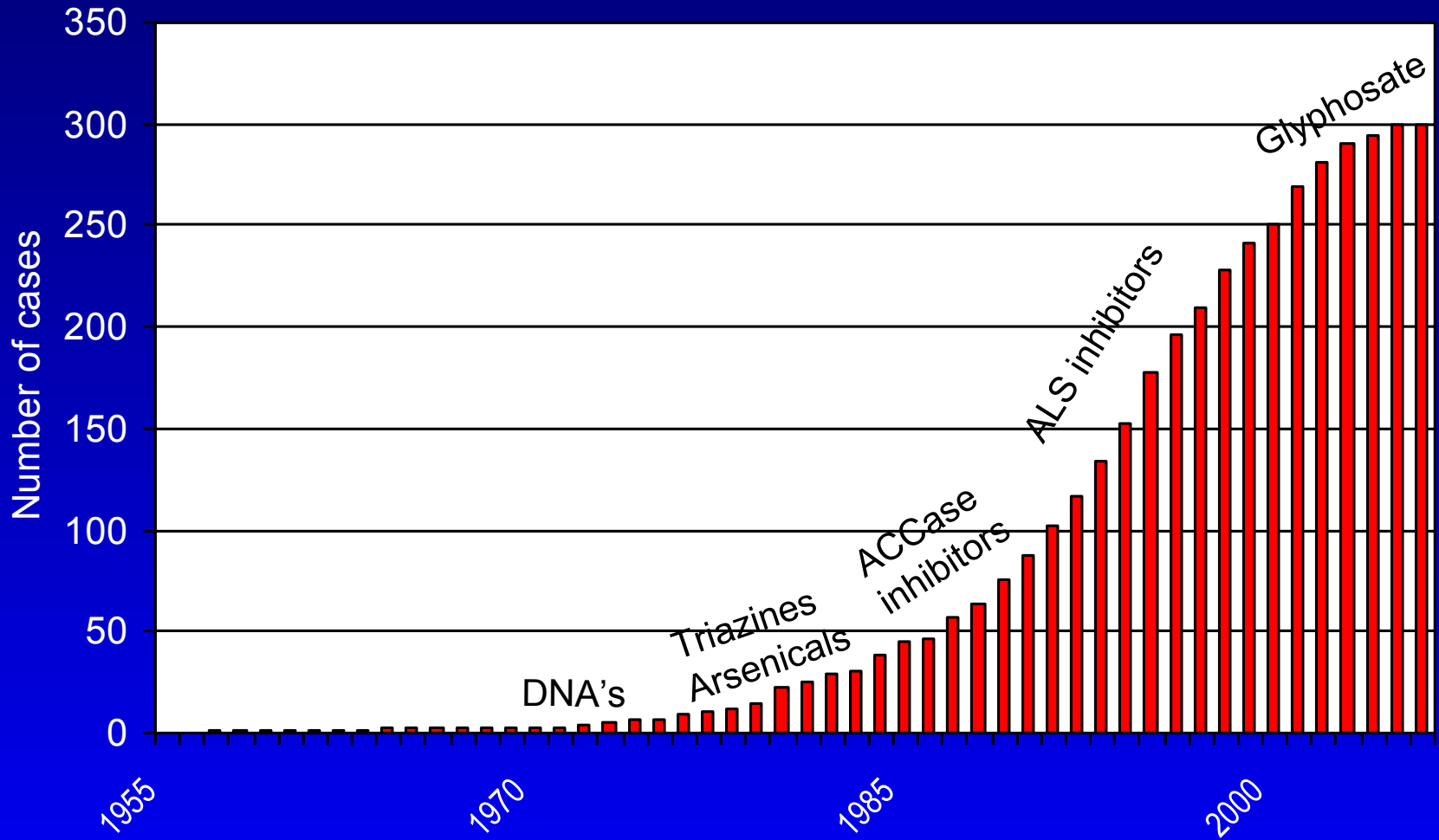


Herbicide-Resistant Weeds: A Dilemma in Dixie



Reported cases of herbicide-resistant weeds in US



How have growers dealt with herbicide resistance in the past?

- It won't happen to me; deal with it later
- Those companies will bring out something new to fix it
- Don't hold your breath; no new chemistry in foreseeable future



Glyphosate-Resistant Horseweed



Martin Co., NC



Glyphosate-resistant
horseweed

Bertie Co., NC



Shields, E.J., J.T. Dauer, M.J. VanGessel, and G. Neuman. 2006. Horseweed (*Conyza canadensis*) seed collected in the planetary boundary layer. *Weed Sci.* 54:1063-1067.

Altitude (ft)	Seeds found (#/1000 m ³)*
230	3.3
460	1.7

* Approximately 33 by 33 by 33 ft



Glyphosate 3.38 lb ae/A

Untreated

Williamston, NC





Poston and Koger
Miss. State Univ.



Untreated



Glyphosate 3.0 lb ae/A

14 DAT

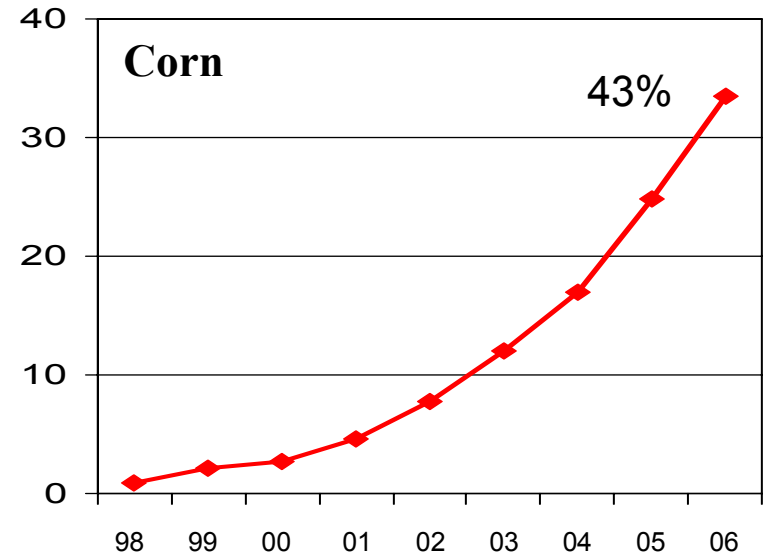
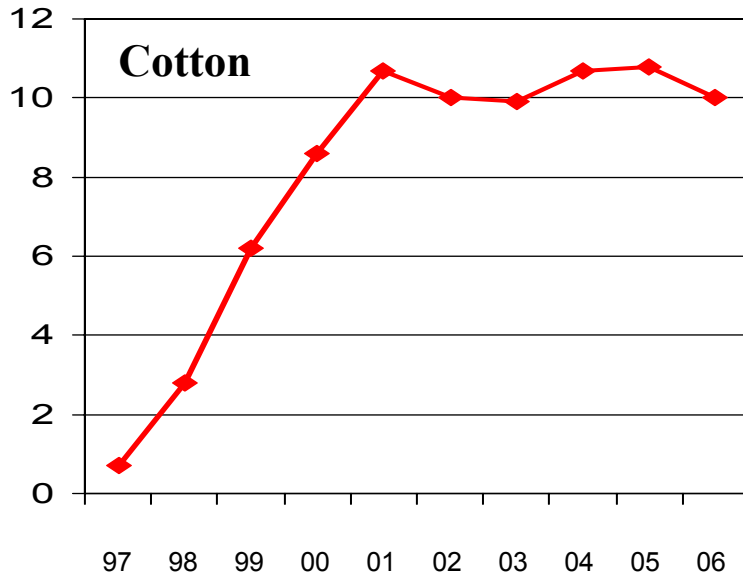
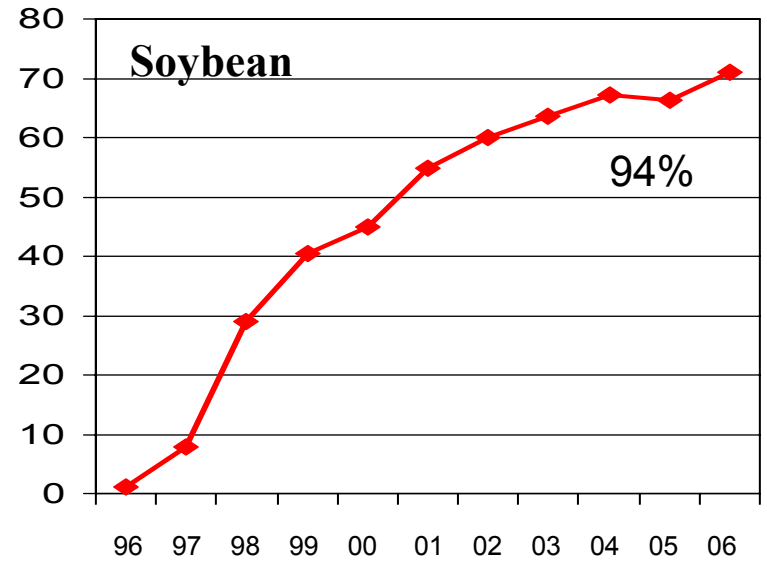
Parkton, NC 2005

Why is glyphosate resistance showing up?

- It wasn't supposed to happen.*
 - Very few species naturally resistant
 - Long history of use without problems
 - Limited success in developing resistant crops using whole plant or tissue culture selection techniques; unlikely to be duplicated in nature
 - Alterations to EPSPS that confer resistance would be detrimental
 - Complex manipulations required to develop resistant crops unlikely to be duplicated in nature

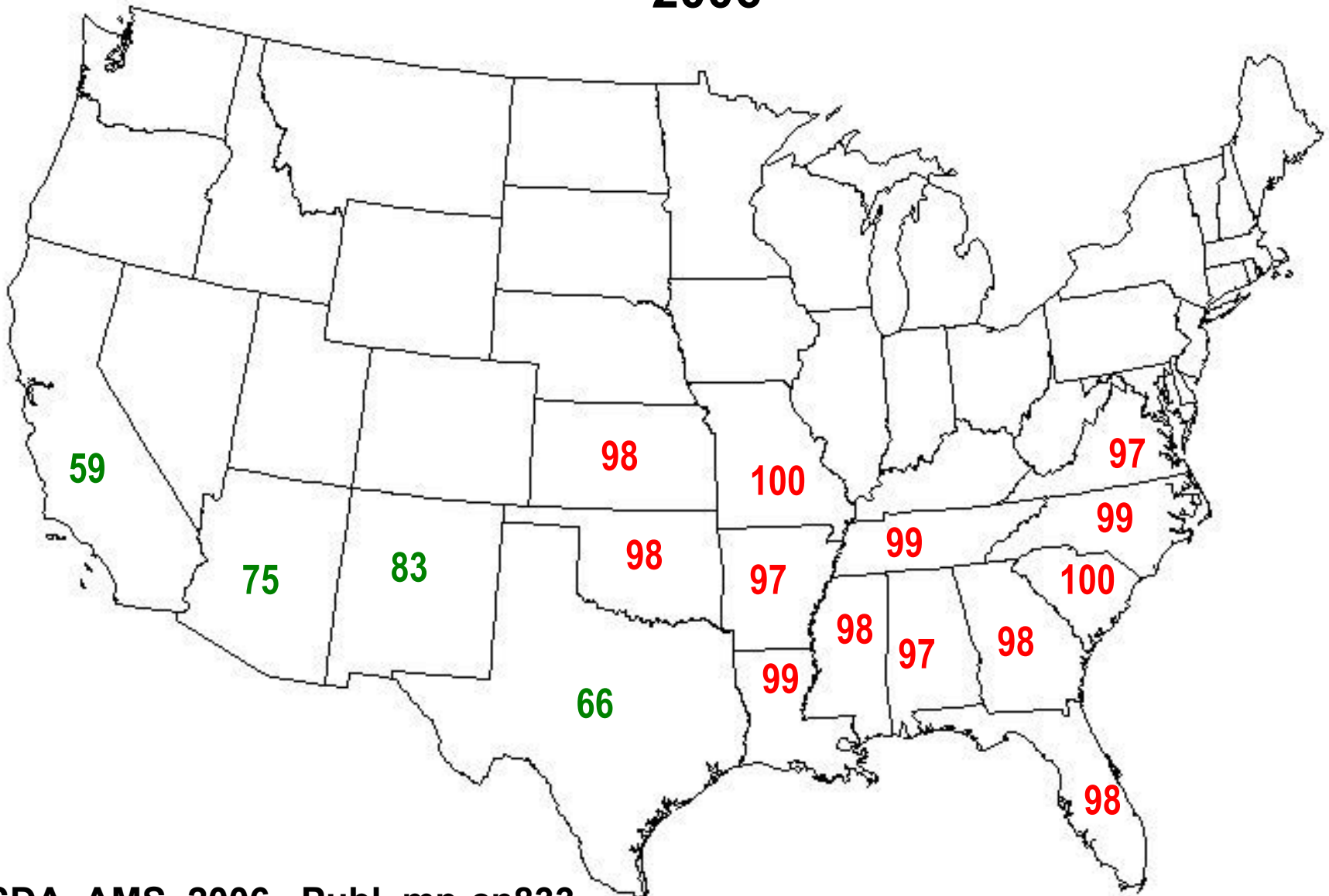
*Bradshaw, Padgett, Kimball, and Wells. Perspectives on glyphosate resistance. Weed Technol. 11:189-198.

Adoption of Roundup Ready Technology in the US (million acres)



Percent of cotton acreage planted to RR varieties

2006¹



¹USDA, AMS. 2006. Publ. mp-cn833.

Changes Due to RR Technology

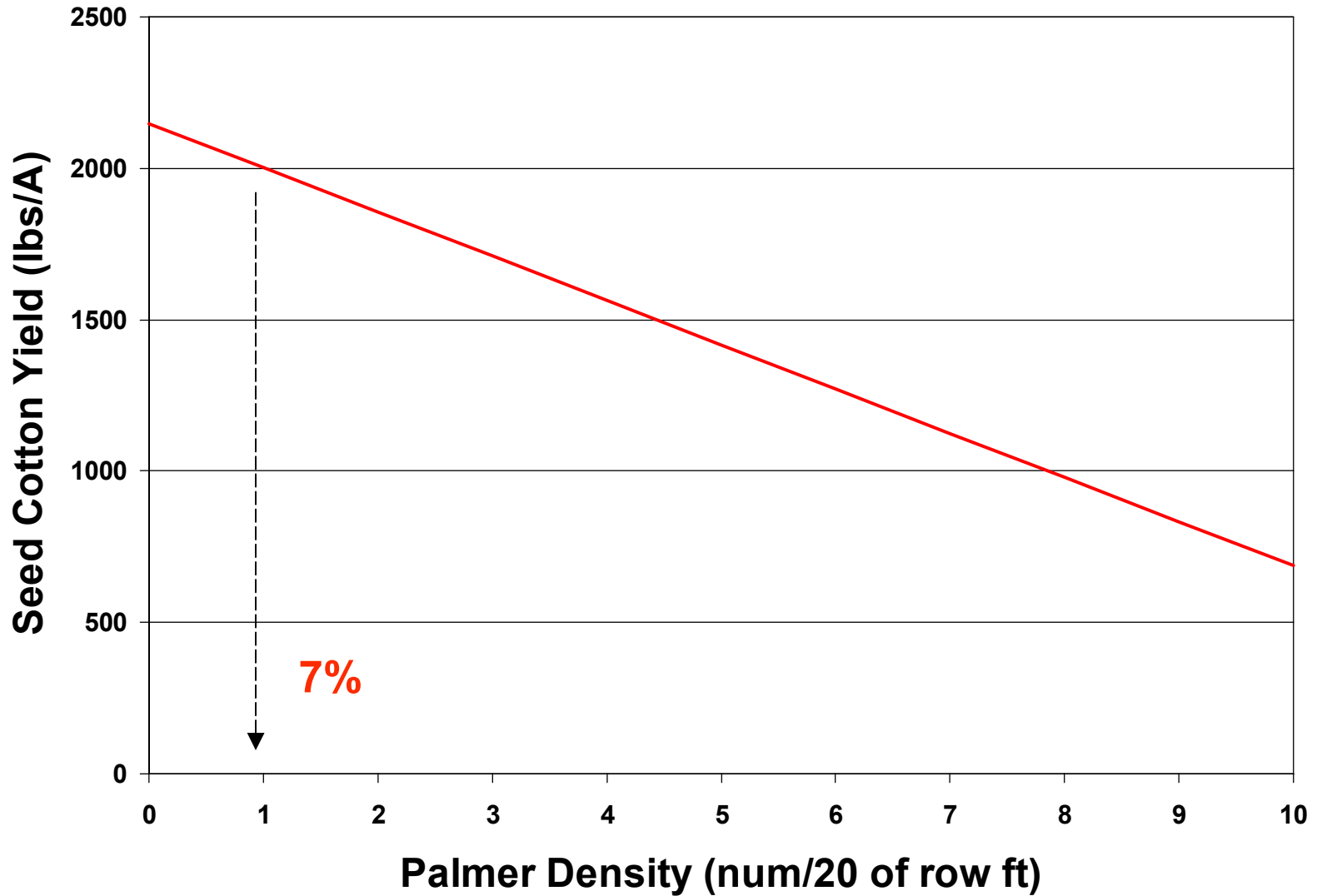
Before RR:	After RR:
Conventional tillage	Conservation tillage
DNA incorporated	Little or no at-planting
Cotoran PRE	herbicides
± Command or Zorial	Extensive reliance on
Cotoran + MSMA EPDIR	glyphosate POST,
Bladex + MSMA LPDIR	often nothing else
Cultivations	No cultivation

Why is glyphosate resistance becoming a problem?

- Wide-spread planting of Roundup Ready crops
- Heavy reliance on glyphosate for weed control
- Has lead to unprecedented selection pressure



Cotton Yield vs. Palmer Density







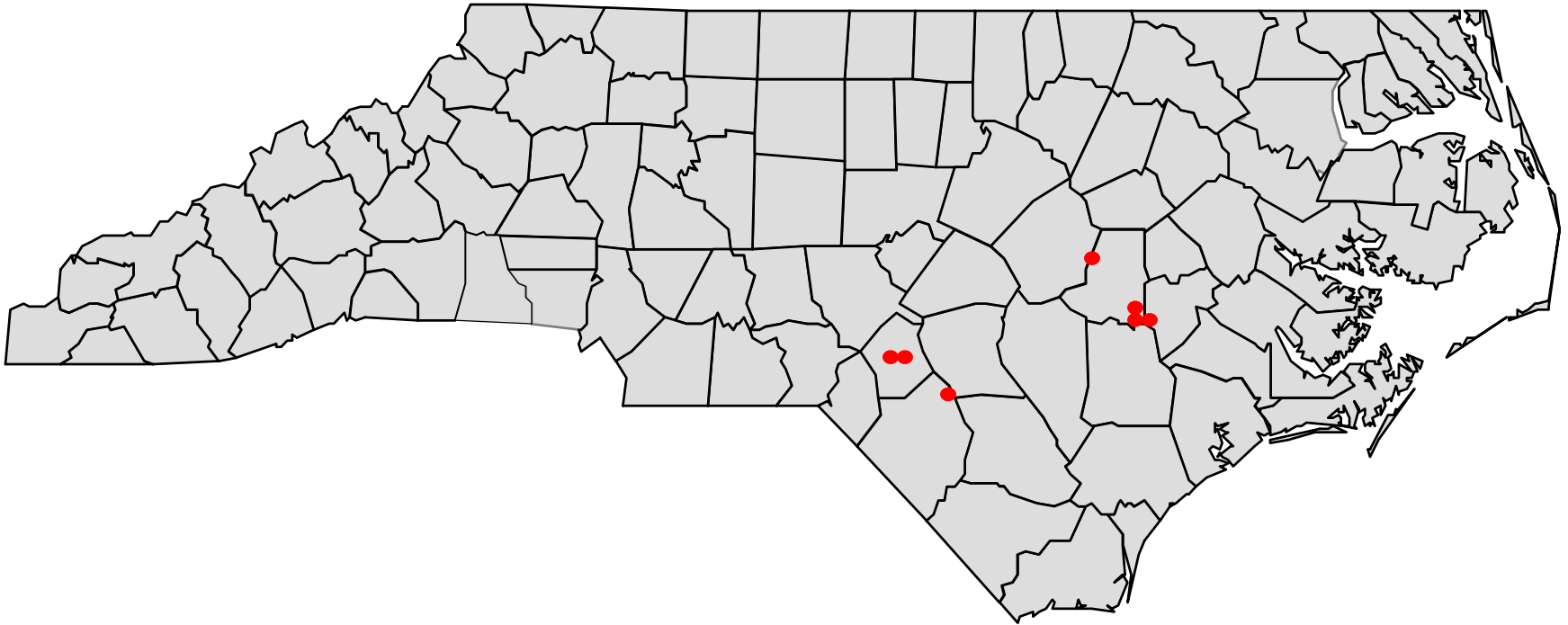




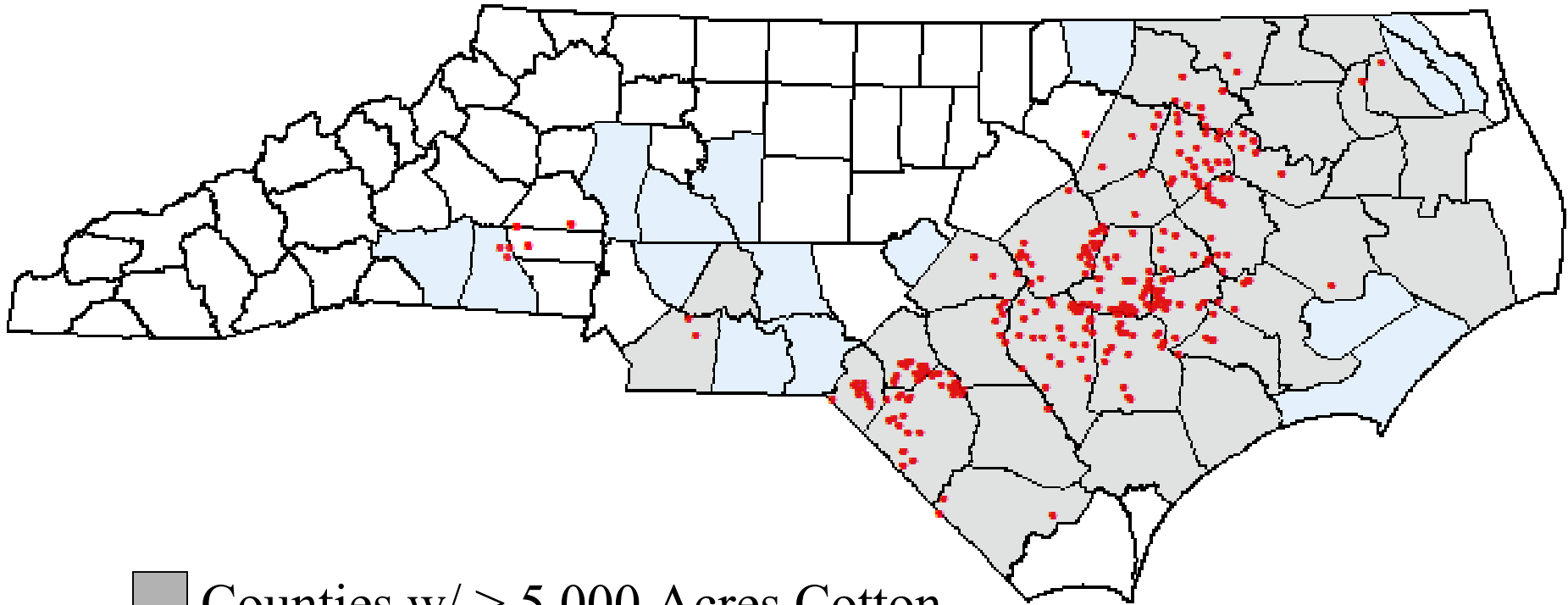
Back: untreated

Front: glyphosate-
only program

Suspected Glyphosate-Resistant Palmer Amaranth -- 2005



290 Fields Sampled in Fall 2005

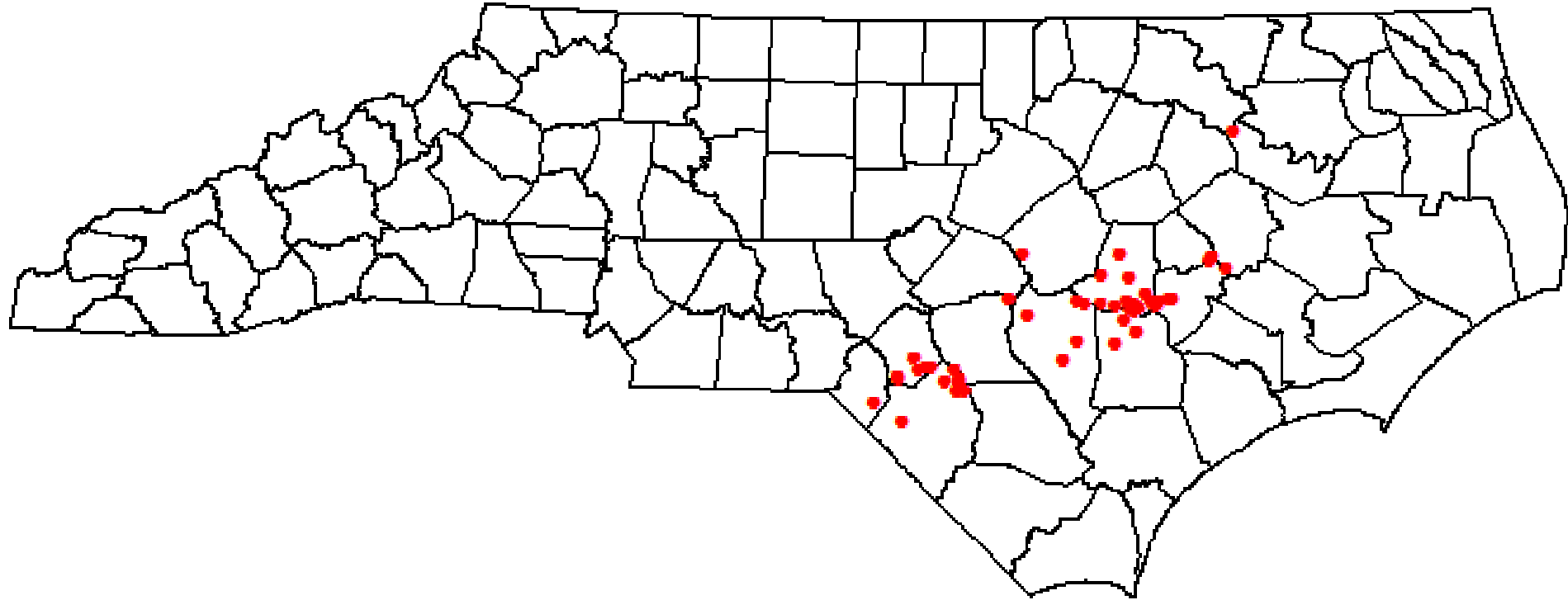


■ Counties w/ > 5,000 Acres Cotton

■ Counties w/ 250 – 4,999 Acres Cotton

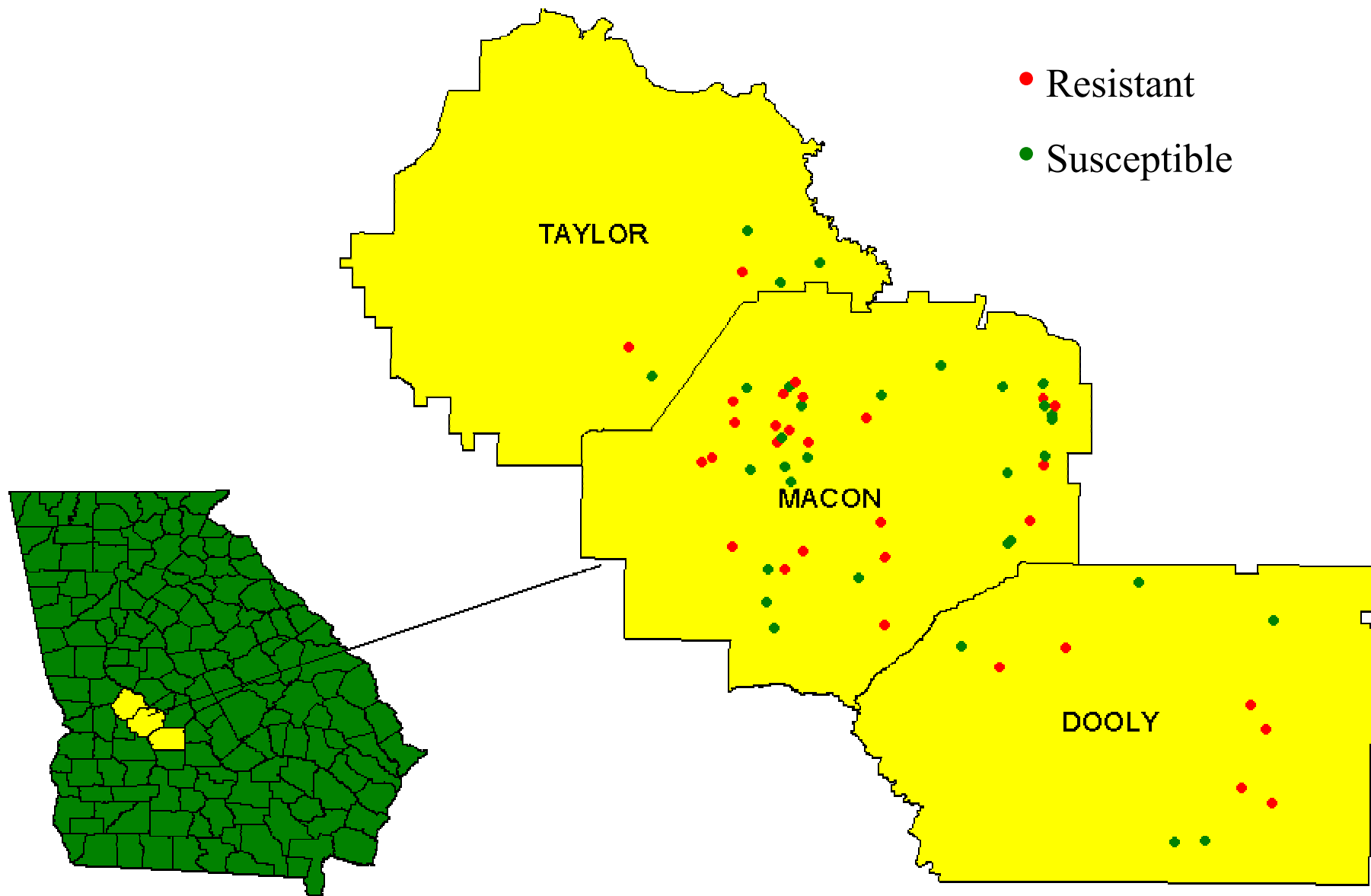


Resistant Locations



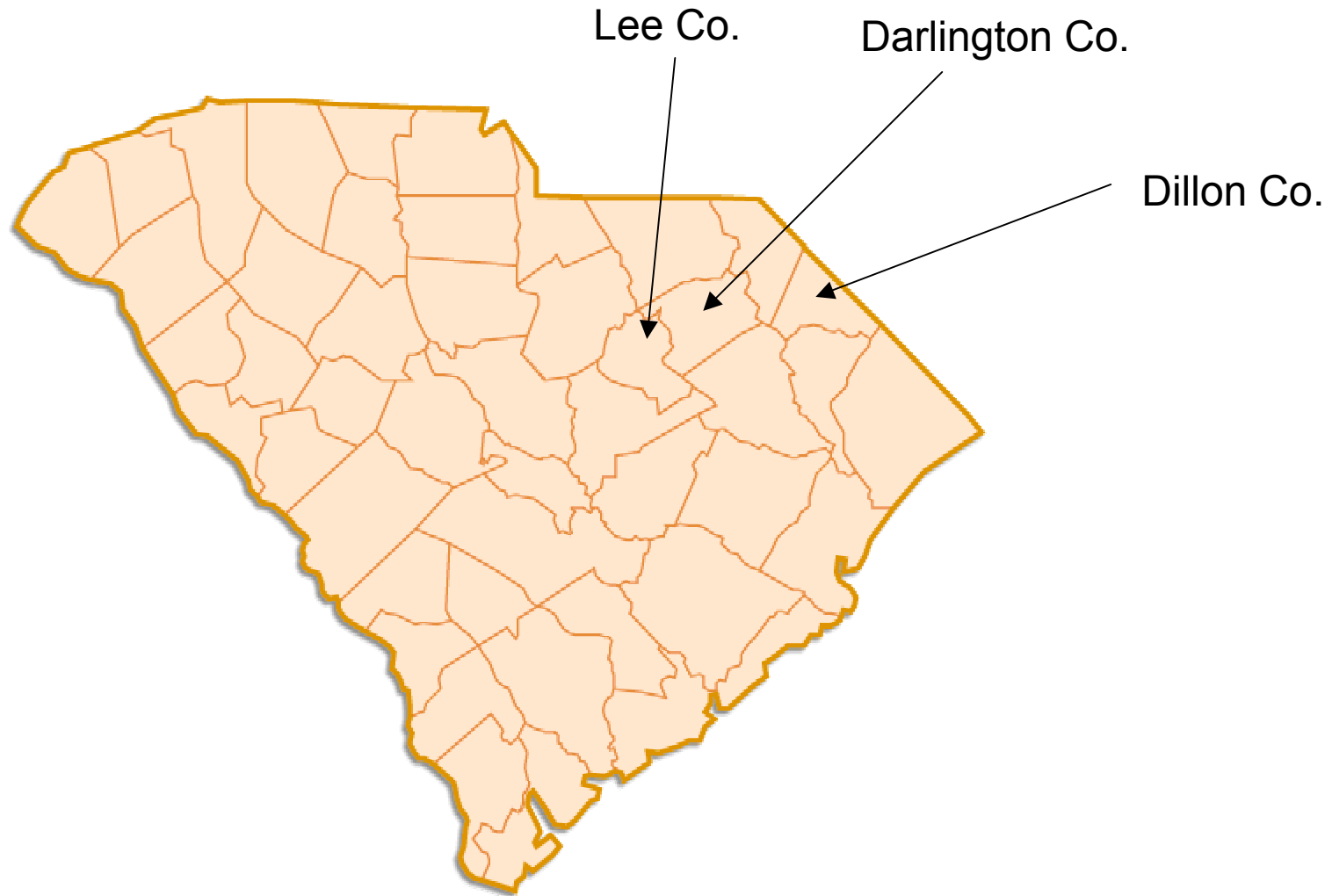
52 of 290 fields with resistance
Located in 12 counties

Locations of Resistance in 2005



100 total samples = 47 R; 53 S

Glyphosate-resistant Palmer amaranth, 2006

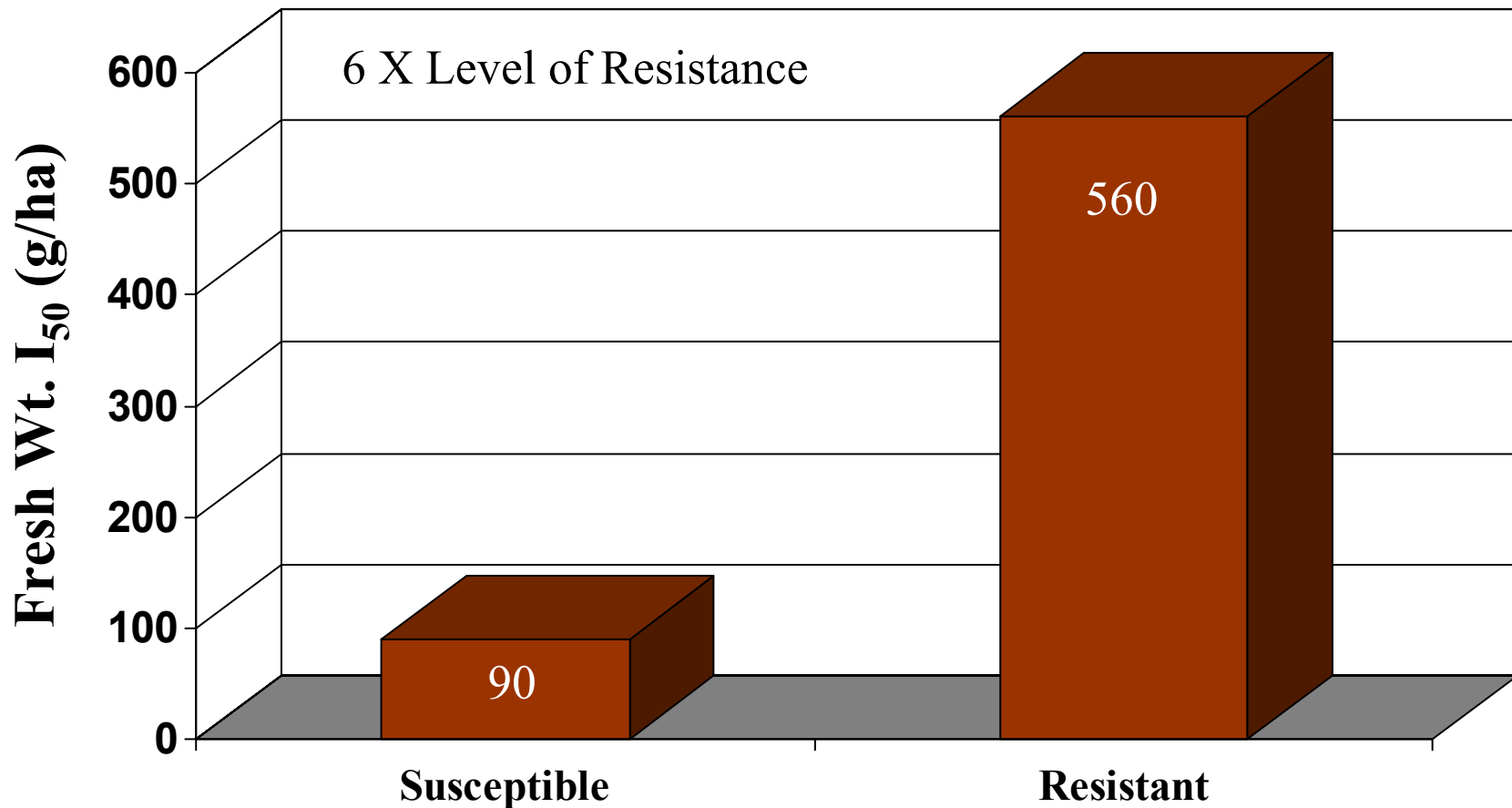


Glyphosate-Resistant Palmer Amaranth In South Carolina*

Biotype	Fr. Wt. I ₅₀ (g ae/ha)
Susceptible	400
Dillon Co.	1800 (4.5X)
Darlington Co.	1920 (4.8X)
Lee Co.	2100 (5.25X)

Main and Jones. 2007. Beltwide Cotton Conf.

Georgia Palmer amaranth response to glyphosate rates in the greenhouse



Culpepper et al., 2006. Weed Sci. 54:620-626.

Known susceptible
population



Untreated ← Treated →



Untreated ← Treated →

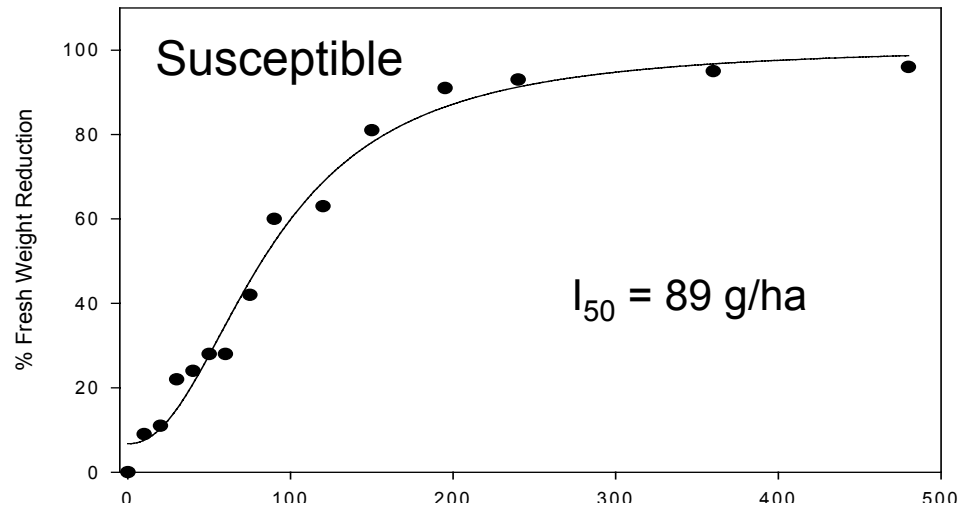


Untreated ← Treated →



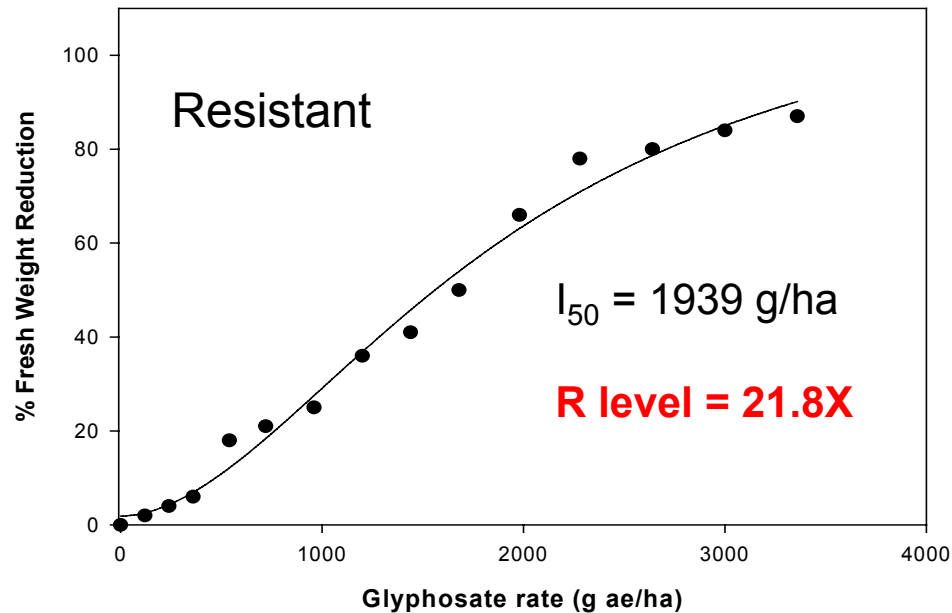
Untreated ← Treated →

Percent fresh weight reduction, greenhouse: North Carolina.



$$y = 6.747 + \frac{101.0643 - 6.7470}{1 + (x/88.9212)^{-2.1698}}$$

$$R^2 = 0.984$$



$$y = 1.8664 + \frac{121.9982 - 1.8644}{1 + (x/1939.2205)^{-1.8546}}$$

$$R^2 = 0.989$$



Untreated

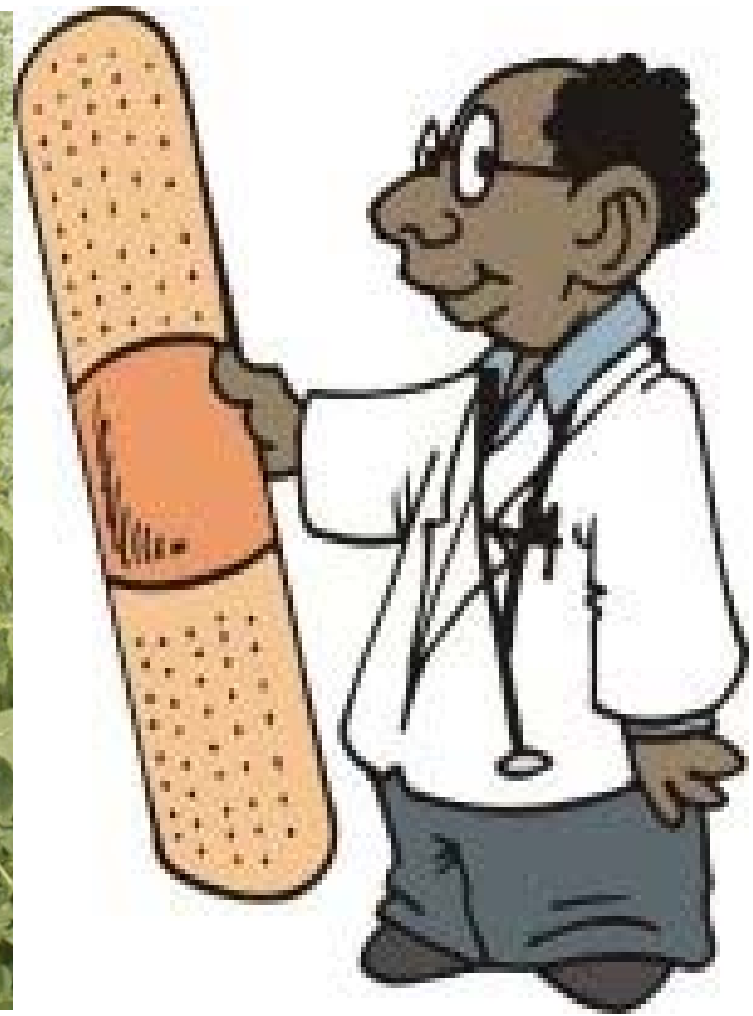


Glyphosate 4X rate, applied
three times

Herbicide Resistance Management

An aerial photograph of a vast agricultural field, likely a cornfield, showing neat, parallel rows of green crops stretching towards a distant horizon under a clear sky. The perspective is from a high angle, looking down the length of the field.

1. Reduce herbicide reliance (as practical)
Competitive crop, cover crop, cultivation
2. Crop rotation, with appropriate herbicide selection
3. Diversity of chemistry
Multiple modes of action within a crop
Residuals
Full use rates



From 2007 NC Ag Chem Manual (159 entries)

TABLE 8-11 HERBICIDE MODES OF ACTION

Brand Names	Active Ingredient(s)	Chemical Family	Mode of Action ¹
AAtrex	atrazine	Triazine	5
Accent	nicosulfuron	Sulfonylurea	2
Aim	carfentrazone	Triazolinone	14
Alachlor	alachlor	Chloroacetamide	15
Alanap	naptalam	Phthalamate simicarbazon	19
Arrow	clethodim	Cyclohexanedione	1
Atrazine	atrazine	Triazine	5
Assure II	quizalofop	Aryloxyphenoxy-propionate	1
Axiom	flufenacet + metribuzin	Oxyacetamide + triazinone	15 + 5
Backdraft	glyphosate + imazaquin	Glycine + imidazolinone	9 + 2
Balan	benefin	Dinitroaniline	3
Banvel	dicamba	Benzoic acid	4
Banvel-K + Atrazine	dicamba + atrazine	Benzoic acid + triazine	4 + 5
Basagran	bentazon	Benzothiadiazinone	6
Basis	rimsulfuron + thifensulfuron	Sulfonylurea	2 + 2
Blazer	acifluorfen	Diphenylether	14
Boundary	s-metolachlor + metribuzin	Chloroacetamide + triazinone	15 + 5

¹ The numerical system to describe modes of action is taken from the Weed Science Society of America. Modes of action are as follows:

- 1 ACCase inhibition
- 2 ALS inhibition
- 3 Microtubule assembly inhibition
- 4 Synthetic auxin
- 5 Photosystem II inhibition, different binding behavior than groups 6 and 7
- 6 Photosystem II inhibition, different binding behavior than groups 5 and 7
- 7 Photosystem II inhibition, different binding behavior than groups 5 and 6
- 8 Inhibition of lipid synthesis - not ACCase inhibition
- 9 EPSP synthase inhibition
- 10 Glutamine synthase inhibition
- 12 Inhibition of carotenoid biosynthesis at PDS
- 13 Inhibition of carotenoid biosynthesis, unknown target
- 14 PPO inhibition
- 15 Inhibition of very long-chain fatty acids
- 17 Unknown mode of action
- 19 Auxin transport inhibition
- 22 Photosystem I electron diversion
- 27 Inhibition of HPPD

GROUP 2 HERBICIDE

ENVOKE®

Herbicide

A selective herbicide for control of certain broadleaf, sedge, and grass weeds in cotton, sugarcane, and transplanted tomato

GROUP 1 HERBICIDE

AXIAL™

Herbicide

Postemergence herbicide for control of grass weeds in wheat and barley

Active Ingredient:

Pinoxaden*	9.71%
Other Ingredients:	90.29%
Total:	100.00%



Roundup® WEATHERMAX®

HERBICIDE

GROUP 9 HERBICIDE

Complete Directions for Use

EPA Reg. No. 524-537

2006-1

Resistance Management in RR Cotton

1. Do not depend entirely on glyphosate; incorporate multiple modes of action in system

a. Residual herbicides preplant or preemergence

Preplant

Direx, Valor

Preemergence

Cotoran, Direx, Prowl,
Reflex, Staple

b. Tank mix postemergence

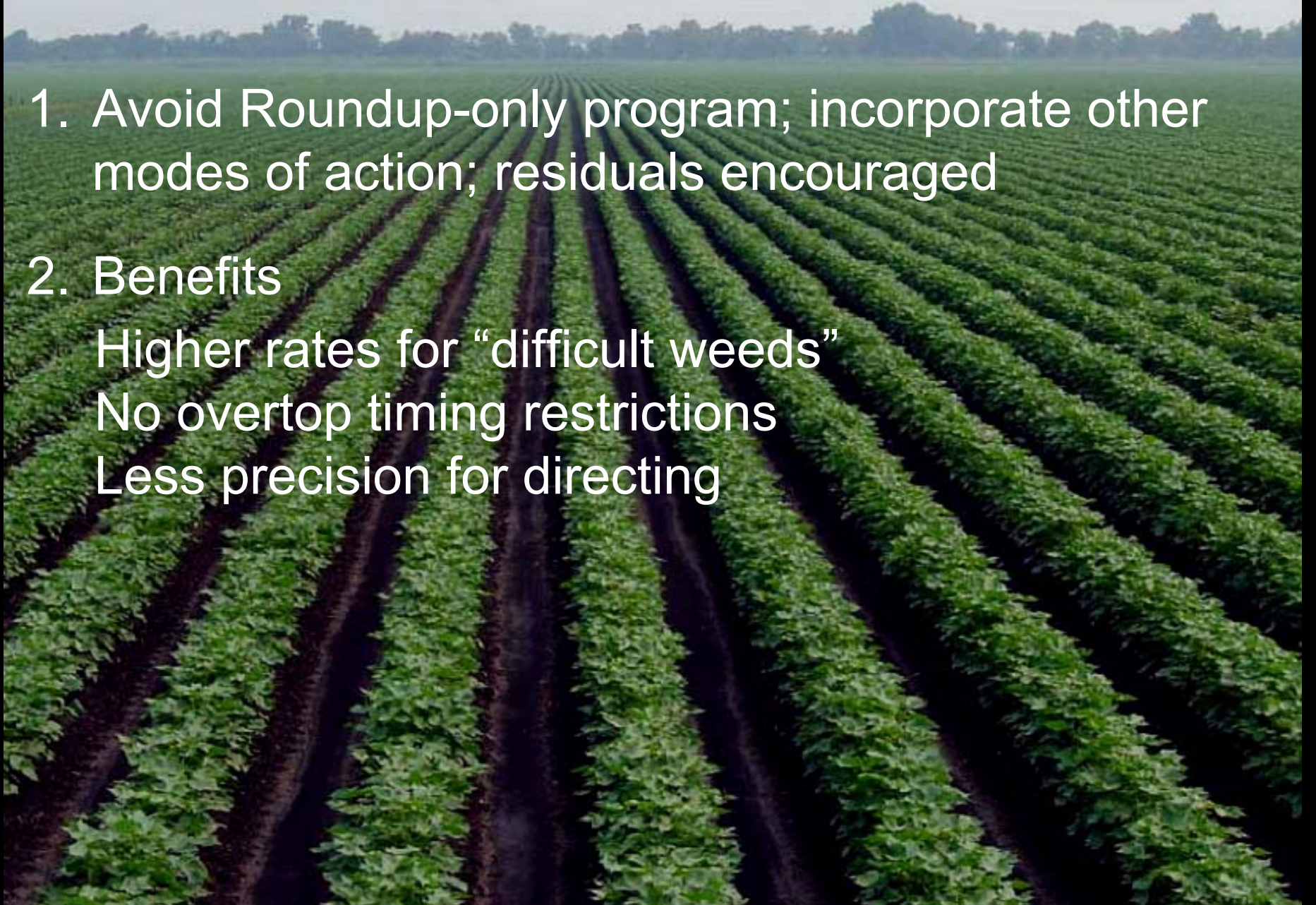
Dual Magnum, Envoke, Staple

c. Residual at layby

Direx, Layby Pro, Suprend, Valor mixed with either MSMA or glyphosate

Does RR Flex Have a Fit?

1. Avoid Roundup-only program; incorporate other modes of action; residuals encouraged
2. Benefits
 - Higher rates for “difficult weeds”
 - No overtop timing restrictions
 - Less precision for directing



Palmer Amaranth Resistance Management

- Reduce the seedbank



Palmer Amaranth Resistance Management

- Reduce the seedbank
- Residual control is important



North Carolina, 2006



Untreated



Treated



Palmer Amaranth Resistance Management

- Reduce the seedbank
- Residual control is important
- Need to protect ALS inhibitors



ALS Inhibitors

Imidazolinones

Cadre

Pursuit

Scepter

Triazolopyrimidines

Broadstrike

Firstrate

Strongarm

Pyrimidinylthiobenzoates

Staple

Sulfonylureas

Accent

Canopy EX

Classic

Envoke

Express

Finesse

Harmony GT

Harmony Extra

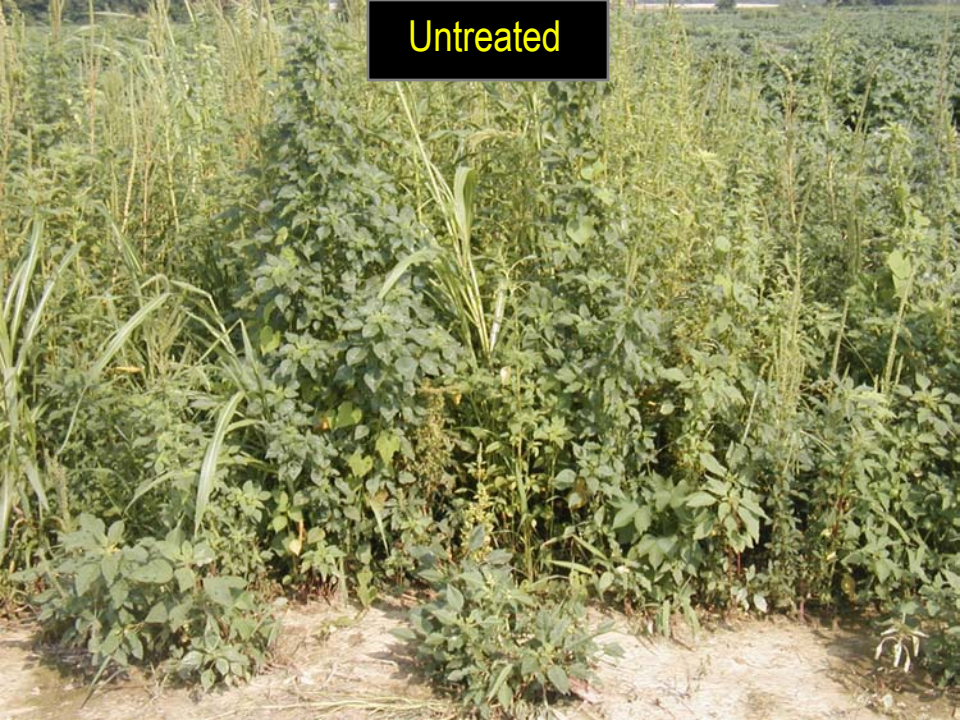
Resolve

Steadfast

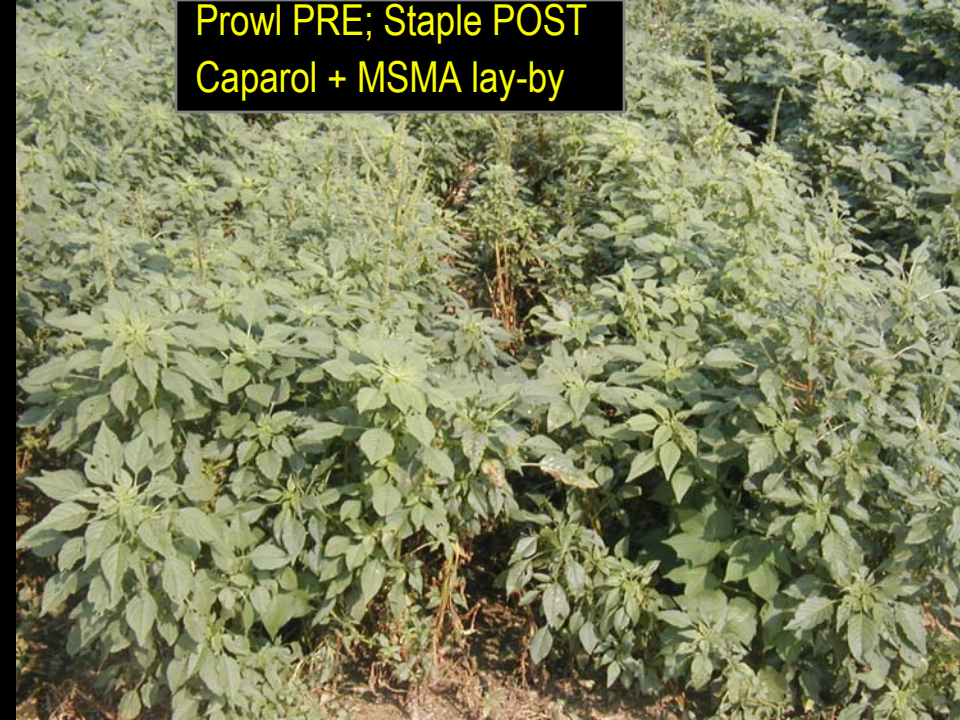
Stout

Synchrony

Untreated



Prowl PRE; Staple POST
Caparol + MSMA lay-by



Prowl PRE; glyphosate POST
Caparol + MSMA lay-by



ALS-Resistant Palmer Amaranth



System w/o Staple



System w/ Staple

Untreated



North Carolina

2006

GR Palmer after two annual applications of Staple; Georgia

2004



Staple LX 0 1.3 2.6 5.2 10.2 20.4 fl oz/A

2006



1X glyphosate + 1X Staple; Palmer 0.5 inches when treated



Culpepper, UGA

Recommended southeastern herbicide programs for Palmer amaranth control in RR cotton

Glyph. resist.	ALS resist.	Preemergence	
No	No	Staple*, Reflex**, Direx, Cotoran, Caparol, or Prowl	

* Limit to one application per year.

** Caution if Valor burndown.

Recommended southeastern herbicide programs for Palmer amaranth control in RR cotton

Glyph. resist.	ALS resist.	Preemergence	Postemergence 1- to 4-leaf	
No	No	Staple*, Reflex**, Direx, Cotoran, Caparol, or Prowl	Light infestation: Glyphosate	
			Heavy infestation: Glyph. + Dual Mag. or Sequence	

* Limit to one application per year.

** Caution if Valor burndown.

Recommended southeastern herbicide programs for Palmer amaranth control in RR cotton

Glyph. resist.	ALS resist.	Preemergence	Postemergence 1- to 4-leaf	Layby (Palmer < 3")
No	No	Staple*, Reflex**, Direx, Cotoran, Caparol, or Prowl	Light infestation: Glyphosate	MSMA + Valor, MSMA + Suprend, MSMA + Direx, MSMA + Layby Pro or Glyph. + Valor, Glyph. + Suprend, Glyph. + Direx, Glyph. + Layby Pro
			Heavy infestation: Glyph. + Dual Mag. or Sequence	

* Limit to one application per year.

** Caution if Valor burndown.

Recommended southeastern herbicide programs for Palmer amaranth control in RR cotton

Glyph. resist.	ALS resist.	Preemergence	Postemergence 1- to 4-leaf	Layby (Palmer < 3")
No	Yes	Reflex*, Direx, Cotoran, Caparol, or Prowl	Light infestation: Glyphosate	MSMA + Valor, MSMA + Direx, MSMA + Layby Pro or Glyph. + Valor, Glyph. + Direx, Glyph. + Layby Pro
			Heavy infestation: Glyph. + Dual Mag. or Sequence	

* Caution if Valor burndown.

Recommended southeastern herbicide programs for Palmer amaranth control in RR cotton

Glyph. resist.	ALS resist.	Preemergence	Postemergence 1- to 4-leaf	Layby (Palmer < 3")
Yes	No	Prowl + Reflex* (Prowl + Direx on heavier soils)	No emerged Palmer: Glyph. + Dual Mag. or Sequence (early)	MSMA + Valor, MSMA + Suprend, MSMA + Direx, or MSMA + Layby Pro
			Palmer < 2 in.: Glyph. + Staple**	

*Caution if Valor burndown.

**Limit to one application per year.



Detect Resistance
Early



Mt. Olive, NC

July 1, 2006



PRE Herbicides Under RR Soybeans

Alachlor¹, Dual Magnum², Outlook, Prowl

Boundary³

Reflex

Canopy⁴

Scepter⁵

Lorox

Sencor

Prefix

Valor

¹ Intro, Micro-Tech, others

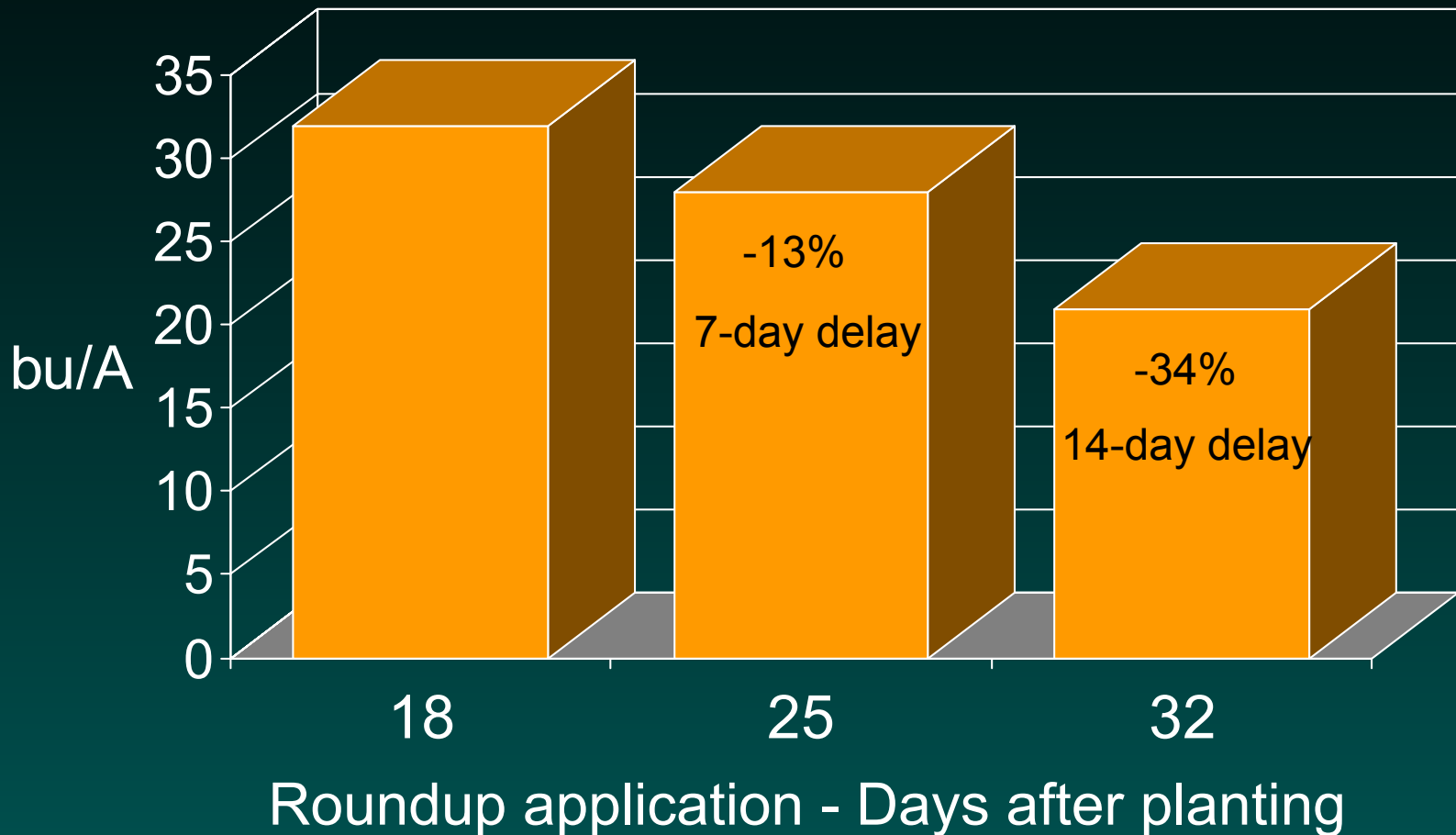
² s-metolachlor products preferred

³ Metribuzin + S-metolachlor

⁴ Reduced-rate label if followed by glyphosate

⁵ An ALS inhibitor

Effect of Roundup application timing and PRE herbicide on soybean yield. NC, 1998. Under heavy weed pressure.*



* All treatments had complete weed control after treatment.

POST Herbicides with Glyphosate in RR Soybeans

Blazer

Harmony GT¹

Classic¹

Pursuit¹

Firstrate¹

Resource

Flexstar

Storm

¹ ALS inhibitor

In RR soybeans, glyphosate tank-mix partner rate depends upon your objective

Objective	Tank-mix partner rate	
	Reduced	Full
Boost morningglory control	✓	
Weeds not controlled by glyphosate		✓
Residual control*		✓
Resistance management		✓

* Must select a herbicide with residual activity.

Residual PRE Herbicides Under RR Corn

Atrazine

Atrazine/Princep

Bicep II Magnum*

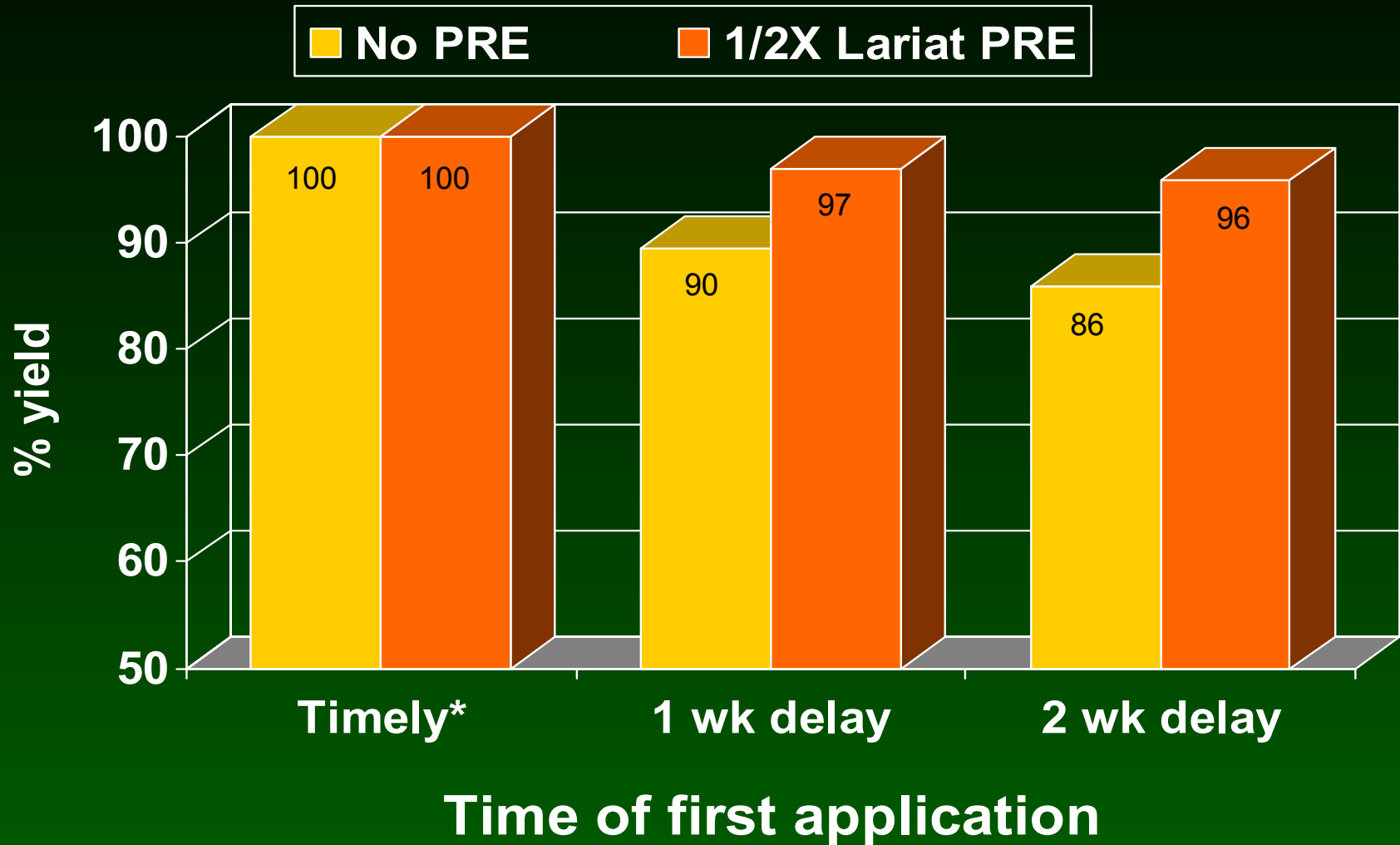
Guardman Max*

Lariat*

Lexar*

* Two-thirds to 1X normal rate.

Time of Glyphosate Application on RR Corn. Average of 6 locations, NC.**



* 2- to 3.5-inch weeds.

** Parker, York, and Jordan. 2006. Weed Technol. 20:564-570.



Multiple MOAs for POST in RR Corn

Glyphosate + atrazine

Glyphosate + dicamba

Glyphosate + Aim

Glyphosate + Resource

Sequence + atrazine

Glyphosate-Resistant Weeds

- Is the situation hopeless? **NO.**
- Is RR technology done? **NO.**
- Will it change our ways? **YES.**
 - More management
 - More inputs costs

