

World Congress of In Vitro Biology

**Symposium: Management of Resistance
in Genetically-Modified Plants**

San Diego, California June 13, 2016

**Weed Resistance in Herbicide-Resistant Cultivars:
Challenges to Profitability of Agronomic Crops**

R. L. Nichols

Cotton Incorporated, Cary, North Carolina

Weed Resistance to Herbicides of Herbicide-Resistant Cultivars

- 1. Herbicide Mechanisms of Action**
- 2. U. S. Crops, Weeds, and Weed Management Systems**
- 3. Herbicide-Resistant Cultivars and their Adoption.**
- 4. Evolution of Resistant Weeds in Herbicide-Resistant Cultivars**
- 5. What Will the Humans Do?**

Sources of Weed and Herbicide Data

Data	References
Major Weeds	Southern Weed Science Society Surveys
Resistant Weeds	Herbicide Resistance Action Committee <i>weedscience.org</i>
Herbicides Used	National Agricultural Statistics Service
Weed Management Programs	State Cooperative Extension Services

Herbicide Mechanisms of Action (MOA)

Definition: 'How the herbicide kills the weed'

MOA (Inhibitors)

Typical Chemical Classes

Pre-emergence Herbicides

- | | |
|--------------------|-----------------------|
| • Mitosis | Dinitroaniline (DNAs) |
| • Long Fatty Acids | Acetanilides |
| • Photosystem II | Triazines |

Pre- and Post emergence Herbicides

- | | |
|--------|-----------------------------------|
| • ALS | Four Classes – ex. Imidazolinones |
| • PPOs | Diphenyl Ethers |

Post Emergence Herbicides

- | | |
|------------------------|-------------------------|
| • ACCase | Fops & Dims |
| • EPSPS | Glyphosate |
| • Glutamine Synthetase | Glufosinate |
| • Auxins | 2,4-D; Dicamba (Others) |

U. S. Crops, Weeds, and Weed Management Systems

<u>Crop</u>	10 ⁶ acres	<u>Weeds – Problem Weeds</u>
Cotton	10	summer weeds - broadleaves
Soybean	76	summer weeds - broadleaves
Corn	87	summer weeds - grasses
Rice	2.5	water tolerant grasses
Wheat	49	winter grasses

Citation: U. S. Census of Ag. 2012

U. S. Crops, Weeds, and Weed Management Systems

Weed Management Systems Before Transgenic Herbicide-Resistant Crop Cultivars

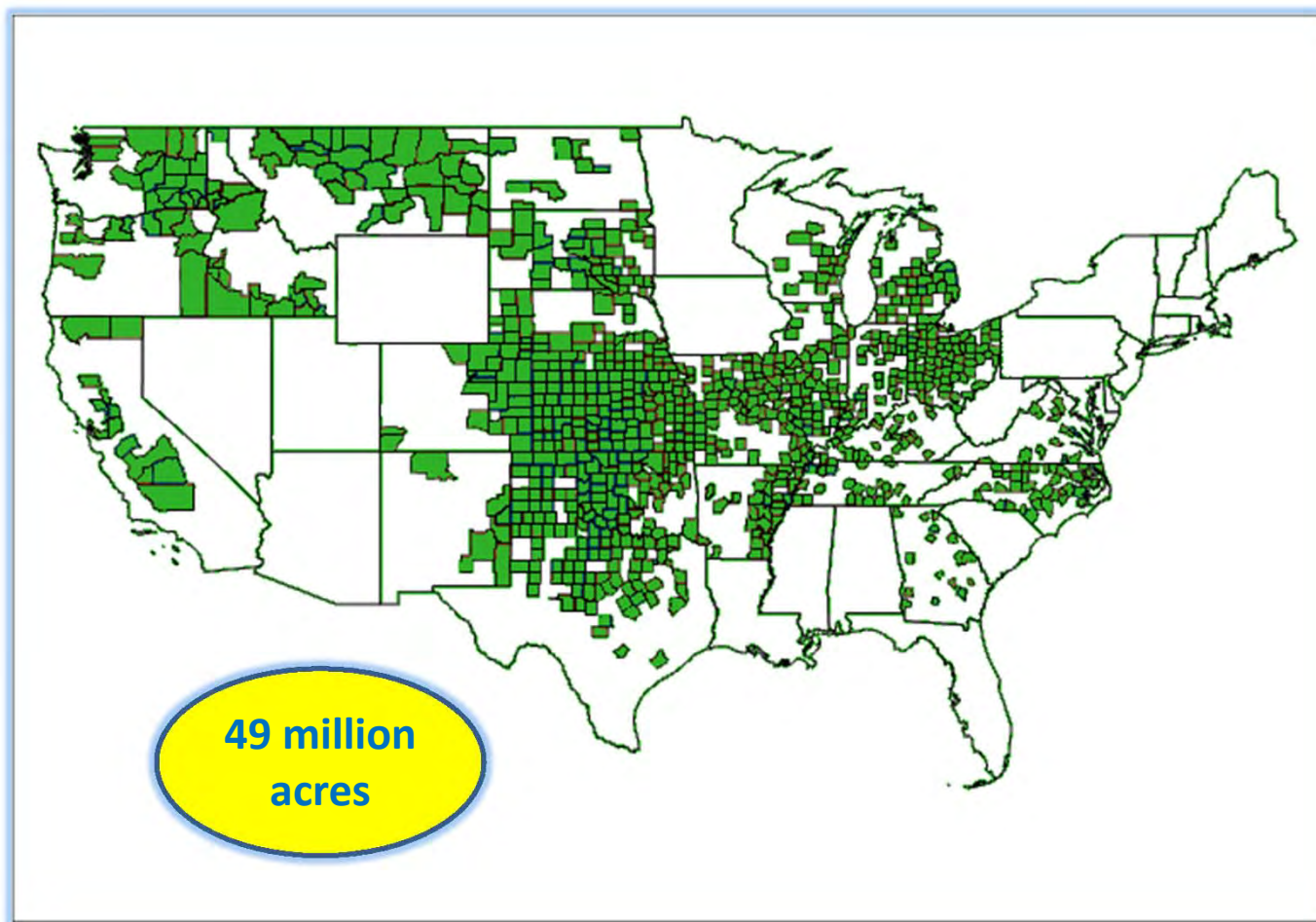
<u>Crop</u>	<u>Management System</u>	<u>Mechanism of Action</u>
• Cotton	pre's/ early posts/laybys	3-4
• Soybean	pre's /ALS (post)	2
• Corn	pre's/ (possible post)	2
• Rice	pre/posts	2+
• Wheat	post (broadleaf)	1/1

U. S. Crops, Weeds, and Weed Management Systems

Weed Management System in Transgenic Herbicide-Resistant Crop Cultivars

<u>Crop</u>	<u>Management System</u>	<u>Mechanisms of Action</u>
• Cotton	post (3-5)	1
• Soybean	posts (2)	1
• Corn	pre/post	2
.....	No Transgenic Cultivars	
• Rice	pre/posts	2+
• Wheat	post(broadleaf) post (grass)	1/1

U. S. Counties Growing Wheat



Herbicide Resistance - Winter Wheat

- Broadleaf weeds are managed with inexpensive phenoxy herbicides.
- Problem weeds are grasses, broadleaf biennials, and certain monocots such as wild garlic.
- ALS resistance is wide-spread in the western states; ACCase resistance also occurs in several southern states.
- ACCase resistance frequently changes a one-application program to a two-application program.
- Where both ALS and ACCase resistances occur, pre-emergence herbicides are applied between wheat emergence and the emergence of weedy grasses, a difficult timing.

Herbicide Resistance in Small Grains

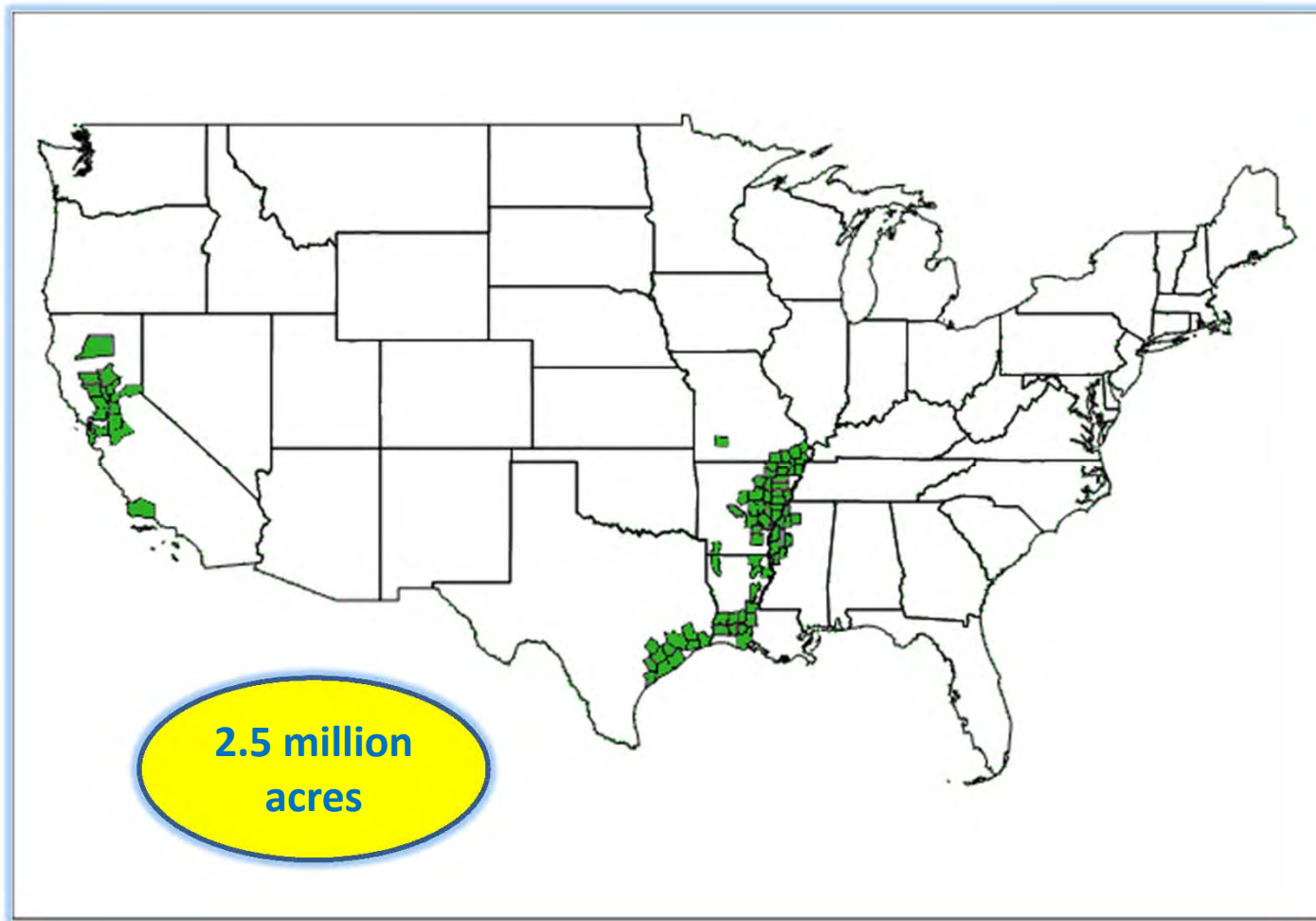
Critical issue because of international importance of cereal grains in human diet.

Margin of selectivity between grass crops and grass weeds is narrow.

In the U. S. from north to south there are significant resistance issues with wild oat, cheat grass, and ryegrass in wheat, and barnyardgrass in rice.

The resistance problems in wheat and rice may be our worst, because of the availability of few mechanisms of action.

U. S. Counties Growing Rice



Herbicide Resistance in Rice

- The principal problems are with weedy grasses, especially barnyardgrass (*Echinochloa crus-galli*).
- Barnyardgrass is widely resistant to propanil (PSII) and often resistant to quinclorac (phenoxy).
- The standard treatment for grasses is clomazone (phtoene desaturase inhibitor).
- Red rice is a continuing problem because it is con-specific with the crop.
- 'Clearfield' rice cultivars are ALS-resistant by means of conventional breeding. A resistance management program is recommended by the vender.

Herbicide-Resistant Crop Cultivars

Trait Introductions

Bromoxynil – (1995; dropped 1999)

Glyphosate – EPSPS Synthase Inhibitor (1996)

Glufosinate – Glutamine Synthetase Inhibitor (2004)

2,4-D – Auxin Mimic - 2015

Dicamba – Auxin Mimic – (pending)

Characteristics of Herbicides used to make Transgenic Herbicide-Resistant Cultivars

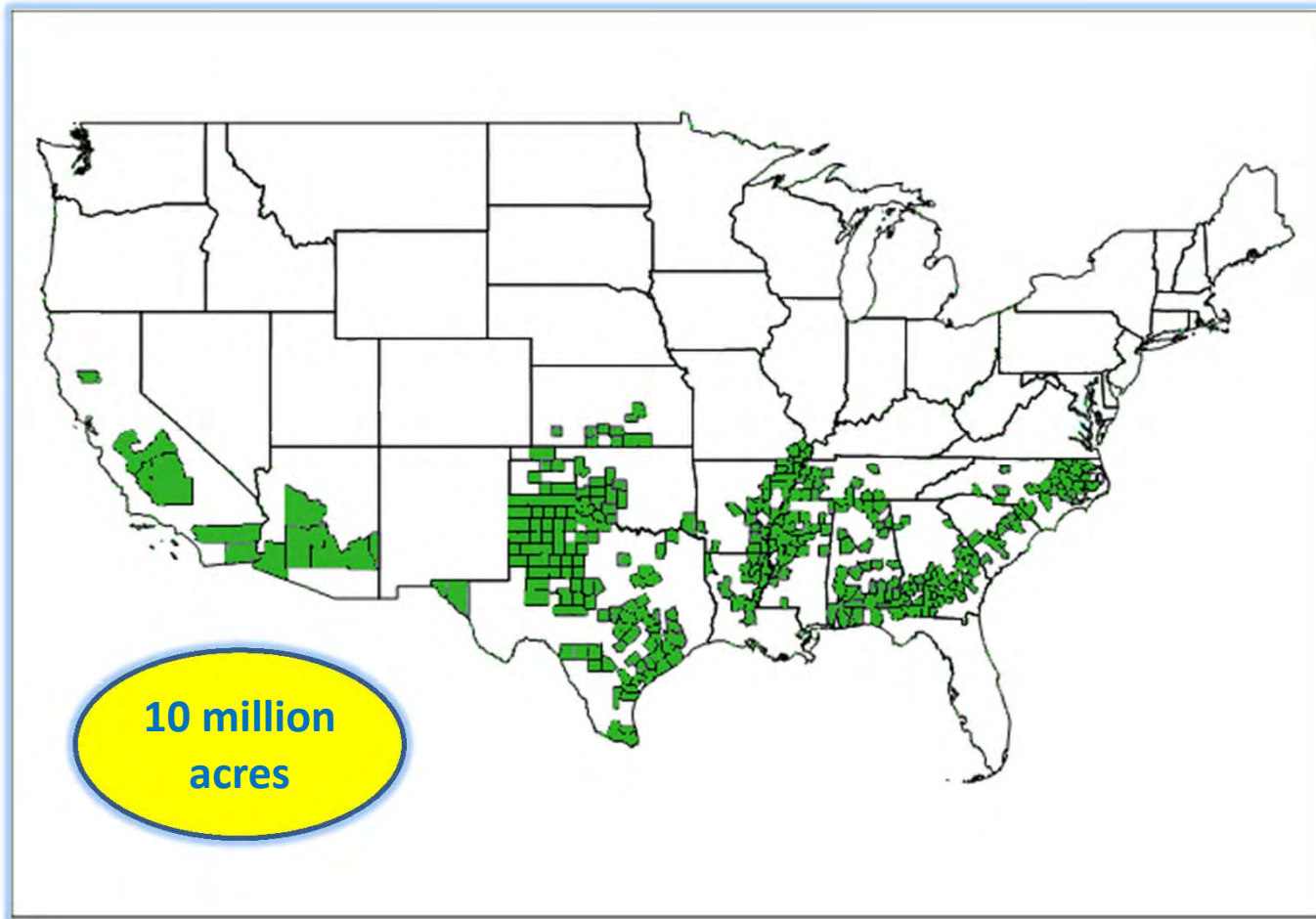
**Have Broad-Spectrum Activity, because
They Need to Replace Other Herbicides to
Justify Development Costs & Tech. Fees.**

Therefore:

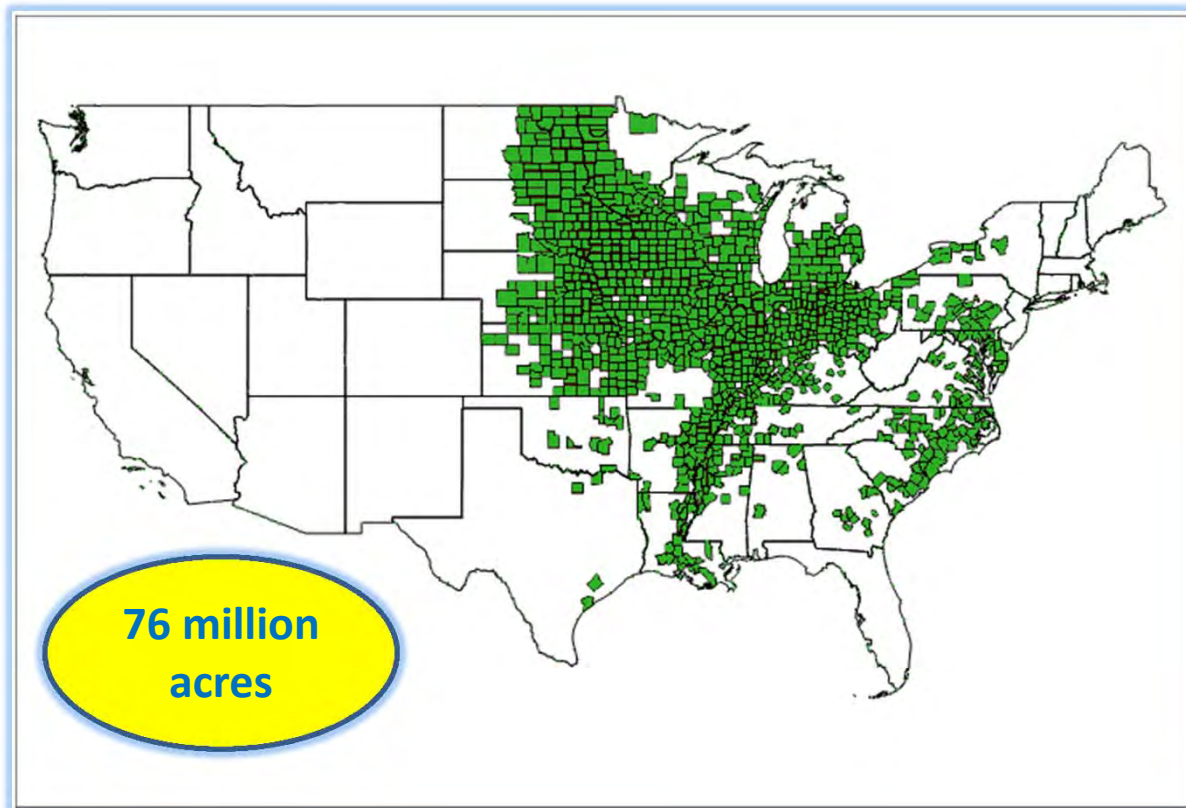
**They Reduce Use of other Mechanisms of Action
& Tend to Accelerate Evolution of Resistance**

Vencill et al. 2012 Special Issue of Weed Science 60: 2-30.

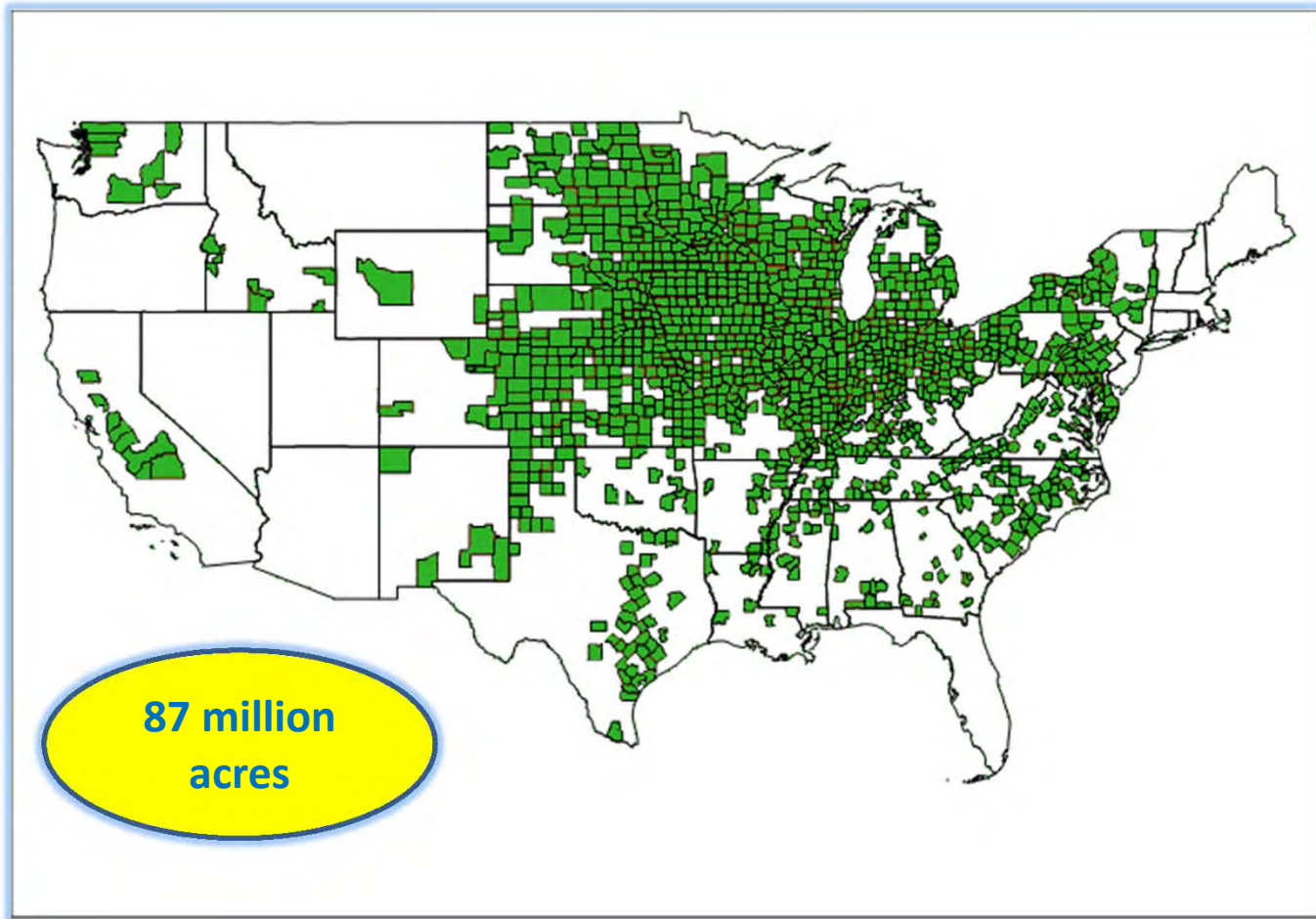
U. S. Counties Growing Cotton



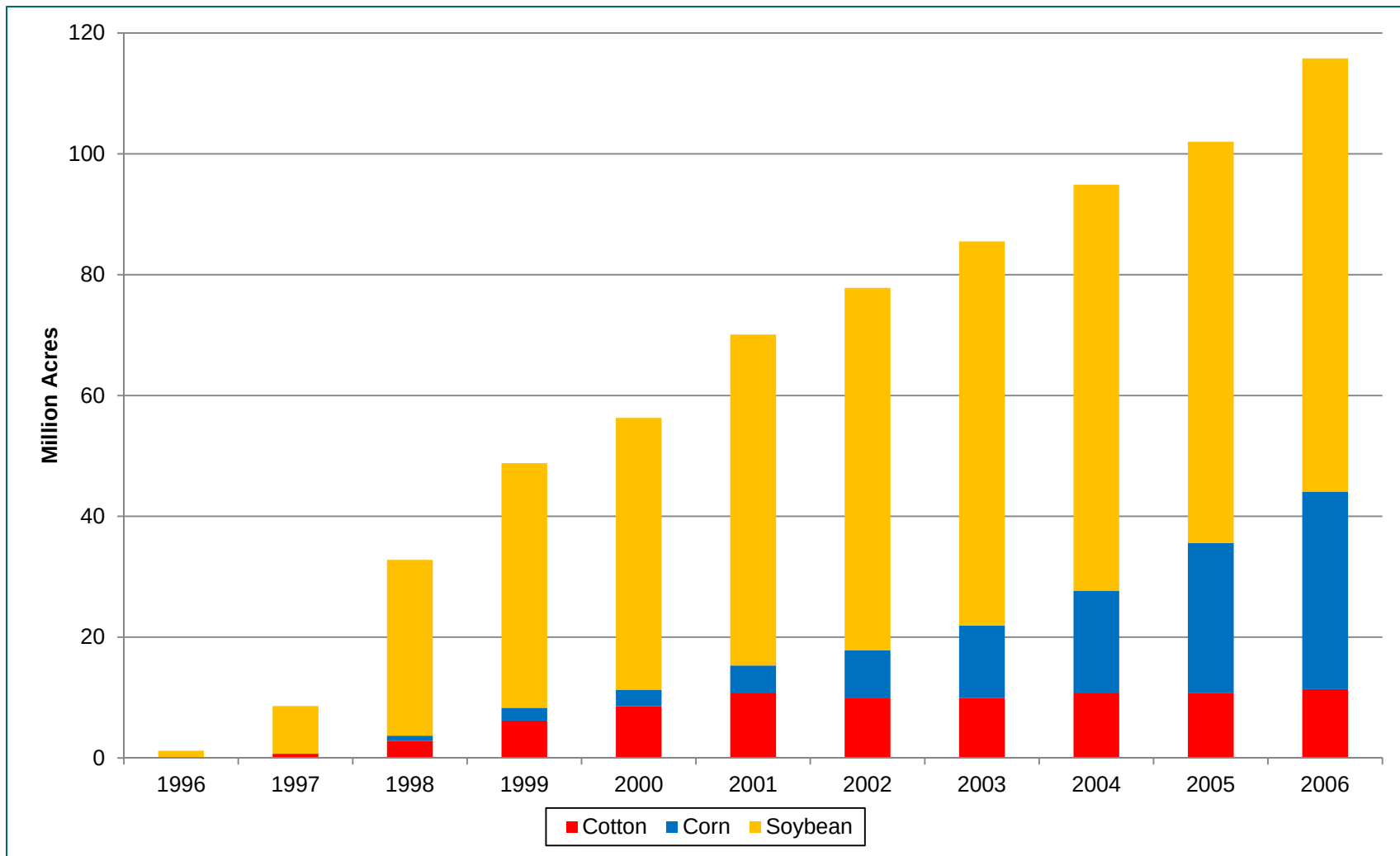
U. S. Counties Growing Soybeans



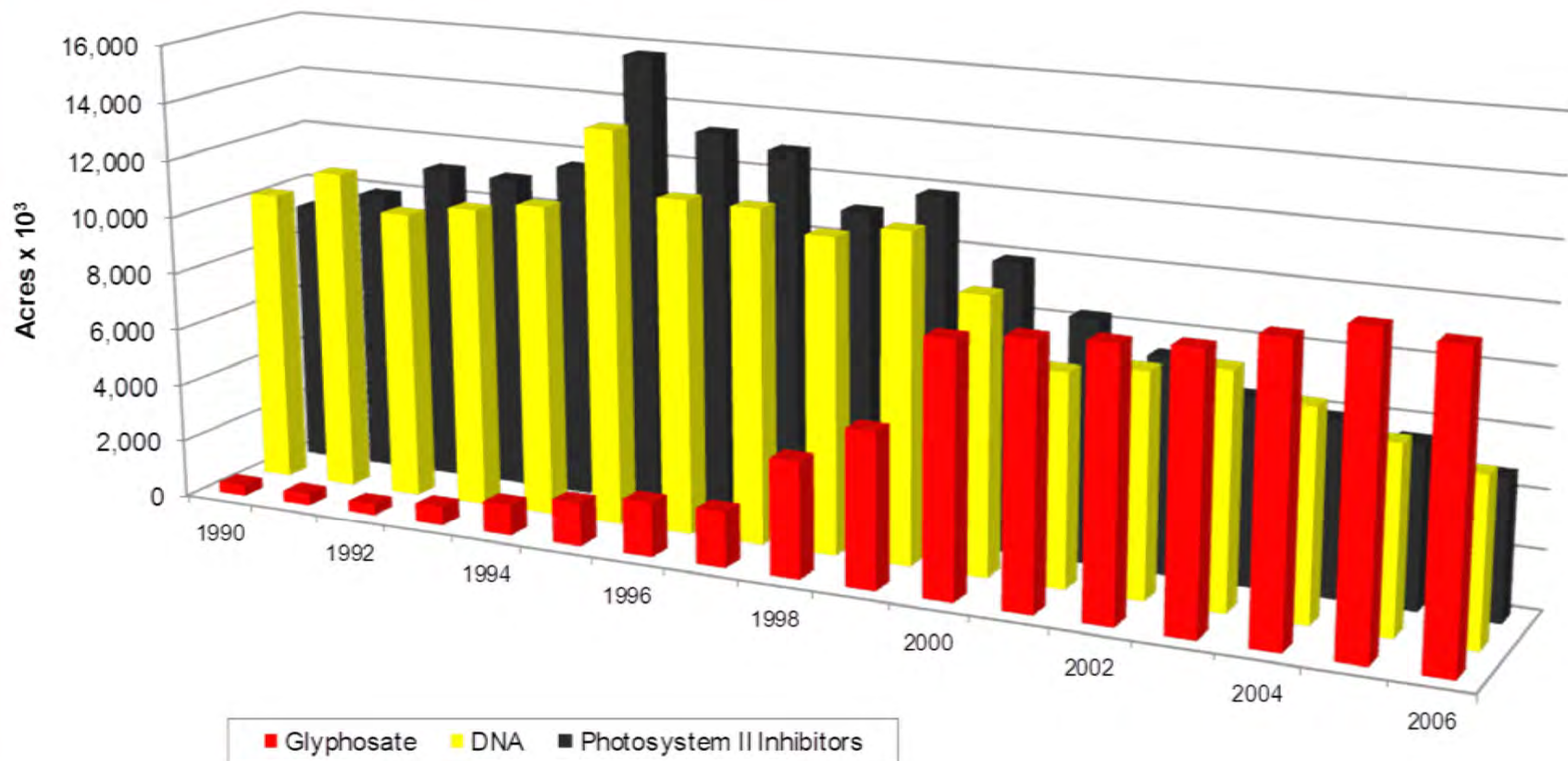
U. S. Counties Growing - Corn



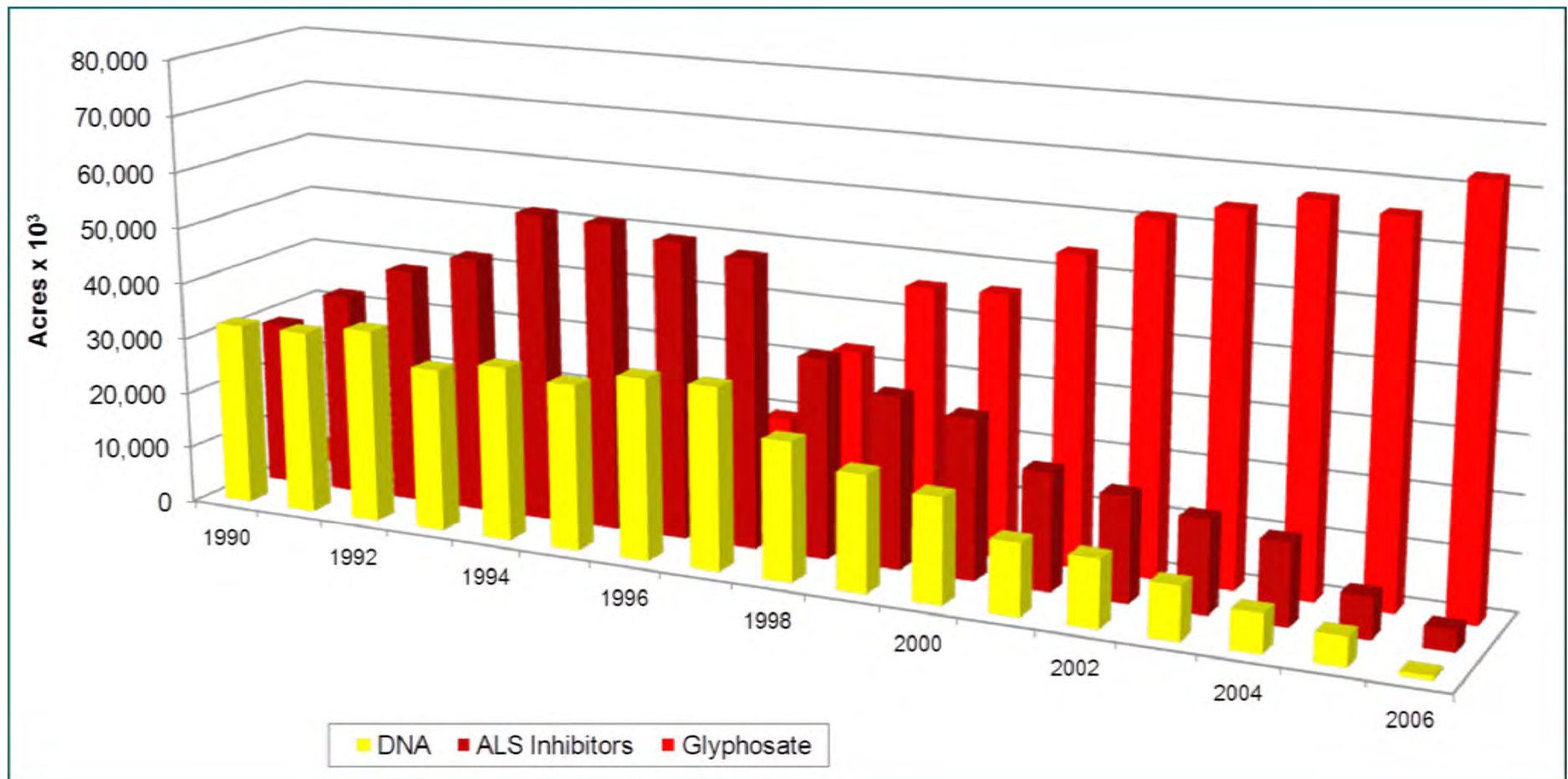
Adoption of Herbicide-Resistant Crop Cultivars



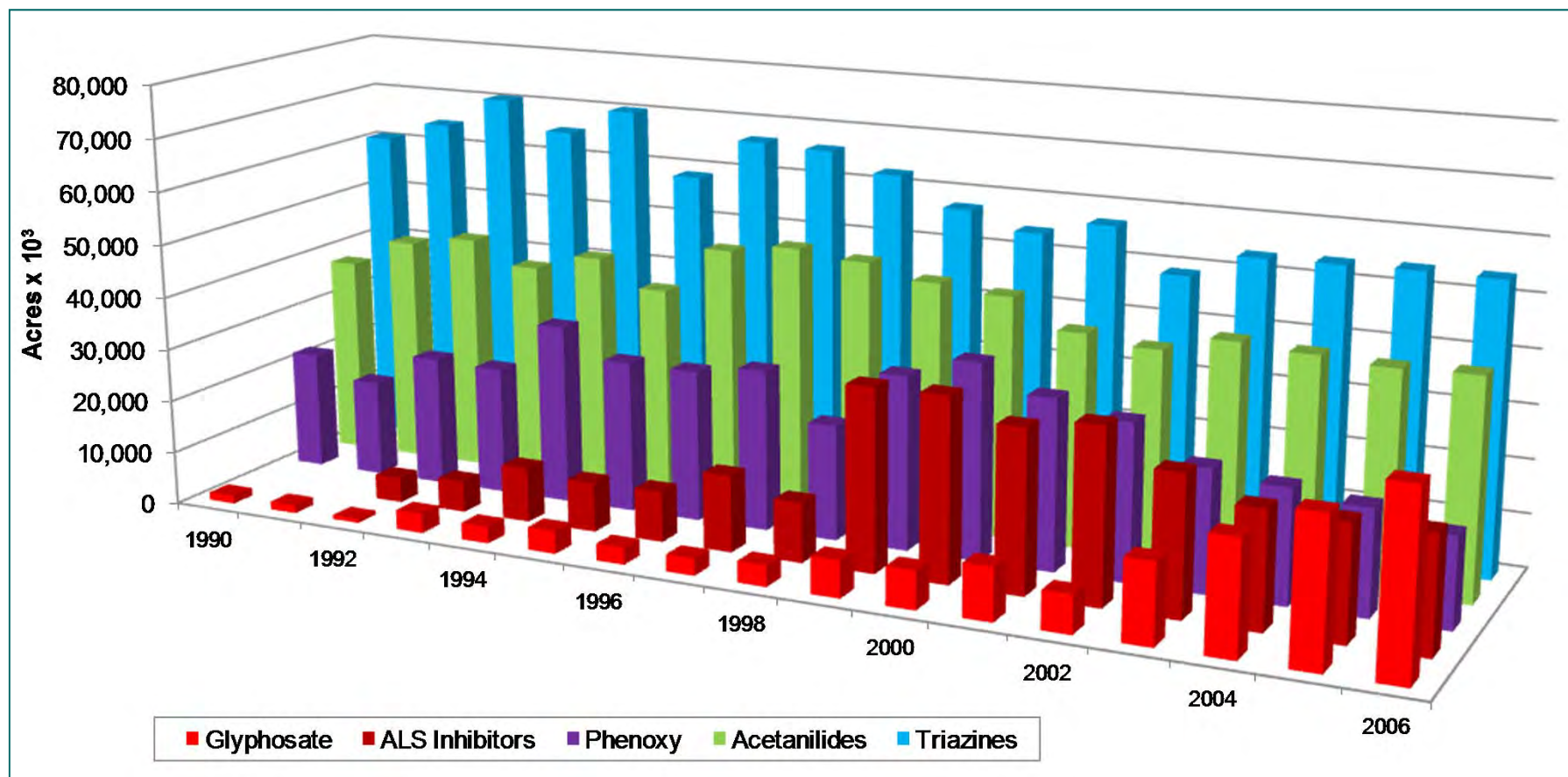
Cotton Acres Exposed to Herbicide Modes of Action



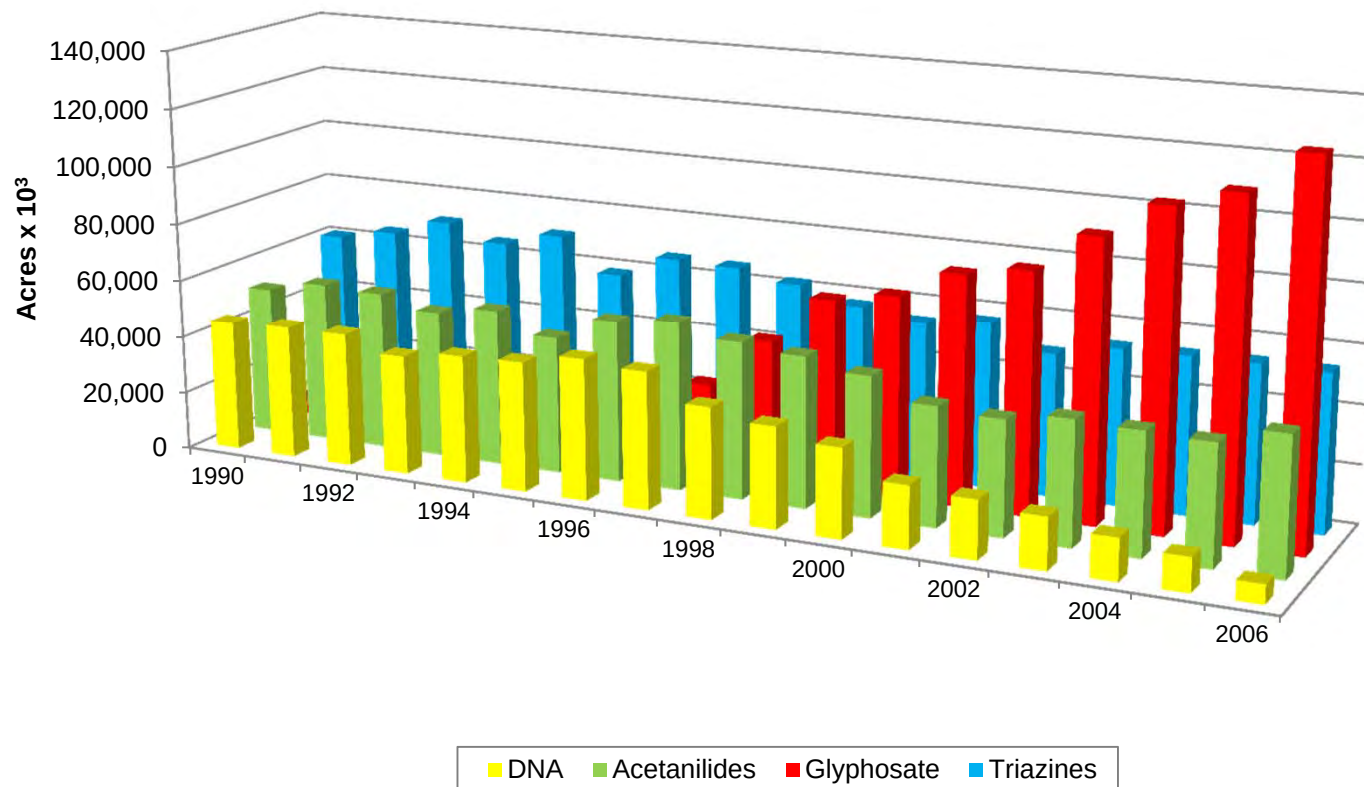
Soybean Acres Exposed to Herbicide Modes of Action



Corn Acres Exposed to Herbicide Modes of Action



Total Acres Exposed to Herbicide Modes of Action for Corn, Soybean, Cotton



Evolution of Herbicide-Resistant Weeds

- Resistance is a random genetic event
- Probability increases with
 - Weed populations
 - Genetic Recombination Events
 - Selection
- Diversification Extends Time of Use
- Reinforcing MOAs Increases Number of Effective Applications

Two Dioecious Amaranths in North America

- *Amaranthus tuberculatus* – Tall Waterhemp
 - Midwest; heavy soils - South Central
- *Amaranthus palmeri* – Palmer amaranth, Palmer pigweed
 - light soils - South & many soils Southwest
- The two dicots resistant to the most herbicide modes of action (6 each)
 - *A. palmeri* is invading the Midwest

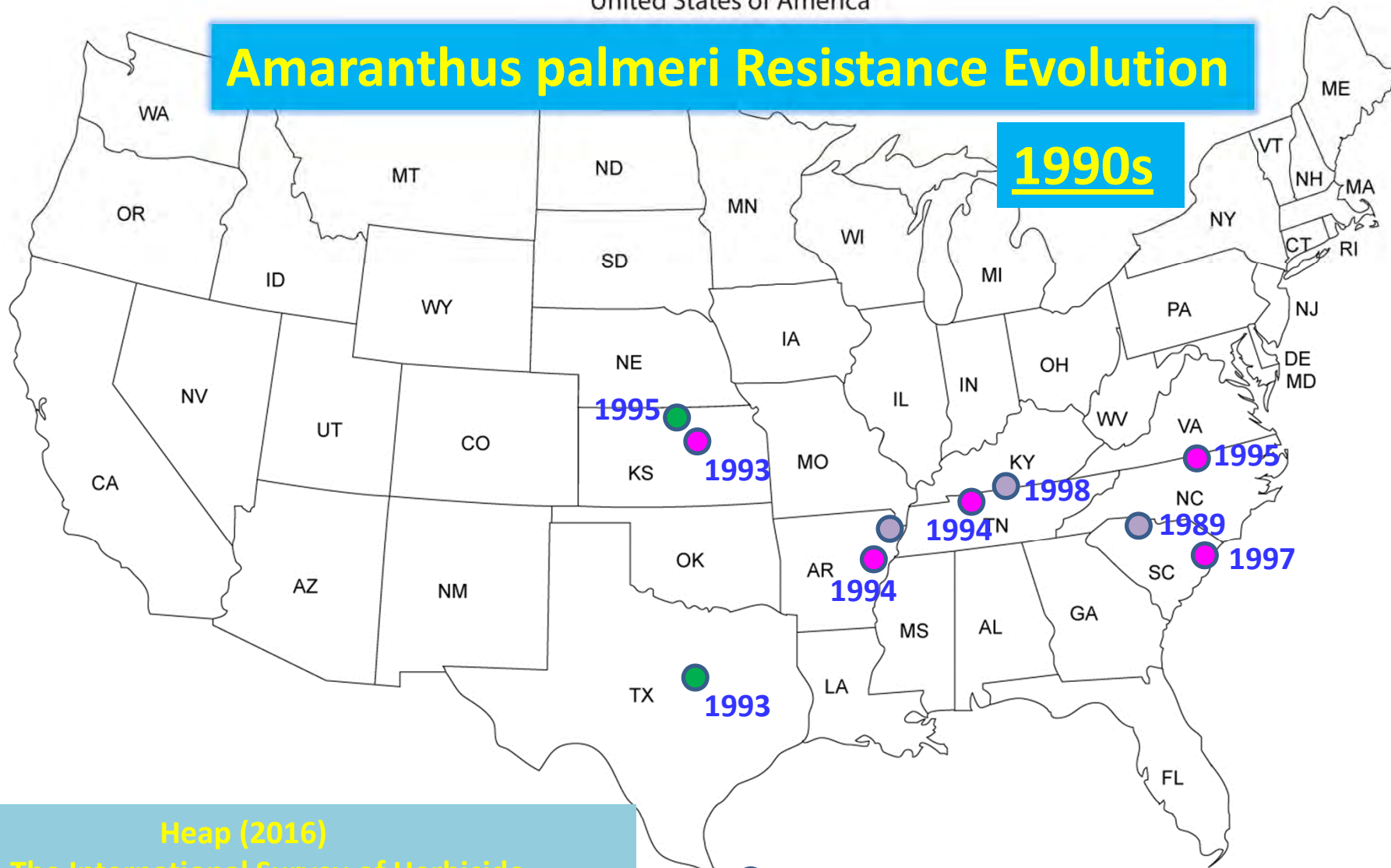
Palmer Amaranth



United States of America

Amaranthus palmeri Resistance Evolution

1990s



Heap (2016)

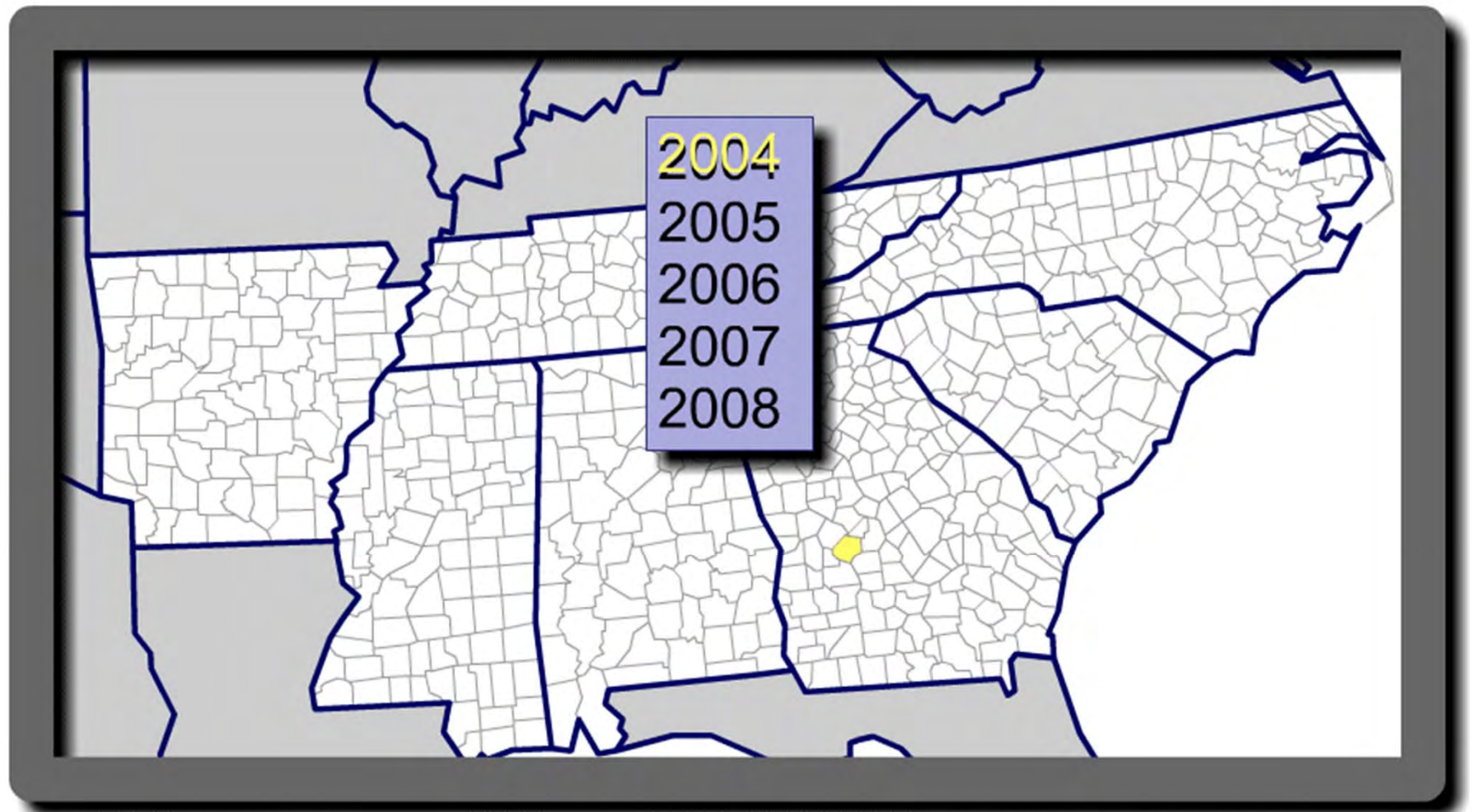
The International Survey of Herbicide Resistant Weeds.

Available www.weedscience.org

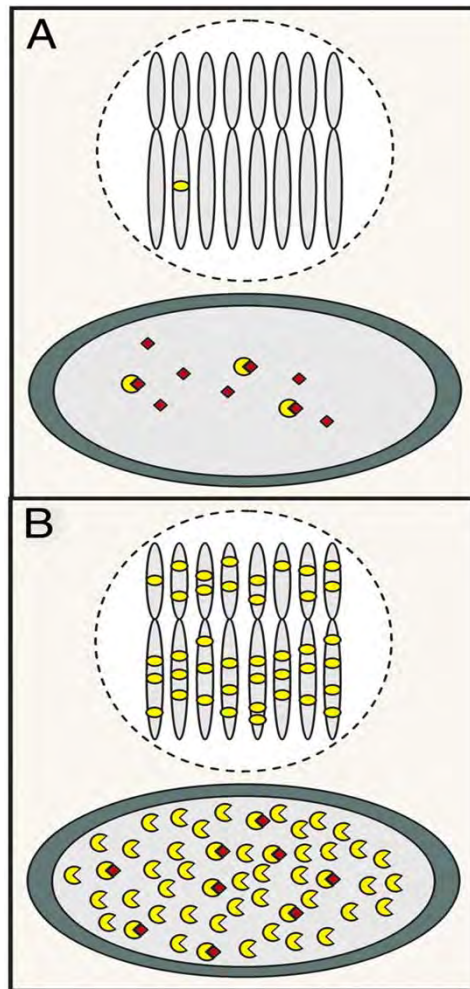
- microtubule inhib. (trifluralin, others)
- ALS inhib. (imazethapyr, others)
- PS II inhib. (atrazine)

This is a royalty free image that can be used for your personal, corporate or education projects. It can not be resold or freely distributed, if you need an editable PowerPoint or Adobe Illustrator version of this map please visit www.bjdesign.com or www.mapsfordesign.com.

Discovery of Glyphosate-Resistant Palmer Amaranth – 2004



EPSPS Gene Duplication: Glyphosate Resistance Mechanism

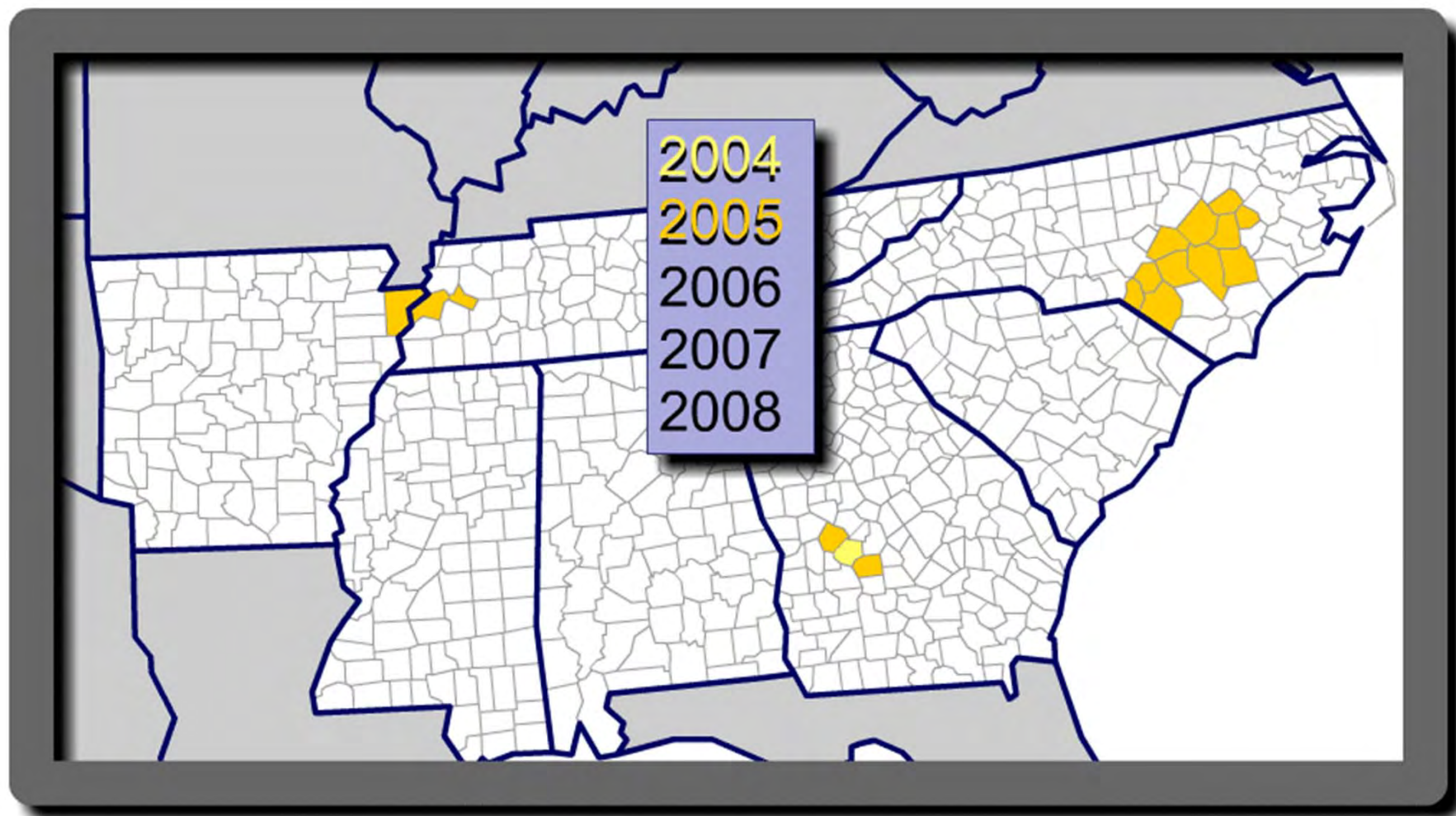


Susceptible

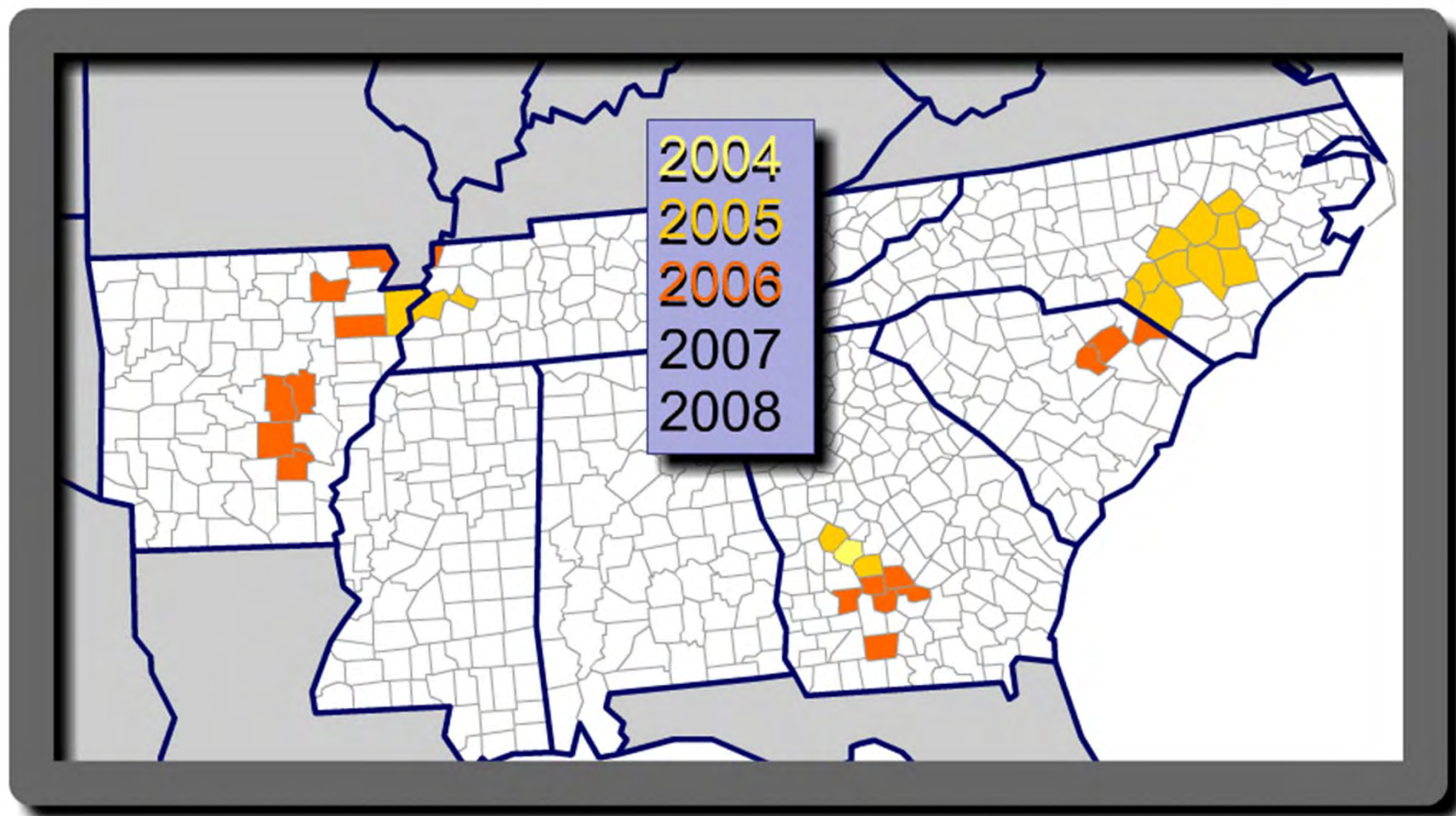
Powles, PNAS 2010;107:955-956

Resistant

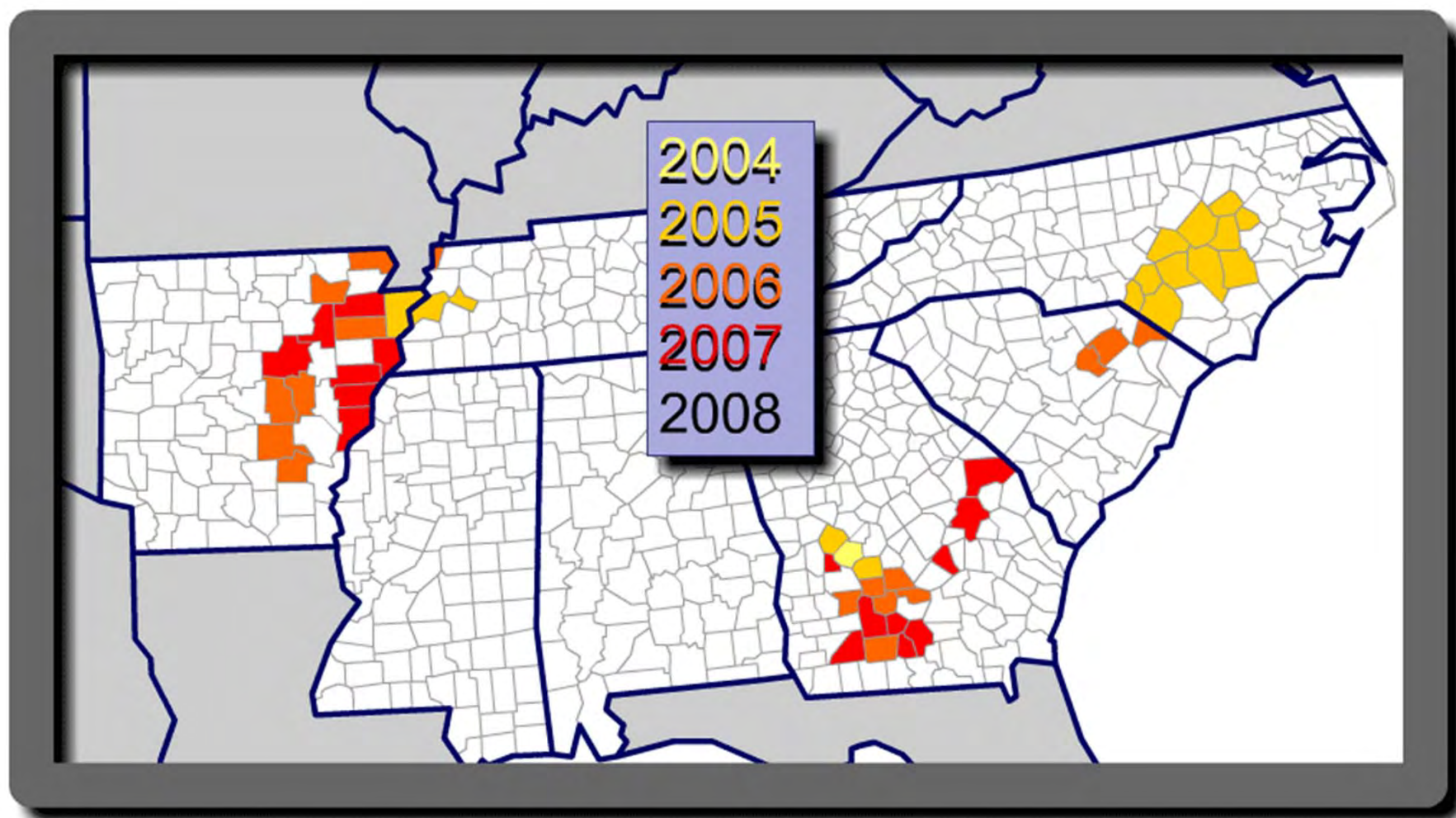
Counties Affected by Glyphosate-Resistant Palmer Amaranth - 2005



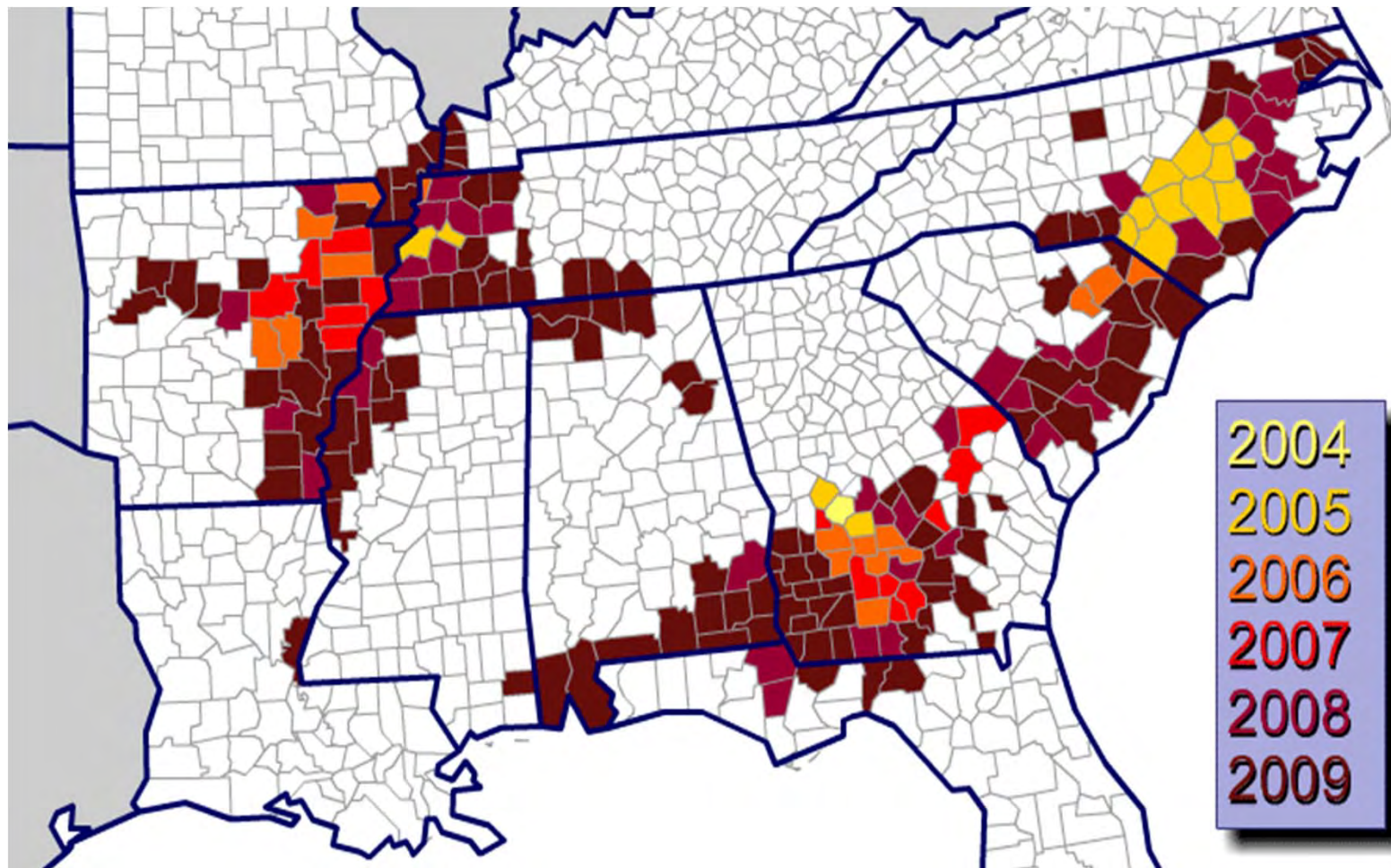
Counties Affected by Glyphosate-Resistant Palmer Amaranth - 2006



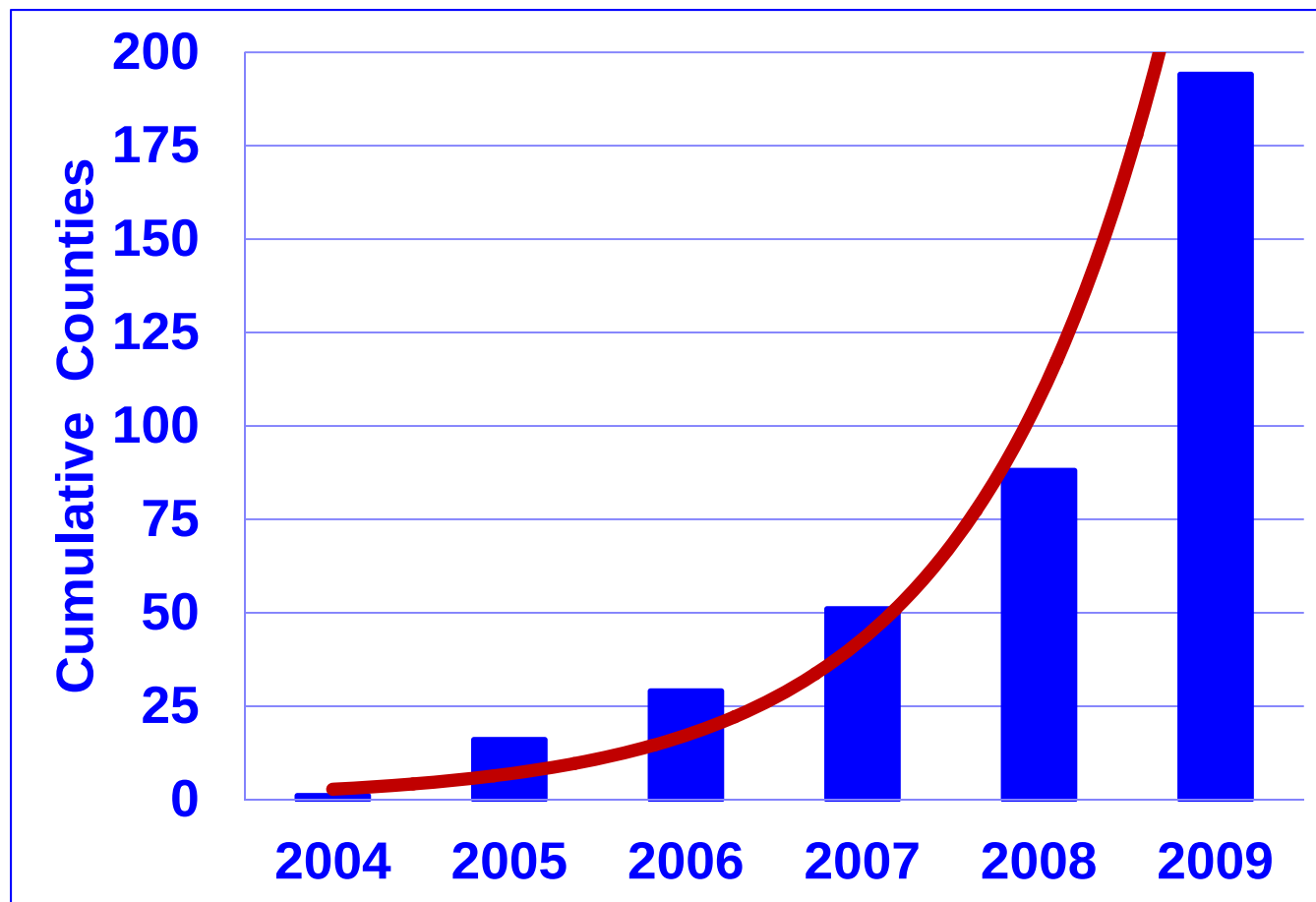
Counties Affected by Glyphosate-Resistant Palmer Amaranth - 2007



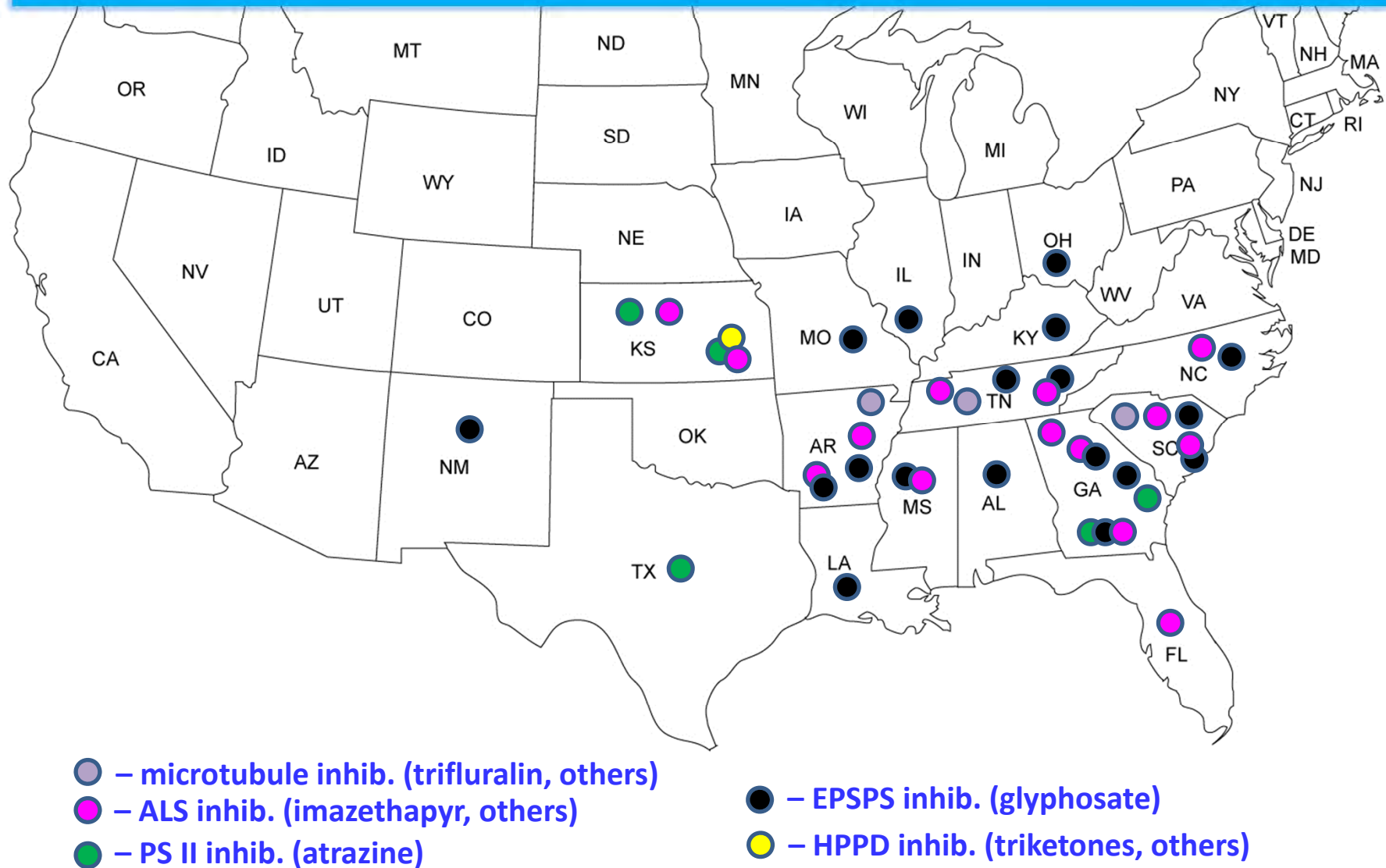
Expansion of Glyphosate-Resistant Palmer Amaranth – counties infested



Counties with Glyphosate-Resistant Palmer Amaranth



Amaranthus palmeri resistance evolution - 2010



Impacts of Glyphosate-Resistant Palmer Amaranth

- **Increase complexity and costs of weed management in cotton and soybean**
- **Compromise conservation tillage in the short-term**
- **May precipitate a cascade of resistance in post emergence broadleaf herbicides**

Glyphosate-Resistant Palmer Amaranth

Economic Threat to Soybeans

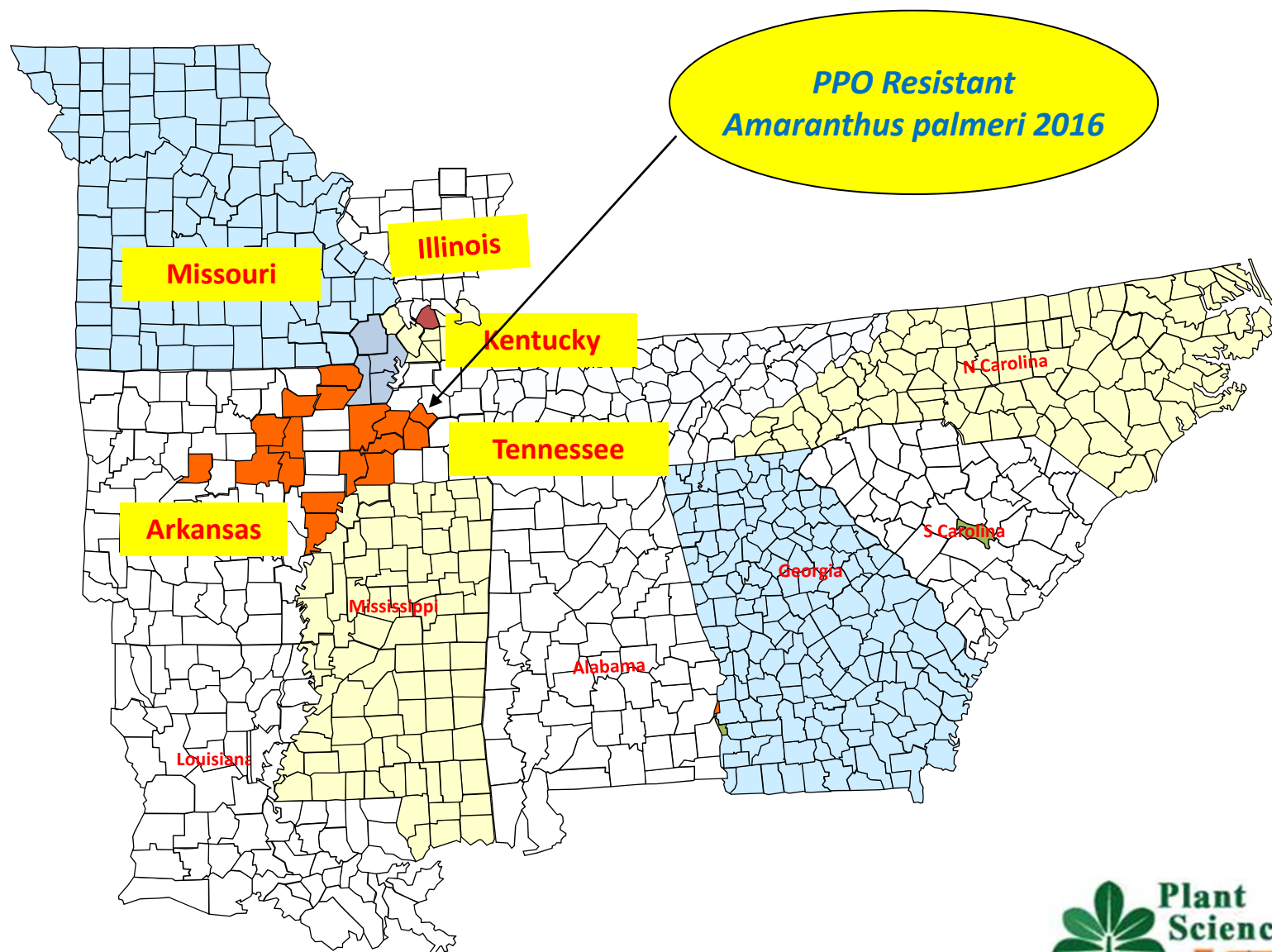
If ALS and glyphosate are compromised, **PPO herbicides are the only post emergence option except glufosinate**

Economic Threat to Cotton

PPO herbicides are not an over-the-top option. If ALS herbicides and glyphosate are compromised, there are **no selective post emergence options except glufosinate**

Nichols, R. L. 2010 – “Pigposium”,
Forest City, Arkansas

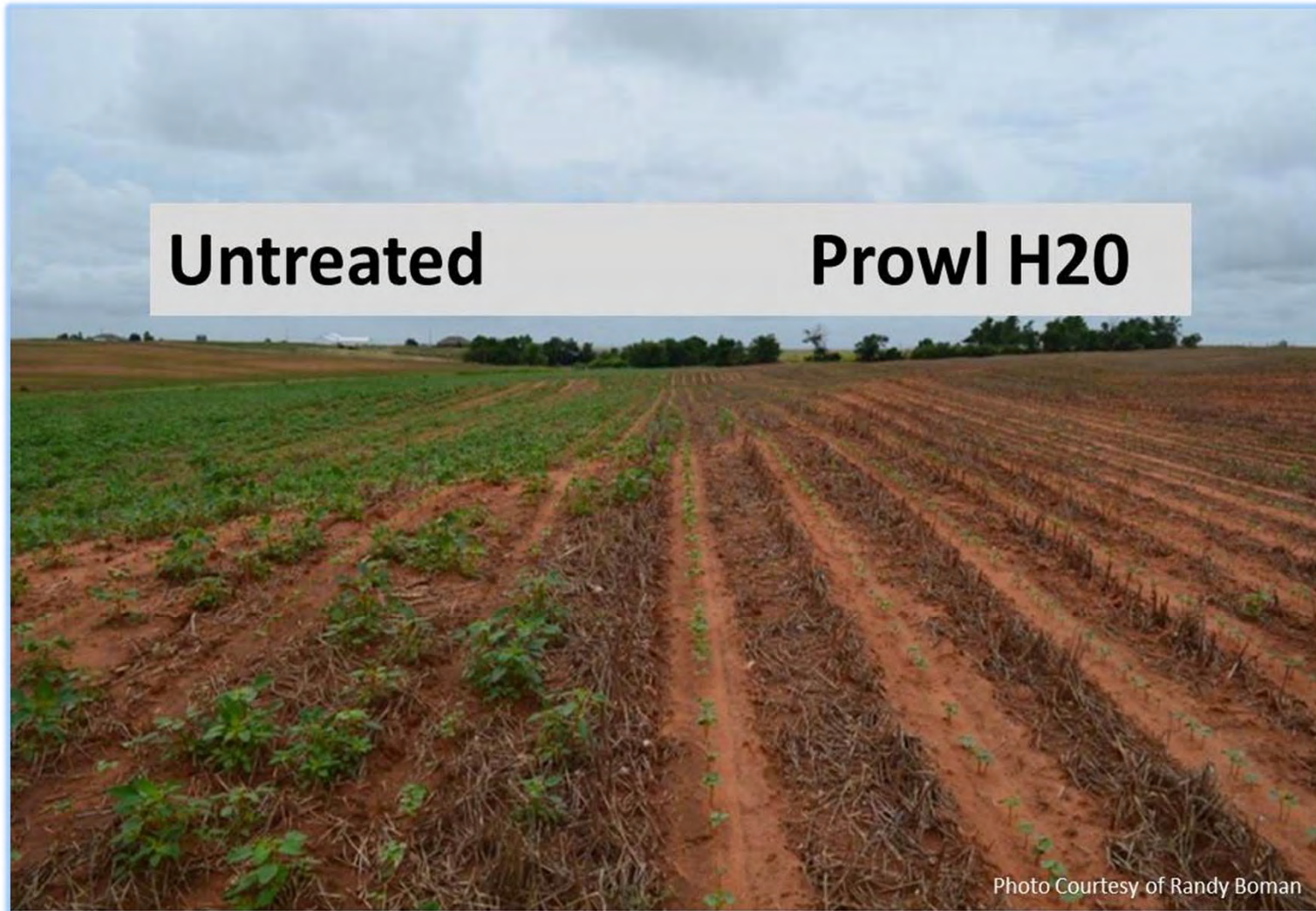
Glyphosate and PPO –Resistant Palmer Amaranth





Glyphosate + PPO Resistant Palmer Amaranth - Tennessee

Soil-Active Herbicides are a Must



Greater Selection Pressure On Glufosinate

- Glyphosate is still a very useful herbicide, but
- Palmer amaranth is the 'driver' weed in the system.
- When glyphosate, ALS, and PPO herbicides fail, the only current post option is glufosinate.
- Traits that will be used:
'Gytol Liberty Link', 'Wide Strike', and eventually 'Enlist', and 'Xtend Flex'.



2015 – Demonstration

No-till Drip Field

(Confirmed glyphosate resistant pigweed in 2014)

Total costs to control resistant pigweed in cotton this year



Liberty Link Systems
ST 4946 GLB2

\$129/acre



Roundup Ready Flex System (no dicamba)
DP 1522 B2XF

\$126/acre

Current Cotton Situation

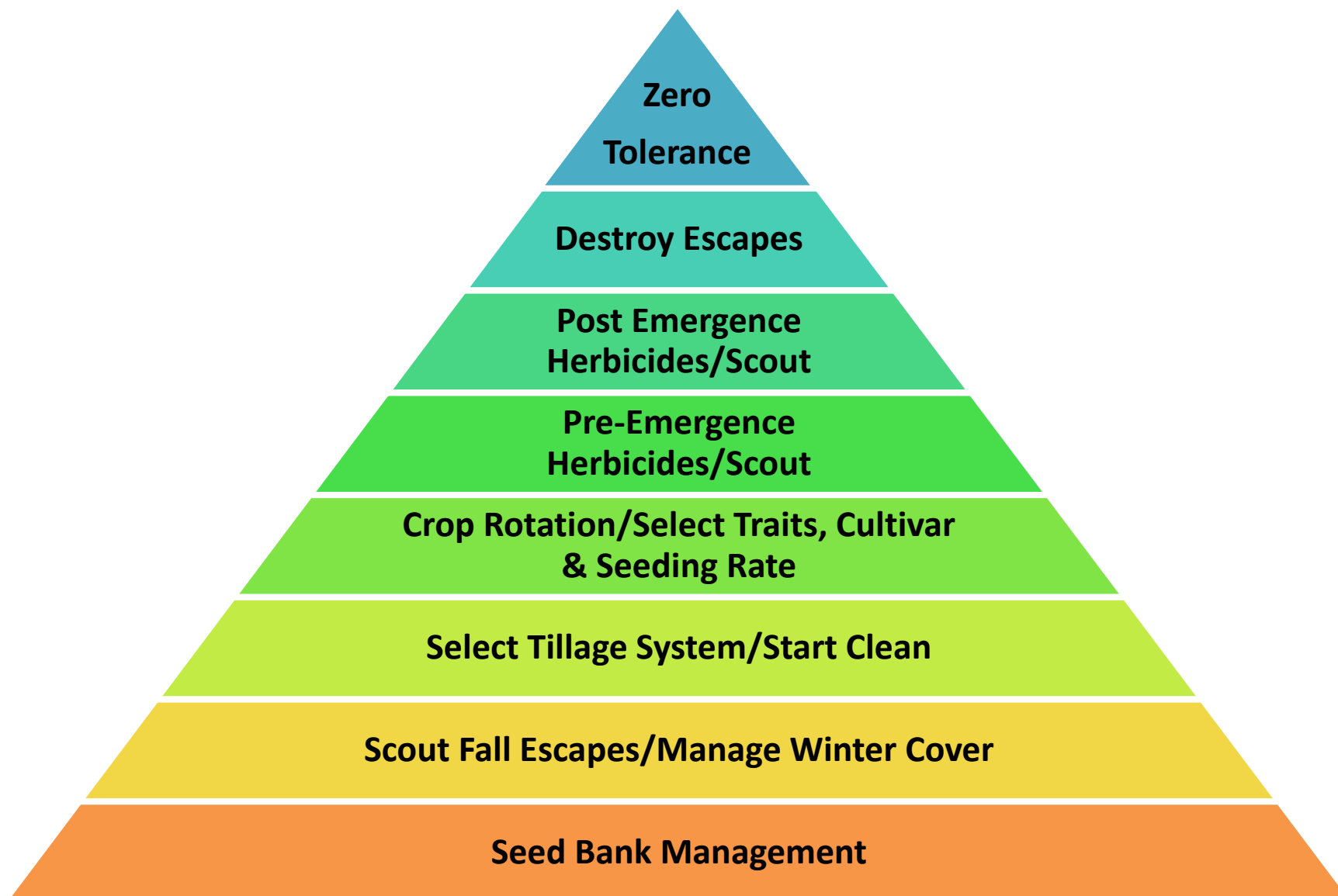
Cost to Manage Palmer in GA Cotton

1. Herbicide input:	\$68.00/acre	\$88 million
2. Hand weeding:	\$11.40/acre	\$15 million
3. Additional tillage:	\$5.84/acre	\$7.6 million
4. Yield loss	???	????
		\$110 million

Control with Trait-Based Auxin Herbicide Weed Management Program



Alan York, NCSU



What Will the Humans Do?

- Resistance Management depends on the interaction of three groups – Growers, Manufacturers (Registrants) and Regulatory Agencies
- Growers and Manufacturers have responded to Economics.
- Economics now says that Resistance Costs.
- Regulation is Focusing on Resistance

Current Situation

- **Need New Weed Management Programs.**
- **Need to Save Conservation Tillage.**
- **Need to Implement Resistance Management -
Manufacturers and Growers.**
- **Does Resistance Management Include
Trait Management?**

Weed Management Theme

Herbicide Stewardship



Protecting
Crops
Environment
Technology