Managing Resistance: Successfully Staying Ahead Using Our Heads

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Overview

- Importance of herbicide resistance
- Putting herbicide resistance into an evolutionary context
- Results from a real-world study of glyphosate resistance
- Interpreting results from an evolutionary perspective

PS II inhibitors
ALS inhibitors
1990
1995
PPO inhibitors
2000
Glyphosate
2005
HPPD inhibitors
2,4-D
2010
2015

Timeline of herbicide resistances in waterhemp

Timeline of herbicide resistances in waterhemp

1990 PS II inhibitors
ALS inhibitors

1995 ALS and PS II inhibitors

2000 PPO and ALS inhibitors
PS II, ALS, and PPO inhibitors

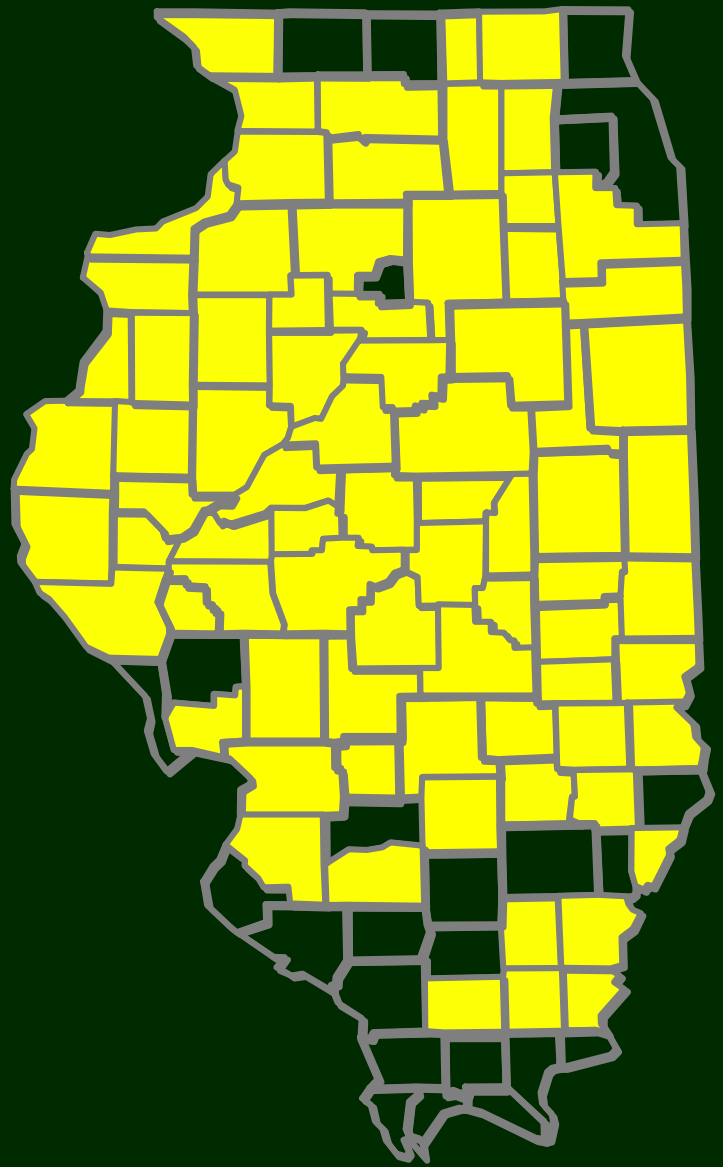
2005 Glyphosate and ALS and PPO inhibitors

2010 Glyphosate and PSII, ALS, and PPO
HPPD inhibitors
2,4-D

2015 Tri. Gly. PPO ALS HPPD
Tri. PPO ALS
HPPD 2,4-D


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

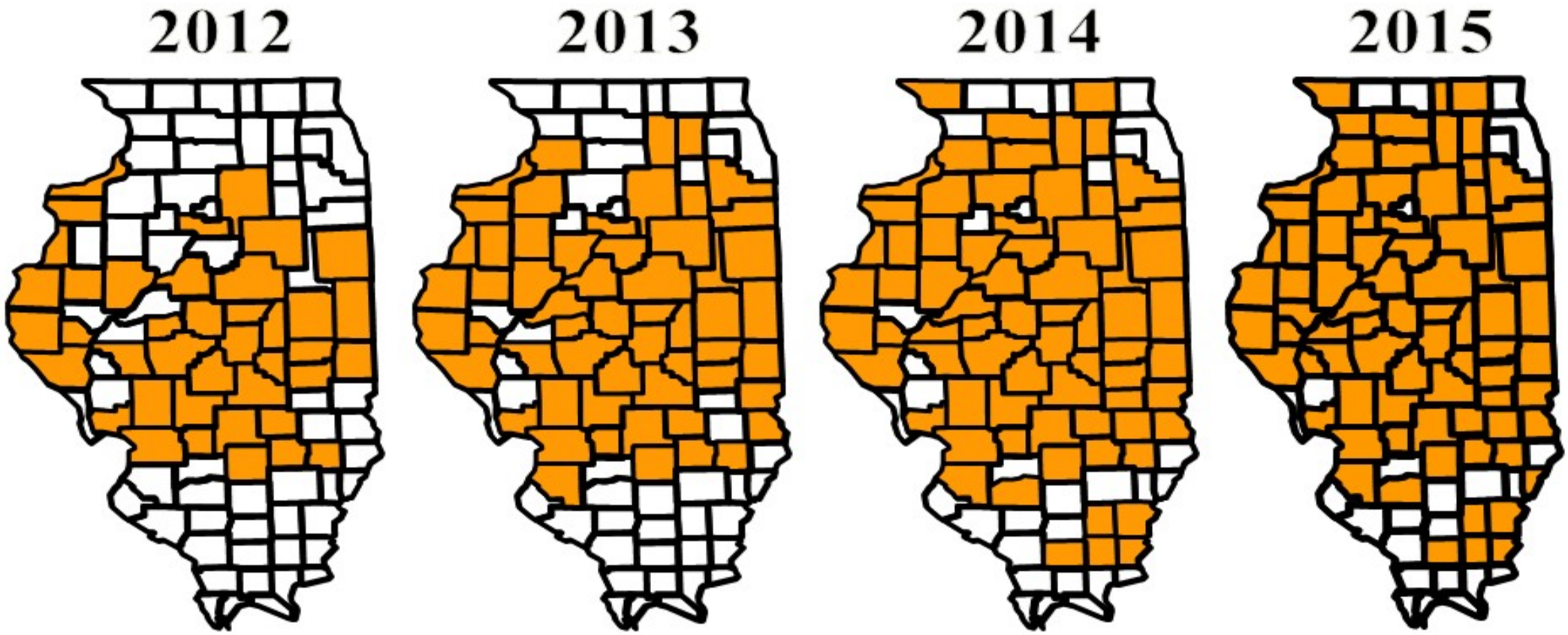
Counties confirmed with waterhemp resistant to glyphosate



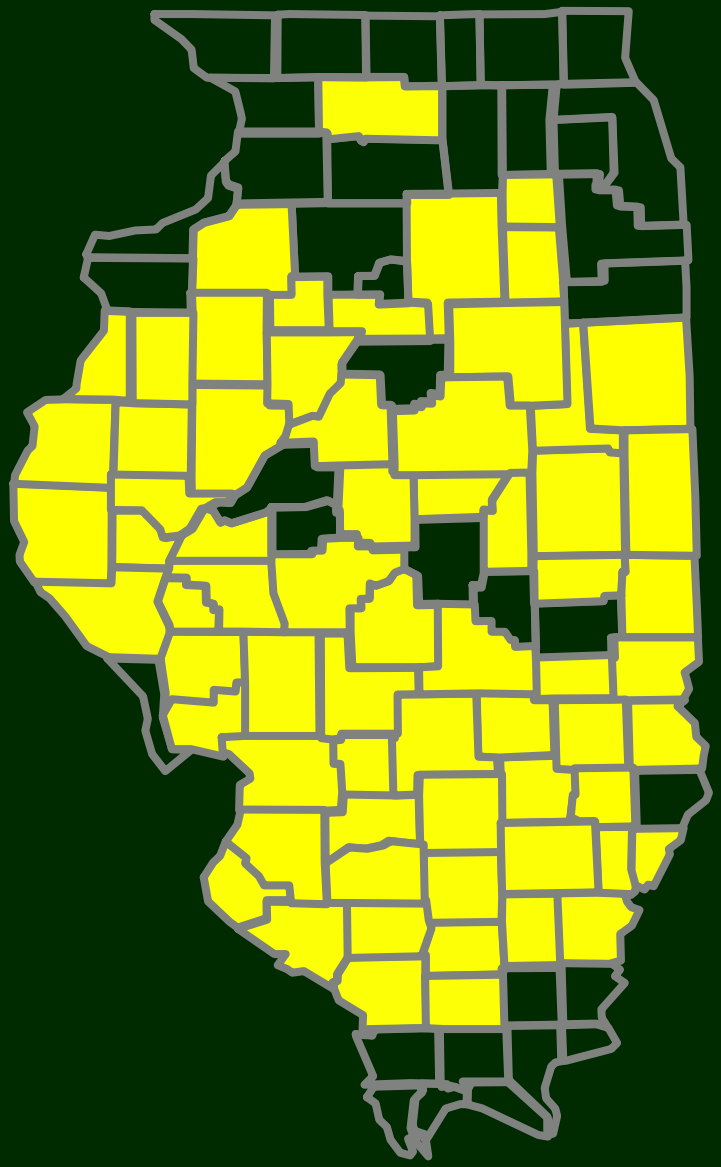
Based on grower submissions through 2015

Figure 1. Range expansion of glyphosate-resistant waterhemp

Counties confirmed with GR waterhemp, based on grower submissions

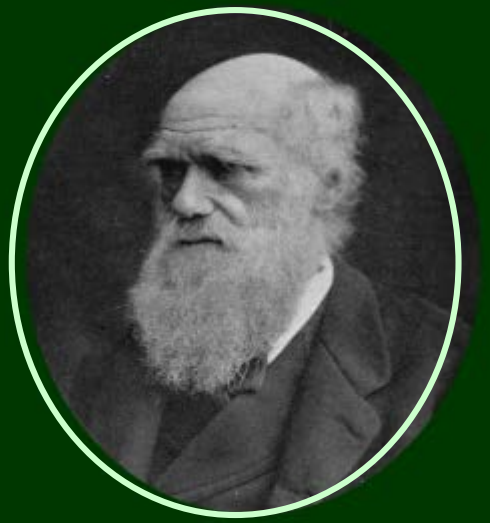


Counties confirmed with waterhemp resistant to PPO inhibitors



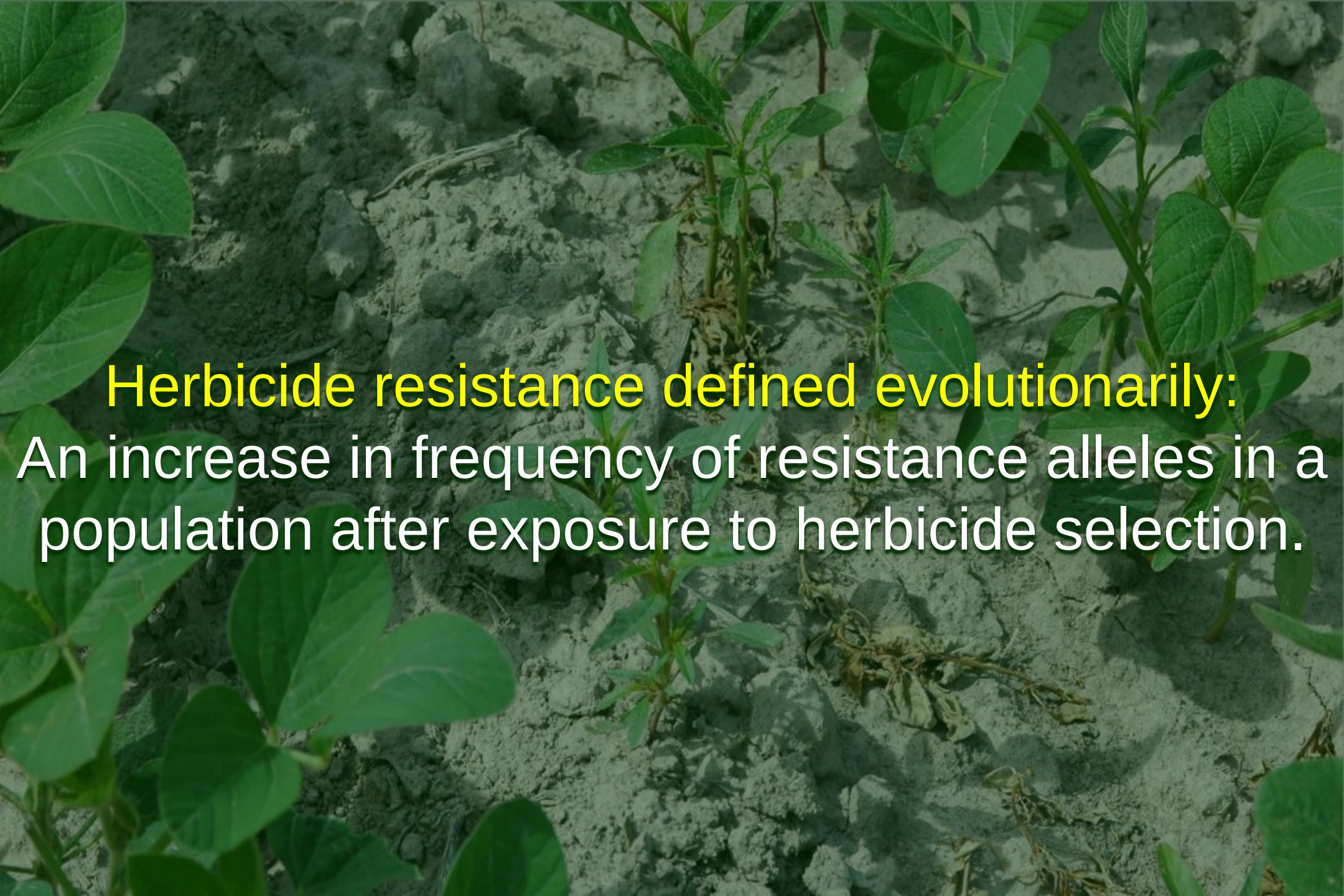
Based on grower submissions through 2015

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

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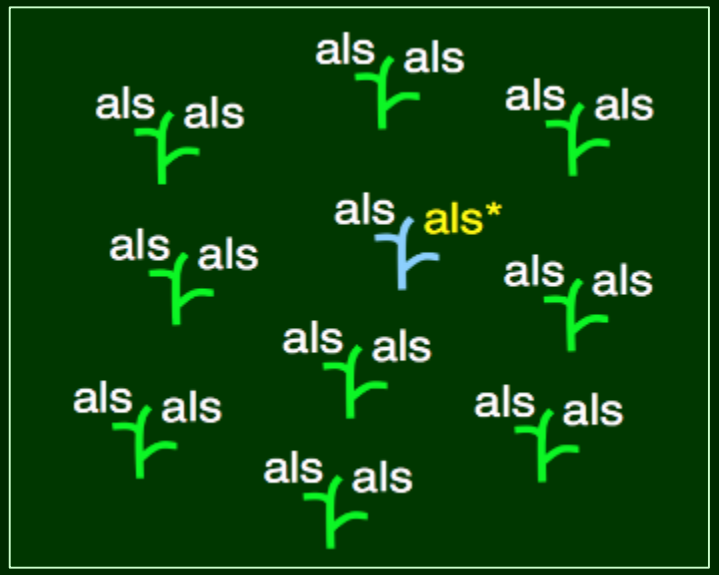
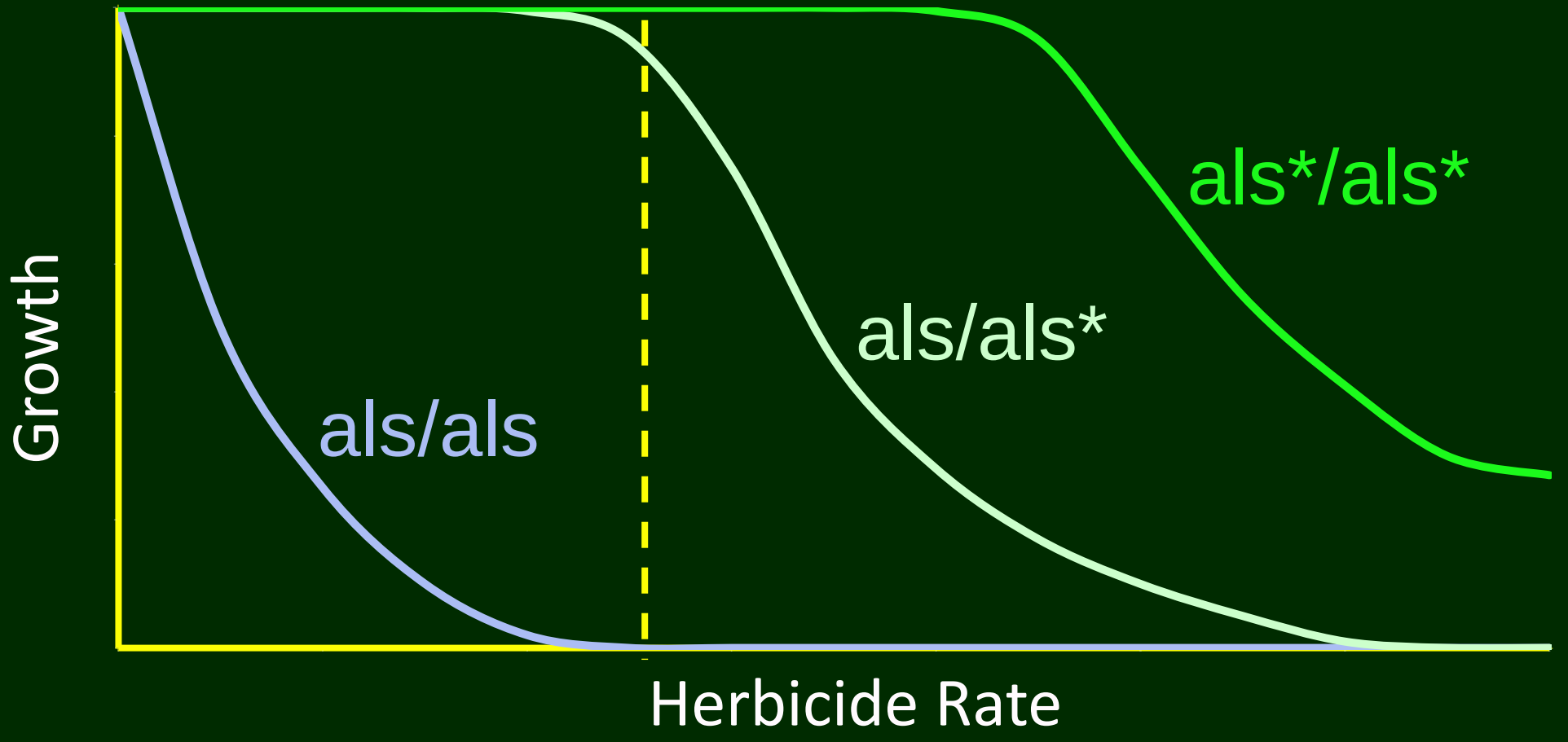


Dominant/recessive nature of alleles influences phenotypes

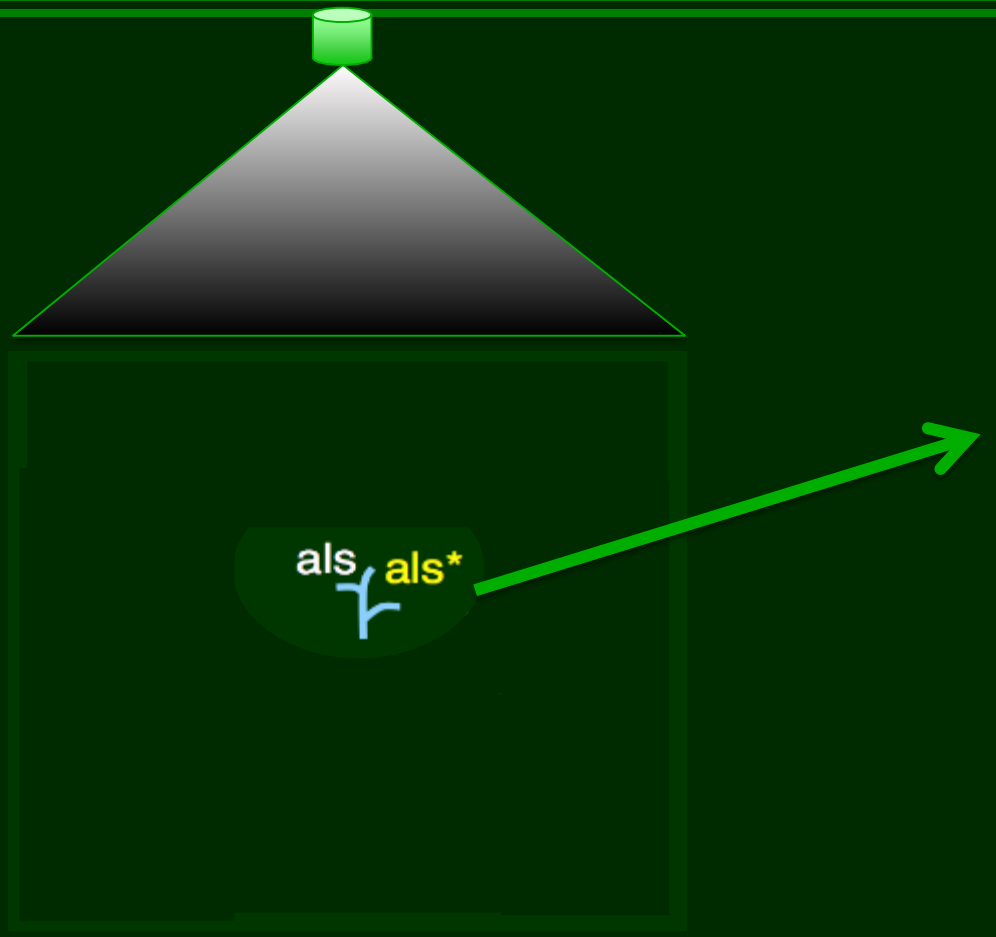
	Phenotype		
Genotype	Dominant	Recessive	Additive
als/als	sensitive	sensitive	sensitive
als/als*	resistant	sensitive	intermediate
als*/als*	resistant	resistant	resistant

The refuge practice for Bt resistance management is predicated on Bt resistance alleles being recessive.

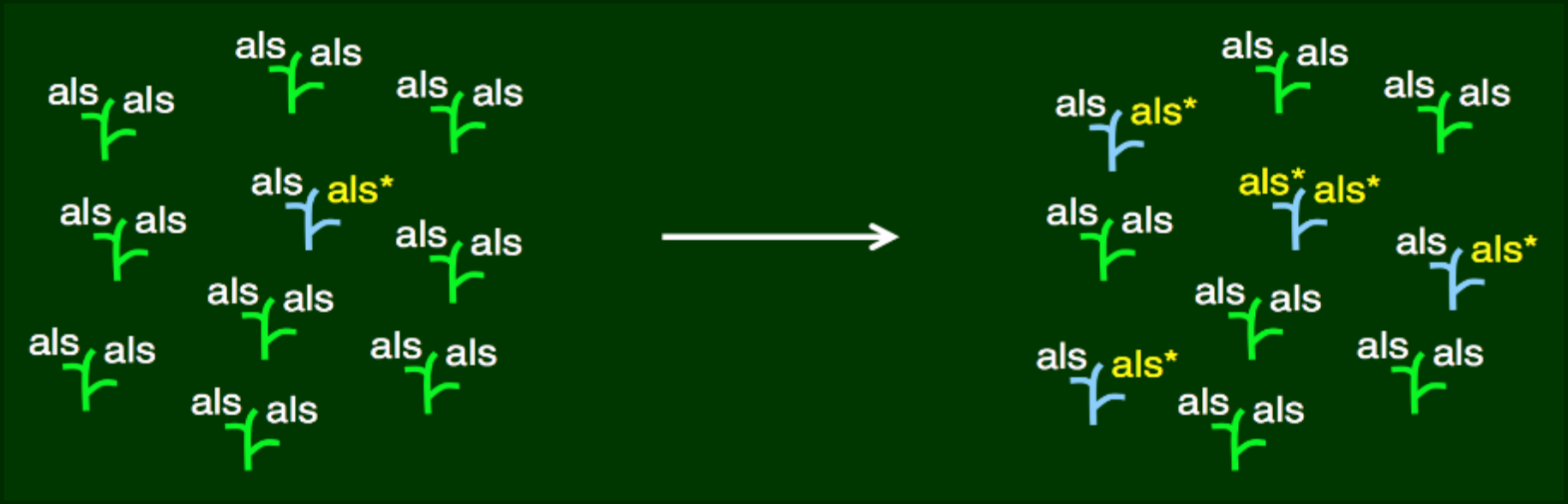
Most herbicide-resistance alleles are additive, but functionally dominant



Evolution in action



Transmit its alleles to the next generation



How fast this happens depends on numerous factors, such as:

- Effectiveness of the herbicide
- Presence of other selective factors (e.g., other herbicides, tillage, etc.)
- Biology of the weed
  - Reproduction
  - Seed dormancy

What is the source of rare resistance alleles?

- New mutations
- Standing genetic variation
- Immigration (gene flow from other population)

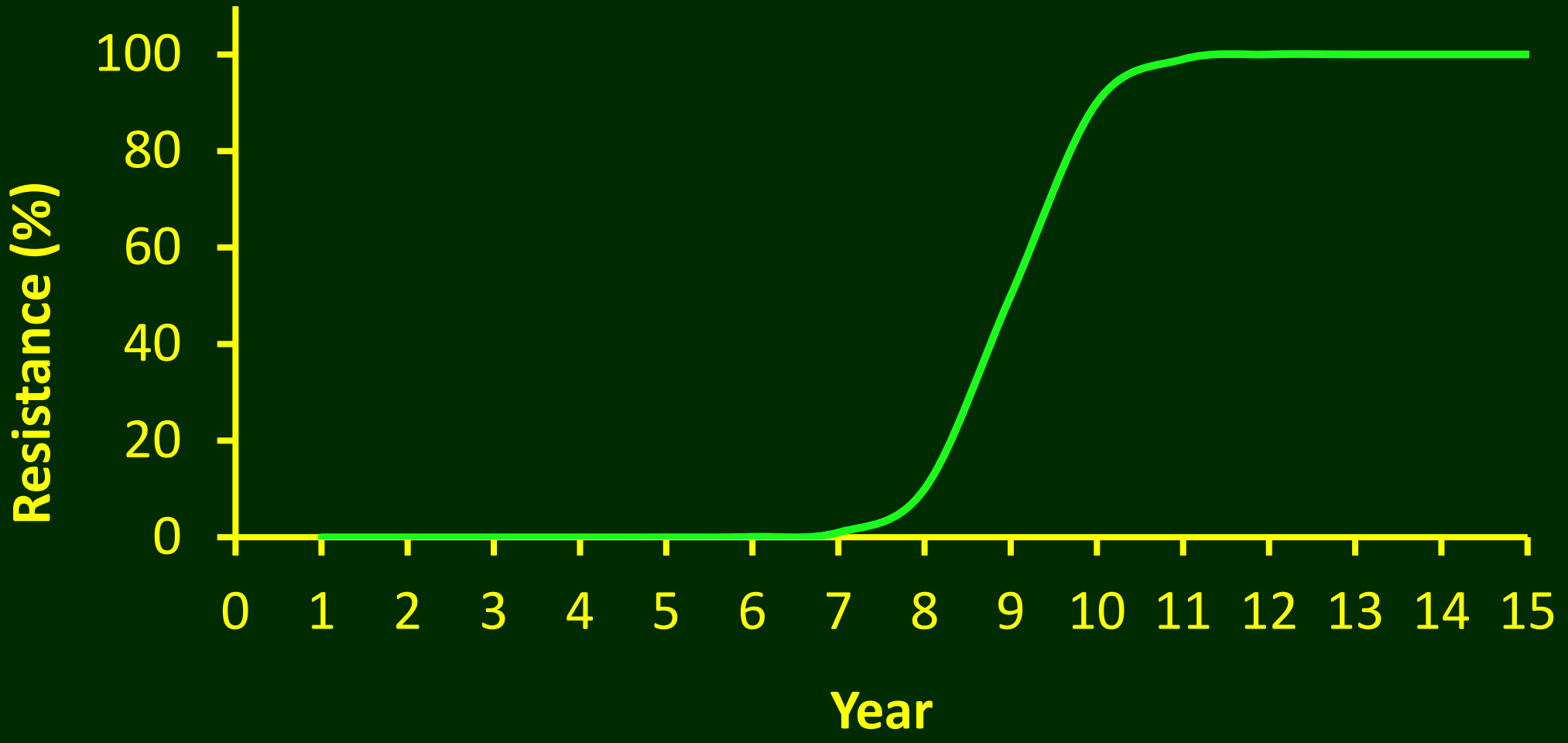
Numbers game

IL corn/soybean acres	22,000,000
% with waterhemp	75%
% with escapes in given year	5%
Escapes/acre	25
Potential seeds/escape	500,000
% of potential seed production	10%
% surviving/germinating next year	10%
New individuals for selection/year	100×10^9

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



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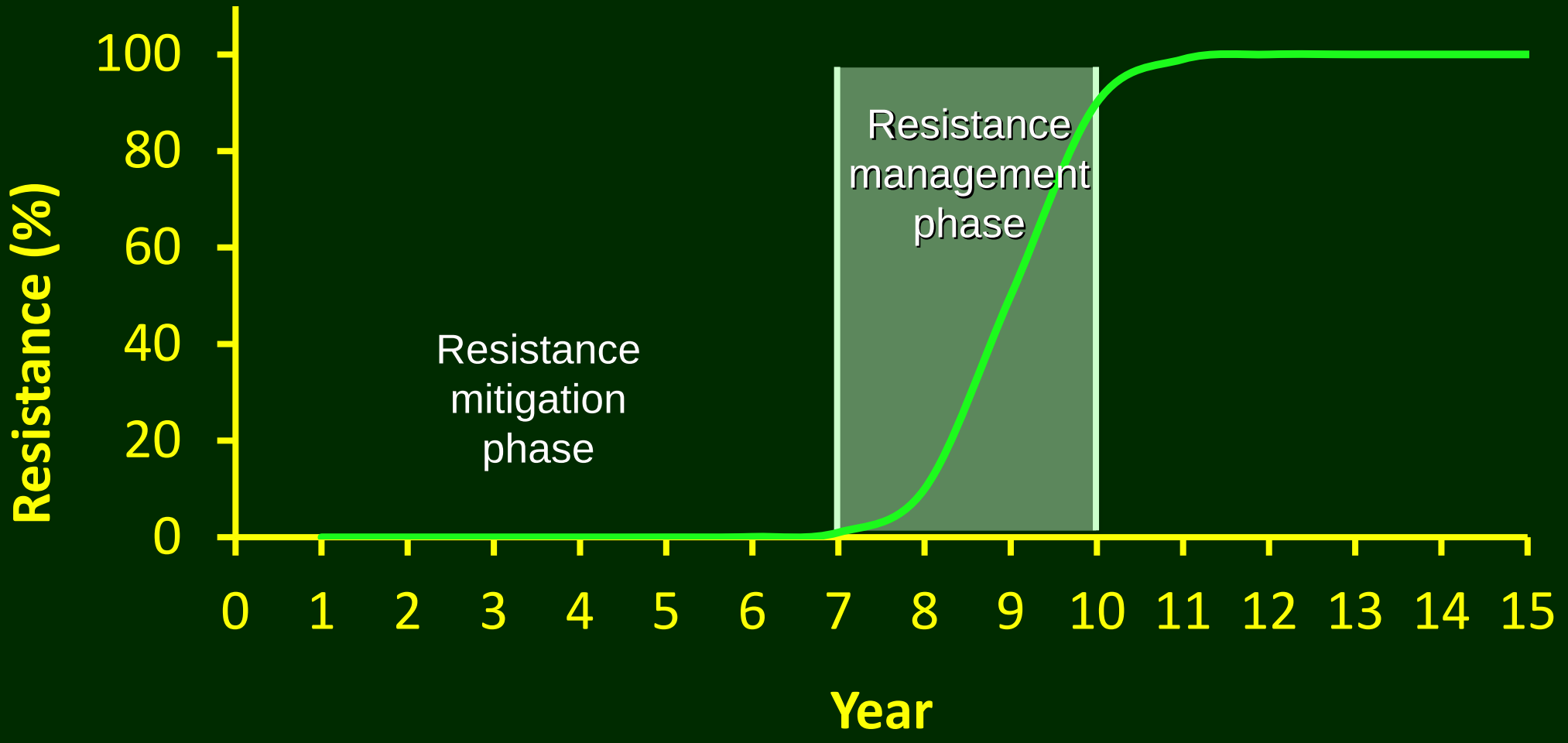

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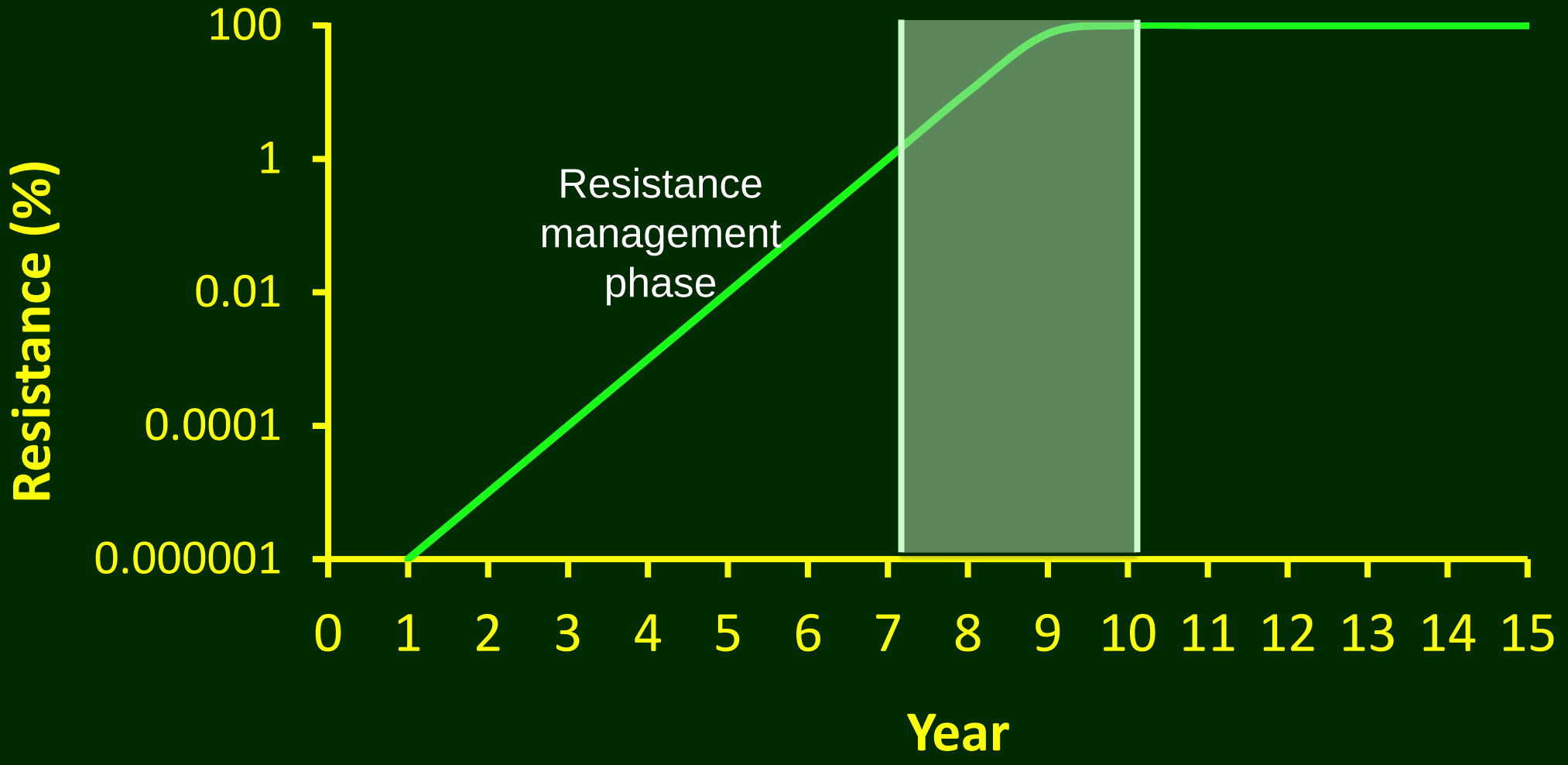

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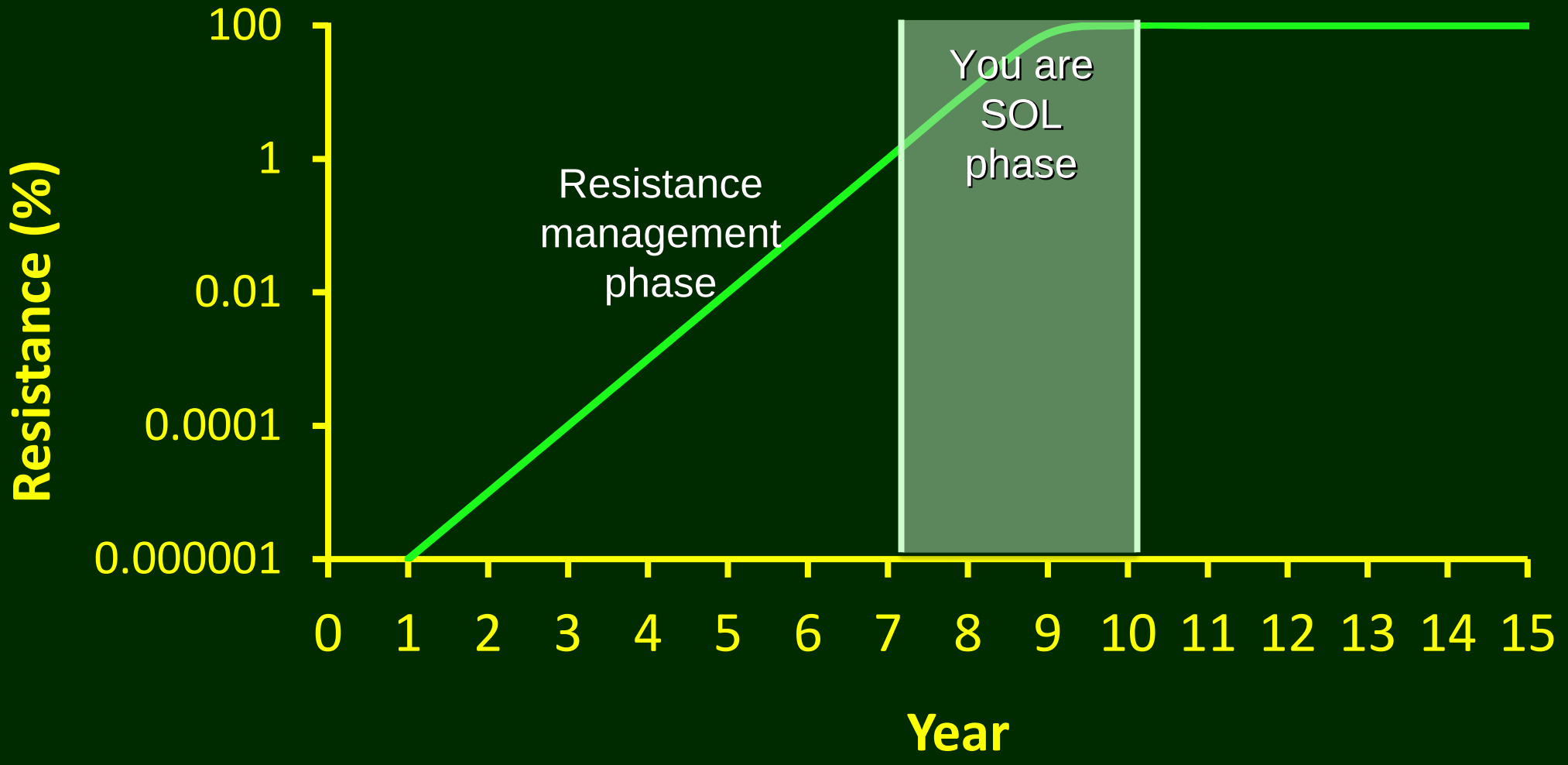

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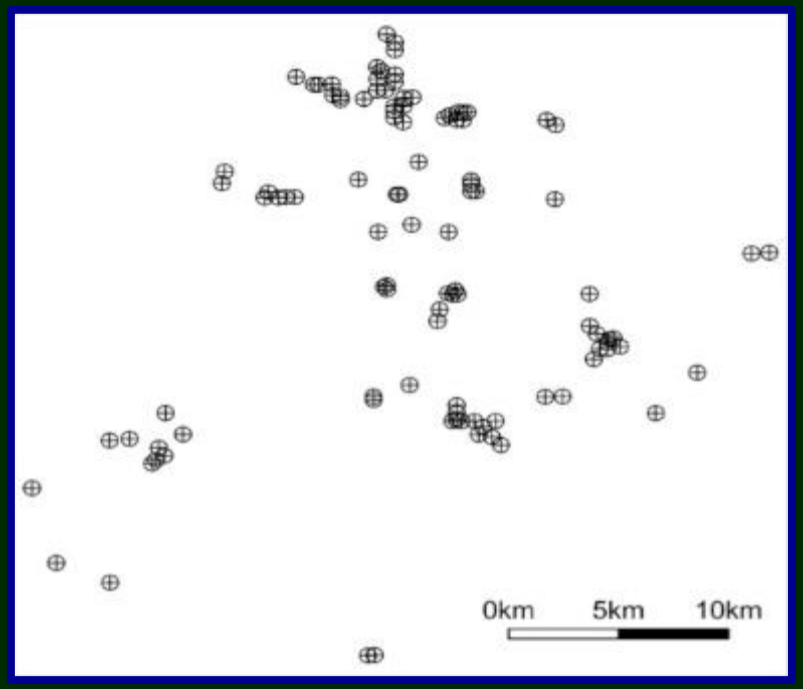
A landscape-scale approach to understand glyphosate-resistant waterhemp

Evans et al. (2016)
Pest Manag. Sci. 72:74-80.

Glyphosate-resistant waterhemp confirmed in Illinois in 2006

What factors contribute to the occurrence of GR waterhemp?



» 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

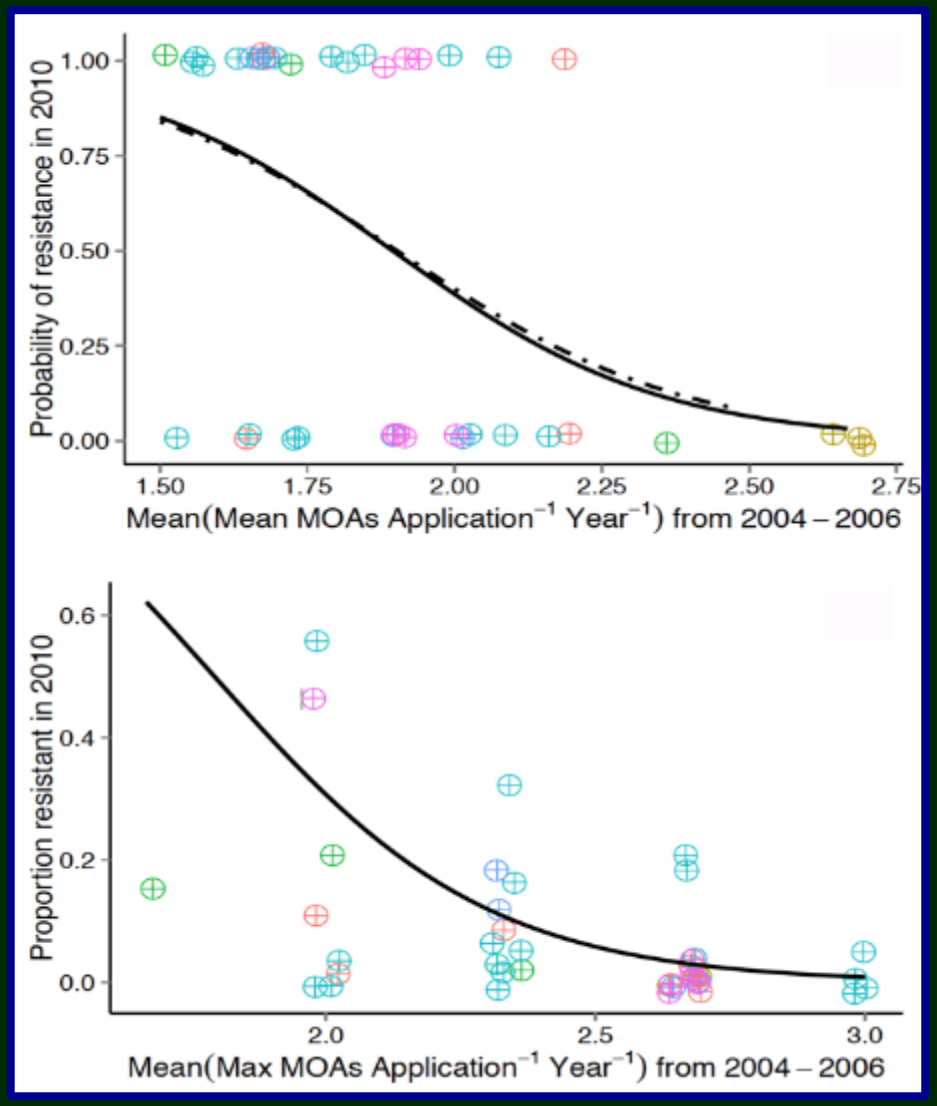

Site 5
Image USDA Farm Service Agency
© 2020 Google
761 m

Management factors are most important

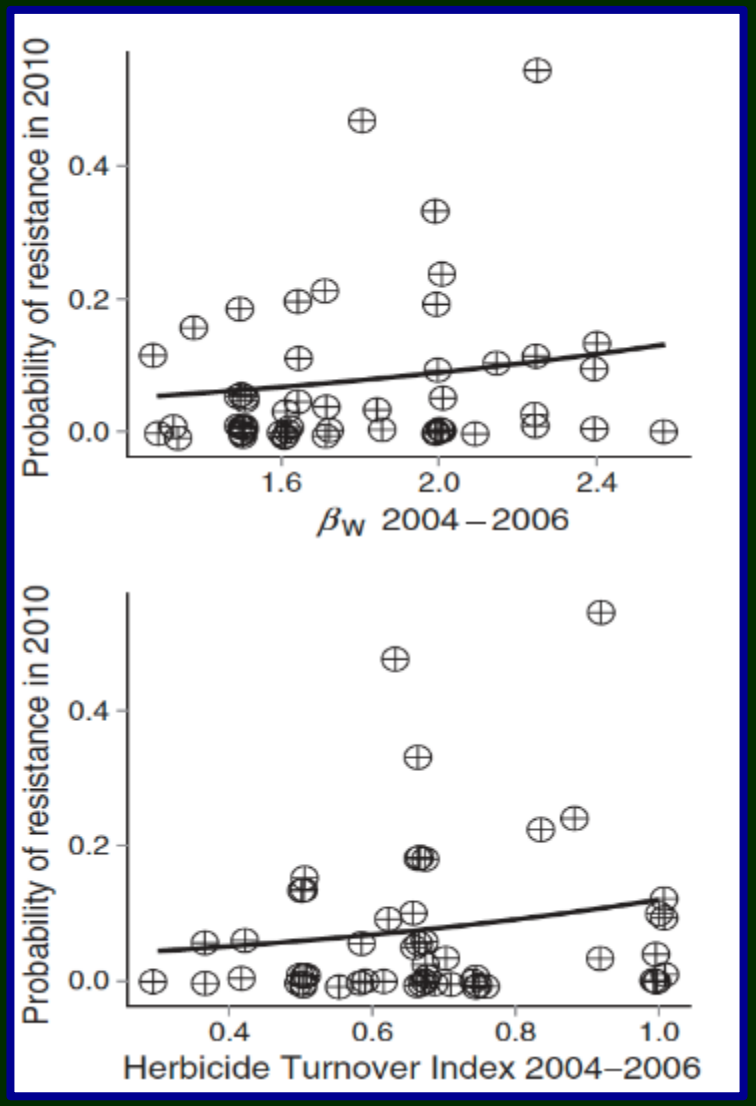
Dependent var.	Model	R^2
% Resistance	Management	0.27
	Soil	0.18
	Landscape	0.18
	Weeds	0.09
	M + S + L + W	0.26
	S + L + W	0.18
Presence/absence of resistance	Management	0.53
	Soil	0.29
	Landscape	0.44
	Weeds	0.38
	M + S + L + W	0.41
	S + L + W	0.29

What management factors in 2004-2006 predicted resistance in 2010?

Herbicide mixing



Herbicide rotation



Three key findings:

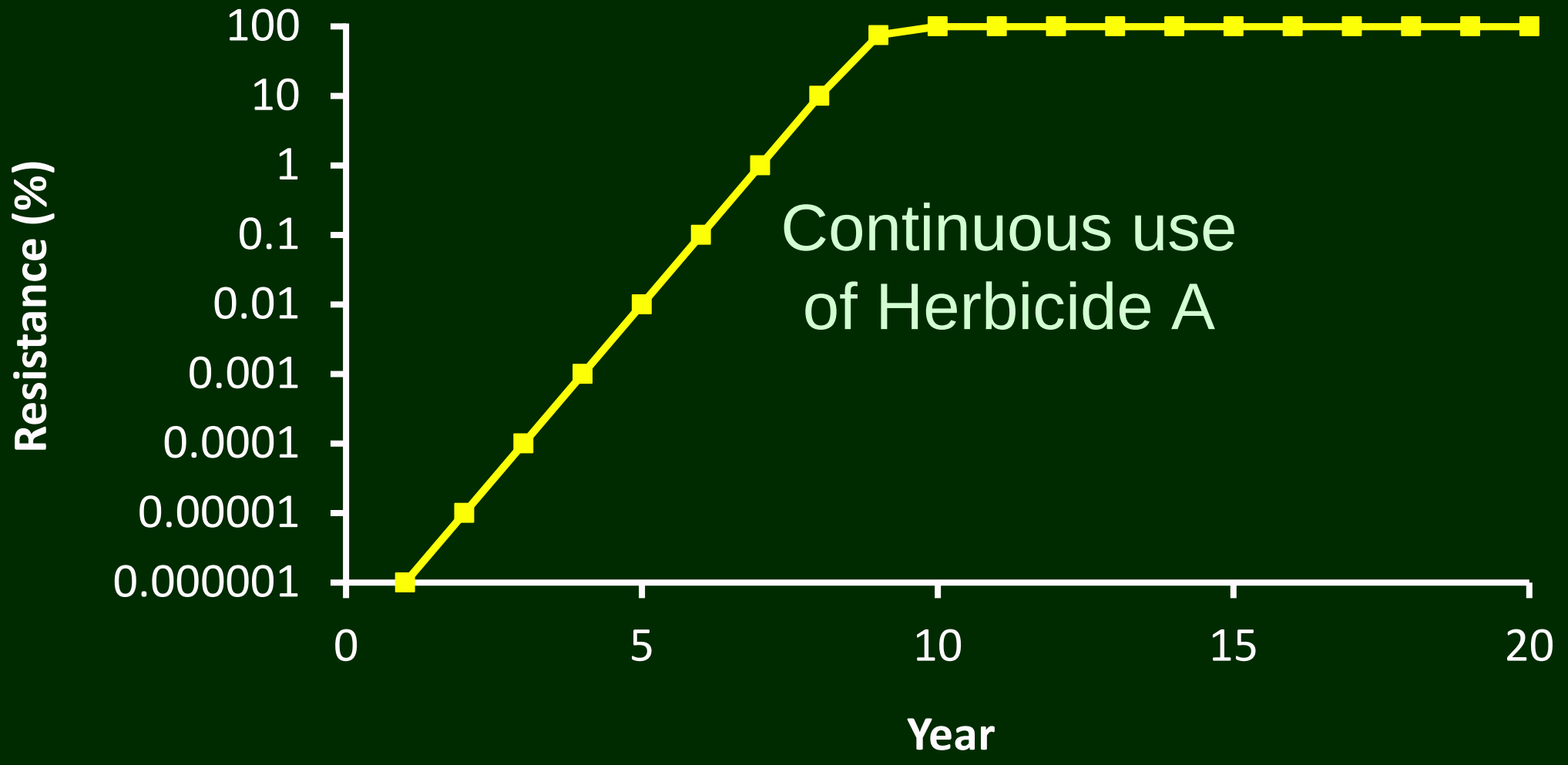
- Herbicide mixing was effective
- Herbicide rotation was NOT effective
- Whether or not your neighbor had resistance was not important

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



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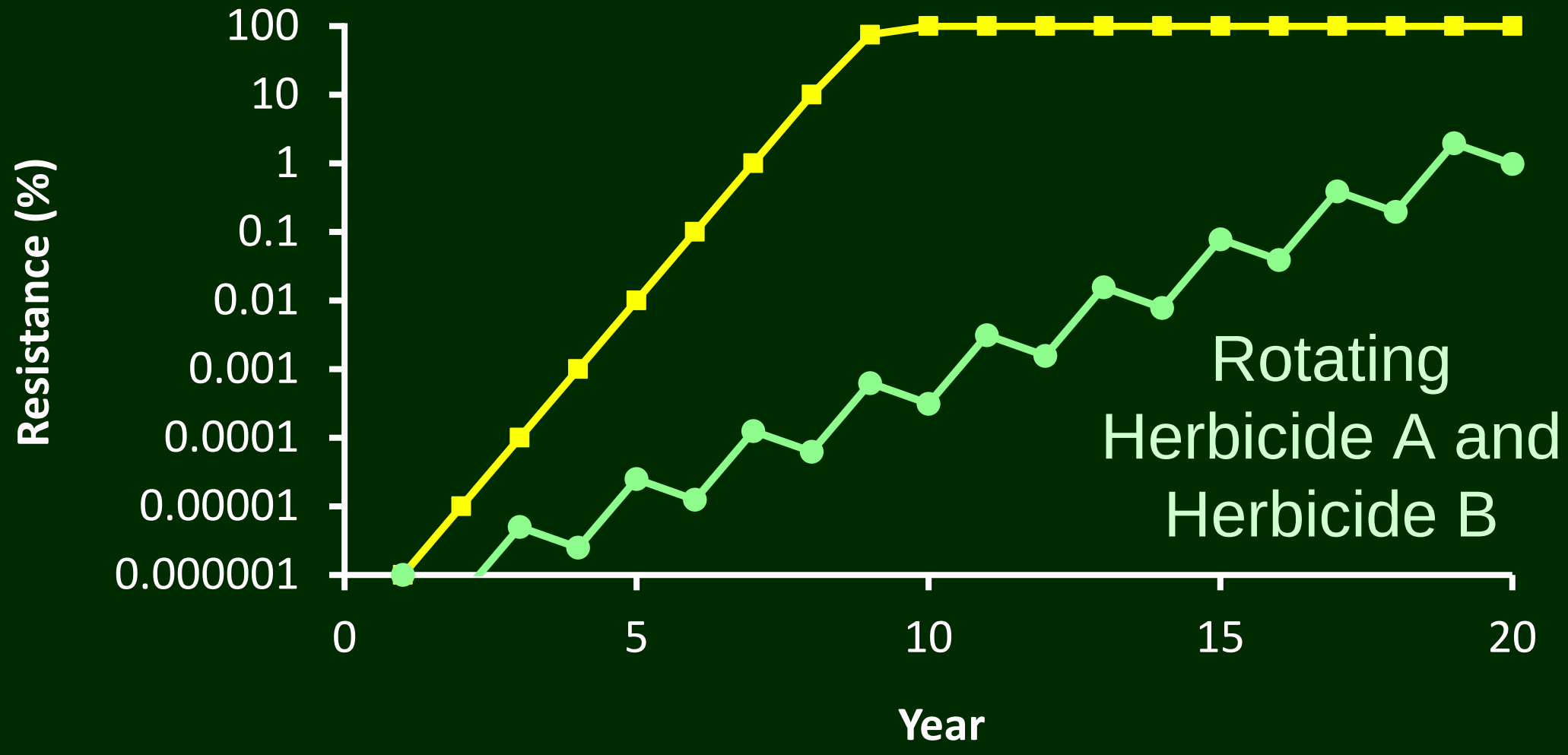

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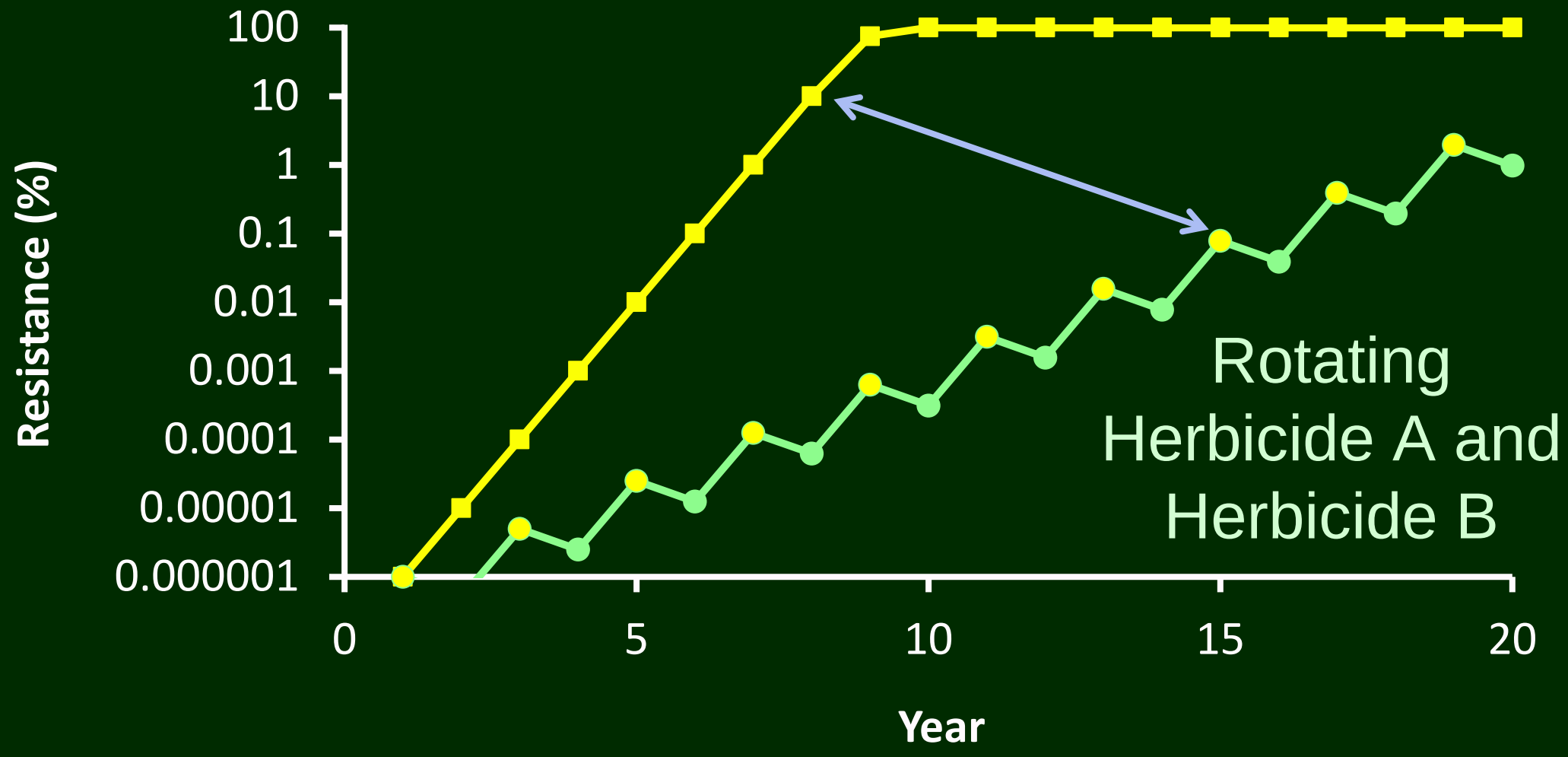
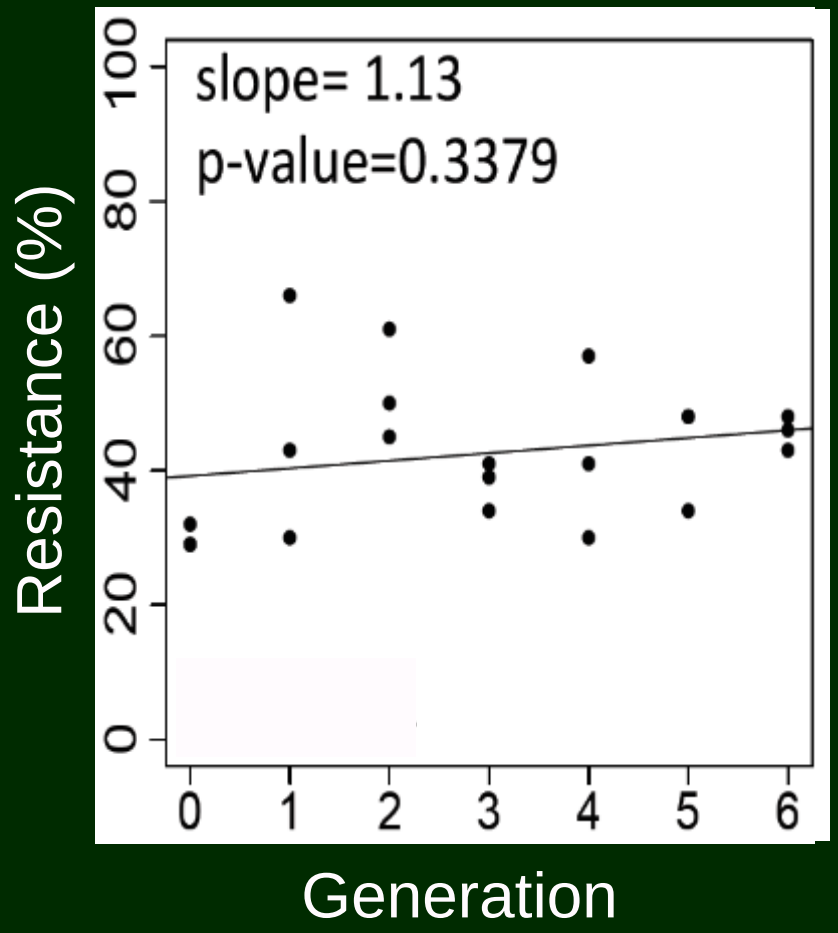
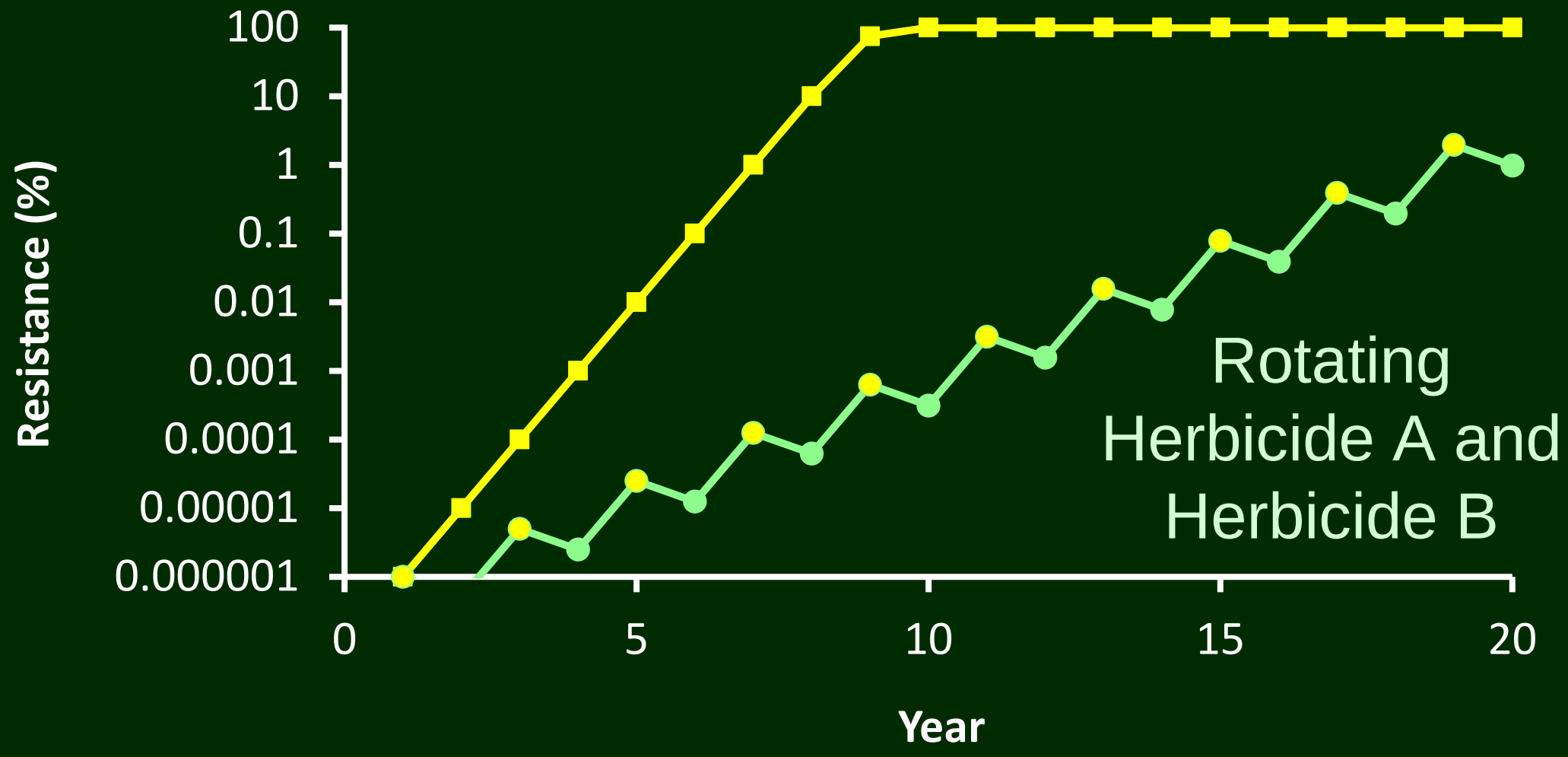


Contemporary research indicates that most resistances have very little fitness costs

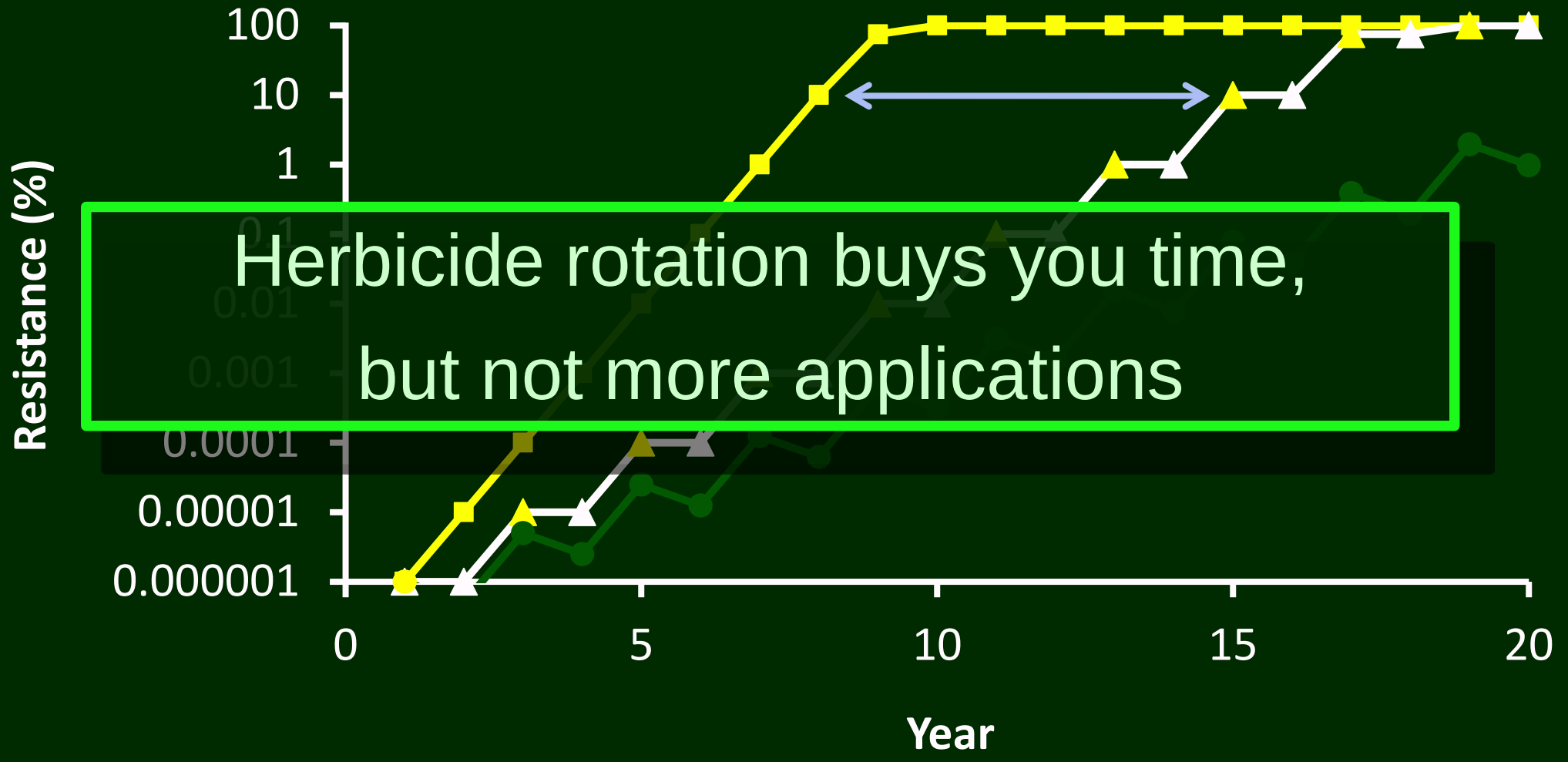


Change in glyphosate resistance frequency in three replicate waterhemp populations after six generations, in the absence of glyphosate selection.

Effectiveness of herbicide rotation depends on fitness cost



Effectiveness of herbicide rotation depends on fitness cost



Why herbicide mixing is effective

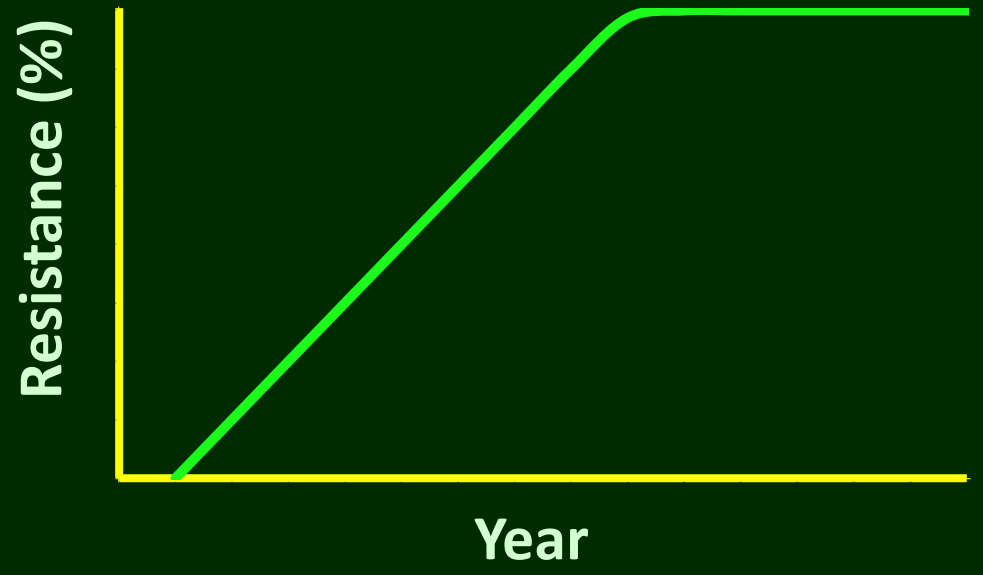
The probability of a plant being resistant to two herbicides is the product of the probabilities of being resistant to each herbicide.

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

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

What about dicamba use in soybean

- US EPA grants a Section 3 label for one dicamba formulation (Xtendimax) on November 9, 2016
  - Engenia (BASF) labeled December 21
- Perceived expectations about what the technology can do tend be more optimistic than what it will be able to deliver
  - will NOT "re-set" the glyphosate clock
- Where will it fit best and what will it provide?
  - UI weed science program has no data on yield or volatility. *Remember, lower volatility is NOT the same as no volatility!!*

REMEMBER!!

- **Glyphosate is excellent against waterhemp.**

- **Dicamba is good-to-very good, but not excellent.**

Thank you for your attention!