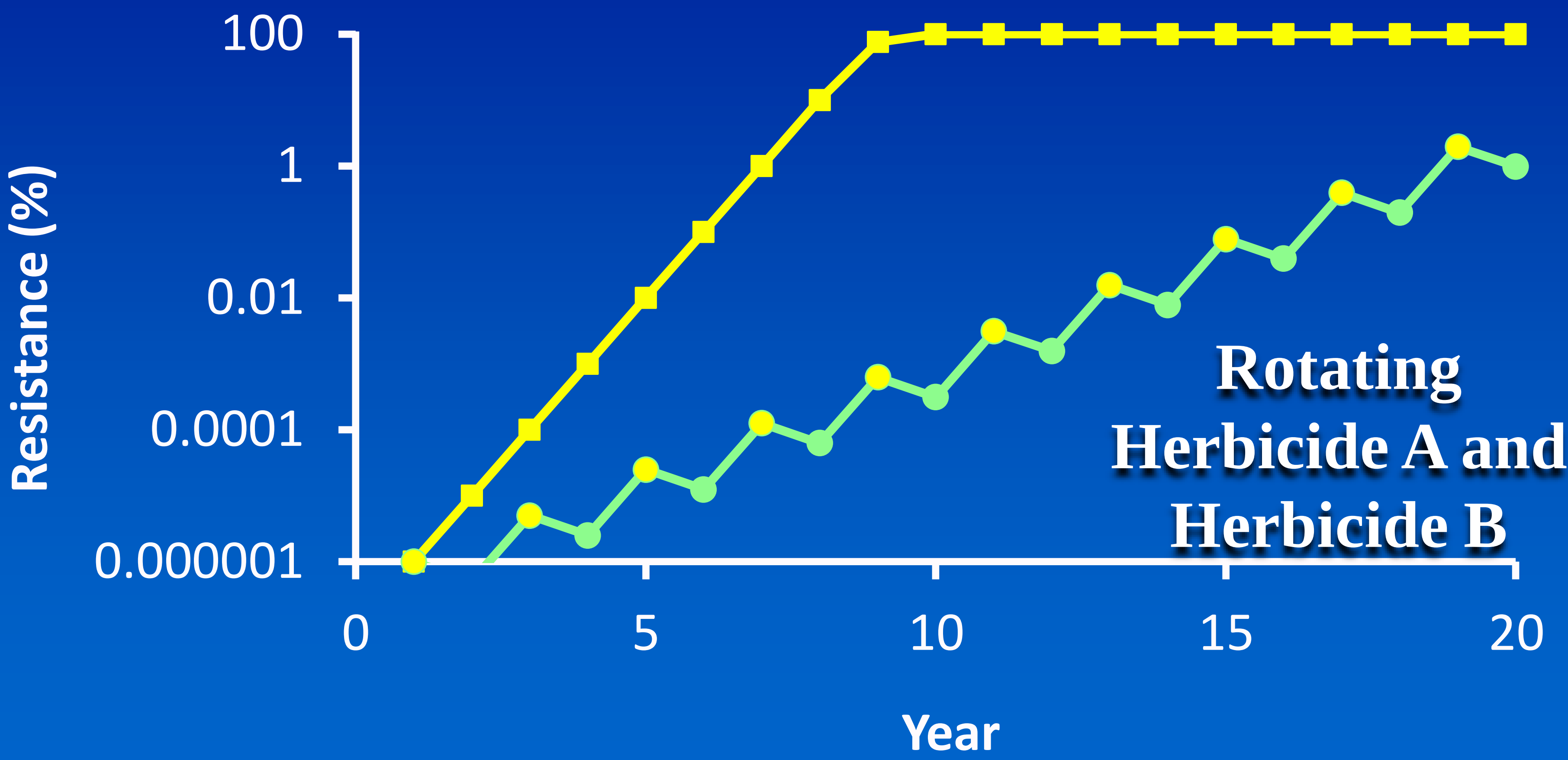


Contemporary research indicates that most resistances have very little fitness costs

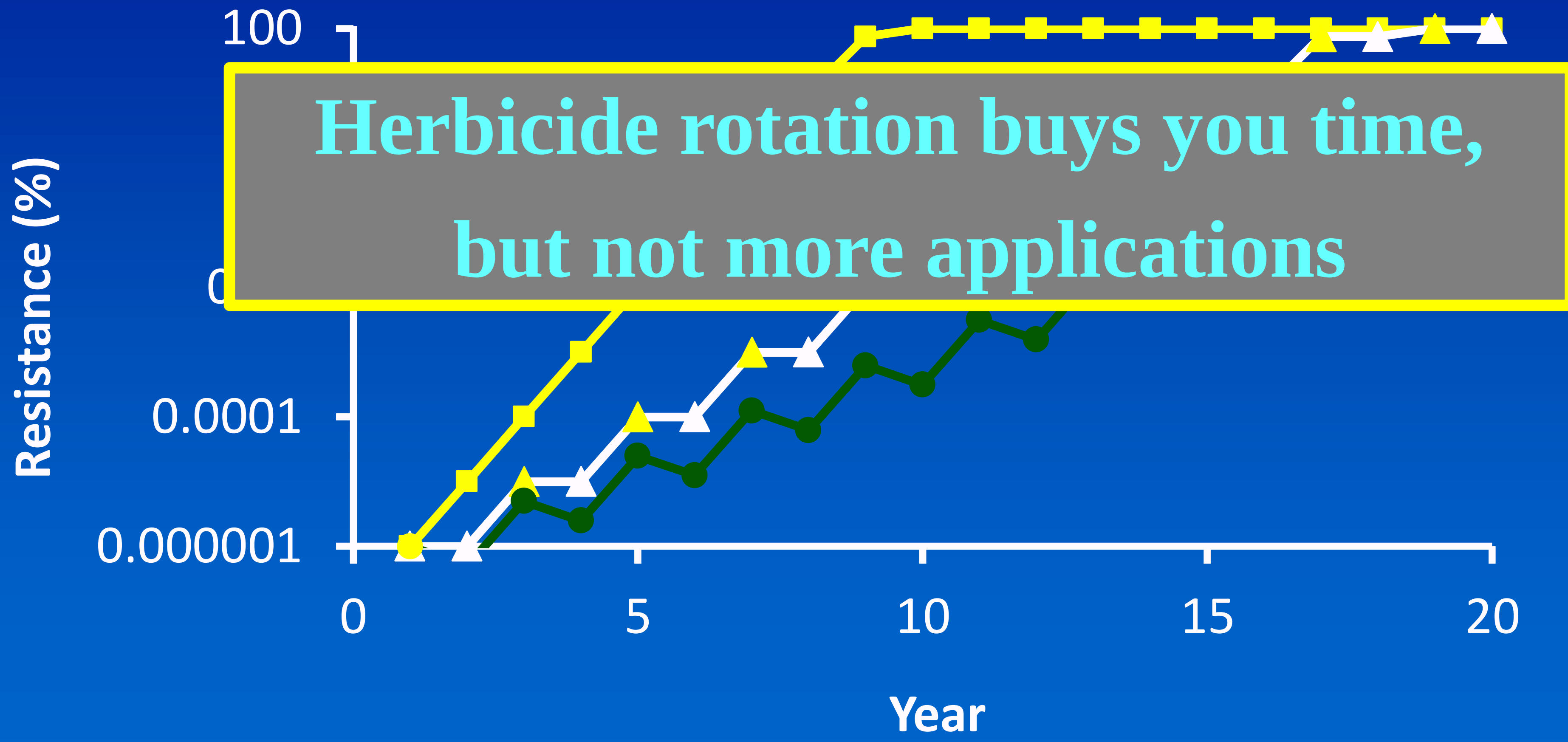


Change in glyphosate resistance frequency in three replicate waterhemp populations after six generations, in the absence of glyphosate selection.

Effectiveness of herbicide rotation depends on fitness cost



Effectiveness of herbicide rotation depends on fitness cost



Why herbicide mixing is effective

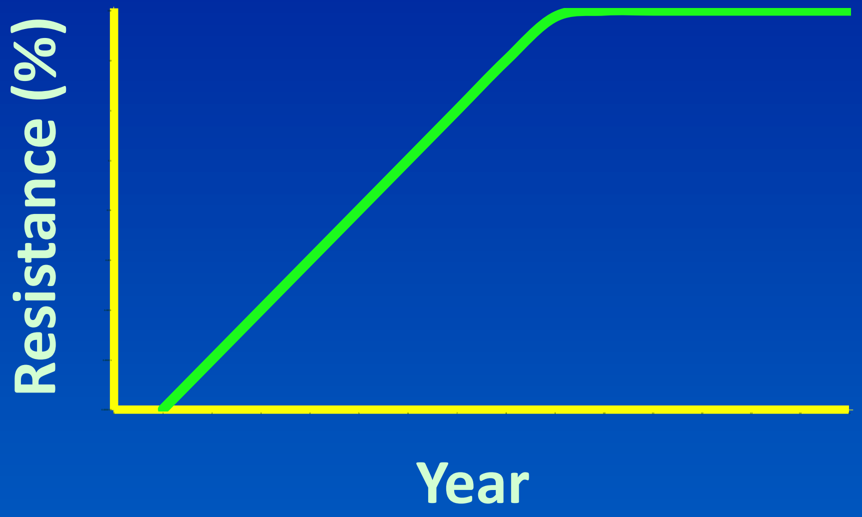
The probability of a plant being resistant to two herbicides is the product of the probabilities of being resistant to each herbicide.

$$10^{-6} \times 10^{-6} = 10^{-12}$$

How many waterhemp selected/year in IL?

$$100 \times 10^{9}$$

Two components to resistance management



1. **Reduce the number of weeds exposed to herbicides**
   – Incorporate non-chemical strategies

2. **Don't allow a herbicide-resistant individual to reproduce**
   - Aim to target every individual weed with two lethal blows

Thinking differently about *Amaranthus*

- **Dioecious species of *Amaranthus* (i.e., waterhemp and Palmer amaranth) are more prone to evolve resistance than monoecious species (i.e., powell, redroot, smooth)**
  - **once resistance alleles occur, they do NOT exit the population**

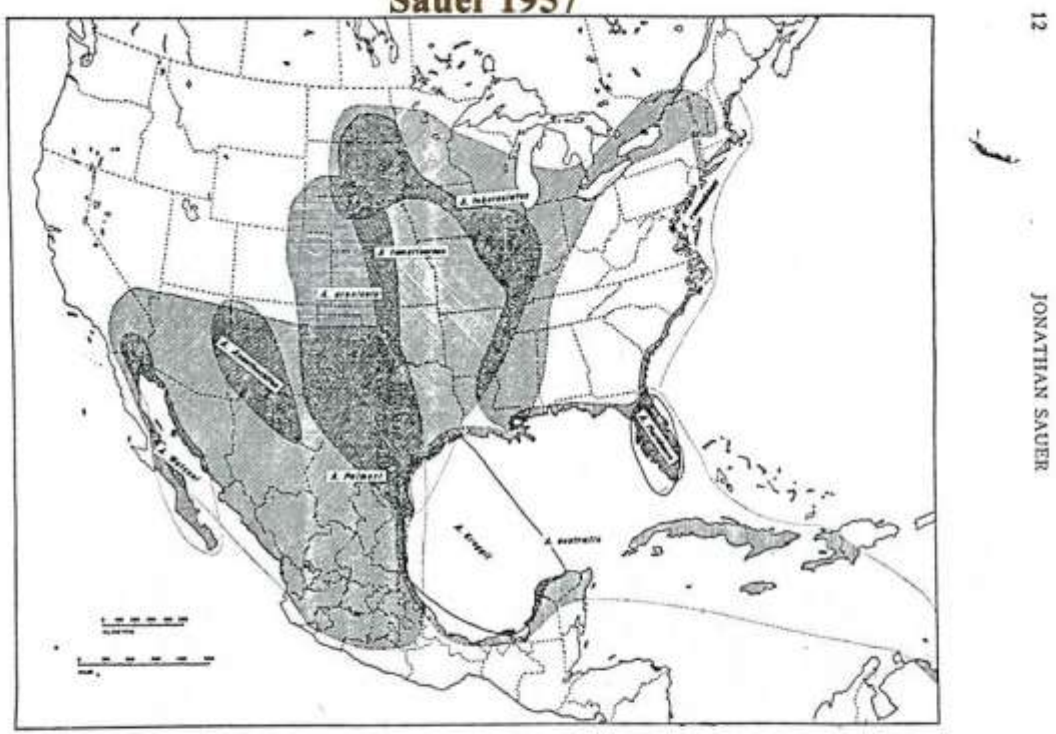
- **Multiple resistance is the norm rather than the exception**
  - **"stacking" another resistance about every 5 years**

- **Herbicide mixing, not herbicide rotation, is a better strategy to forestall the evolution of resistance**
  - **during which application?**
  - **forestall, NOT prevent**

Palmer amaranth historical distribution

- Originally, a species of the southwestern United States
  - southern California to Texas, adapted to arid climate

Recent migration and evolution of the dioecious Amaranths
Sauer 1957



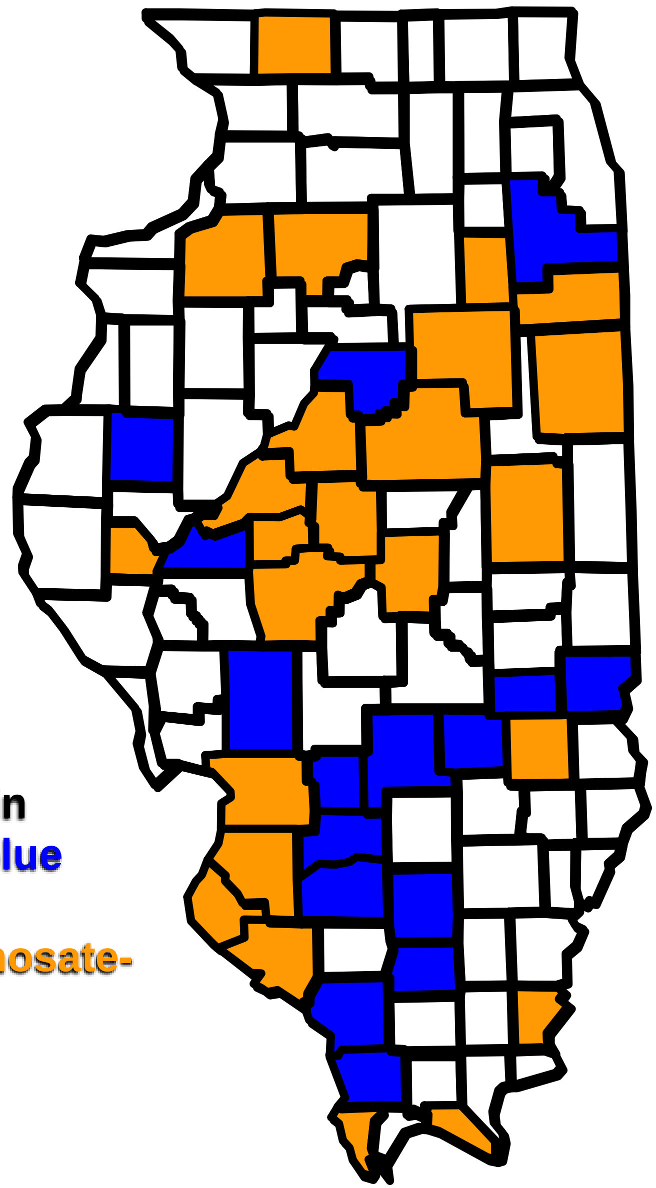
Source: Evolution 11:11-31

Palmer amaranth historical distribution

- **Herbarium records prior to 1900 confined to:**
  - **Sonora, California, Arizona, New Mexico, Texas**

- ***"It looks as if there has been recent and substantial northeastward expansion of A. palmeri resulting in its present wide area of cohabitation with interior species."***
  - *Dr. Jonathan Sauer, Recent Migration and Evolution of the dioecious amaranths, March 1957*

Amaranthus palmeri Distribution in Illinois 2012–2016 sampling

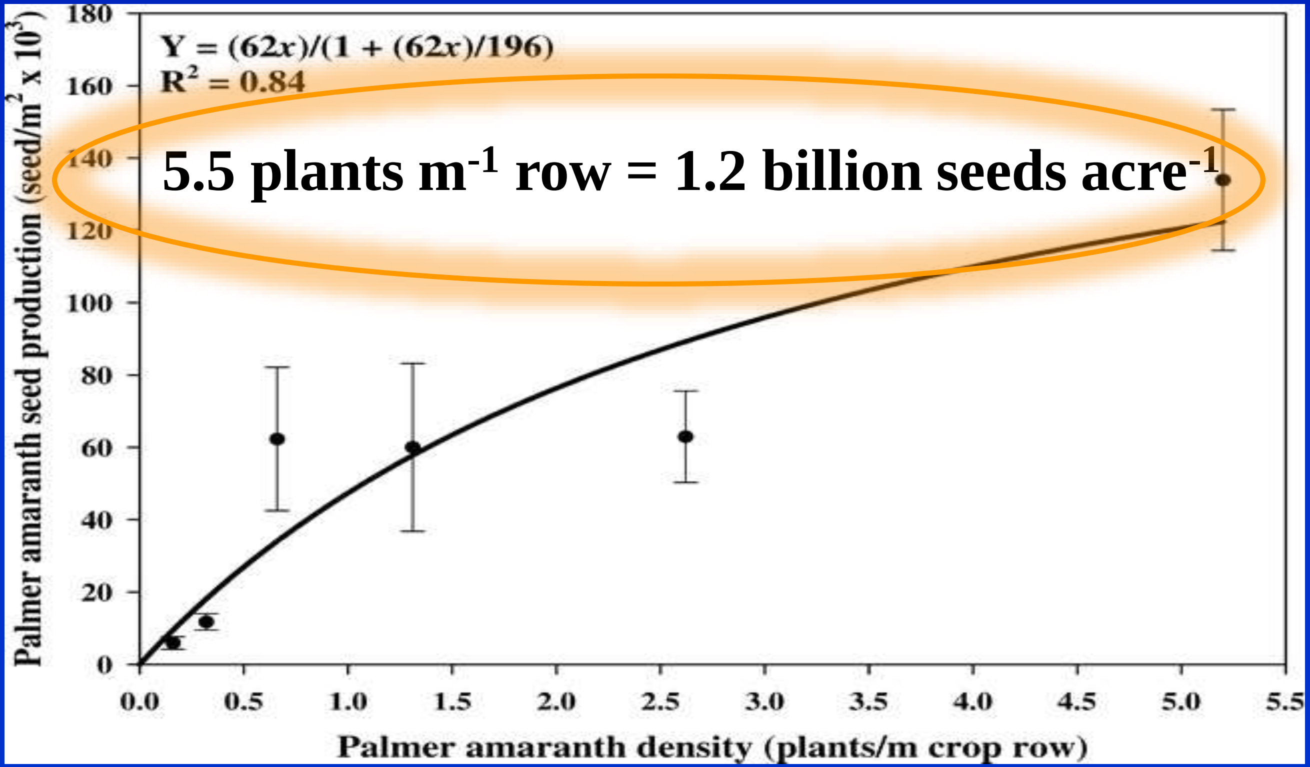


Palmer amaranth confirmed in counties colored orange or blue

Orange – counties with glyphosate-resistant Palmer amaranth

Palmer amaranth introduction

- **Seed production:**
  - comparable with waterhemp
    - 460,000 seeds/plant after full-season growth with cotton
    - likely > 1,000,000/plant under non-competitive conditions



Burke et al. 2007
Weed Technol. 21:367–371

Why Palmer amaranth Spreads so Rapidly

- **Practical exercise with Palmer amaranth seed production:**
  - Single female Palmer amaranth plant produces 1,000,000 seeds at the end of the season
    - assume only 10% viable portion added to soil seedbank
    - assume only 25% germination of viable seed the following season
    - assume 99% control of these plants
  - 250 Palmer amaranth plants survive the following season


Photo courtesy
Dr. Jason Norsworthy


Photo courtesy
Dr. Jason Norsworthy

Palmer amaranth biology

- **Growth rate:**
  - **has a high photosynthetic rate, 3–4x that of soybean (Ehleringer 1983)**
- **Previous research has demonstrated Palmer amaranth has a higher growth rate than other *Amaranthus* species (Horak and Loughin 2000)**
  - **average height increase per GDD_{50}:**
    - **Palmer = 0.195 cm/GDD   Waterhemp = 0.135 cm/GDD**
    - **30-yr average GDD at Urbana for June 10–11 (42.5) and July 10–11 (50.5):**
    - **Palmer = 3.2–3.8”/24 hr   Waterhemp = 2.2–2.6”/24 hr**

Soybean planted into weed-free soil May 16

Rapid Growth Becoming Extremely Large


Photo courtesy
Dr. Stanley Culpepper

How competitive is Palmer amaranth?

- The most competitive *Amaranthus* species
  - reported yield losses include:
    - Soybean 78% (Weed Sci. 51:37–43)
    - Corn 91% (Weed Sci. 49:202–208)
    - Peanut 28% at 1 plant/m row (Wd. Tech. 21:367–371)
    - Cotton up to 92% lint loss (Weed Sci. 47:305–309)

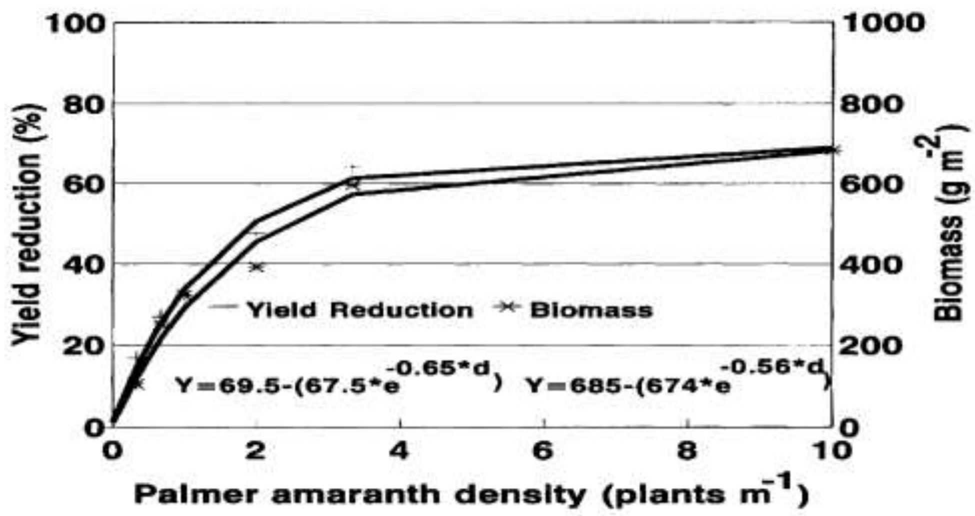


Figure 4. Effect of Palmer amaranth density on Palmer amaranth biomass at harvest and soybean yield reduction. Curves are predicted values and symbols are actual means.

Predicted soybean yield loss from one Palmer amaranth per 3 ft of row:

32%

Klingaman and Oliver 1994
Weed Sci. 42:523–527

Progression of Palmer amaranth growth 2014

Planted May 22

7 days after planting

14 days after planting

21 days after planting

Six weeks after planting

Principles of Palmer amaranth Management

- **Prevention is far better than eradication**
  - **any tactic that will prevent seed introduction or production**

- **Once established, herbicide costs generally double**
  - **often requires at least three to four applications**

- **Thinking differently about *Amaranthus*: Control *should not* be less than 100 percent**
  - **"zero tolerance threshold"**

Think differently about *Amaranthus*

- Not many other weed species in the Midwest resistant to herbicides from 6 SOA groups
  - multiple resistance at the population and individual plant levels
- We've tried opening new jugs for *Amaranthus*, but resistance evolved
  - no new jugs in the near future
- Metabolic resistance will be the next "game changer"
  - think differently about how resistance evolves

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 2019