Market-Based Instruments for the Optimal Control of Invasive Insect Species: B. tabaci in Arizona

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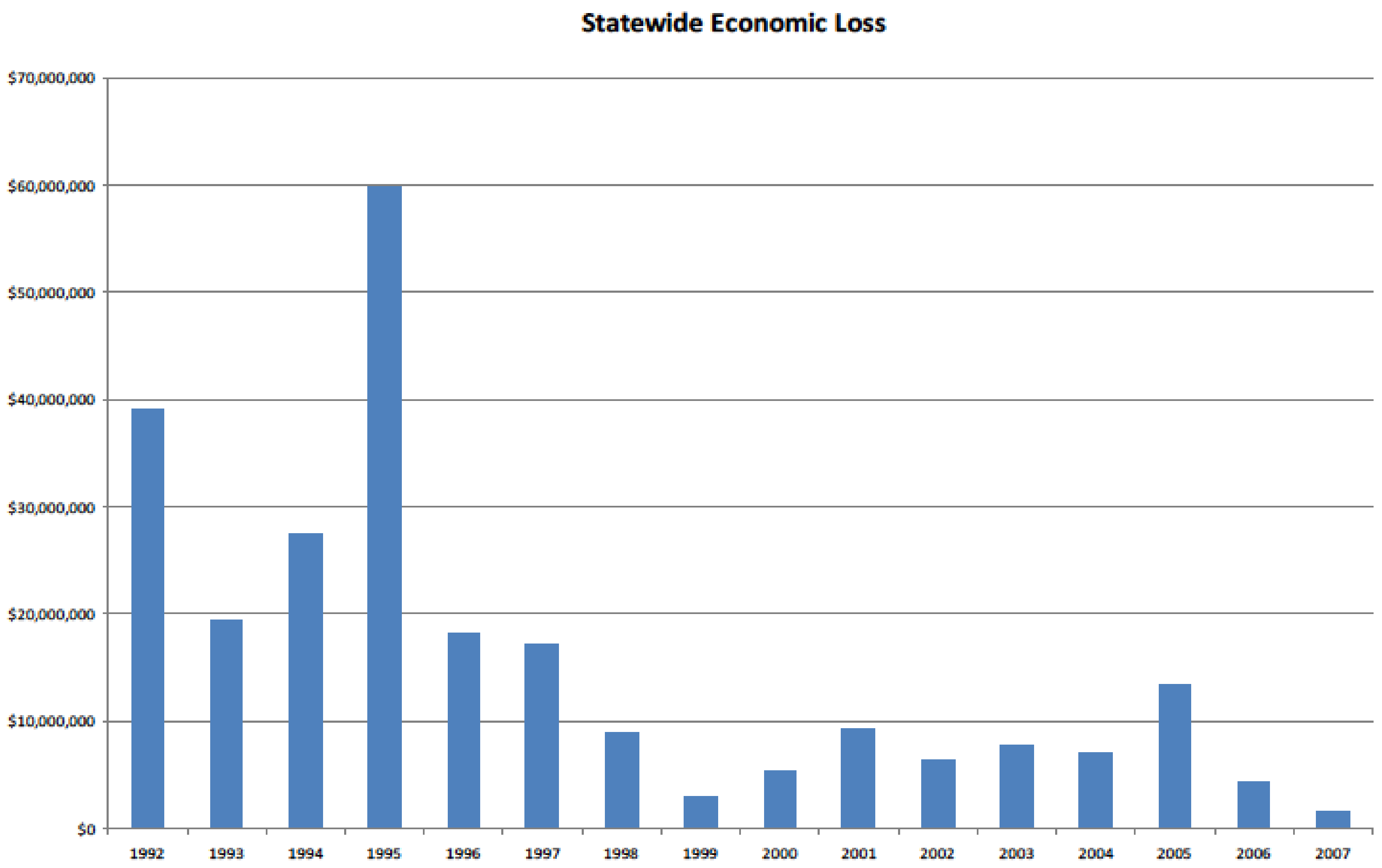
Cost of Whitefly Infestation in AZ

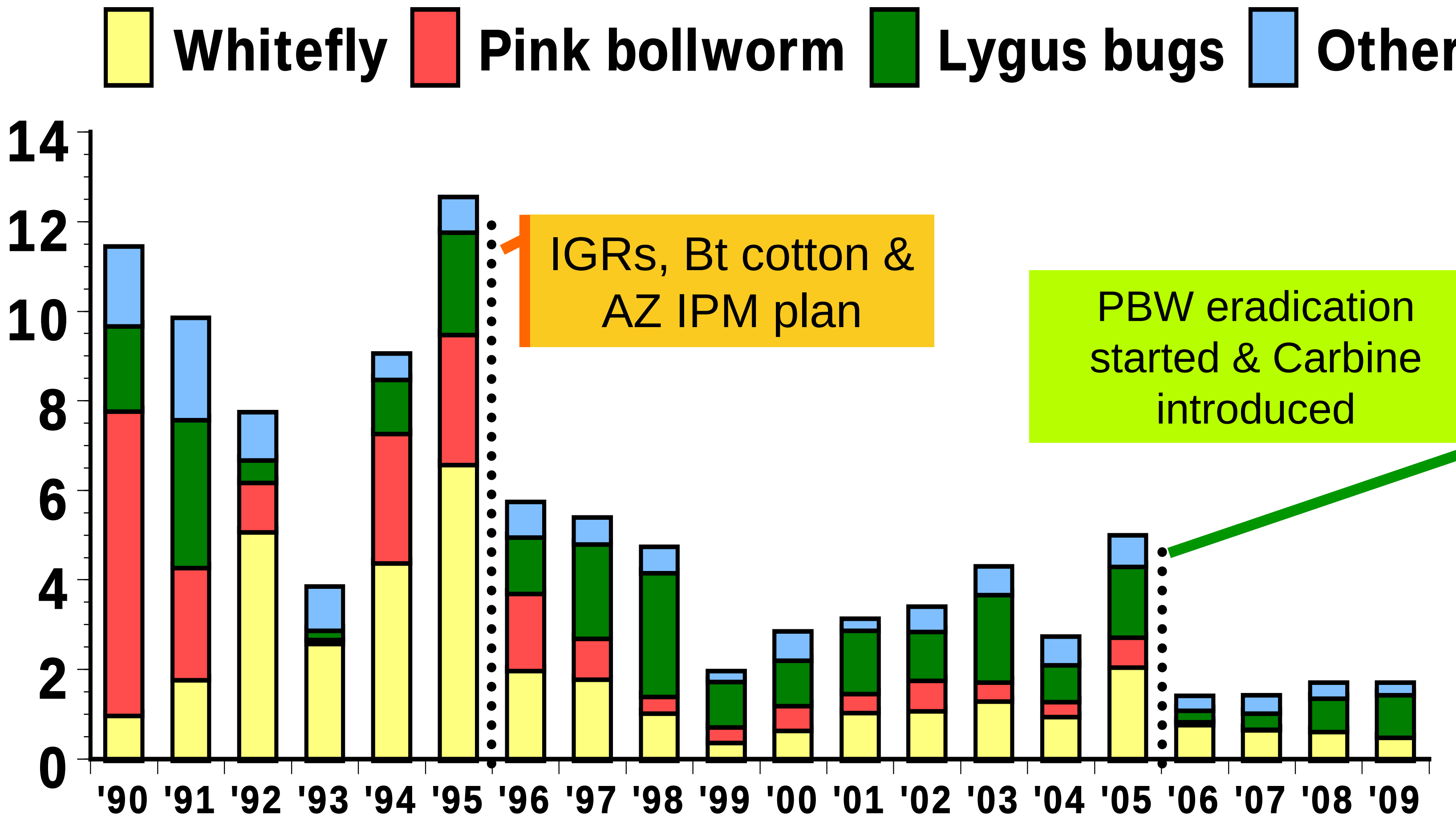


Source: ARS

Economic Cost of Invasive Insects

- Cost due to both control and yield loss
- Arizona Invasive Species Advisory Council (AISAC) est. by Gov. Napolitano
  - Loss below $10.0m annual due in part to lower cotton acreage
  - Important component of sustainability strategy
  - Economic imperative in Arizona to control whitefly

Number of Sprays for Pests



Ellsworth et al. 2009

Whitefly Problem, 1992 Phoenix

Whitefly Problem

- B-biotype versus Q-biotype
  - polyphagous
  - vector for plant viruses
  - develops resistance quickly
  - travel and breed rapidly
- Negative externality if not controlled privately

Does the Market Fail?

- Two types of market failure:
  - negative externality if not controlled privately
  - weaker-link public good
- Community-based action, or
- Some system of taxes and / or permits with corresponding policies and institutions

Objective

- Evaluate taxes versus market-based permits for preferred control mechanism of whitefly.

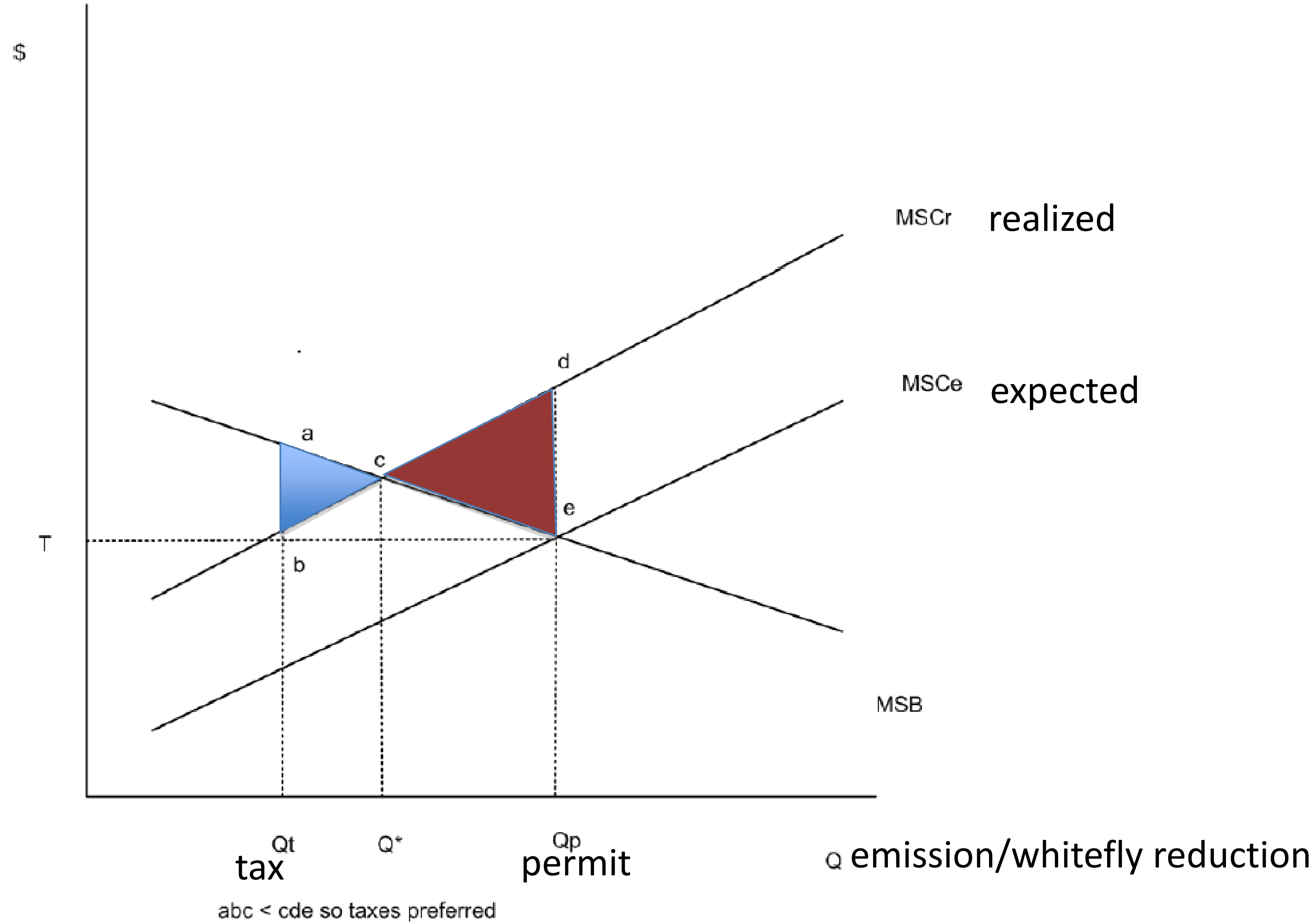
Taxes versus Permits

- Weitzman (1974) shows taxes preferred under cost uncertainty
  - if MSB flat and MSC steep, then taxes preferred
  - If MSB steep and MSC flat, then permits preferred

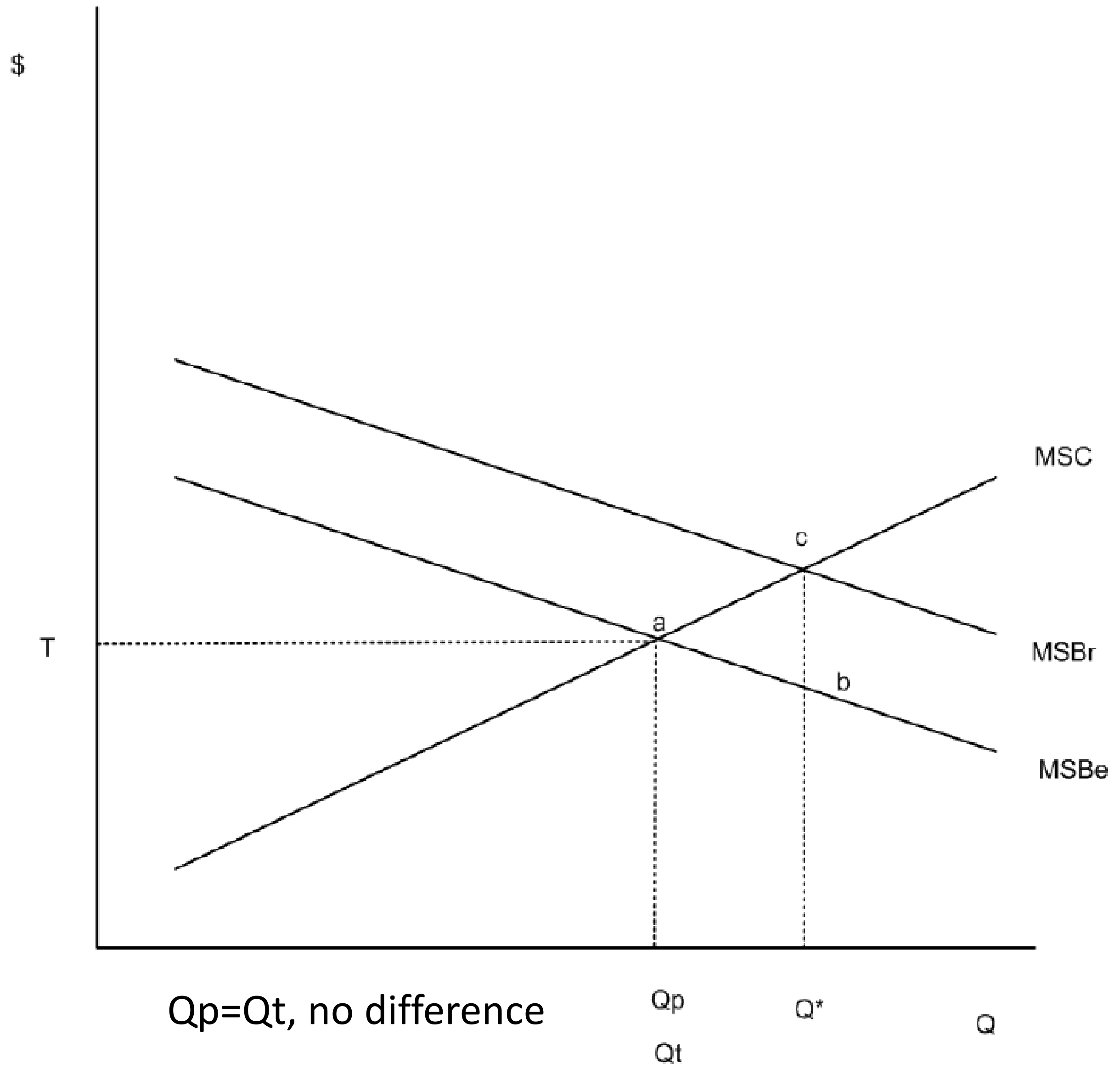
Taxes versus Permits, Uncertainty

- Stavins (1996) shows that correlated uncertainty in MSB/MSC favors permits
  - sunny/calm day and pollution
  - conditions for favorable yields also conducive to insect growth
- Reversal to favor price instrument not likely to occur

Preference for Taxes, Uncertainty

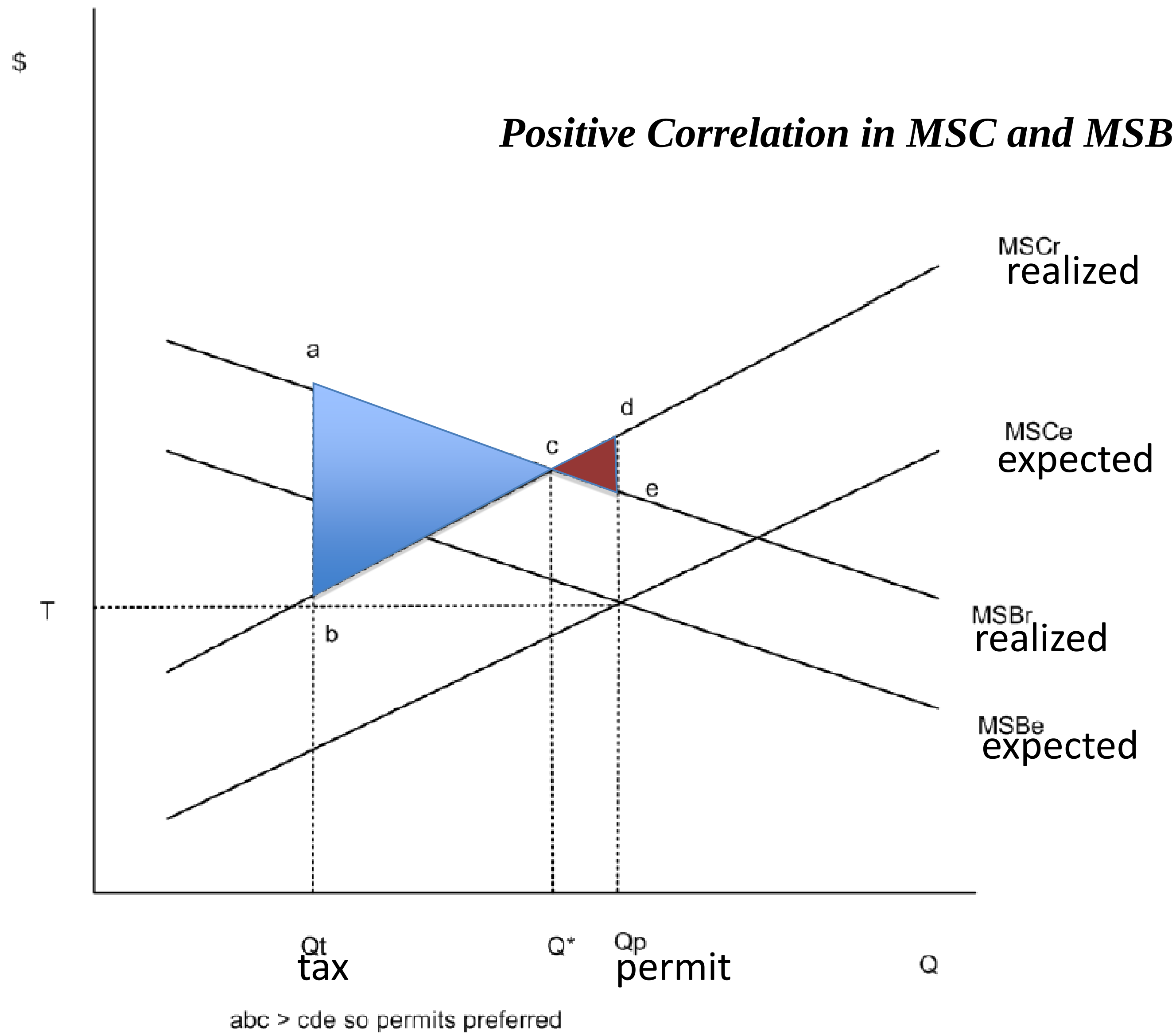


No Preference, MSB uncertainty



Qp=Qt, no difference

Permits Preferred



Spatial-Temporal Problem

- Invasive species case:

- uncertainty in arrival and dispersion
- uncertainty in both MSB and MSC
- spatial dimension adds to uncertainty

- Hypothesis: quantity-based regulation preferred for invasive species

Spatial Externality

- Each location represents one grower
- Each location provides host habitat
- Grower doesn't account for insects that migrate to neighbors
- Total population growth faster with migration
- Weaker-link public good problem

Social Planner's Objective

Socially-optimal control:

$$V^s = \underset{x_{st}}{Max} \int_0^\infty e^{-\delta t} \sum_{s \in \theta} [(p_t - c_{st}) y(b_{st}) - D(ND_s(b_{1t,} b_{2t}, ..., b_{St})) - k(b_{st}, x_{st})] dt$$

- p_t = cotton price,
- c_{st} = marginal cost of production at location s, time t,
- y_{st} = cotton yield,
- b_{st} = insect population,
- $D()$ = external damage function,
- k = control cost function,

Equations of Motion

Subject to:

$$\frac{\partial b_{st}}{\partial t} = g_{st}(b_{st}) + ND_s(b_{1t,}b_{2t}, ..., b_{St}) - x_{st}$$

- g_{st} = growth function:

$$g_{st}(b_{st}) = r_s b_{st}(1 - b_{st}/K_s),$$

- ND_s = net dispersion function for location s,

$$ND_s(b_{1t,}b_{2t}, ..., b_{St}) = \sum_{j=1}^{S} d_{js} b_{jt},$$

- d_{js} = net dispersion from j to s,
- r_s = growth rate, K_s = carrying capacity of environment

Dispersion Coefficients

- Elements of dispersion matrix (d_{sj}) estimated with Fick's Law
- Fick's Law:

$$b_{st} = b_{s_0 t_0} \left(\frac{e^{-q^2/4Gt}}{2\sqrt{\pi G t}} \right)$$

- G = dispersion rate,
- q = Euclidean distance between locations,
- $b_{s_0 t_0}$ = starting value at location s and time t
- Implies insects normally distributed at time t and distance q
- Allow d_{sj} to be random to reflect uncertainty in movement

Firm's Objective

- Privately-optimal control:

$$V^p = \underset{x_{st}}{Max} \int_0^\infty e^{-\delta t}[(p_t - c_{st})y(b_{st}) - k(b_{st}, x_{st})]dt$$

- Not additive over spatial locations
- Include elements that reflect policy tools:
  - Tax: $\tau_{st}(ND_s)$ = location-specific tax = MSB - MSC,
  - Permit Price: $\pi_{st}(ND_s)$ = solve for permit price with fixed b_{st}

Planners Problems

- Population levels:

$$b^*_{st} = (K_s/r_s)(x_{st} - \sum_{j \neq s} d_{st} b_{jt} - d_{ss} - 1)$$

- Control level:

$$x^*_{st} = (1/k_{xb})((((p_t - c_{st})y_b - \sum_j D'(ND_{bj}) - k_b + k_x(r_s(1 - b_{st}/K_s -$$

$$r_s(b_{st}/K_s) + \delta + \sum_j d_{sj}) + k_{xb}(r_s b_{st}(1 - b_{st}/K_s) + \sum_{j \neq s} d_{sj} b_{st})$$

- Multiplier:

$$\lambda^*_{st} = (1/\delta)((((p_t - c_{st})y_b - \sum_j D'(ND_{bj}) - k_b + k_x(g_b + ND_b + \delta) - \sum_{j \neq s} k_x d_{sj}$$

Net Benefits

- Follow Newell and Pizer (2003)
- Difference in expected net benefits.

$$\Delta_t = E[V^p_{t,tax}] - E[V^p_{t,permit}]$$

- Monte Carlo simulation over random d_{sj}
- Sensitivity analysis with respect to:

$$\partial y_{st}/\partial b_{st} = \text{slope of MSB function},$$
$$\partial k/\partial x_{st} = \text{slope of MSC function},$$

Whitefly Spatial Data

- ARS-USDA insecticide trial data
- Experimental plot: 5 x 5 grid
- Solve for steady-state values:

- state variable, insect population, b_s
- level of control, x_s (#/leaf)
- multiplier, λ_s ($/insect)

Social vs. Private Solution

Table 1. Base-Case Solution: Social versus Private Optima

	Socially Optimal		Privately Optimal	
Location (Row, Col.)	Control Level	Population	Control Level	Population
(1, 1)	4.000	6.687	4.960	10.095
(1, 2)	3.876	6.366	4.800	9.759
(1, 3)	3.420	5.814	4.240	8.900
(2, 1)	3.875	6.363	4.799	9.757
(2, 2)	3.694	6.005	4.575	9.371
(2, 3)	3.045	5.382	3.784	8.381
(3, 1)	3.381	5.779	4.200	8.863
(3, 2)	3.042	5.378	3.782	8.377
(3, 3)	0.862	4.247	1.599	6.820
Objective Function	$69,674.391		$64,321.862	

- Lower Control Levels and Populations for Socially Optimal generates 8.3% more surplus.

Taxes versus Permits

Table 2. Value of Net Benefit Under Taxes and Permits

	V^p	σ	Min	Max	t-ratio
Taxes	742.38	89.45	636.30	964.96	-16.351
Permits	1,524.90	478.57	794.36	2,304.00	

- Permits preferred to taxes in invasive species case.
- Opposite to GHG regulation example of Newell and Pizer (2003)

Comparative Dynamics

Table 3. Effect of Slope of MSB on Taxes vs Permits

	Tax		Permits	
y_b	V^p	σ_{V^p}	V^p	σ_{V^p}
2.500	527.06	55.64	1,532.20	573.42
3.500	634.58	71.42	1,533.60	531.17
4.656	*742.38*	*89.45*	*1,524.90*	*478.57*
5.500	809.53	102.53	1,510.70	440.18
6.500	876.01	118.06	1,483.80	396.41

Slope of damage function increase from $2.5 to $6.5 per insect on leaf

Optimal value of cotton production net of damage costs,

increases by 66.2% under taxes and

decreases by 1.5% under permits.

- Steeper MSB favors taxes

Comparative Dynamics

Table 4. Effect of Slope of MSC on Taxes vs Permits

	Tax		Permits	
k_x	V^p	σ_{V^p}	V^p	σ_{V^p}
0.050	553.00	71.67	913.49	280.58
0.075	636.20	79.92	1,151.30	358.27
0.*101*	*742.38*	*89.45*	*1,524.90*	*478.57*
0.125	855.17	96.27	2,016.30	639.64
0.150	982.36	100.94	2,697.70	865.82

Slope of marginal control-cost function increases from $.05 to $.15 per insect on leaf

Optimal value of cotton production net of damage costs,

increases by 84.3% under taxes and

increases by 195.3% under permits.

- Steeper MSC favors permits

Conclusions

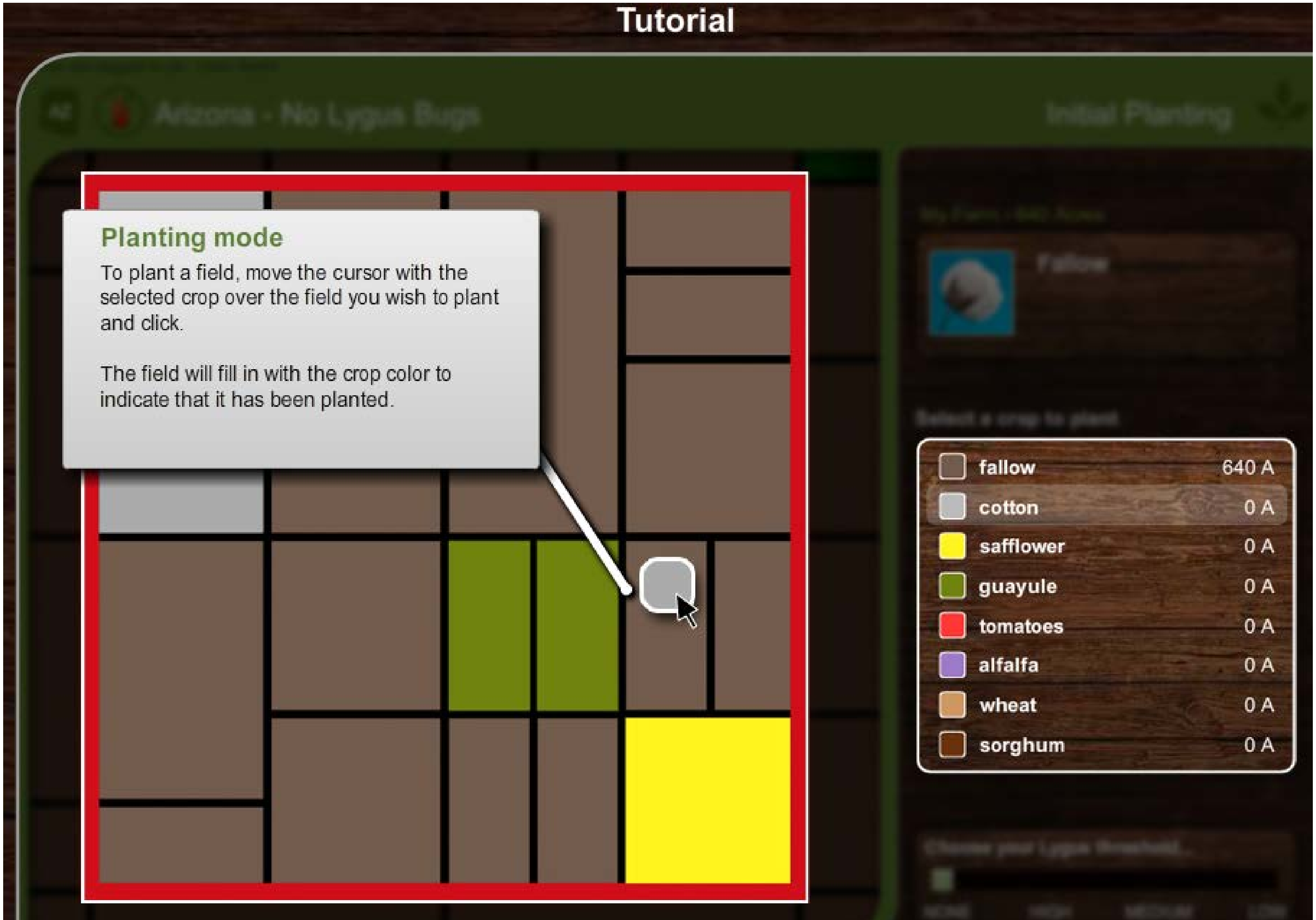
- Permits preferred to taxes for whitefly control
- Conditions opposite to emissions abatement:

- Steeper MSB favors taxes
- Steeper MSC favors permits

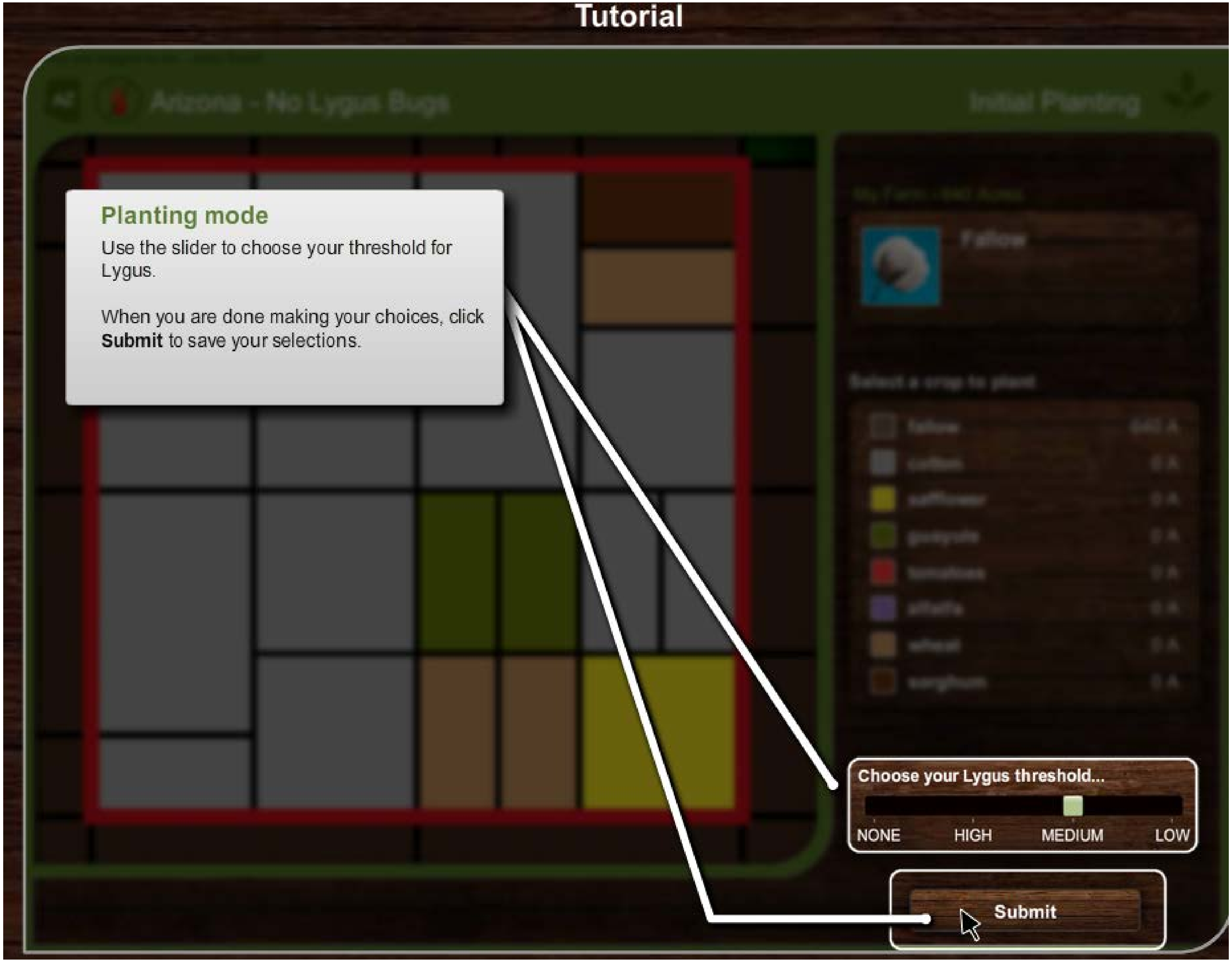
- Quantity-based whitefly regulation possible.
- Community-based initiatives consistent with model – community game/planning

Community/Farm Based "Game"

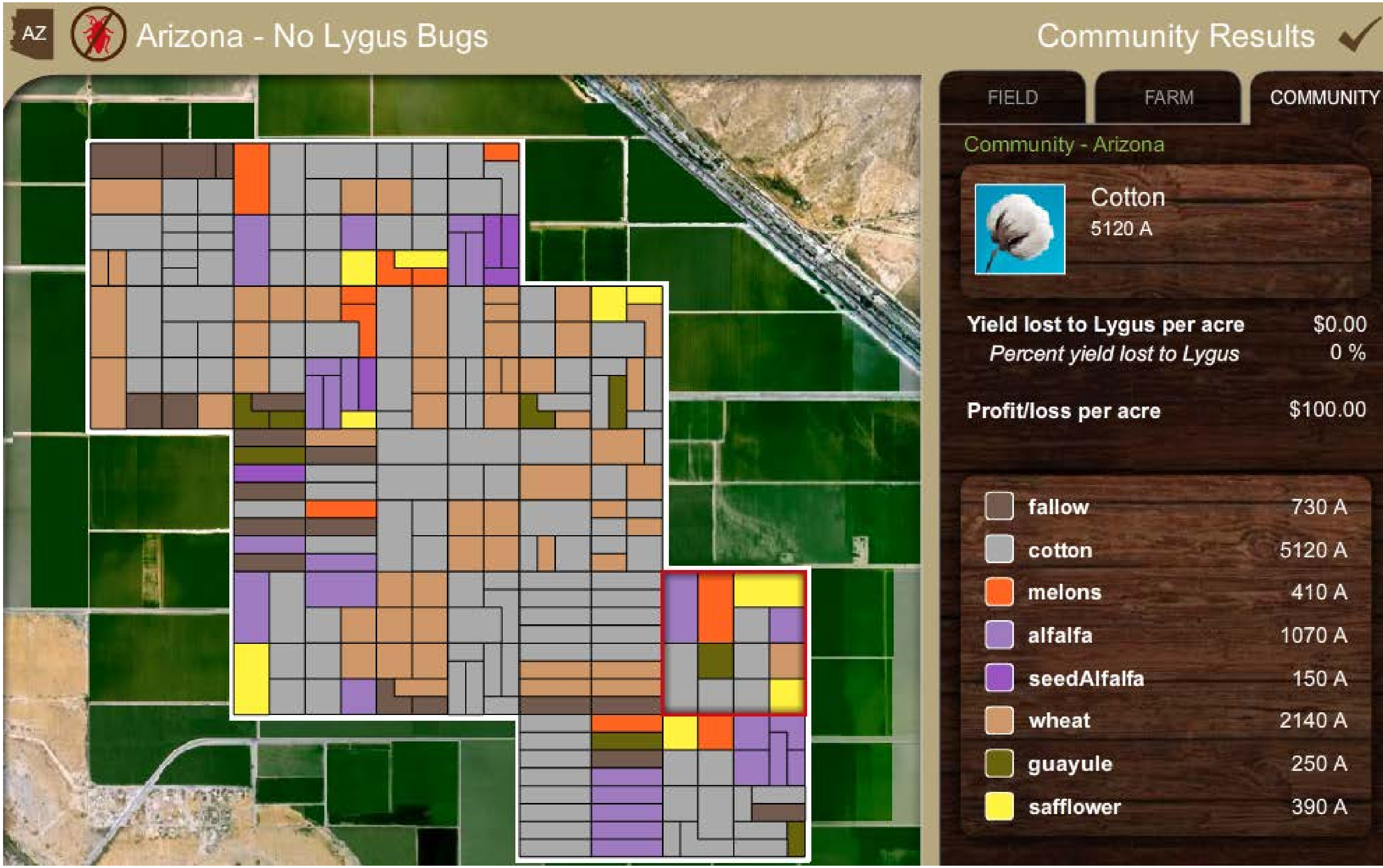
Individual Farm Select Crops



Choose Action Threshold (x_s)

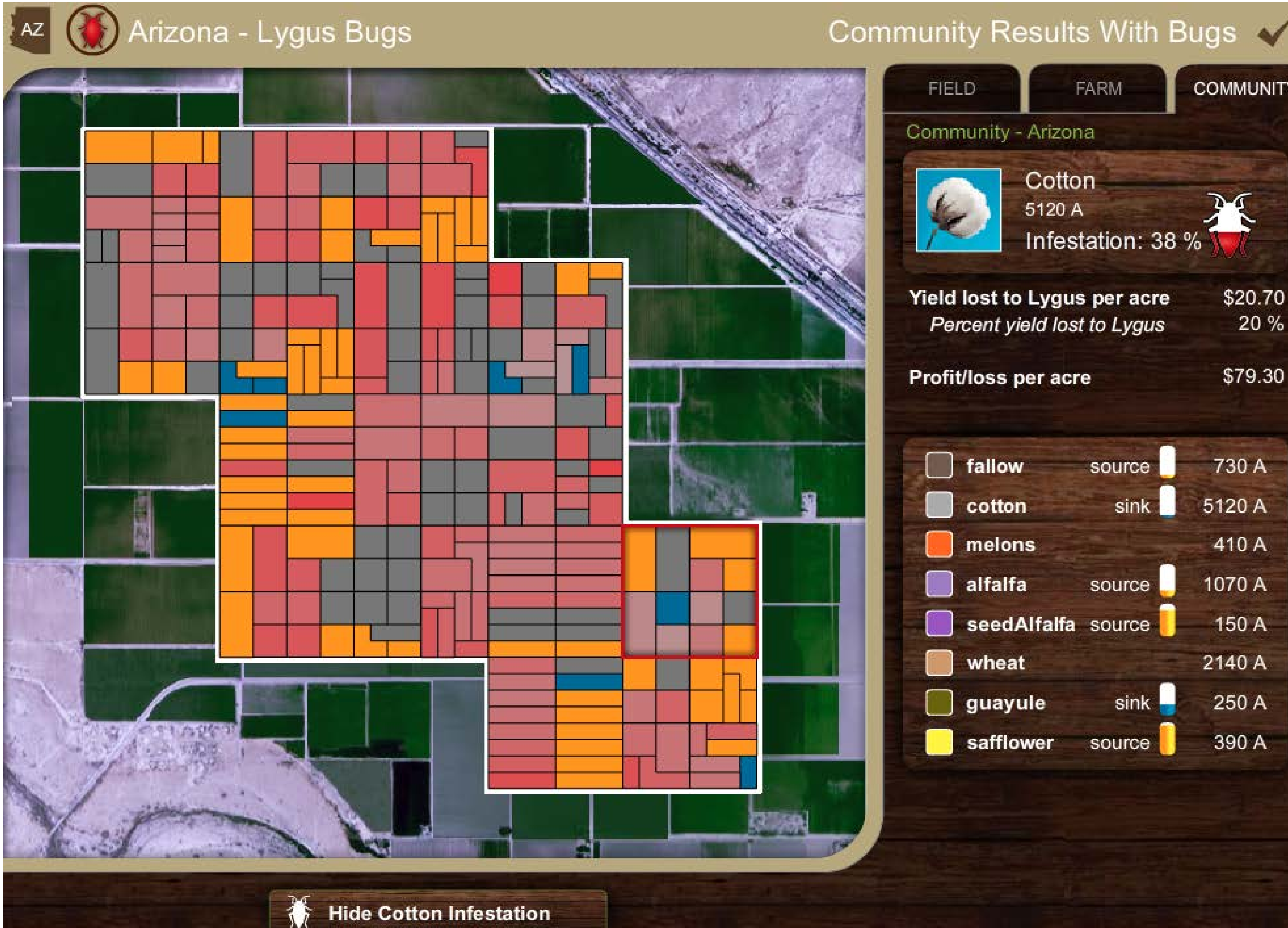


Initial round: No Pest Infestation



Farm Infestation

Community Infestation



Farm Infestation

Field Infestation

Multiple Plantings / Interactions

AZ Arizona - Lygus Bugs

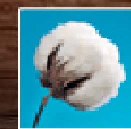
Community Results With Bugs

Community - Arizona	Run 1	Run 2	Run 3	Run 4
Infestation per acre	38 %	33 %	13 %	16 %
Yield loss per acre	$20.70	$4.90	$0.90	$0.90
Spraying cost per acre	$0.00	$14.50	$6.40	$8.70
Profit/loss per acre	$79.30	$80.60	$92.70	$90.40
fallow	730 A	280 A	160 A	20 A
cotton	5120 A	5150 A	5500 A	5240 A
melons	410 A	320 A	240 A	40 A
alfalfa	1070 A	470 A	100 A	140 A
seedAlfalfa	150 A	340 A	280 A	430 A
wheat	2140 A	2810 A	2470 A	1890 A
guayule	250 A	710 A	1430 A	2010 A
safflower	390 A	180 A	80 A	490 A

My Farm	Run 1	Run 2	Run 3	Run 4
Infestation per acre	23 %	30 %	25 %	19 %
Yield loss per acre	$3.30	$7.90	$5.00	$1.70
Spraying cost per acre	$0.00	$7.70	$2.60	$0.00
Profit/loss per acre	$96.70	$84.40	$92.40	$98.30
fallow	0 A	0 A	0 A	0 A
cotton	240 A	280 A	280 A	360 A
melons	80 A	80 A	40 A	40 A
alfalfa	120 A	80 A	80 A	120 A
seedAlfalfa	0 A	0 A	80 A	0 A
wheat	40 A	80 A	80 A	80 A
guayule	40 A	40 A	80 A	40 A
safflower	120 A	80 A	0 A	0 A

FIELD | FARM | COMMUNITY

Community - Arizona

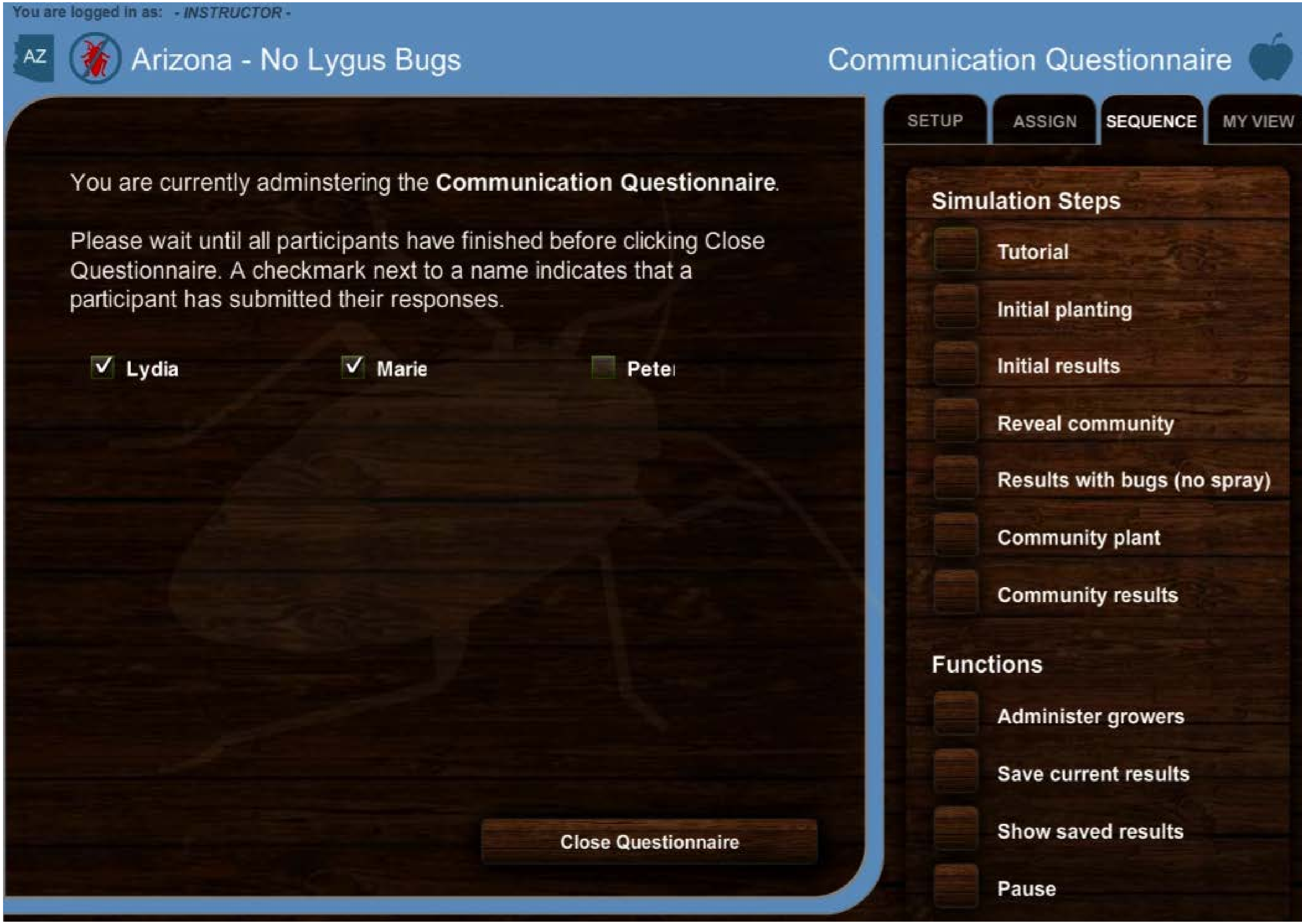


Cotton
5240 A
Infestation: 16 %

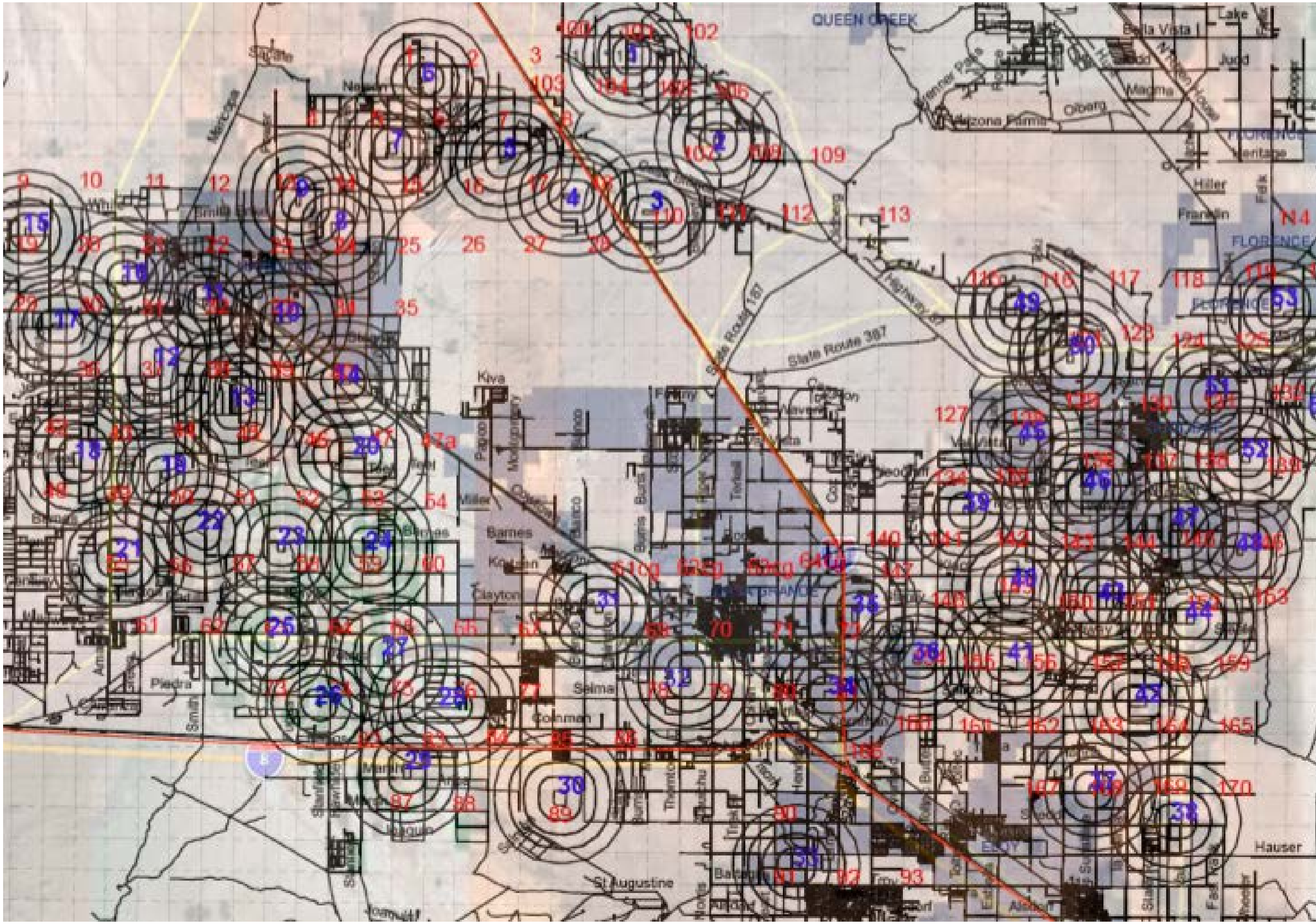
Yield lost to Lygus per acre	$0.90
Percent yield lost to Lygus	0 %
Cost of spraying per acre	$8.70
Number of sprays per acre	0.48
Profit/loss per acre	$90.40

fallow	source	20 A
cotton	sink	5240 A
melons		40 A
alfalfa	source	140 A
seedAlfalfa	source	430 A
wheat		1890 A
guayule	sink	2010 A
safflower	source	490 A

Instructor Functions



Crop Interactions, Insects



Community Planning Game

- Cotton centric with Lygus

- adapt for resistance management

- modify for other insects

- CA, AZ, NM, and TX (RAMP project)

- Community-based planning attractive for near horizon.