Bollworm Issues in Transgenic Cotton

R. G. Luttrell
Department of Entomology
University of Arkansas

The Beginning – Pre Bt Cotton

- **Foliar sprays of Bt used with limited success on cotton, insecticidal activity of *Bacillus thuringiensis* known for 100 years**
- **Plants transformed to express insecticidal toxins of *Bacillus thuringiensis* in 1980s**
- **In 1995 Bt cotton becomes first crop that EPA mandated resistance management**
- **Bt corn, Bt cotton, Bt potato registered by EPA in 1995**

Things We Knew Pre Bt Cotton

- **Bollworm less susceptible to Bt than tobacco budworm**
- **Pyrethroids ineffective against tobacco budworm but efficacious on bollworm**
- **Bt cotton had good control of bollworm (not perfect), but highly effective (high dose) against tobacco budworm**
- **Insect have genetic capacity to develop resistance to Bt endotoxin proteins**
- **Tobacco budworm strains selected for resistance to Bt do not survive on expressing Bt cotton plants**

Amazing New Capacity – Bt Cotton

Table 5. Summary of studies that compare net returns for *Bt* cotton varieties compared with conventional varieties.†

Source	Crop year	Region	Change in net return ($ ha⁻¹)‡
Allen et al. (1999)	1998	AR	–27.61
Bryant et al. (1997)	1996	AR	196.39
Bryant et al. (1997)	1997	AR	–155.34
Carlson et al. (1998)	1996	NC, SC	131.43
Carlson et al. (1998)	1996	GA, AL	201.38
Gibson et al. (1997)	1995	MS	234.23
Gibson et al. (1997)	1996	MS	40.05
Mullins and Mills (1999)	1998	AL, AR, GA, LA, MS, NC, SC, TN, VA	98.45
ReJesus et al. (1997)	1996	SC	259.15
ReJesus et al. (1997)	1997	SC	–201.75
Stark (1997)	1996	GA	179.82
Wier et al. (1998)	1995	MS	203.78
Wier et al. (1998)	1996	MS	61.03
Wier et al. (1998)	1997	MS	132.71
Wier et al. (1998)	1995-97	AL, GA, FL	134.69
Wier et al. (1998)	1995-97	MS, AR, LA	87.76
Wier et al. (1998)	1996-97	East TX	27.22
		High	259.15
		Low	–201.75
		Average	94.32

† Source: Modified from Gianessi and Carpenter (1999).
‡ A minus (–) sign indicates a decrease in growers' net return after introduction of *Bt* cotton, and a plus sign (+) indicates an increase.

1996 - 1998

Returns from Bt cotton as compared to conventional cotton
Average of $94 per hectare ($38 per acre)
High of $259 per hectare ($104 per acre)
Low of -$201 per hectare (-$81.38 per acre)

Edge et al. 2001. Journal of Cotton Science. 5:121-136

Table 3. Differences between number of sprays per hectare for *Bt* vs. non-*Bt* cotton varieties.

Location	Difference in number of sprays per hectare†	Source
Australia	7.70	Addison (1999)
Mississippi	5.50	Davis et al. (1995)
Spain	5.00	Novillo et al. (1999)
Arkansas	4.00	Bryant et al. (1997)
South Carolina	4.00	ReJesus et al. (1997)
South Carolina	3.25	Roof and DuRant (1997)
Georgia	2.50	Stark (1997)
North Carolina	2.50	Bacheler et al. (1997)
Southern and southeastern United States	2.40	Mullins and Mills (1999)
Midsouth and southeastern United States	2.20	Benedict and Altman (2001)
Georgia	2.00	Carlson et al. (1998)
Mexico	1.00	Obando-Rodriquex et al. (1999)
Average across studies	3.50	

† A minus sign is implied in all cases because *Bt* cotton required fewer sprays at all locations.

1996 - 1998

Average of 3.5 fewer sprays per hectare (1.4 per acre)

Edge et al. 2001. Journal of Cotton Science. 5:121-136




"Bollgard/Bollworm Debate"
Chris Demaske, Cotton Times, Fall 1996

This season marked the entrance of the transgenic, worm-resistant Bollgard cotton into commercial use. But the product, which is virtually 100% resistant to tobacco budworm, came under fire mid-summer due to the bollworm damage it incurred in some areas across the Belt. As a result, Monsanto, Bollgard's producer, also came under fire from several growers, consultants, and researchers claiming that the company misrepresented the product.

"Bollgard/Bollworm Debate"
Chris Demaske, Cotton Times, Fall 1996

"The whole thing is that it just didn't do what it was supposed to do when it came to controlling the range of insects they said it would," says Paul Pilsner, one of the first consultants to alert Monsanto of the bollworm damage to Bt cotton this year and one of the several South Texas consultants dealing with angry and upset growers over bollworm damage to Bt cotton. "The main people at Monsanto told me that it was going to work on the bollworm enough to where we wouldn't have to be doing any spraying; that it had enough suppression of the bollworm where it wouldn't be an economic problem."

"Bollgard/Bollworm Debate"
Chris Demaske, Cotton Times, Fall 1996

Other growers across the Belt, however, were more pleased with the product.

We grew a little over 500 acres of Bt cotton in the whole operation -- it's here to stay," says Tchula, MS, grower Sonny Diggs.

"Bollgard/Bollworm Debate"
Chris Demaske, Cotton Times, Fall 1996

And, Randy Deaton, a product development manager at Monsanto who has worked with Bt cotton for almost a decade, claims the product did just what it was supposed to do -- give 90% to 95% control against bollworms, and that it was extraordinarily high numbers of bollworms, not product failure or product misrepresentation, that led growers in many states to spray.

"Bollgard/Bollworm Debate"
Chris Demaske, Cotton Times, Fall 1996

"With any new product in any given year you're going to find someone who is unhappy with it," Deaton says. "We'll certainly be honest with people -- under certain circumstances it may need supplemental treatments."

"Bollgard/Bollworm Debate"
Chris Demaske, Cotton Times, Fall 1996

SCOUTING AND OTHER CHANGES

Growers who do plant Bt cotton next year will go into it with new knowledge gained from this 1996 season. "We learned a lot about Bt cotton," says Louisiana consultant Grady Coburn. "We are going to have to bone up on our sampling techniques, monitoring frequencies, and the amount of time we spend in the fields to better assess the damage potential of the cotton bollworm in Bt cotton."

"Bollgard/Bollworm Debate"
Chris Demaske, Cotton Times, Fall 1996

In addition to scouting techniques, Monsanto and other researchers across the Belt are looking at the following:

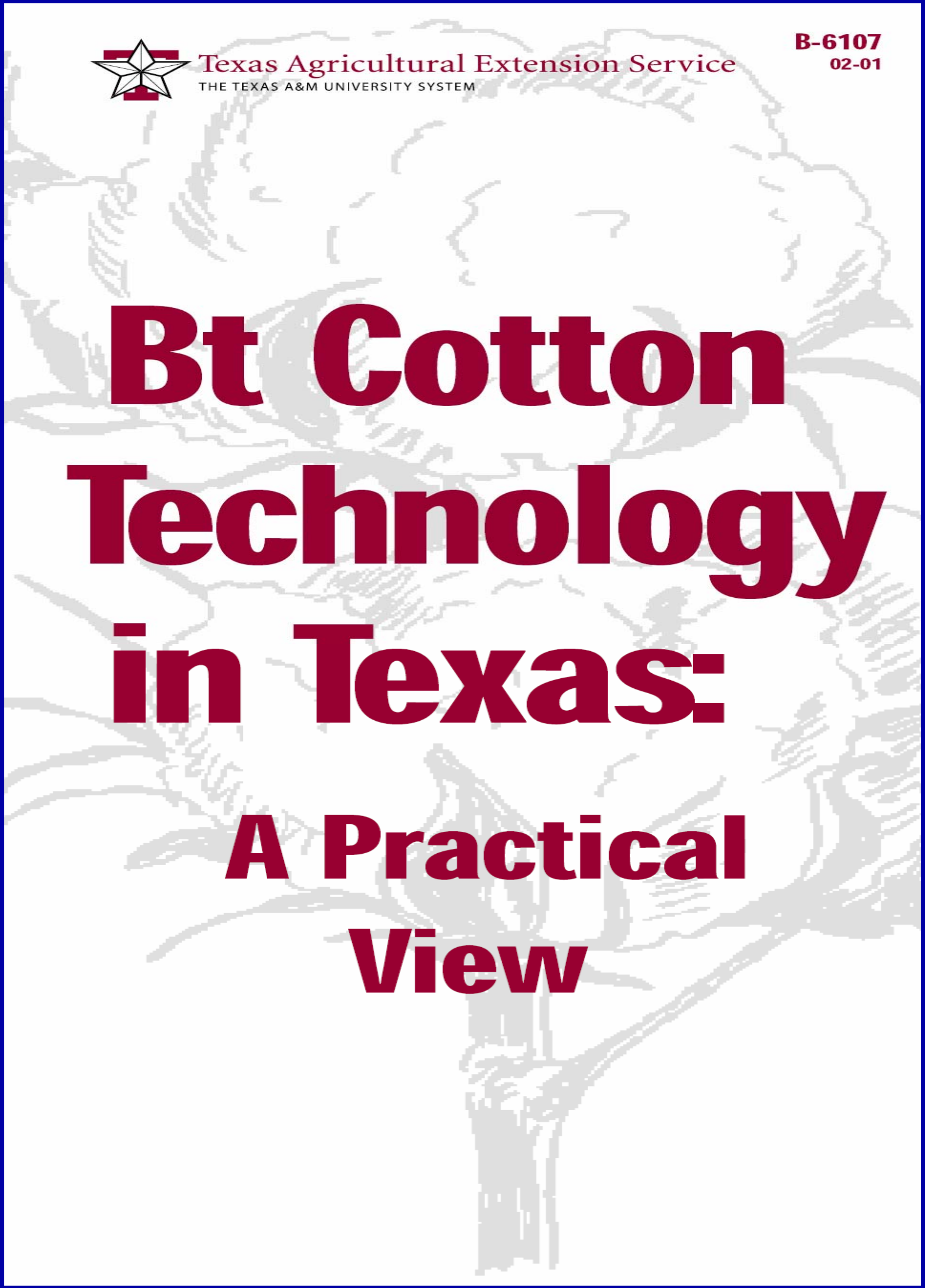
- **the distribution of the *Bt* toxin throughout the plant (is it evenly distributed?);**
- **the effect of corn acreage on bollworm populations and how to monitor those populations in corn to prepare for their flight to cotton;**

"Bollgard/Bollworm Debate"
Chris Demaske, Cotton Times, Fall 1996

– **how suppression of early-season tobacco budworm by *Bt* cotton plants may have enhanced area-wide suppression of the insect that devastated large portions of cotton in 1995;**

– **and how the lack of early season chemical application in *Bt* cotton enabled beneficials to keep other non-*Bt*-affected insect pests down to low populations**

Increased Knowledge and Maturity


Texas Agricultural Extension Service
THE TEXAS A&M UNIVERSITY SYSTEM

B-6107
02-01

Bt Cotton Technology in Texas:

A Practical View

Species	% Control*
Bollworm prebloom	90
Bollworm blooming	70
Tobacco budworm	95
Pink bollworm	99
Cabbage looper	95
Beet armyworm	25
Fall armyworm	20 or less
Saltmarsh caterpillar	85 or more
Cotton leaf perforator	85 or more
European corn borer	85 or more

*Measured as percent mortality of larvae

Source: Benedict et al. (1991, 1999), Bradley (1995), Wilson et al, (1992, 1994)

Estimating the economic value of Bollgard® cotton versus new or conventional insecticides is paramount! This is a question that each producer must consider for specific production situations.

- Q. How will producers scout Bollgard cottons?
- A. Whole plant inspections should be made, just as for non-Bollgard cotton….
- Q. What type of insect injury can be expected in Bollgard cottton?
- A. Little terminal injury and very few large larvae of tobacco budworm…Slight feeding (grazing) on the bracts and calyx…When egg-laying is high, this can lead to bollworm numbers, and square and boll injury in excess of the economic threshold.

- Q. Are thresholds for tobacco budworms/bollworms different for Bollgard cotton?
- A. No. Treatment with foliar insecticides should be considered when: A) there are 4,000 to 8,000 larvae per acre larger than ¼ inch…or B) there are eight to 12 larvae larger than ¼ inch per 100 plants and 5 to 15 percent of the squares or bolls are worm damaged. Many factors influence where in this range the treatment is made…

H. zea **damages Bt cotton and there is a benefit for spraying Bt cotton under high population densities**

Mahaffey et al. 1995. Proc. Beltwide Conf. pp. 795-98.
Lambert et al. 1997. Proc. Beltwide Conf, pp. 870-873.
Bacheler and Mott, Layton et al., Smith. 1997. Proc. Beltwide Conf. pp. 856-861.
Gore et al. 2001. J. Econ. Entomol. 94:1445-51.

Bt cotton often requires treatment with pyrethroid insecticides for control of *H. zea*

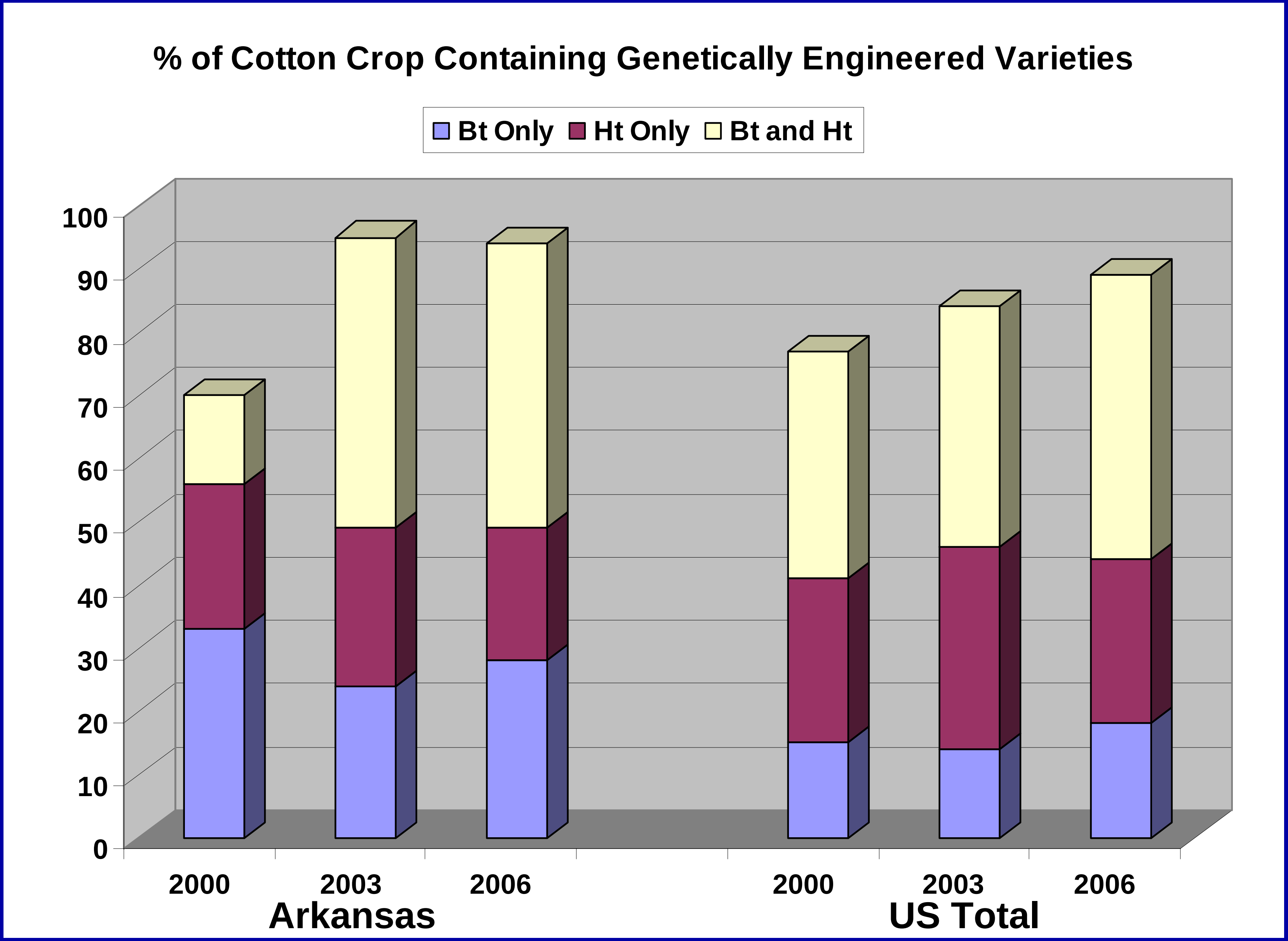
Bacheler and Mott, Layton et al., Leonard et al., Roof and Durant, Smith 1997. Proc. Beltwide Conf.
Leonard et al. 1998. Proc. Beltwide Conf.
Smith 1997 and 1998. Proc. Beltwide Conf.
Burd et al. 1999. Proc. Beltwide Conf.
Williams. 1997-2002. Proc. Beltwide Conf.

Cotton plants vary in expression at different plant parts and among varieties during different times of the year

Adamczyk et al. 2001. J. Econ. Entomol. 94:284-90.
Gore et al. 2001. J. Econ. Entomol. 94:1445-51.
Aiken et al. 2002. Proc. Beltwide Conf.
Greenplate 1998. Proc. Beltwide Conf. pp. 1030-33.
Adamczyk and Sumerford. 2001. J. Insect Sci. 1:13

Resistance is reported in field populations of *H. zea* and inferences are made about inheritance

Burd et al. 2003. J. Econ. Entomol. 96:137-42.
Jackson et al. 2002. Proc. Beltwide Conf.
Luttrell et al. 2004. Proc. Beltwide Conf.
Anilkumar and Moar. 2006 Proc. Beltwide Conf.


% of Cotton Crop Containing Genetically Engineered Varieties
Bt Only
Ht Only
Bt and Ht
100
90
80
70
60
50
40
30
20
10
0
2000
2003
2006
Arkansas
2000
2003
2006
US Total

Specific Research

- Greenplate 1999. J. Econ. Entomol. 92:1377-1383
  - Cry1Ac decreased from 57 ug/g dry weight at 53 dap to 7 ug/g dry weight at 116 dap (node 9)
  - Cry1Ac decreased from 163 ug/g dry weight at 53 dap to 35 ug/g dry weight at 116 dap (terminal)

- Gore et al. 2000. J. Econ. Entomol. 93:690-696.
  - Non Bt bolls safe from feeding by neonates at 426 heat units (17 d)
  - Bt bolls safe from feeding at 299 heat units (12 d)

Specific Research

- Brickle et al. 2001. J. Econ. Entomol. 94:86-92
  - Reduced rates of larvicides controlled low populations of bollworm on dryland Bt cotton but not irrigated Bt cotton
- Layton et al. 2002. Beltwide Cotton Conference
  - Summarized 7 years of Bt cotton in Mississippi
  - 2.6% boll damage in Bt and 4.3% in non-Bt
  - 1.2 sprays for heliothines in Bt
  - 3.4 sprays for heliothins in non-Bt

Specific Research

- Hudson et. al. 2003. Proc. Beltwide Conf.
  - 8 years of economic comparisons
  - $49.80/acre advantage in independent studies
  - $40.18/acre advantage in 549 Monsanto comparisons
  - 1.86% boll damage in BG, 4.6% in non-Bt
- Gore et al. 2003. J. Econ. Entomol. 96:699-705.
  - 6.6 fruit damage/larva on non-Bt
  - 3.5 fruit damaged/larva on BG
  - 0.8 fruit damaged/larva on BGII

Specific Research

- Jackson et al. 2003. Proc. Beltwide Conf.
  - Estimated bollworm emergence
    - Conventional – Untreated 26,172 a
    - Bollgard – Untreated 15,777 ab
    - Conventional – Treated 5, 714 b
    - BG II – Untreated 1,067 c
    - BG – Treated 999 c
    - BG II – Treated 0 c

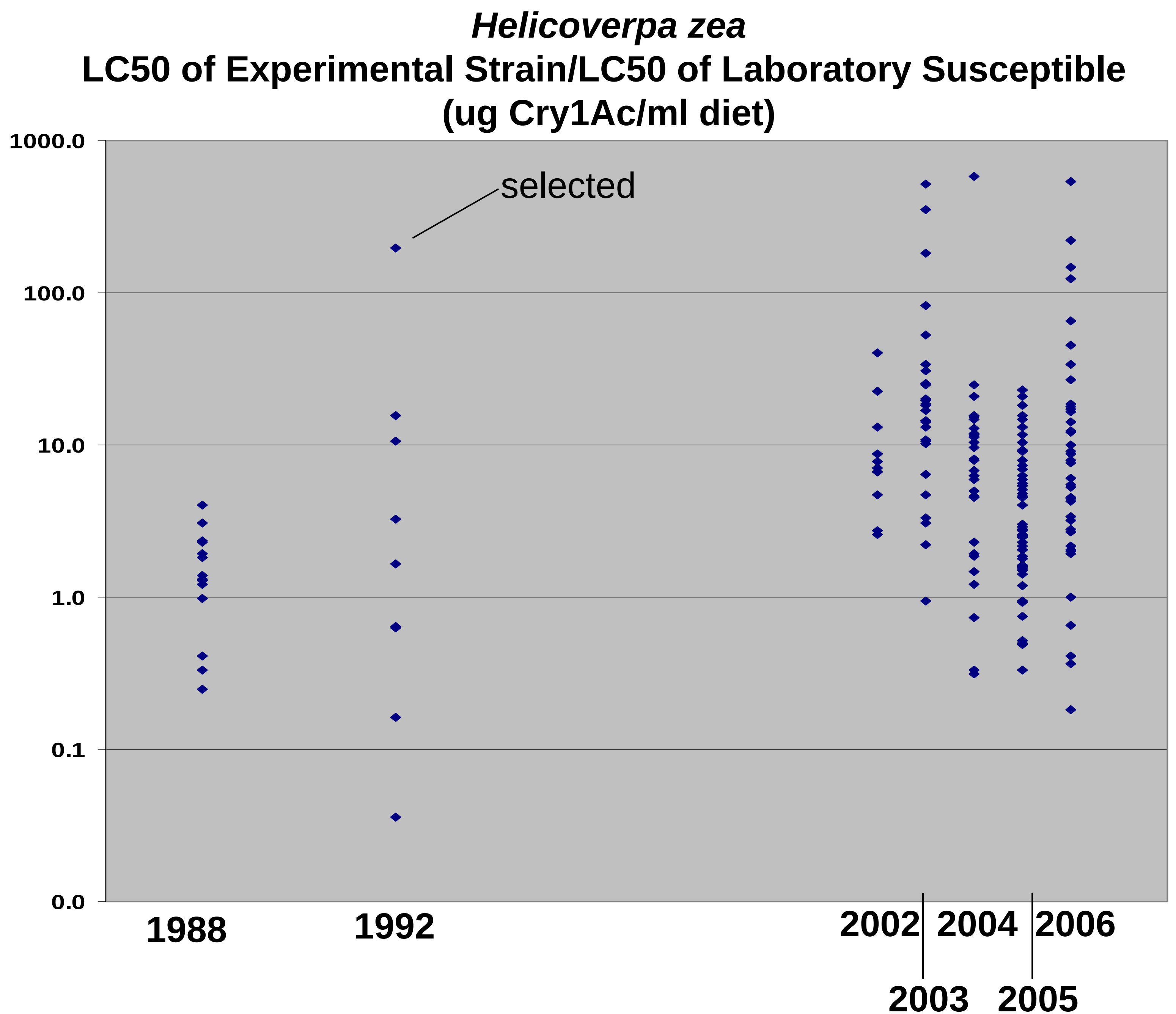
Specific Research

- Jackson et al. 2004. Proc. Beltwide Conf.
  - One in 1834 bollworm carried a major dominant gene for resistance to Cry1Ac – frequency of 0.000132

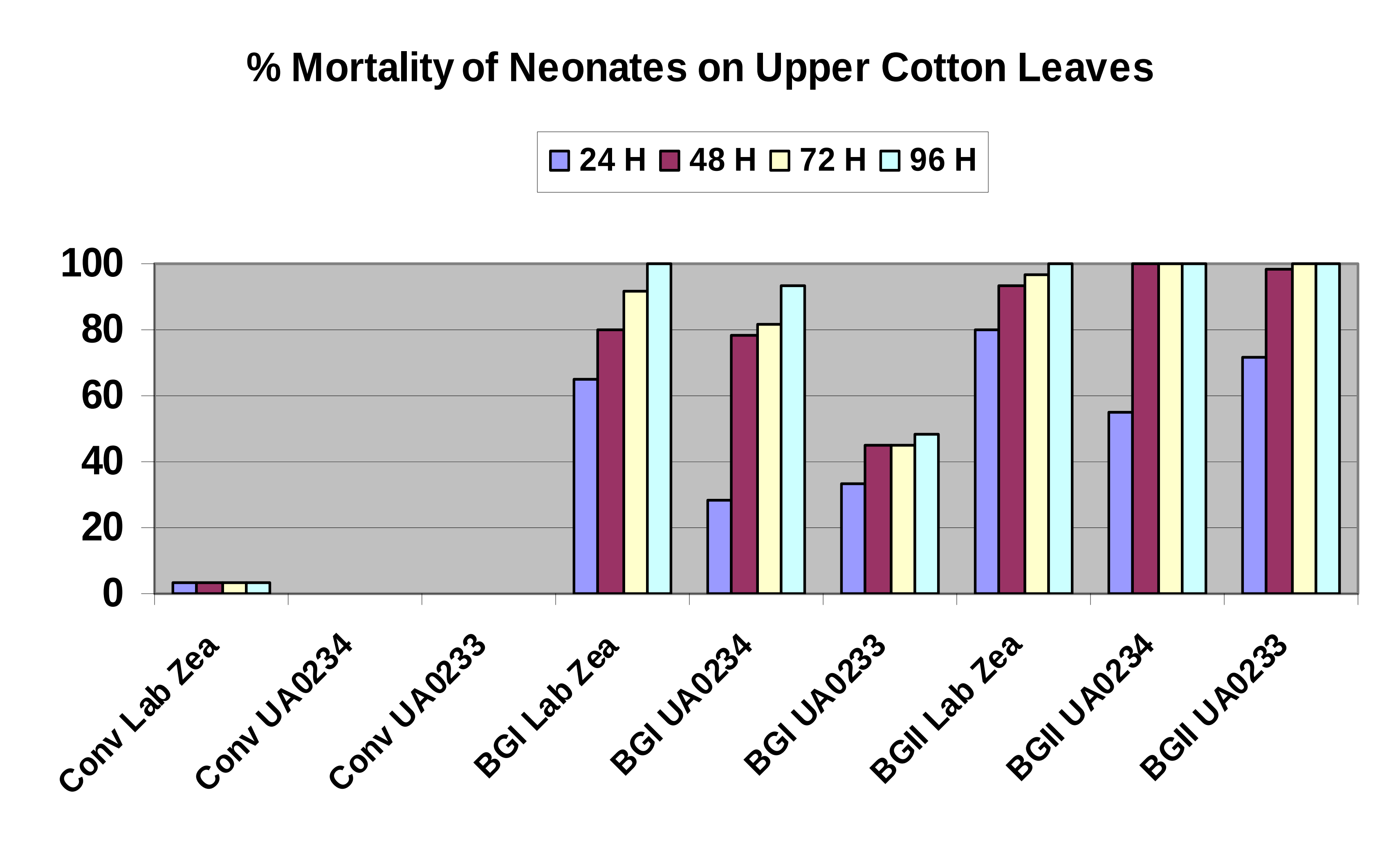
- Mullins and Hudson. 2004. Proc. Beltwide Conf.
  - BGII averaged 0.6 fewer sprays, 19 lb more lint/acre, $14.63 more returns than BG
  - BGII averaged 1.6 fewer sprays and $39.63 more returns than non-BT

Specific Research

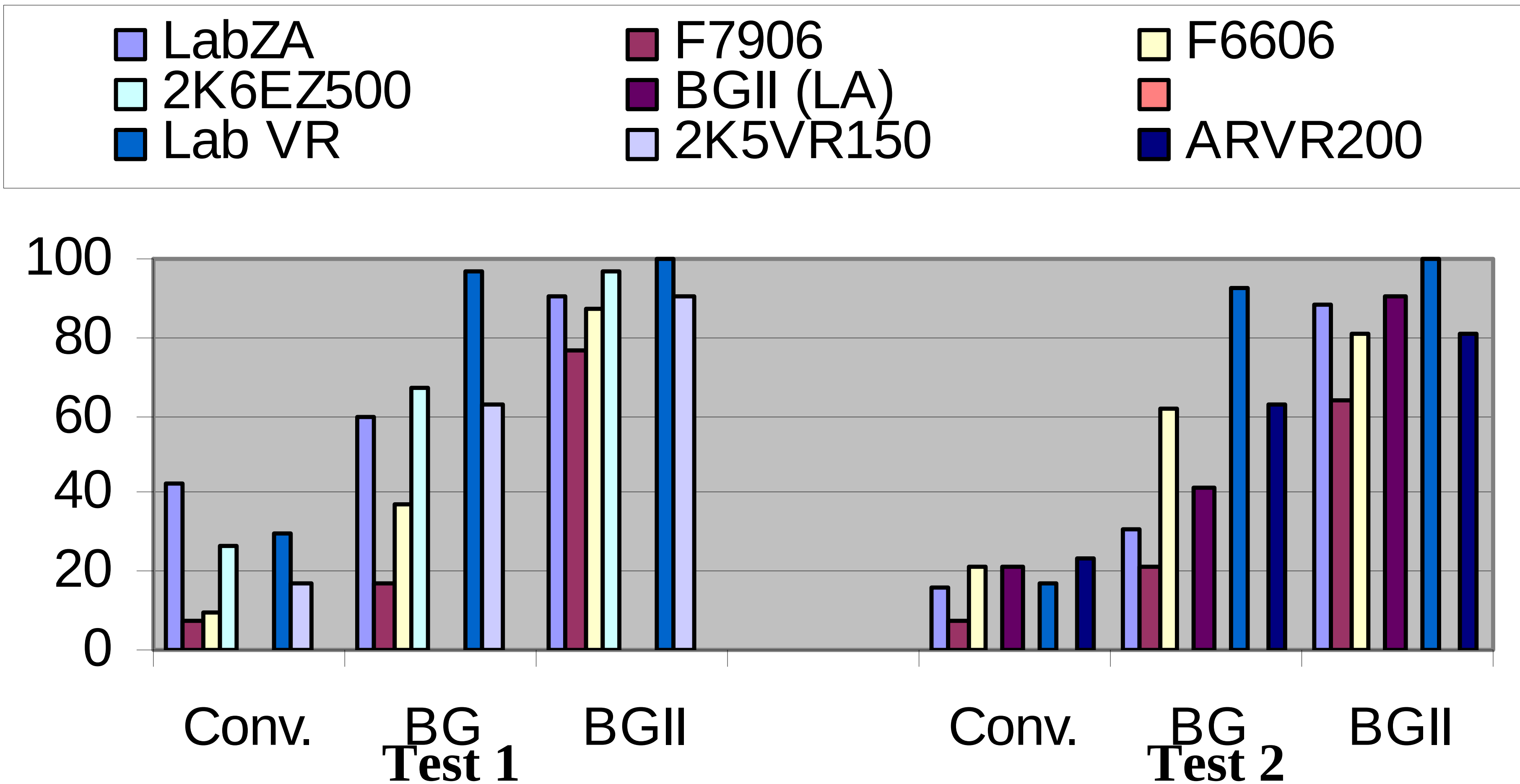
- Adamcyzk et al. 2005. Proc. Beltwide Conf.
  - Smaller moths from Bt corn than non-Bt corn
  - 3-fold reduction in number of moths from Bt corn
  - Fitness costs for moths from Bt corn small
- Hagerty et al. 2005. Proc. Beltwide Conf.
  - Threshold densities of bollworm on BGII cotton
- Jackson et al. 2006. Proc. Beltwide Conf.
  - Bollgard II provided more protection than Widestrike under high densities of bollworm
  - Under low to moderate pressure, Widestrike and Bollgard II were comparable in North Carolina and Virginia

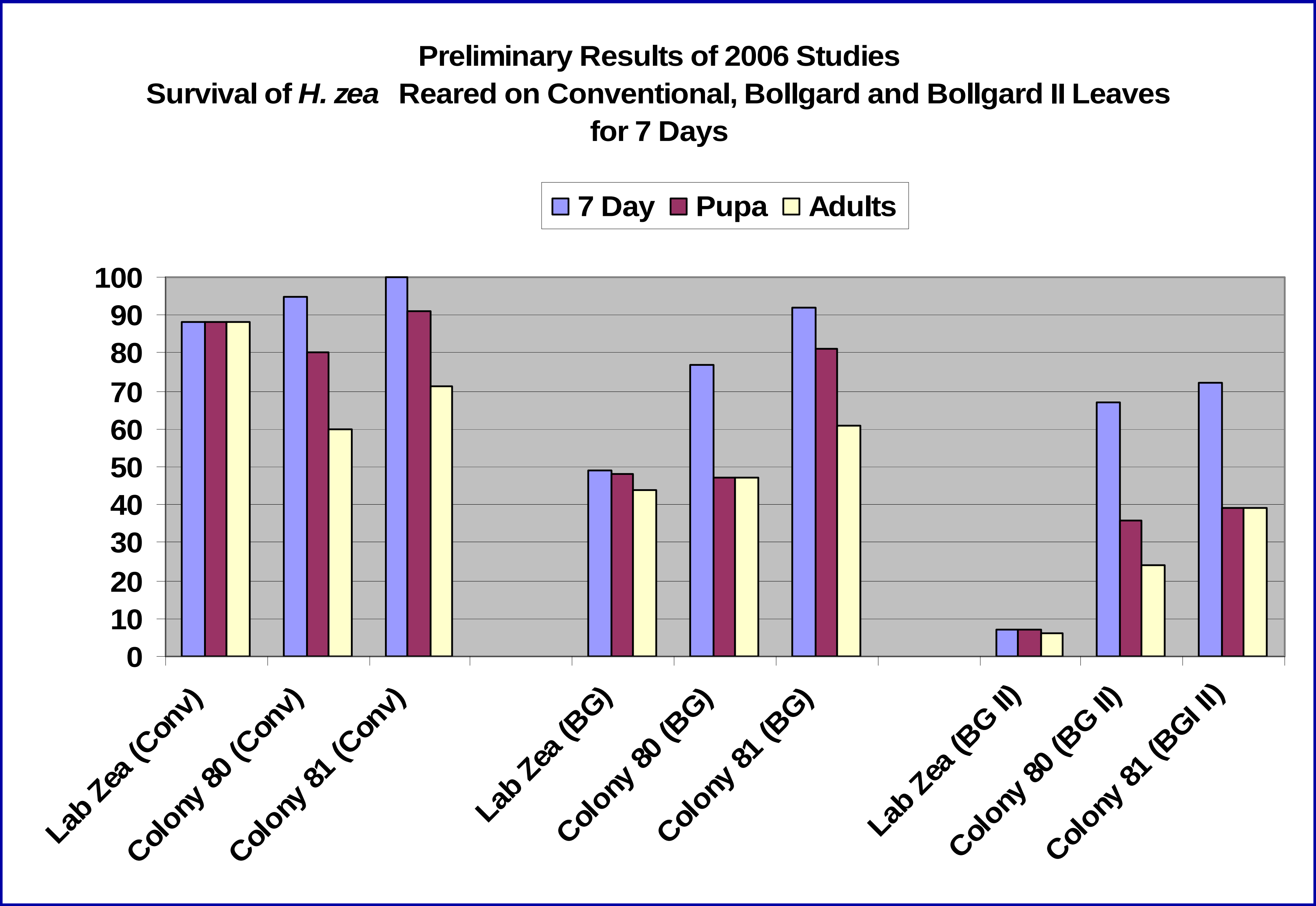


Helicoverpa zea
LC50 of Experimental Strain/LC50 of Laboratory Susceptible
(ug Cry1Ac/ml diet)
1000.0
100.0
10.0
1.0
0.1
0.0
selected
1988
1992
2002
2004
2006
2003
2005


% Mortality of Neonates on Upper Cotton Leaves
24 H
48 H
72 H
96 H
100
80
60
40
20
0
Conv Lab Zea
Conv UA0234
Conv UA0233
BGI Lab Zea
BGI UA0234
BGI UA0233
BGII Lab Zea
BGII UA0234
BGII UA0233

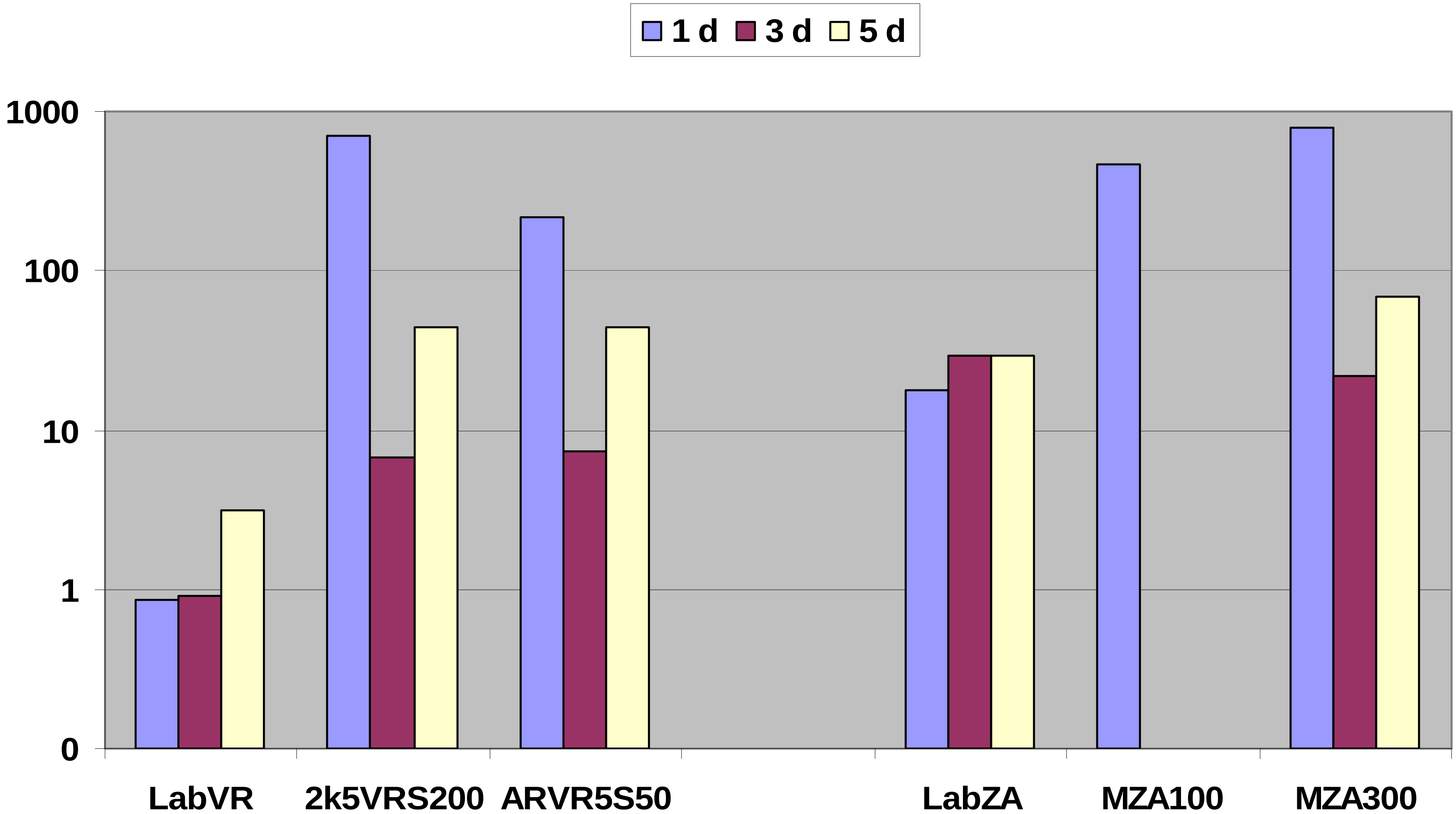
Preliminary Data 2006 Leaf Assays
(% mortality 6 days)

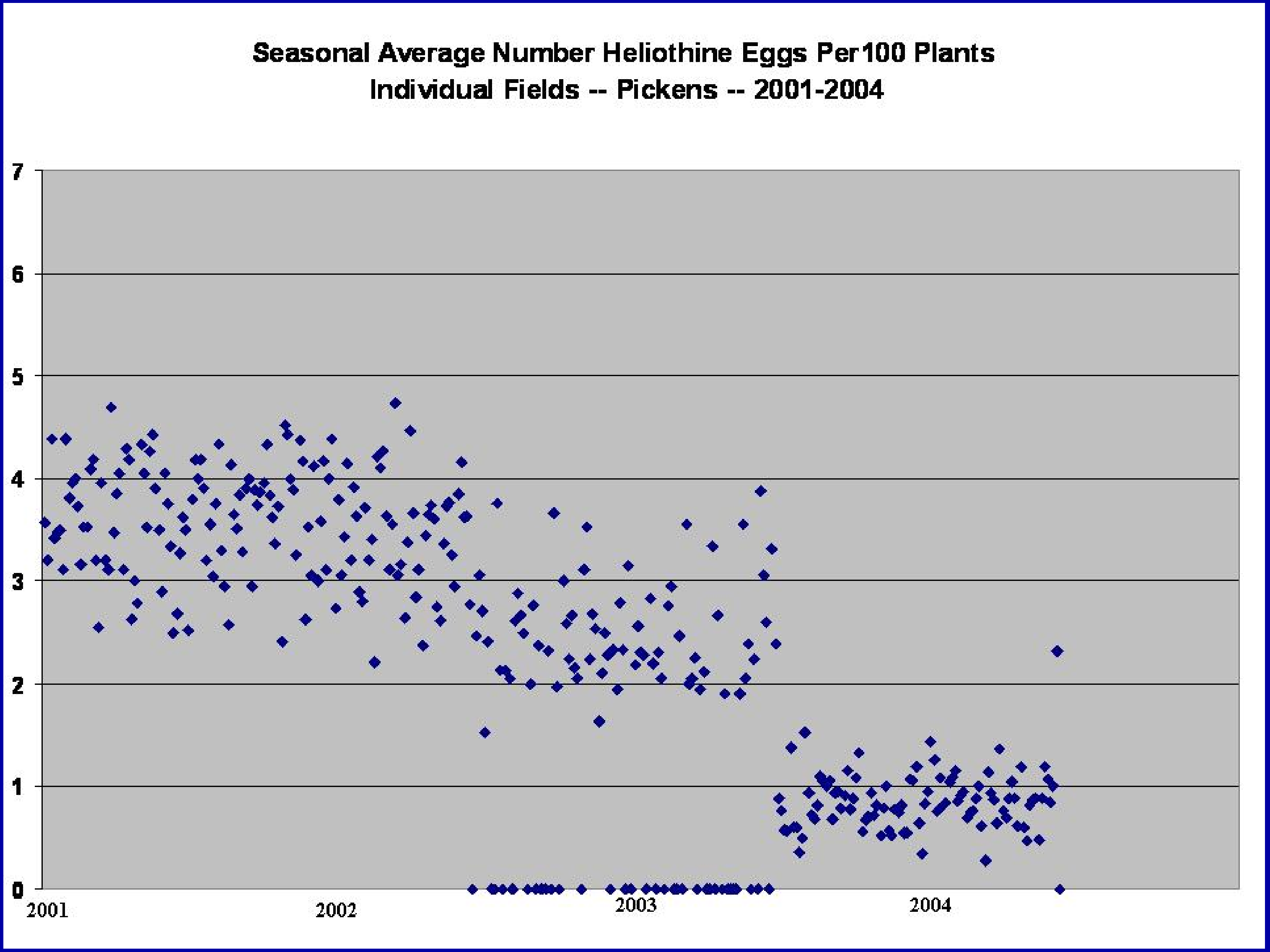


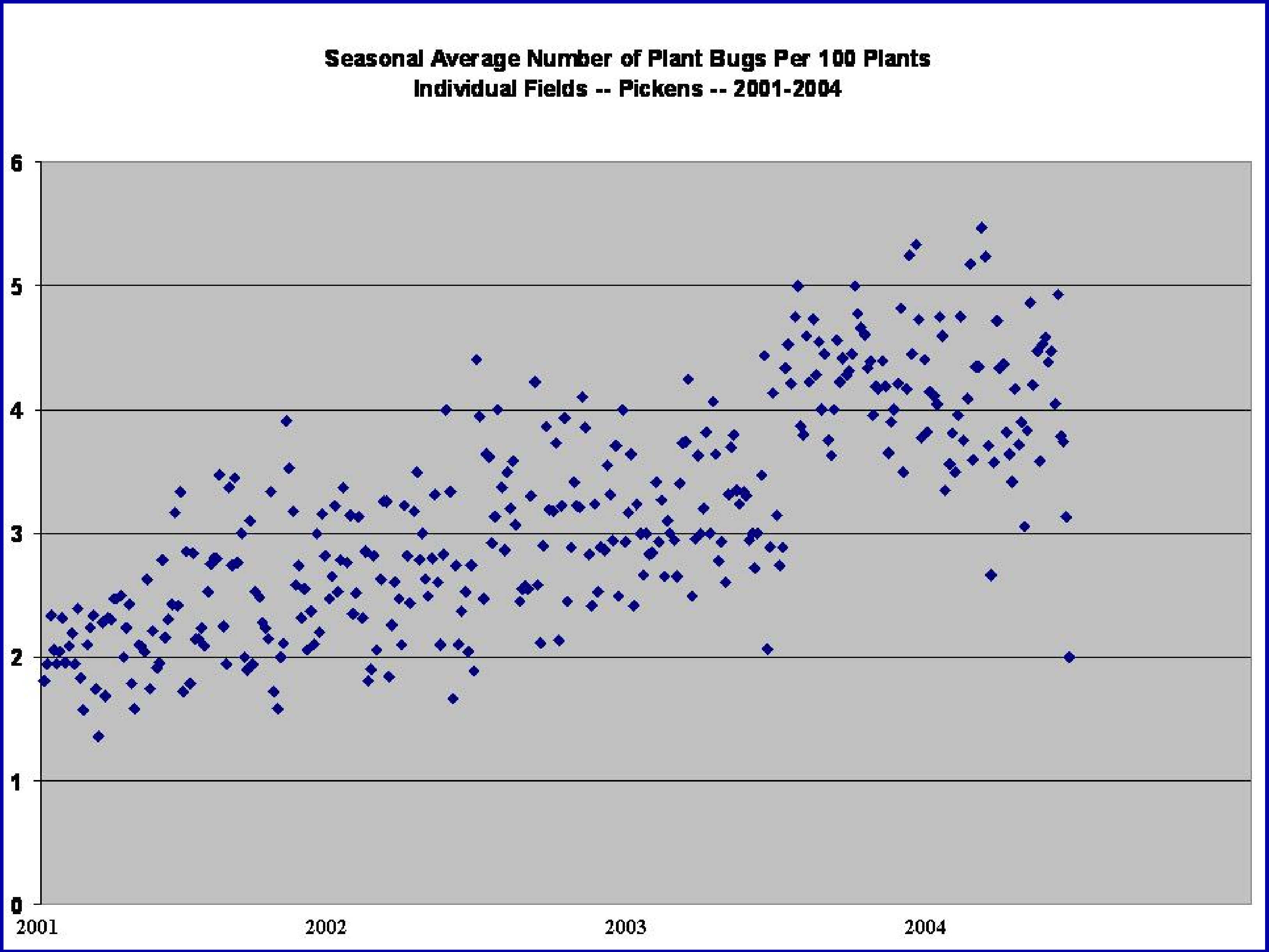


Preliminary Results of 2006 Studies
Survival of *H. zea* Reared on Conventional, Bollgard and Bollgard II Leaves for 7 Days
7 Day
Pupa
Adults
100
90
80
70
60
50
40
30
20
10
0
Lab Zea (Conv)
Colony 80 (Conv)
Colony 81 (Conv)
Lab Zea (BG)
Colony 80 (BG)
Colony 81 (BG)
Lab Zea (BG II)
Colony 80 (BG II)
Colony 81 (BGI II)

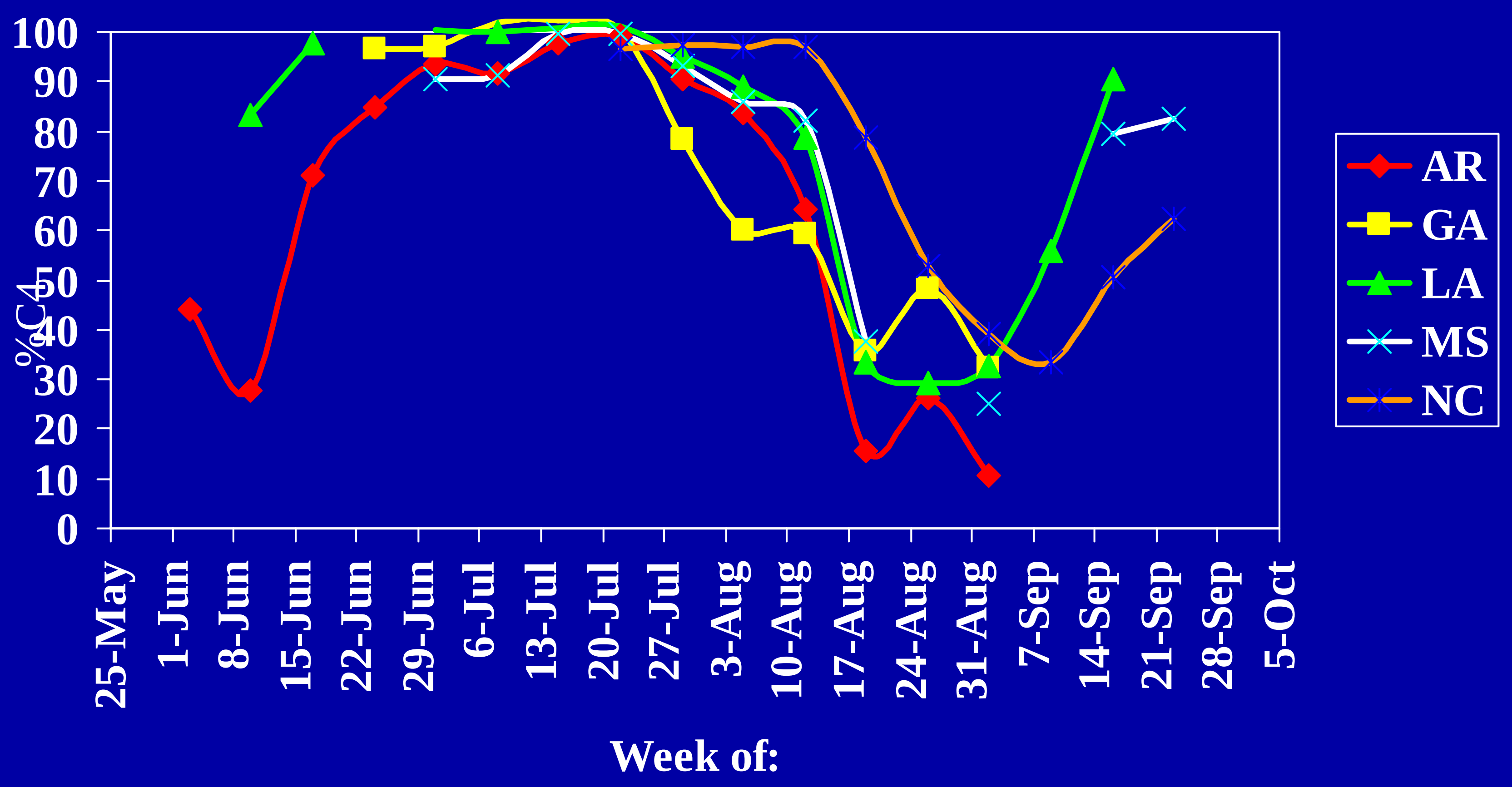
Preliminary 2006 Data
LC50s for Different Size Larvae from Different Colonies in Diet Incorporation Assays
LC50 = ug Cry1Ac/ml diet




Seasonal Average Number Heliothine Eggs Per100 Plants
Individual Fields -- Pickens -- 2001-2004
7
6
5
4
3
2
1
0
2001
2002
2003
2004


Seasonal Average Number of Plant Bugs Per 100 Plants
Individual Fields -- Pickens -- 2001-2004
6
5
4
3
2
1
0
2001
2002
2003
2004

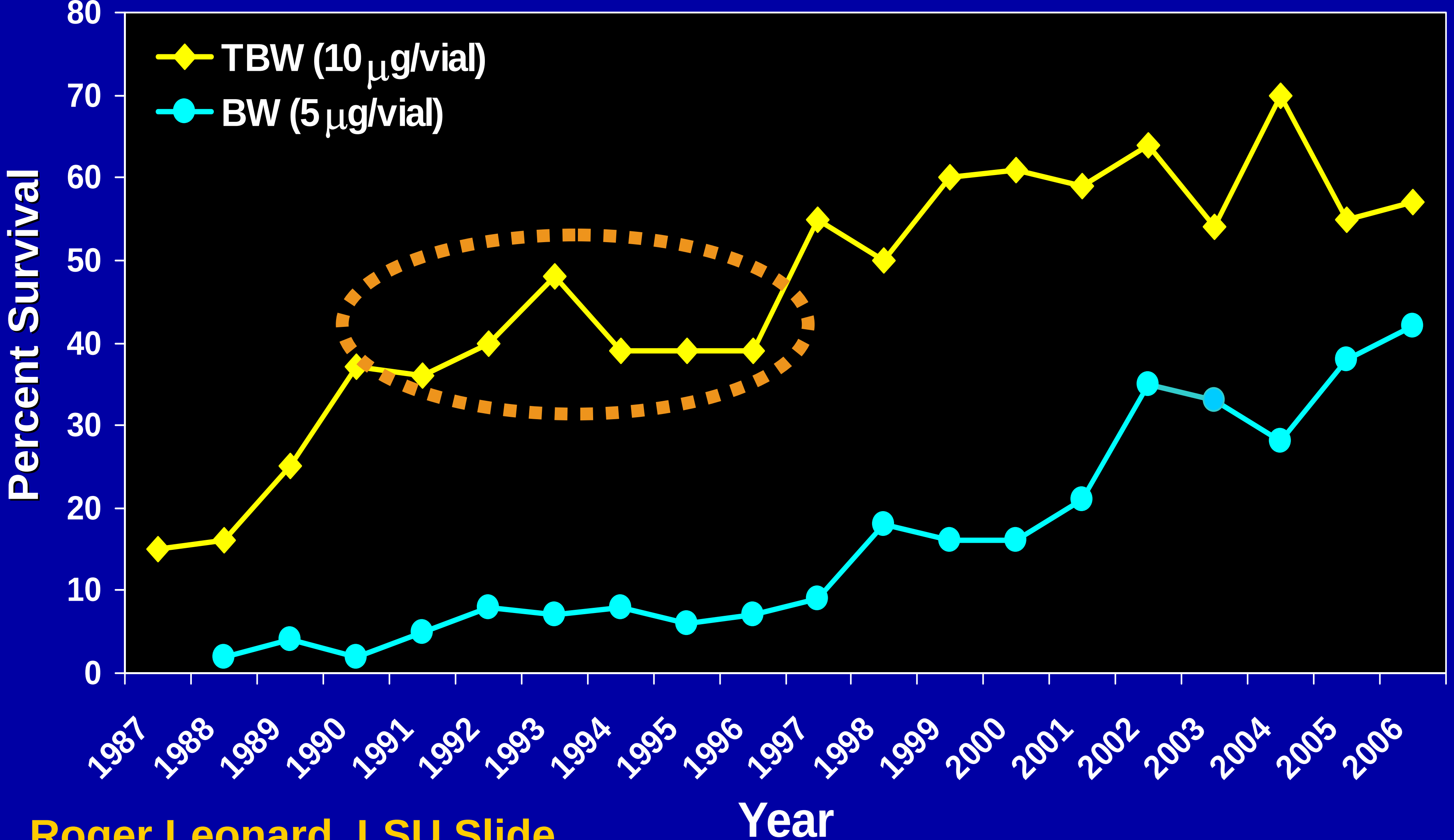
% of Moths from C4 Hosts in 2002



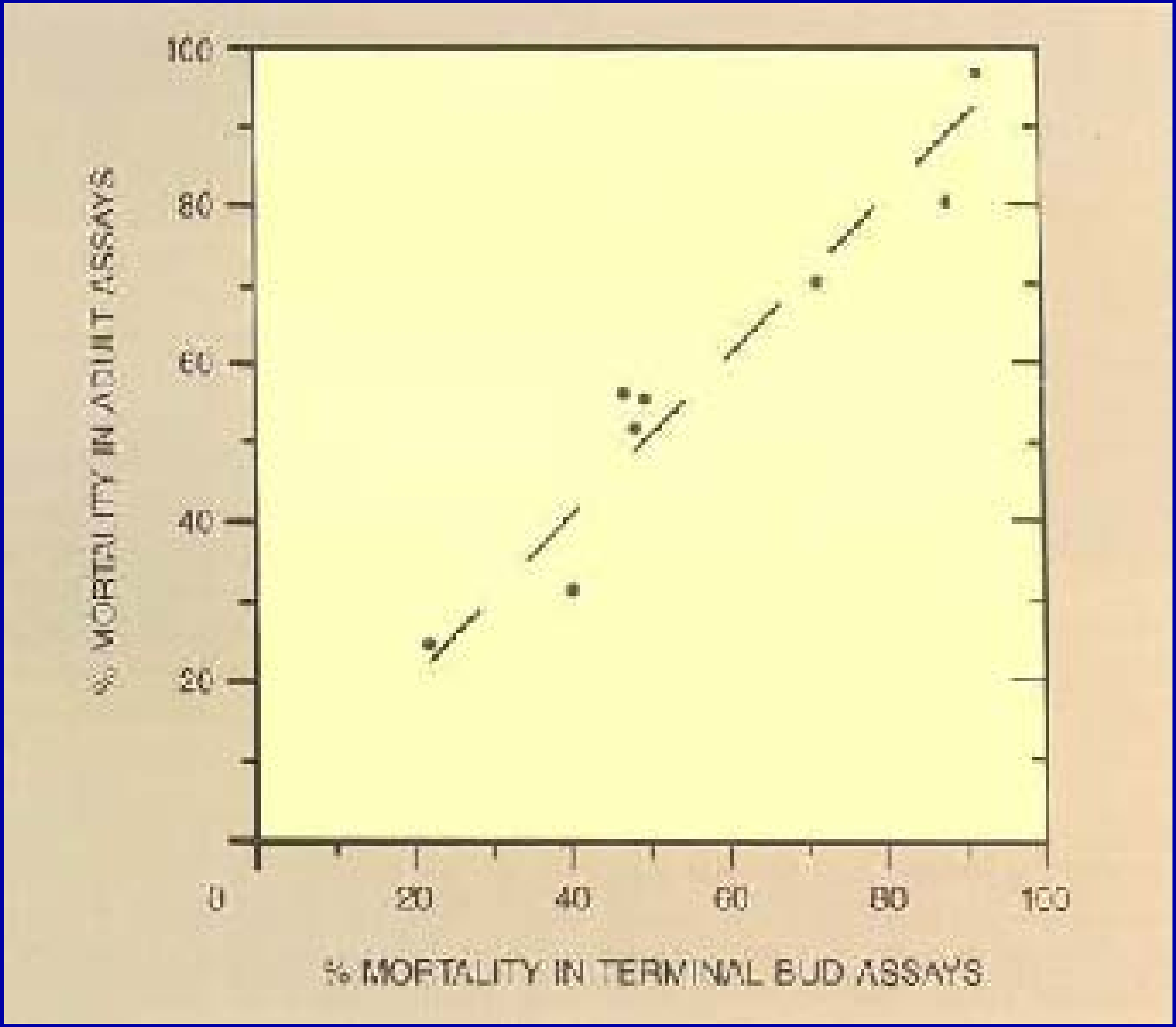
Time to Think About the Future

Resistance Monitoring Survey

Cypermethrin (May-Sep Mean Survival)



Roger Leonard LSU Slide



Roush and Luttrell. 1988. J. Econ. Entomol.

What if Gore et al. 2003 reflected damage potential of bollworm?

- 6.6 fruit damaged/larva non-Bt
- 3.5 fruit damaged/larva BG
- 0.8 fruit damaged/larva BGII

- Threshold of 4000 larvae on non-Bt (26,400 damaged bolls)?
- Threshold of 7543 larvae on BG?
- Threshold of 33,000 larvae on BG II?

What if Jackson et al. 2003 moth production represented damage?

- 26,172 moths on untreated conventional and 5,714 moths on treated conventional (78% control)
- 15,777 moths on untreated BG and 999 moths on treated BG (94% control)
- 1067 moths on untreated BG II and 0 moths on treated BG II (100% control)

- Threshold of 4000 on conventional = 880 survivors (78% control)
- Threshold of 14,667 on BG = 880 survivors (94% control)
- Threshold of >40,000 on BG II = 880 survivors (100% control

What if Mullins and Hudson 2004 reflected equivalence of management?

- BG II 0.6 few sprays than BG, BG II 1.6 fewer sprays than non Bt
- BG II $14.63 more profit than BG, BG II $39.63 more profit than non Bt
- Assume scouting $10 per acre, cost of insecticide is $10 per acre, yield potential is equivalent

- Conventional system could add ~4 sprays or 3 sprays and double scouting or 2 sprays and triple scouting
- BG system could add ~1.5 sprays or double scouting and 0.5 sprays
- Why not reinvest? Convenience, reduced management of BGII versus technology confidence and perceived risk (insurance) of BG and conventional cottons

Full Circle or New Direction?