Costs and Benefits of Controlling *Diabrotica*: The USA Experience

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Presentation to EU DIABR-ACT Project Group
Wageningen, Netherlands April 3, 2007

Outline of Presentation

- CRW species and distribution in USA
- Current problems in USA
- My work: Damage functions, IPM, IRM
- Cost of CRW control and damage in USA

Diabrotica Pests of Corn in USA

- Western CRW *D. virgifera virgifera*
- Northern CRW *D. barberi*
- Southern CRW *D. undecimpunctata howardi*
- Mexican CRW *D. virgifera zea*

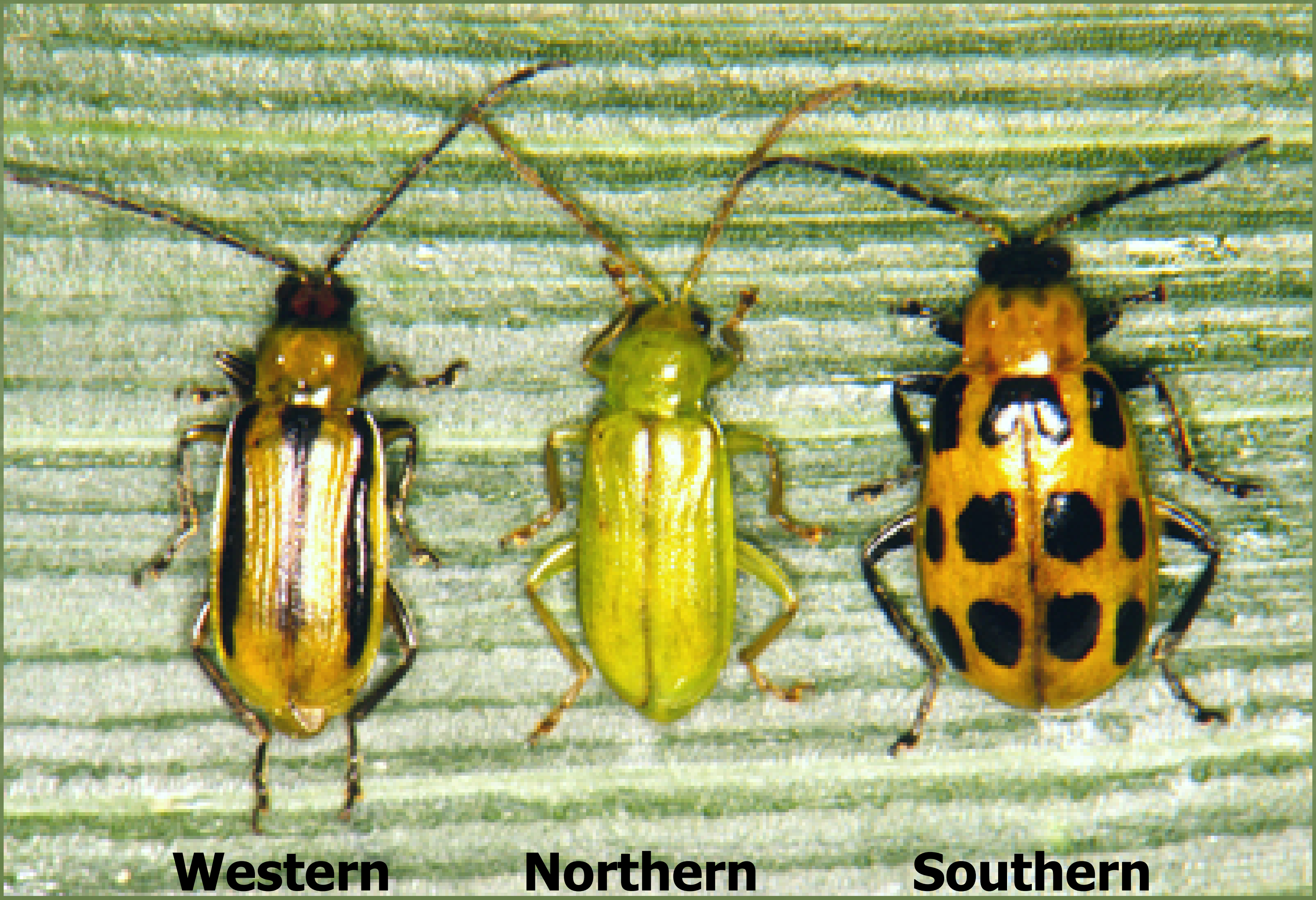
- Major pests: Western and Northern CRW, where I will focus except for this overview


Northern Corn Rootworm
©Marlin E. Rice

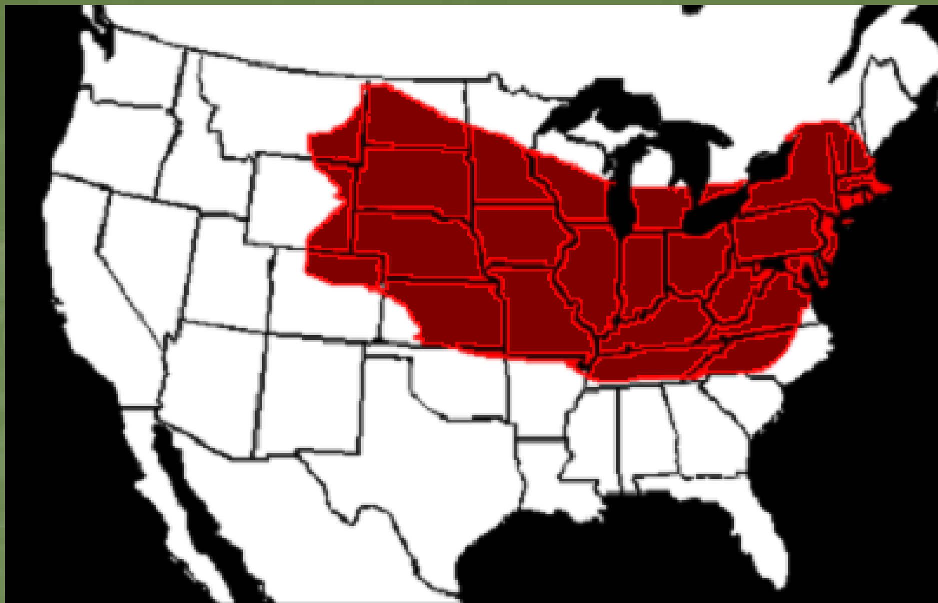

Western Corn Rootworm


Mexican Corn Rootworm

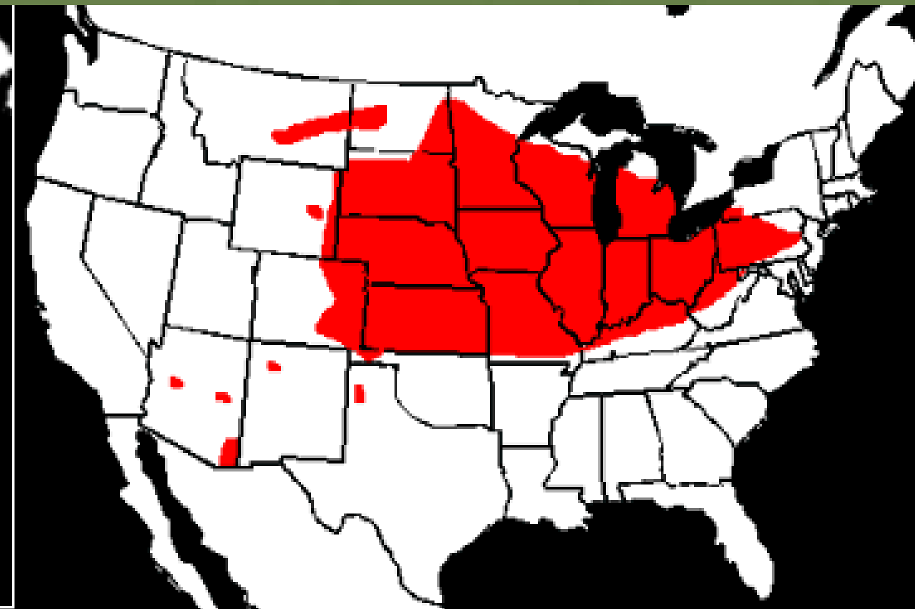

Southern Corn Rootworm

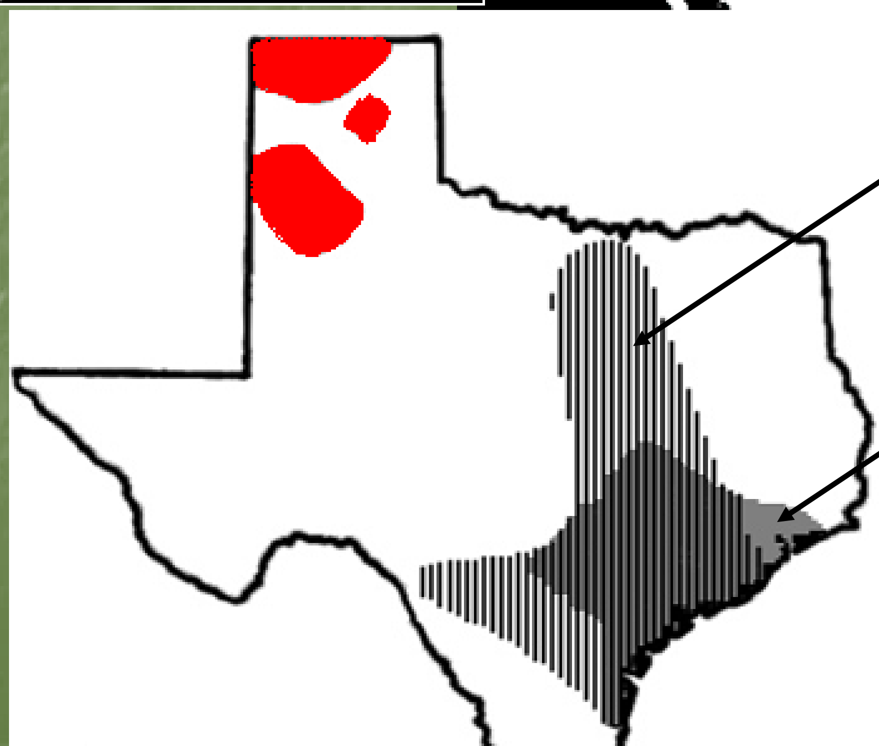

Western
Northern
Southern

Northern

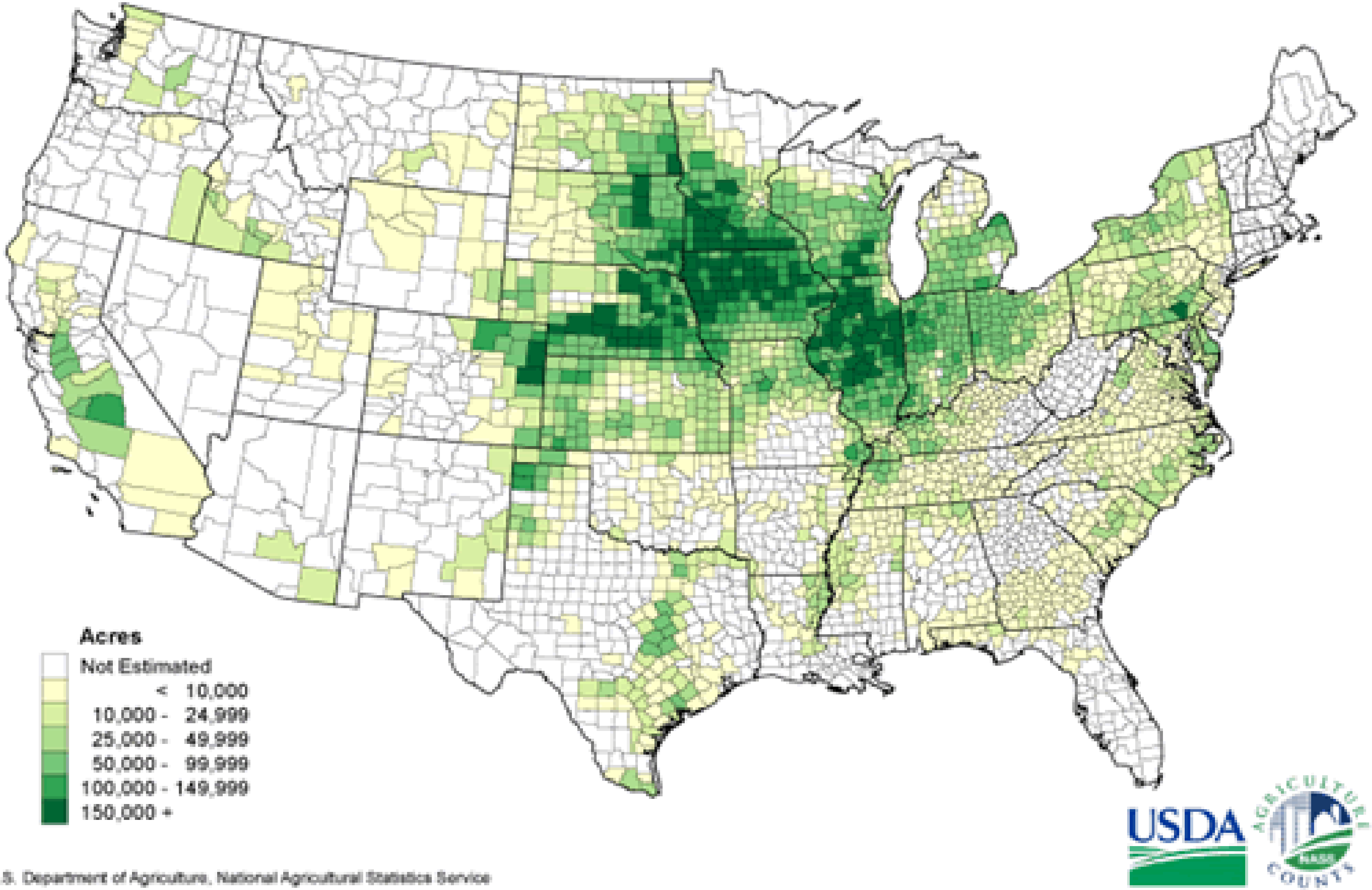


Western





Corn for Grain 2005
Planted Acres by County
for Selected States



U.S. Department of Agriculture, National Agricultural Statistics Service

CRW Control Methods used in USA

- Crop Rotation (CRW mostly monophagous)
  - Most popular, but failing due to resistance
- Soil Insecticides applied at plant for larvae
  - Most popular alternative, but many not like
- Aerial Insecticide to stop adult egg laying
  - Popular where use aerial control for other pests
- Seed Treatment (systemic insecticide)
  - Convenient, wide spectrum control, low efficacy
- Bt Corn (transgenic insecticide)
  - Convenient, effective, but needs refuge for IRM

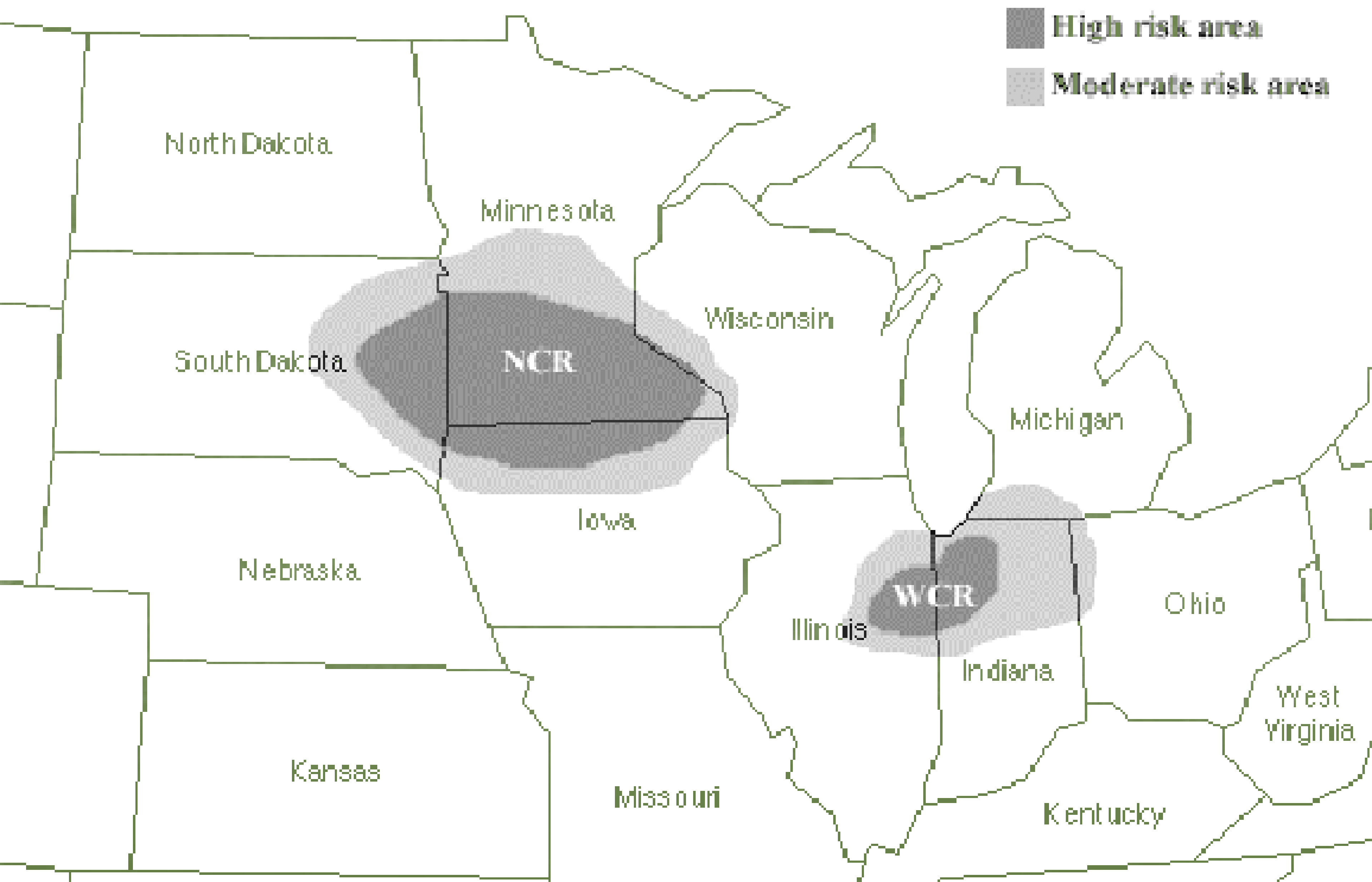
Recent CRW Problems in USA

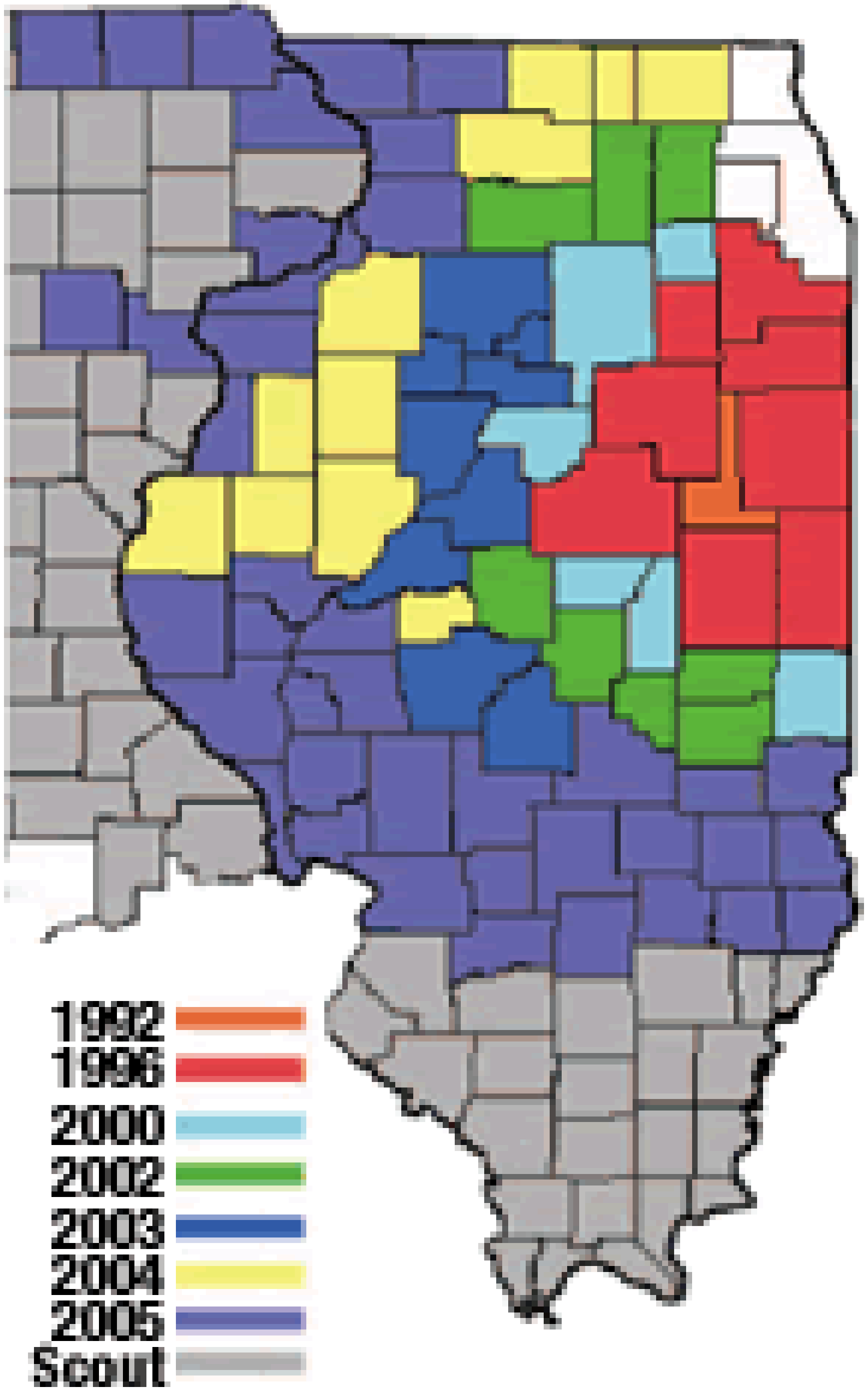
- Resistance Management
  - Development and spread of resistance to previously effective control methods
  - Implementation of IRM for Bt corn
- Valuing new control technologies
  - Seed treatments and Bt corn relatively new
  - Value of control in first-year corn

Rotation Resistance

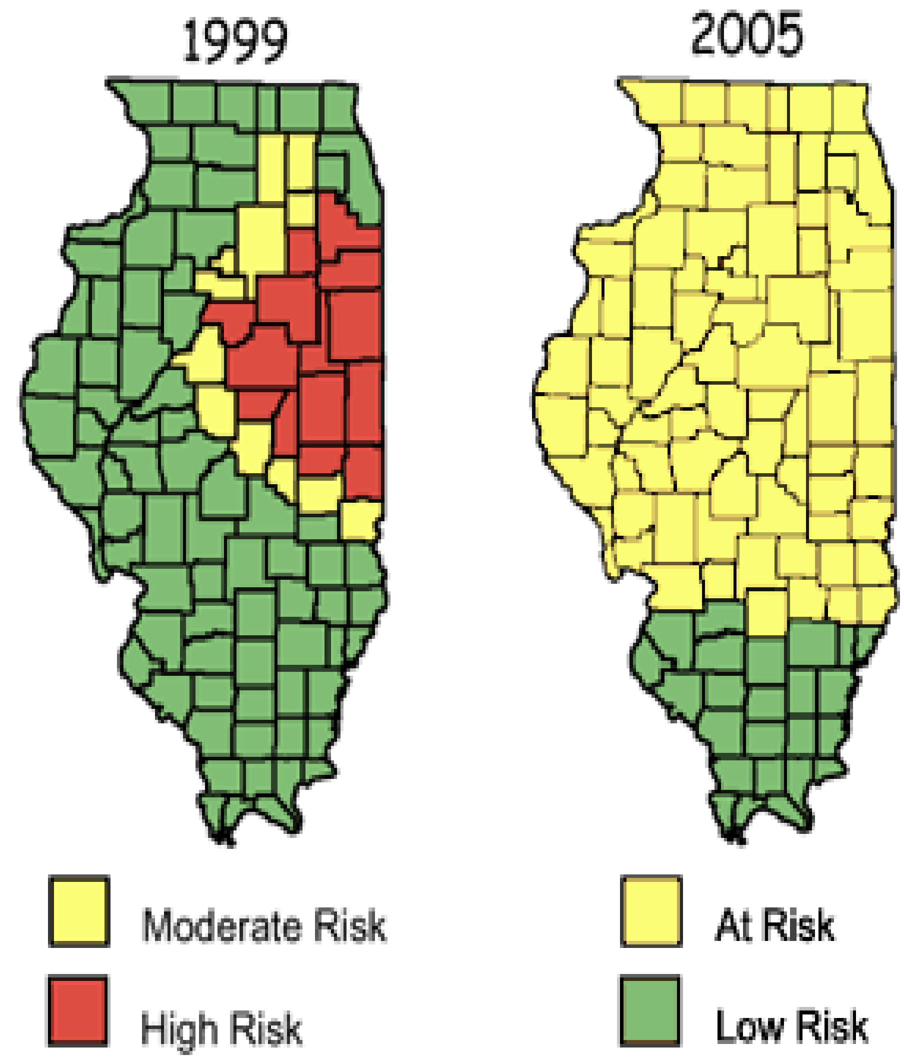
- Rotation widely used to manage CRW, only corn following corn needed chemical control
- Development and spread of WCR soybean variant that lays eggs in non-corn crops (e.g., soybeans)
- NCR extended diapause increased so now many eggs hatch after 2 or more winters
- Both cause collapse of rotation for crw control
- Both arose in mid 1990’s in different areas
- WCR more rapid spread, NCR slower spread
- Rotated corn now needs rootworm control in many areas where it previously did not

Rotation Resistance in 2003



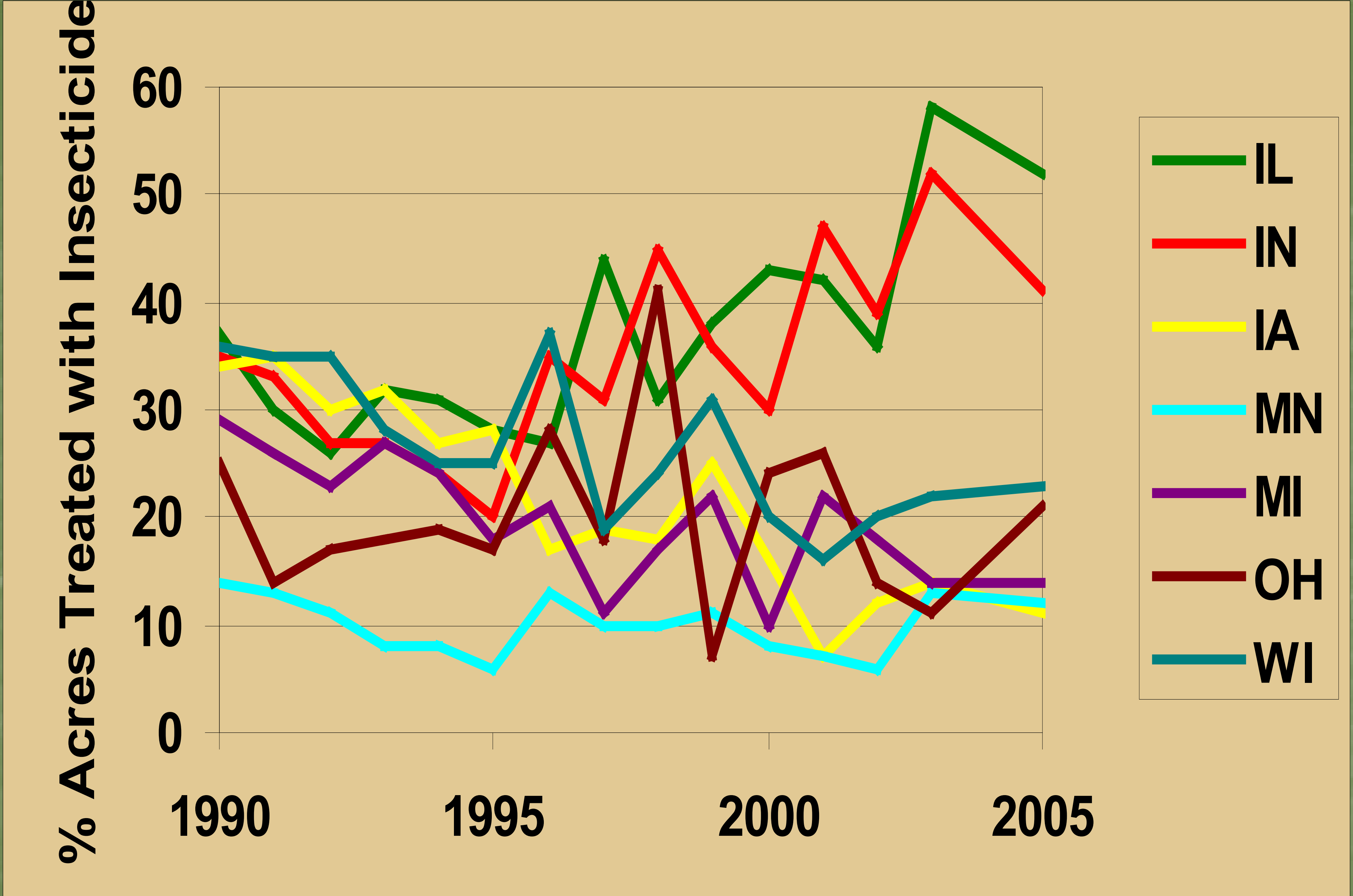


Potential WCR injury in first-year corn

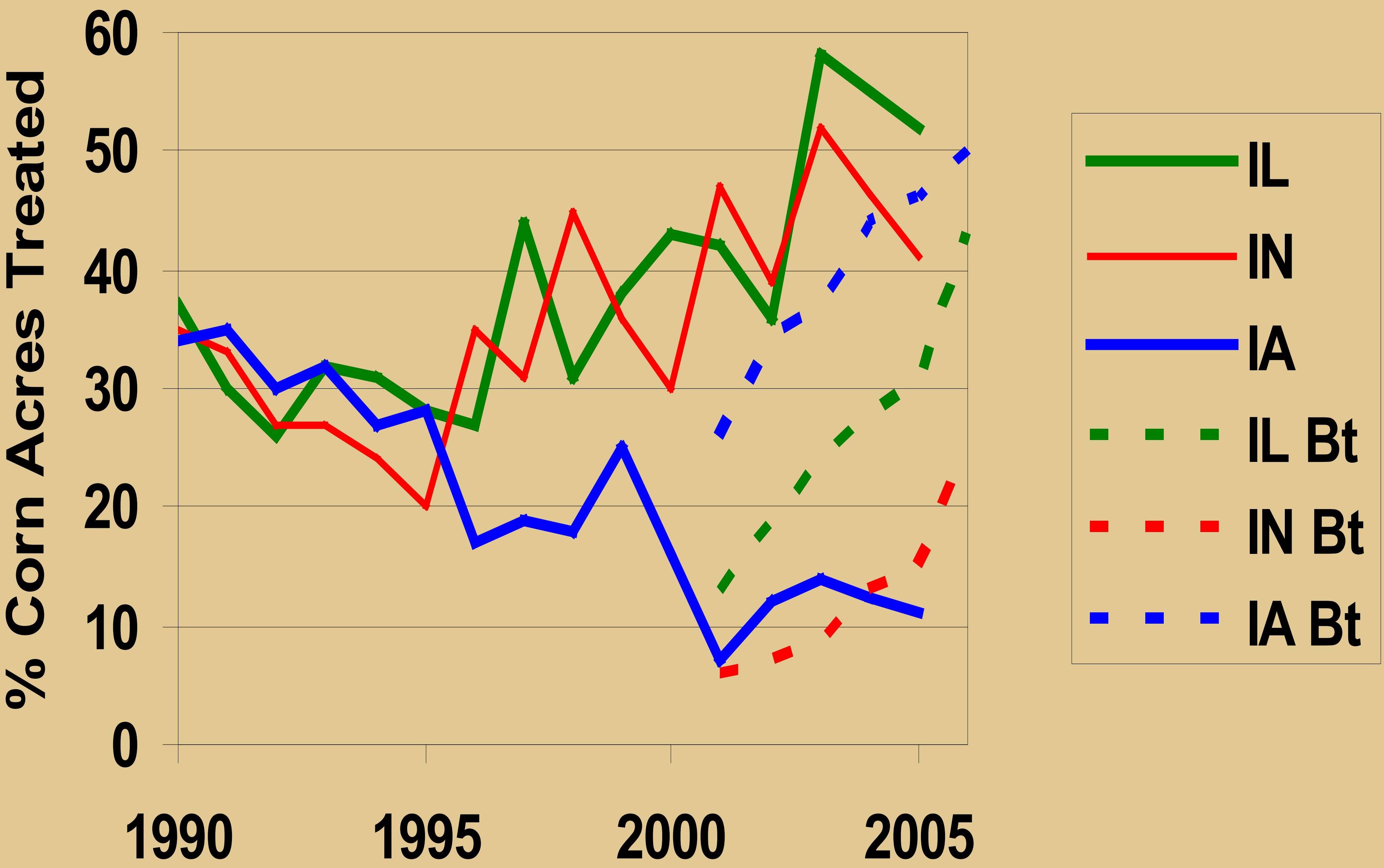


Effect of Rotation Resistance

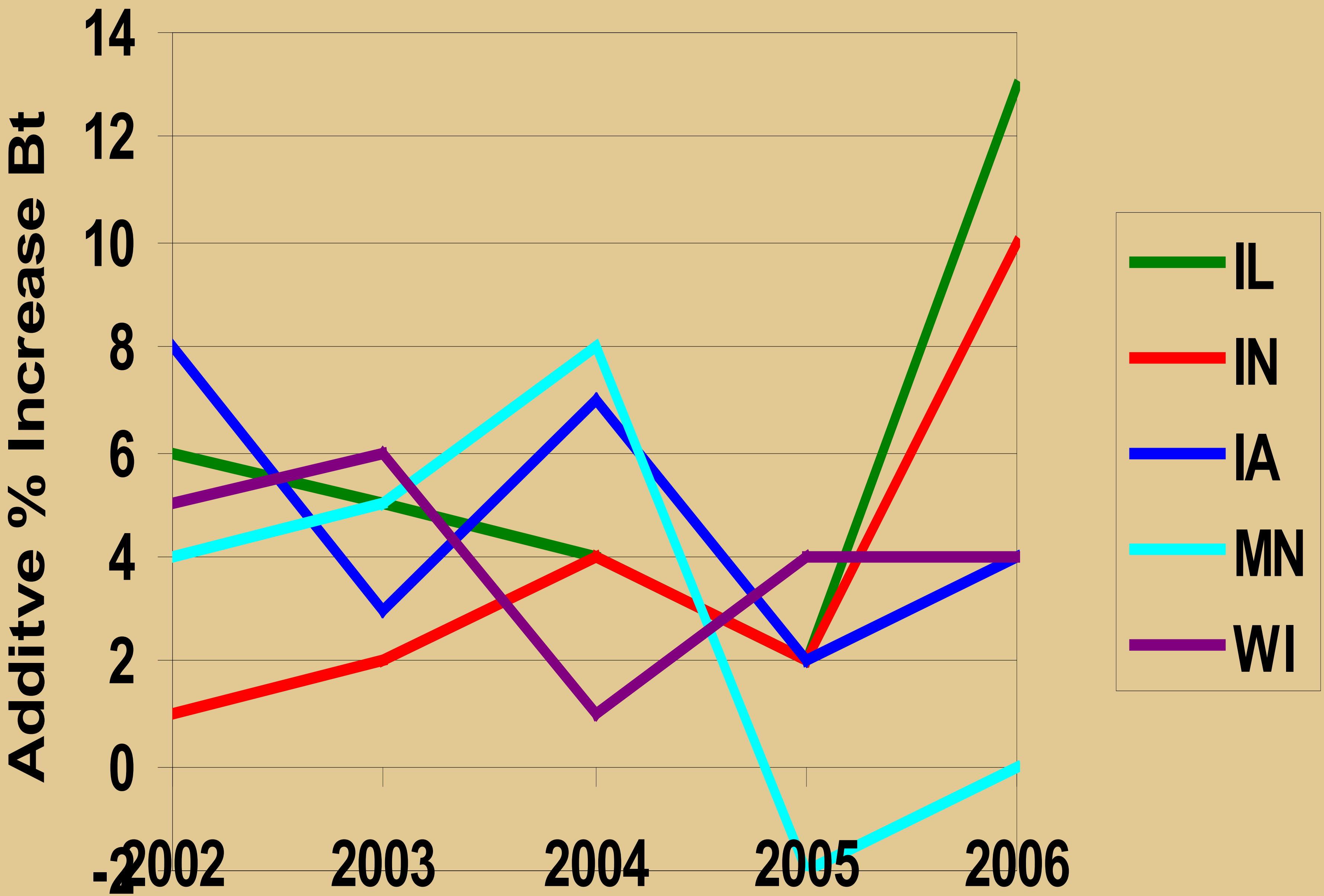
- Initially increased insecticide use, especially in hard hit states of IL and IN
- More recently, increasing adoption of Bt corn in IL and IN where had been relatively low adoption of ECB Bt corn
- Anecdotal data to support these claims



Note: We do not know that CRW was the target pest



Do not know target pest or % RW vs CB Bt corn


Additve % Increase Bt
14
12
10
8
6
4
2
0
-2
2002
2003
2004
2005
2006
IL
IN
IA
MN
WI

Demand for CRW Economics

- With rotation resistance spreading, many farmers were suddenly interested in crw control
  - What is the cost of crw damage in first-year corn?
  - When is crw control worth the cost in first-year corn?
- Seed treatments and RW Bt corn newly commercialized control methods
  - What is the net benefit of a seed treatment?
  - What is the net benefit of RW Bt corn?
- My work was a few papers, but mostly Extension

CRW IPM for Rotation Resistance

- CRW IPM in corn after corn rarely adopted
- Lots of crw treatments were being applied that were not needed or were not economical
- Universities documented spread of rotation resistance so farmers know if in a risk area
- Others worked to develop IPM for first year corn
  - Pherocon AM traps in soybean fields
  - Threshold: 5 beetles/trap/day
- I currently have grants to work on CRW IPM for first-year corn

Insect Resistance Management

- RW Bt corn commercialized with refuge requirement similar to that for CB Bt corn
  - 20% refuge in field or in adjacent field
- What is the cost of refuge?
- Does this cost justify the benefit of refuge?
- Can we manage resistance to rotation?
- My Work on Economics of IRM
  - Simultaneous WCR resistance to Bt and rotation
  - Effect of NCR extended diapause on Bt IRM
  - Economics of refuge compliance programs
  - Incorporating human behavior into IRM models

Damage Functions

- Addressing these economic questions led my research into estimation of pest damage functions with experimental data
- Standard methods use behavioral data
- Loss is $\lambda = f(x)$, where $f(\cdot)$ is damage function
- x is an observable damage measure related to pest population density (root rating, NIS, etc.)
- $x = g(n)$, where n is pest population density and $g(\cdot)$ relates pest density to damage measure
- Can have $x = n$

Damage Functions

$\longleftarrow$ Economics $\longrightarrow$ | $\longleftarrow$ Entomology $\longrightarrow$

	loss	NIS	CRW
$\$$	λ	x	n

$$\$ \xleftarrow{\pi(\lambda)} \lambda \xleftarrow{f(x)} x \xleftarrow{g(n)} n$$

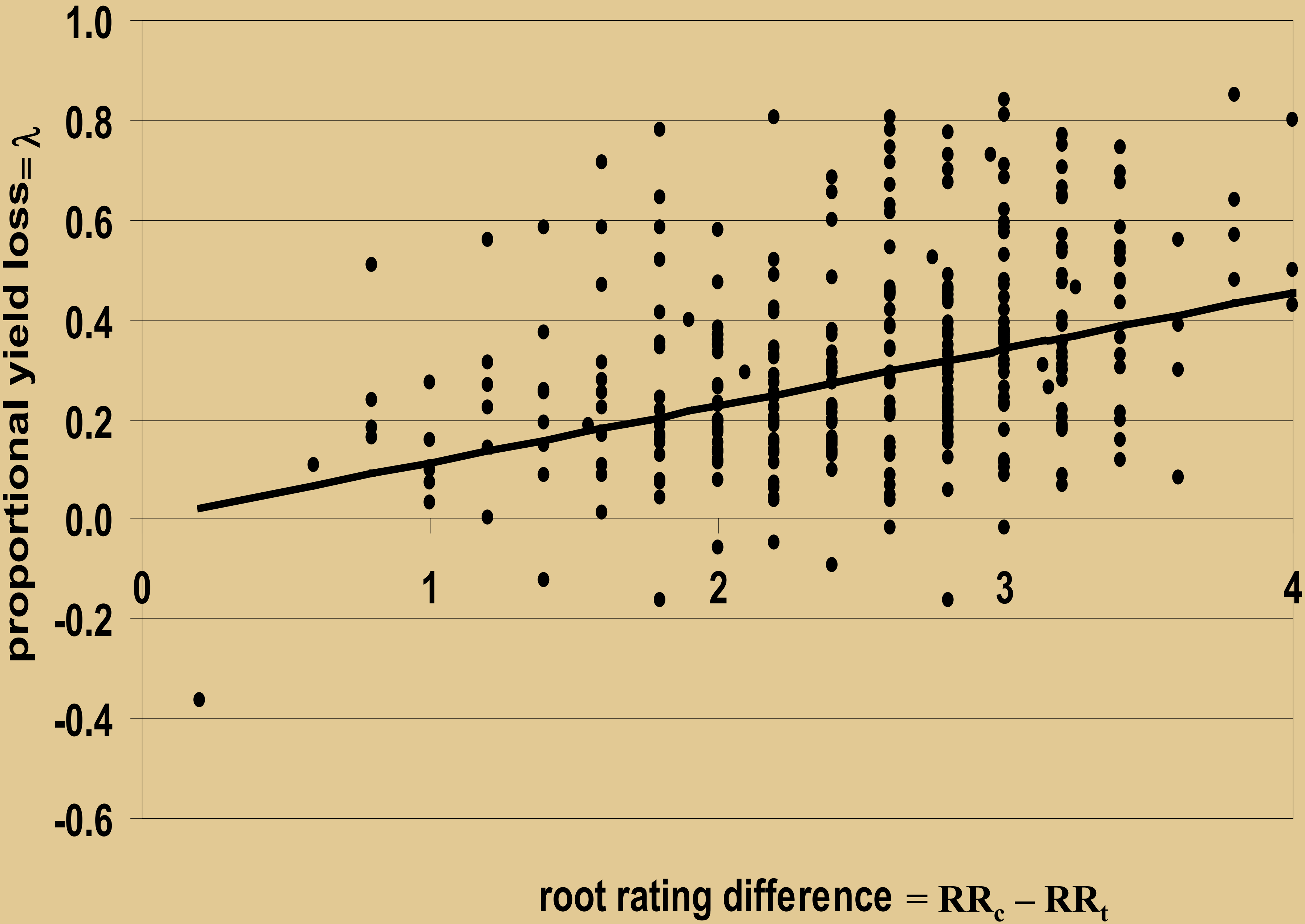
- Scientists conduct experiments to collect data on n and x
- Damage function f(x) connects biology and economics

Example

- Gray and Steffey (1998): 3 years of field experiments on root ratings and yield loss
- Mitchell, Gray and Steffey (2004) used these data to estimate $\lambda = f(x)$, where λ is % loss and x is root rating (1-6 scale)
- Application: Cost of WCR soybean variant to example farmer in Illinois

Gray and Steffey (1998) Data

- Yield for soil insecticide treated and untreated (control) plots: Y_t and Y_c
- Loss $\lambda = (Y_t - Y_c)/Y_t$
- $Y_t = 200$ bu/ac and $Y_t = 150$ bu/ac
- $\lambda = (200 - 150)/200 = 0.25$: 25% loss
- Root Rating for both plots RR_t and RR_c
- x = root rating difference $RR_c - RR_t$
- How much CRW increased damage index



proportional yield loss = λ
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
1
2
3
4
root rating difference = $RR_c - RR_t$

Negative Loss Problem

- Experimental noise can dominate treatment effect so treated yield < control yield, implying a "negative loss" ($\lambda < 0$)
- Assuming pests can only cause positive damage, observed negative losses are due to experimental noise/measurement errors
- Need econometric model that allows <u>observed</u> negative yield losses, but limits loss <u>due to pest</u> to range 0 to 1

Composed Error Model Mitchell et al. (2004)

- Borrow two part error model from technical efficiency estimation, assume
- Experimental noise: $\varepsilon \sim N(0,\sigma^2)$
- Treatment effect: $\delta \sim$ Exponential, where exponential pdf has parameter $\theta = q(x)$
- Estimate σ and parameters of $q(x)$
  - σ captures experimental error
  - $q(x)$ captures pest damage
- For analysis, $\sigma = 0$: no experimental noise

Proportional Yield Loss from WCR Soybean Variant in IL for both Damage Models in Monte Carlo Analysis

Measure	Conventional	Composed Error
Mean	0.113	0.113
St. Dev.	0.197	0.117
Minimum	-0.828	0.000
Maximum	1.017	0.954
2.5% Quantile	-0.274	0.002
97.5% Quantile	0.500	0.435

Lower st. dev. and losses range 0 – 1 with composed error

Cost ($/ac) of WCR Soybean Variant Damage in First-Year Corn in IL for 3 Levels of Farmer Risk Aversion

	E[Yield]	Conventional	Composed Error
Risk Neutral	160	36.10	36.10
	140	31.59	31.59
	120	27.07	27.07
Moderate Risk Aversion	160	43.43	37.46
	140	38.00	32.78
	120	32.57	28.10
High Risk Aversion	160	48.45	38.52
	140	42.40	33.70
	120	36.34	28.89

Yang et al. (2007) Unbalanced Nested Component Error Model

- Use from panel data methods
- Conventional (OLS): $y_{tlr} = x_{tlr}'\beta + u_{tlr}$
- Nested Error: $y_{tlr} = x_{tlr}'\beta + \mu_t + \nu_{tl} + \varepsilon_{tlr}$
  - $\mu_t \sim N(0,\sigma_\mu)$ random year effect
  - $\nu_{tl} \sim N(0,\sigma_\nu)$ nested location effect
  - $\varepsilon_{tlr} \sim N(0,\sigma_\varepsilon)$ experimental noise
- Estimate β and σ_μ, σ_ν, and σ_ε

Yang et al. (2007)

- Paper compares several estimators
- Focus here on Conventional OLS and Maximum Likelihood
- Slope β: OLS = 0.113, MLE = 0.0572
- OLS σ^2 = 0.375, MLE σ^2_μ = 0.0129, σ^2_ν = 0.0130, and σ^2_ε = 0.0225
- Drop σ^2_ε for economic analysis

Net benefit ($/ac) of soil insecticide and Bt corn for WCR soybean variant control in 1st-year corn in IL

Treatment	Risk Aversion	Conventional	Unbalanced Nested
Soil Insecticide	Neutral	17.88	-0.60
	Moderate	16.29	-1.80
	High	14.61	-3.21
Bt Corn	Neutral	35.56	6.94
	Moderate	32.18	4.91
	High	28.61	2.58

Croff et al. (2007)

- Economics of CRW IPM in first year corn
- Need damage function for Node Injury Scale (NIS), not the old Root Rating
- Use NIS and Yield data from standard side-by-side efficacy field trials
- Have data from 17 different field trials, giving a total of 795 observations of ΔNIS and associated % loss λ

Example Data

Obs.	Treatment	NIS	Yield
1	Aztec	0.29	180.6
2	Aztec	0.22	169.7
3	Cruiser	2.74	175.1
4	Force	0.38	179.6
5	Force	0.47	190.6
6	Fortress	0.20	189.1
7	Fortress	0.36	179.6
8	Lorsban	1.40	162.0
9	Poncho	0.78	174.0
10	Bt	0.70	208.1
11	Control	2.37	123.8

- Make all possible pairings of obs. for ΔNIS and yield loss λ from same site-year
- If have K obs., have K!/(K-2)!2! total pairs
- Define λ so $\Delta NIS > 0$
- If $NIS_1 > NIS_2$, $\lambda = (Y_2 – Y_1)/Y_2$
- If $NIS_1 < NIS_2$, $\lambda = (Y_1 – Y_2)/Y_1$

Estimation Results

<u>Estimated model</u>

$\lambda = \beta x + \exp(s_0 + s_1 x)\varepsilon$

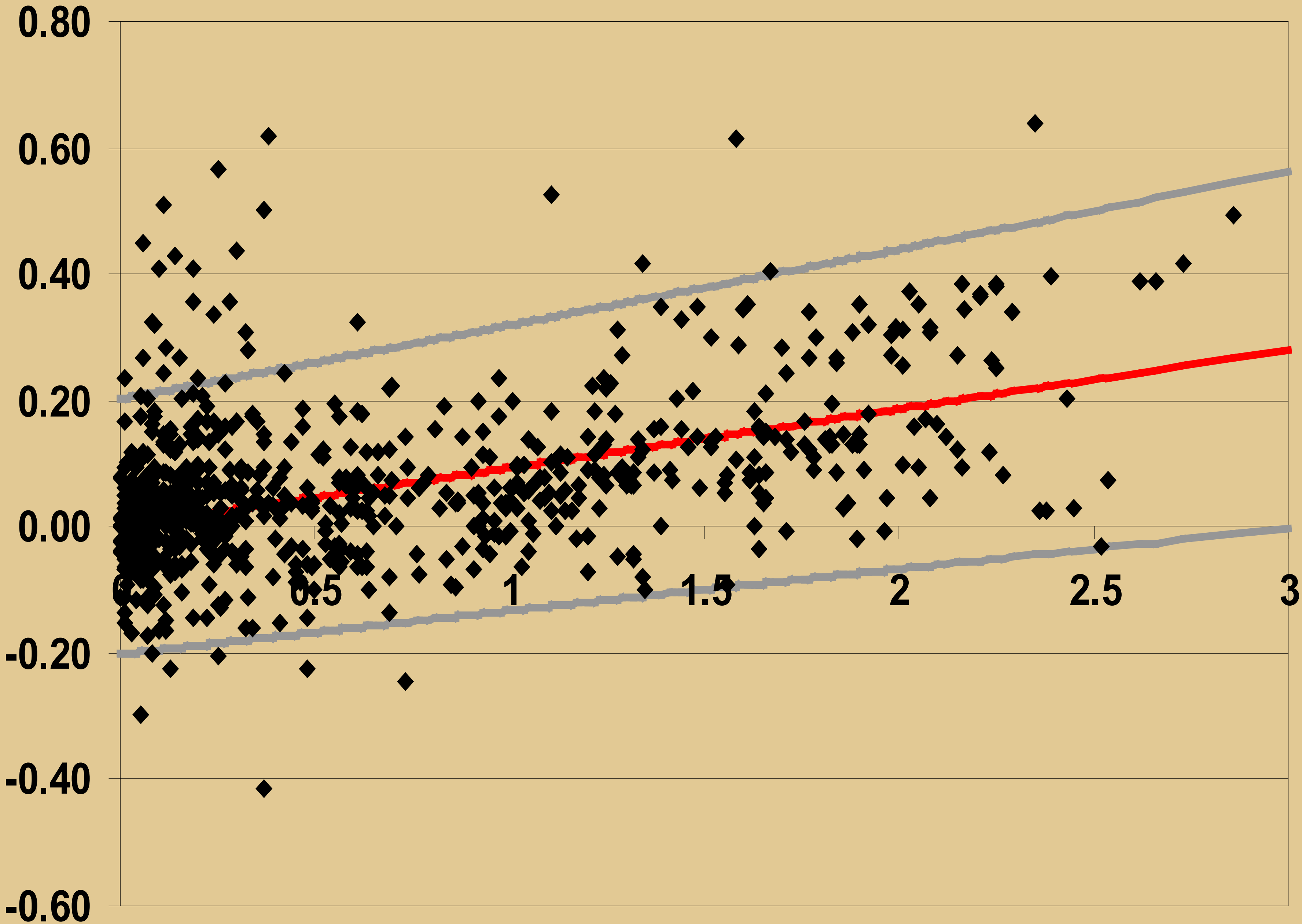
x is ΔNIS, $\varepsilon \sim N(0,1)$

β, s_0, and s_1 parameters

$R^2 = 0.207$ (noisy data)

	Estimate	t stat	p value
β	0.0931	18.92	< 0.001
s_0	– 2.273	– 67.61	< 0.001
s_1	0.1131	3.051	0.002

Means 9.3% yield loss per 1 unit of NIS


0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
0
0.5
1
1.5
2
2.5
3

CRW Damage Functions

- Form the basis of many types of economic analysis of CRW problems
  - Value of new control methods
  - Benefit of eradication/suppression
  - Cost of invasive species
  - Impact of pesticide bans/regulations
  - Derive IPM action thresholds
  - Derive Optimal IRM Strategies
- Some work done, more work in progress, more work needs to be done

Impact of CRW in USA: Updating Metcalf (1986)

- Metcalf (1986): cost from treatment expenditures and yield losses range $1 billion per year in U.S.
- Based on a few sentences from Metcalf's "Forward" in Krysan and Miller's (1986) *Methods for the Study of Pest Diabrotica*
- Update analysis for to 2000 for US

Soil insecticides are routinely applied to 50-60% of the corn (maize) acreage or as much as 30-40 million acres (12-16 million ha) (Eichers et al., 1978). Present day costs of soil insecticide treatments range from $15-20 per acre. During intensive outbreaks of corn rootworms, aerial sprays are applied to as much as 10 million acres (4 million ha) (Chio et al., 1978) at an additional cost of about $4-5 per acre.

The root feeding of the beetles causes direct damage to corn growth and corn yields. Corn rootworm infestations have been shown to decrease yields of corn by 13-16 bu per acre or 10-13% (Apple, 1971; Kuhlman and Petty, 1973). Thus the present day toll paid by U.S. farmers in treatment costs and crop losses is in the range of $1 billion per year.

Overview of Method

- Use Doane's Market Research for 2000 (Alston et al. 2002) to obtain corn acres by rotation, corn rootworm treated acres, and treatment costs by region
- Project (assume) root ratings for treated and untreated corn acres by region to estimate % yield loss
- Use regional average yields and average prices to develop cost of yield loss with Mitchell et al. (2004) and Yang et al. (2007) damage function

Farm Resource Regions

Basin and Range

- Largest share of nonfamily farms, smallest share of U.S. cropland.
- 4% of farms, 4% of value of production, 4% of cropland.
- Cattle, wheat, and sorghum farms.

Northern Great Plains

- Largest farms and smallest population.
- 5% of farms, 6% of production value, 17% of cropland.
- Wheat, cattle, sheep farms.

Heartland

- Most farms (22%), highest value of production (23%), and most cropland (27%).
- Cash grain and cattle farms.

Northern Crescent

- Most populous region.
- 15% of farms, 15% of value of production, 9% of cropland.
- Dairy, general crop, and cash grain farms.

Eastern Uplands

- Most small farms of any region.
- 15% of farms, 5% of production value, and 6% of cropland.
- Part-time cattle, tobacco, and poultry farms.

Fruitful Rim

- Largest share of large and very large family farms and nonfamily farms.
- 10% of farms, 22% of production value, 8% of cropland.
- Fruit, vegetable, nursery, and cotton farms.

Southern Seaboard

- Mix of small and larger farms.
- 11% of farms, 9% of production value, 6% of cropland.
- Part-time cattle, general field crop, and poultry farms.

Prairie Gateway

- Second in wheat, oat, barley, rice, and cotton production.
- 13% of farms, 12% of production value, 17% of cropland.
- Cattle, wheat, sorghum, cotton, and rice farms.

Mississippi Portal

- Higher proportions of both small and larger farms than elsewhere.
- 5% of farms, 4% of value, 5% of cropland.
- Cotton, rice, poultry, and hog farms.

Table 1. Alston et al. (2002): Corn yield, acres (1,000) by rotation, and % treated for rootworm in each region in 2000

USDA Region	Corn Acres	% trt	Cont. corn	% trt	1st yr corn	% trt
Miss Port	1,348	1.0%	503	0.0%	845	1.5%
Sthrn Seab	2,136	7.7%	707	8.3%	1,430	7.3%
Fruitful Rim	882	50.5%	433	52.0%	450	49.1%
Eastrn Up	1,705	11.6%	733	18.4%	972	6.5%
Nrthn Crsnt	11,289	14.9%	4,536	25.6%	6,753	7.7%
Heartland, rem	34,516	14.0%	6,602	45.2%	27,915	6.6%
Heartland, edv	2,788	5.2%	266	12.7%	2,523	4.4%
Heartland, sbv	8,951	33.4%	937	47.6%	8,014	31.8%
N G Plains	4,868	10.9%	1,442	33.8%	3,426	1.3%
Prairie Gway	9,931	31.6%	5,507	48.7%	4,424	10.3%
Basin Range	212	33.7%	112	55.8%	99	8.6%
Total USA	**78,628**		**21,778**		**56,850**	

Table 2. Alston et al.(2002): Corn rootworm treatment costs ($1,000) by rotation and region in 2000

USDA Region	Ac Trt	cost	$/ac	cont trt ac	cost	$/ac	1st yr trt ac	cost	$/ac
Miss Port	13	117	8.94	0	0	10.03	13	117	8.94
Sthrn Seab	163	1,880	11.50	58	627	10.71	105	1,253	11.94
Fruitful Rim	446	5,337	11.98	225	2,758	12.27	221	2,579	11.69
Eastrn Up	198	2,247	11.33	135	1,573	11.63	63	675	10.68
Nrthn Crsnt	1,680	20,992	12.49	1,160	14,266	12.30	521	6,727	12.92
Heartland, rem	4,820	57,538	11.94	2,984	36,527	12.24	1,836	21,011	11.45
Heartland, edv	146	1,819	12.49	34	450	13.37	112	1,369	12.23
Heartland, sbv	2,992	39,936	13.35	446	6,634	14.88	2,547	33,302	13.08
N G Plains	532	5,356	10.07	487	4,984	10.24	45	372	8.20
Prairie Gway	3,135	35,696	11.39	2,680	30,482	11.38	455	5,214	11.45
Basin Range	71	591	8.29	63	510	8.13	9	81	9.49
Total USA	**14,197**	**171,510**		**8,271**	**98,811**		**5,926**	**72,699**	

Estimating % Yield Loss

- Counter-factual analysis: What would the root rating (1-6 scale) be if no treatment were applied: measures CRW "pressure"
  - Assume low, medium, and high pressure
  - For treated and untreated corn in each region
  - For continuous and rotated corn in each region
- For treated acres, estimate RR after treatment applied via Mitchell et al. (2004) $RR_t = f(RR_c)$
- Use Yang et al. (2007) to estimate % yield loss from RR: $\beta = 0.0572$

Continuous corn root rating (1-6 scale) before treatment

	Continuous Corn, Treated			Continuous Corn, Not Treated		
USDA Region	Low RR	Mid RR	Hi RR	Low RR	Mid RR	Hi RR
Mississippi Portal	1	2	3	1	1.25	1.5
Southern Seaboard	1	2	3	1	1.25	1.5
Fruitful Rim	3	4	5	1.25	1.75	2.25
Eastern Uplands	2	3	4	1	1.25	1.5
Northern Crescent	2	3	4	1	1.25	1.5
Heartland, Remaining	2.5	3.5	4.5	1.25	1.75	2.25
Heartland, Ex. Diap.	2	3	4	1.25	1.75	2.25
Heartland, Soyb. Var.	2.5	3.5	4.5	1.25	1.75	2.25
Northern Great Plains	2	3	4	1	1.25	1.5
Prairie Gateway	2.5	3.5	4.5	1.25	1.75	2.25
Basin and Range	3	4	5	1.25	1.75	2.25

Probabilities: Low = 0.15, Mid = 0.70, Hi = 0.15

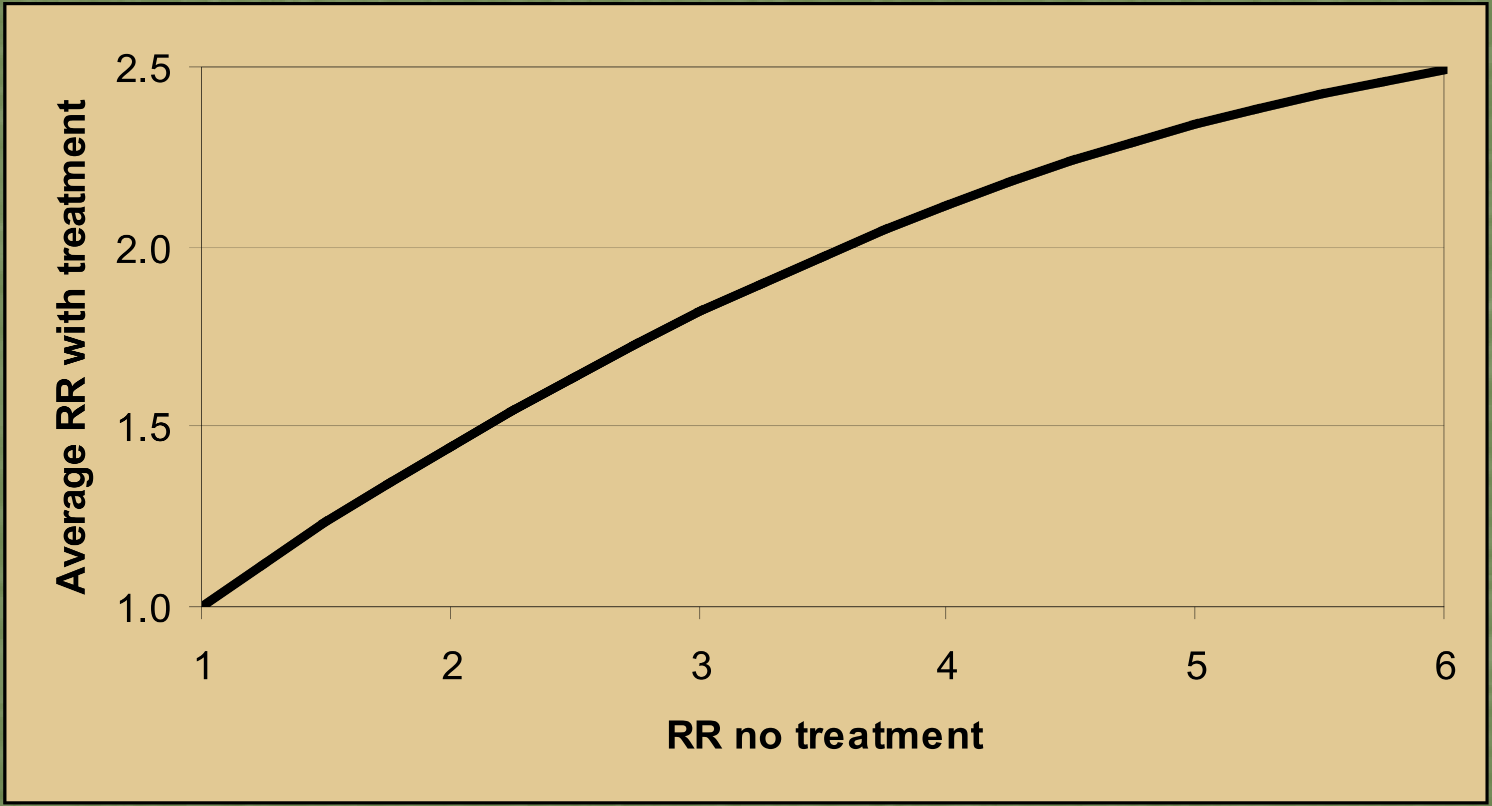
Rotated corn root rating before treatment

	Rotated Corn, Treated			Rotated Corn, Not Treated		
USDA Region	Low RR	Mid RR	Hi RR	Low RR	Mid RR	Hi RR
Mississippi Portal	1	2	3	1	1	1
Southern Seaboard	1	2	3	1	1	1
Fruitful Rim	3	4	5	1.25	1.75	2.25
Eastern Uplands	2	3	4	1	1	1
Northern Crescent	2	3	4	1	1	1
Heartland, Remaining	2.5	3.5	4.5	1	1	1
Heartland, Ex. Diap.	2	3	4	1.25	1.75	2.25
Heartland, Soyb. Var.	2.5	3.5	4.5	1.25	1.75	2.25
Northern Great Plains	2	3	4	1	1	1
Prairie Gateway	2.5	3.5	4.5	1	1	1
Basin and Range	3	4	5	1.25	1.75	2.25

Probabilities: Low = 0.15, Mid = 0.70, Hi = 0.15

Equations (Mitchell et al. 2004)

$$RR_{trt} = 1 + 0.482(RR_{no}-1) - 0.0367(RR_{no}-1)^2$$



$$\lambda = \beta(RR - 1),\ \beta = 0.113 \text{ or } 0.0572$$

$$\$Loss = \text{Price} \times \text{Yield} \times \lambda,\ \text{Price} = \$2.34/\text{bu}$$

Continuous corn % yield loss before treatment

USDA Region	To Be Treated Low	Medium	High	Not To Be Treated Low	Medium	High
Mississippi Portal	0.0%	11.4%	22.8%	0.0%	2.9%	5.7%
Southern Seaboard	0.0%	11.4%	22.8%	0.0%	2.9%	5.7%
Fruitful Rim	22.8%	34.2%	45.6%	2.9%	8.6%	14.3%
Eastern Uplands	11.4%	22.8%	34.2%	0.0%	2.9%	5.7%
Northern Crescent	11.4%	22.8%	34.2%	0.0%	2.9%	5.7%
Heartland, Remaining	17.1%	28.5%	39.9%	2.9%	8.6%	14.3%
Heartland, Ex. Diap.	11.4%	22.8%	34.2%	2.9%	8.6%	14.3%
Heartland, Soyb. Var.	17.1%	28.5%	39.9%	2.9%	8.6%	14.3%
Northern Great Plains	11.4%	22.8%	34.2%	0.0%	2.9%	5.7%
Prairie Gateway	17.1%	28.5%	39.9%	2.9%	8.6%	14.3%
Basin and Range	22.8%	34.2%	45.6%	2.9%	8.6%	14.3%

Rotated corn % yield loss before treatment

USDA Region	To Be Treated Low	To Be Treated Medium	To Be Treated High	Not To Be Treated Low	Not To Be Treated Medium	Not To Be Treated High
Mississippi Portal	0.0%	11.4%	22.8%	0.0%	0.0%	0.0%
Southern Seaboard	0.0%	11.4%	22.8%	0.0%	0.0%	0.0%
Fruitful Rim	22.8%	34.2%	45.6%	2.9%	8.6%	14.3%
Eastern Uplands	11.4%	22.8%	34.2%	0.0%	0.0%	0.0%
Northern Crescent	11.4%	22.8%	34.2%	0.0%	0.0%	0.0%
Heartland, Remaining	17.1%	28.5%	39.9%	0.0%	0.0%	0.0%
Heartland, Ex. Diap.	11.4%	22.8%	34.2%	2.9%	8.6%	14.3%
Heartland, Soyb. Var.	17.1%	28.5%	39.9%	2.9%	8.6%	14.3%
Northern Great Plains	11.4%	22.8%	34.2%	0.0%	0.0%	0.0%
Prairie Gateway	17.1%	28.5%	39.9%	0.0%	0.0%	0.0%
Basin and Range	22.8%	34.2%	45.6%	2.9%	8.6%	14.3%

Continuous corn RR and yield loss <u>after</u> treatment

USDA Region	RR Lo	RR Med	RR Hi	Loss Lo	Loss Med	Loss Hi
Mississippi Portal	1.00	1.45	1.82	0.0%	5.1%	9.3%
Southern Seaboard	1.00	1.45	1.82	0.0%	5.1%	9.3%
Fruitful Rim	1.82	2.12	2.34	9.3%	12.7%	15.3%
Eastern Uplands	1.45	1.82	2.12	5.1%	9.3%	12.7%
Northern Crescent	1.45	1.82	2.12	5.1%	9.3%	12.7%
Heartland, Remaining	1.64	1.98	2.24	7.3%	11.1%	14.1%
Heartland, Ex. Diap.	1.45	1.82	2.12	5.1%	9.3%	12.7%
Heartland, Soyb. Var.	1.64	1.98	2.24	7.3%	11.1%	14.1%
Northern Great Plains	1.45	1.82	2.12	5.1%	9.3%	12.7%
Prairie Gateway	1.64	1.98	2.24	7.3%	11.1%	14.1%
Basin and Range	1.82	2.12	2.34	9.3%	12.7%	15.3%

Rotated corn RR and yield loss after treatment

USDA Region	RR Lo	RR Med	RR Hi	Loss Lo	Loss Med	Loss Hi
Mississippi Portal	1.00	1.45	1.82	0.0%	5.1%	9.3%
Southern Seaboard	1.00	1.45	1.82	0.0%	5.1%	9.3%
Fruitful Rim	1.82	2.12	2.34	9.3%	12.7%	15.3%
Eastern Uplands	1.45	1.82	2.12	5.1%	9.3%	12.7%
Northern Crescent	1.45	1.82	2.12	5.1%	9.3%	12.7%
Heartland, Remaining	1.64	1.98	2.24	7.3%	11.1%	14.1%
Heartland, Ex. Diap.	1.45	1.82	2.12	5.1%	9.3%	12.7%
Heartland, Soyb. Var.	1.64	1.98	2.24	7.3%	11.1%	14.1%
Northern Great Plains	1.45	1.82	2.12	5.1%	9.3%	12.7%
Prairie Gateway	1.64	1.98	2.24	7.3%	11.1%	14.1%
Basin and Range	1.82	2.12	2.34	9.3%	12.7%	15.3%

Loss ($/ac) and total loss ($) for Untreated corn

USDA Region	Continuous Loss $/ac	Rotated Loss $/ac	Continuous $ Loss	Rotated $ Loss
Mississippi Portal	7.54	0.00	$ 3,789,689	$ -
Southern Seaboard	7.07	0.00	$ 4,583,885	$ -
Fruitful Rim	35.01	35.01	$ 7,275,406	$ 8,016,790
Eastern Uplands	8.54	0.00	$ 5,106,427	$ -
Northern Crescent	8.47	0.00	$ 28,594,716	$ -
Heartland, Remaining	29.61	0.00	$ 107,109,614	$ -
Heartland, Ex. Diap.	29.61	29.61	$ 6,877,687	$ 71,378,378
Heartland, Soyb. Var.	29.61	29.61	$ 14,541,352	$ 161,901,394
Northern Great Plains	6.47	0.00	$ 6,180,338	$ -
Prairie Gateway	25.41	0.00	$ 71,836,903	$ -
Basin and Range	25.61	25.61	$ 1,272,791	$ 2,326,420
Total			$ 257,168,807	$ 243,622,983

Loss ($/ac) and total loss ($) for Treated corn

USDA Region	Continuous Loss $/ac	Rotated Loss $/ac	Continuous $ Loss	Rotated $ Loss
Mississippi Portal	13.09	13.09	$ 471	$ 171,220
Southern Seaboard	12.28	12.28	$ 718,356	$ 1,288,748
Fruitful Rim	51.57	51.57	$ 11,594,538	$ 11,380,263
Eastern Uplands	27.53	27.53	$ 3,721,839	$ 1,739,963
Northern Crescent	27.31	27.31	$ 31,679,824	$ 14,216,415
Heartland, Remaining	38.08	38.08	$ 113,653,812	$ 69,910,309
Heartland, Ex. Diap.	31.83	31.83	$ 1,070,720	$ 3,563,358
Heartland, Soyb. Var.	38.08	38.08	$ 16,974,752	$ 96,982,738
Northern Great Plains	20.86	20.86	$ 10,153,426	$ 946,431
Prairie Gateway	32.68	32.68	$ 87,565,529	$ 14,878,165
Basin and Range	37.72	37.72	$ 2,365,758	$ 322,996
Total			$ 279,499,025	$ 215,400,607

Total rootworm loss prevented by treating corn

	$ Loss Prevented on Treated Corn	
USDA Region	Continuous	Rotated
Mississippi Portal	$ 614	$ 223,032
Southern Seaboard	$ 935,737	$ 1,678,735
Fruitful Rim	$ 19,892,679	$ 19,525,050
Eastern Uplands	$ 5,511,318	$ 2,576,546
Northern Crescent	$ 46,911,635	$ 21,051,735
Heartland, Remaining	$ 180,903,634	$ 111,276,767
Heartland, Ex. Diap.	$ 1,585,527	$ 5,276,637
Heartland, Soyb. Var.	$ 27,018,841	$ 154,368,159
Northern Great Plains	$ 15,035,242	$ 1,401,480
Prairie Gateway	$ 139,378,715	$ 23,681,689
Basin and Range	$ 4,058,916	$ 554,162
Total	$ 441,232,856	$ 341,613,992
Sum	$ 782,846,848	

SUMMARY ($1,000,000)	$\beta = 0.114$	$\beta = 0.0572$
Untreated Continuous	257	129
Untreated Rotated	244	122
Treated Continuous	279	140
Treated Rotated	215	108
Total Loss	**996**	**500**
Total Cost	**172**	**172**
Total Loss and Cost	**1,167**	**671**
Continuous Loss Prevented	441	221
Rotated Loss Prevented	342	171
Total Loss Prevented	**783**	**393**

Summary

- Corn Rootworm is a complex if four insect species in USA spread throughout the Corn Belt and more
- Resistance management current hot issue
  - Rotation resistance by WCR and NCR
  - IRM for Bt corn and insecticides
  - Increased use of insecticides and Bt corn
- Recent and on-going work on damage functions to link entomology and economics, more to do

Summary

- Using 2000 as base year
- Loss from corn rootworm in U.S. ranged $500 million to $1 billion per year
- Control costs around $170 million per year
- Control prevented $390 to $780 million in losses (2.3x to 4.6x return)