Reclaimed Water Irrigation:

Plant Accumulation of Contaminants of Emerging Concern (CECs)

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Outline

- Problem - CECs in wastewater and biosolids
- Project objectives and setup
- Planned studies:
  - Controlled experiments
  - Field studies
  - Outreach to stakeholders
- Anticipated results and impacts

What are CECs ?

"Chemicals and other substances that have **no regulatory standard**, have been recently "discovered" in natural waters, and potentially cause deleterious effects in aquatic life at environmentally relevant concentrations" --- US EPA

- Pharmaceuticals and personal care products (PPCPs)
- Veterinary medicines and antibiotics
- Endocrine-disrupting chemicals (EDCs)
- Plasticizers (e.g., phthalates)
- New persistent organic pollutants (e.g., flame retardants)
- Nanomaterials
- …

What are PPCPs ?

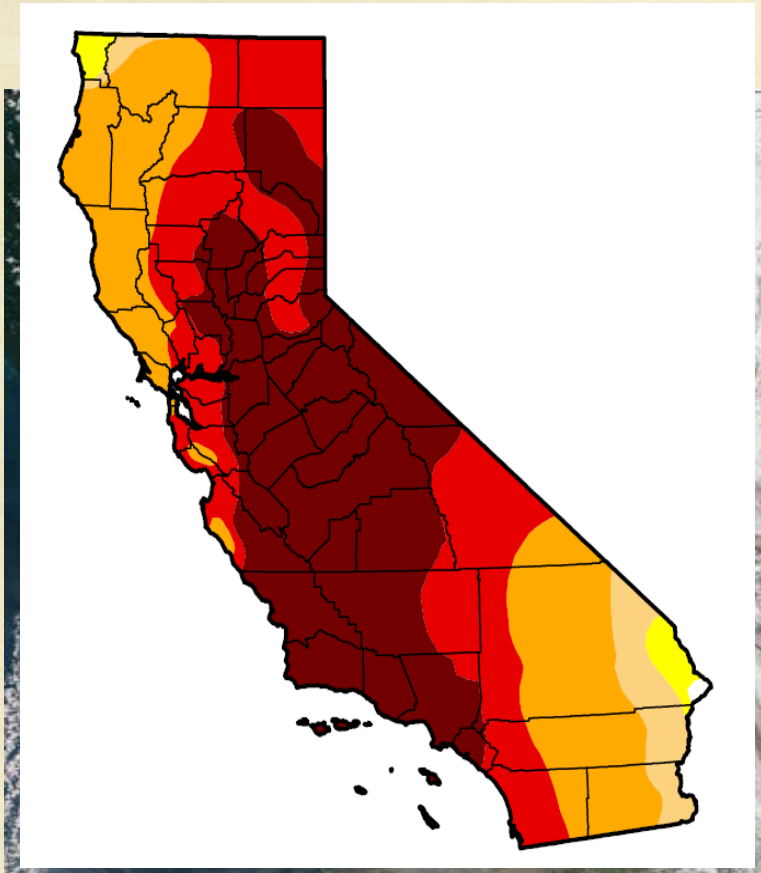
"PPCPs refers, in general, to any product used by individuals for personal health or cosmetic reasons or used by agribusiness to enhance growth or health of livestock."

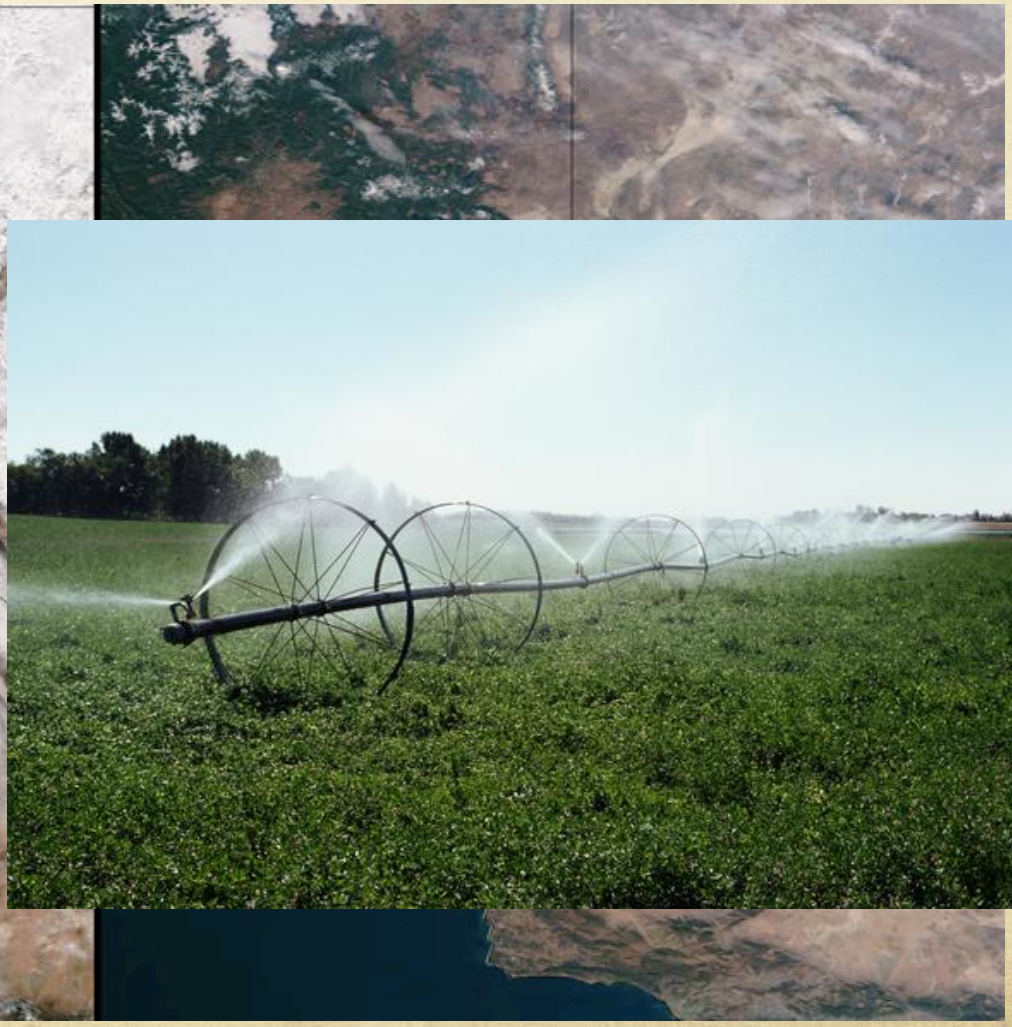
--- US EPA

Routes to Soil Contamination

- Irrigation of reclaimed water
- Biosolids/animal wastes
- Landfills
- Plasticulture
- …

Treated Wastewater Irrigation





Biosolids Land Application

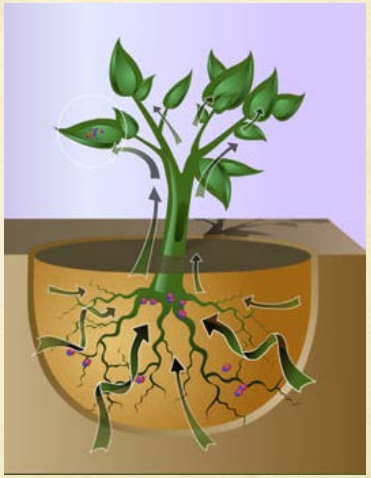
Ma		
Bio		
Tre Wast		

PPCPs in treated wastewater, biosolids and other wastes

Irrigation land application residues

PPCP/EDCs in soils

Plant uptake



PPCP/EDCs in plant

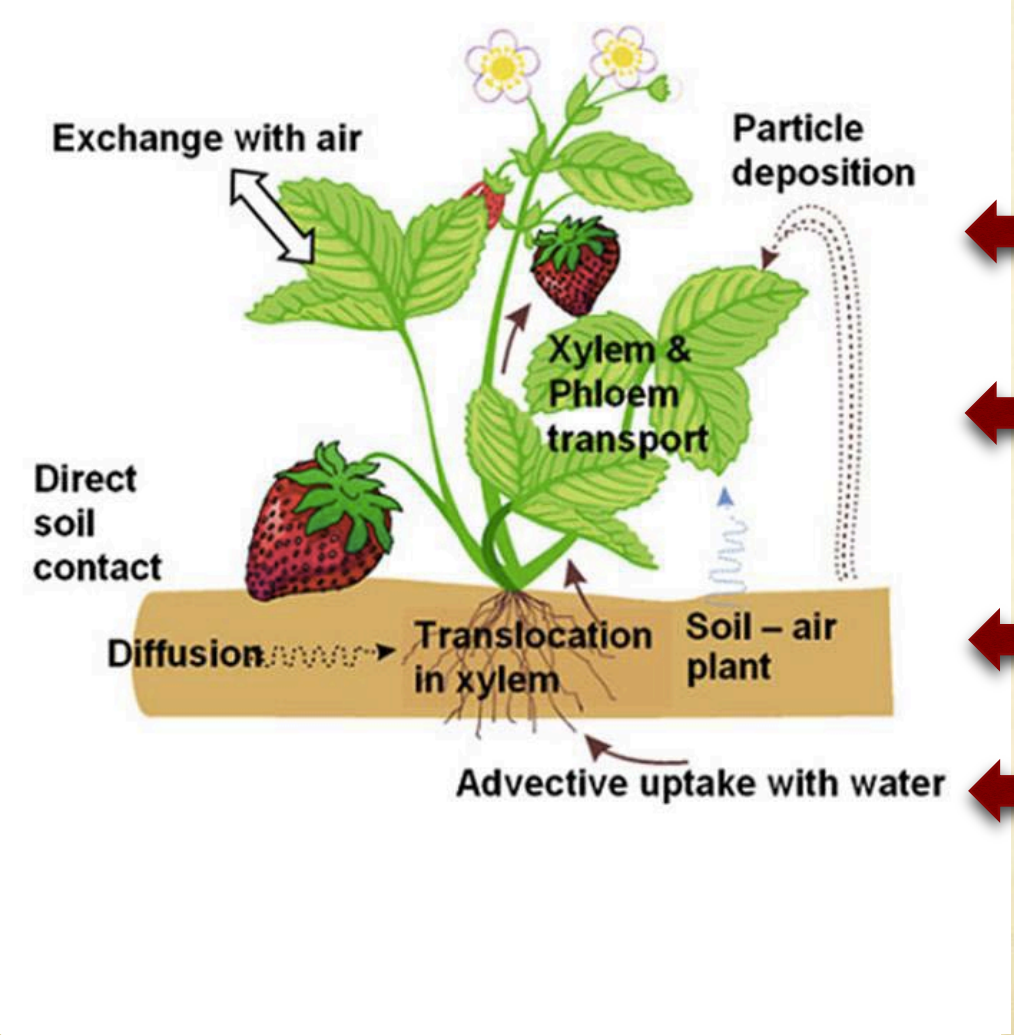
Potential risk to human or terrestrial organisms

The Challenges of CECs

- Thousands of chemical types !
- Different physicochemical properties
- Mixtures
- Pseudo-persistent contaminants

- **Need for a tiered approach in assessment!**

Plant Accumulation of CECs from Soil



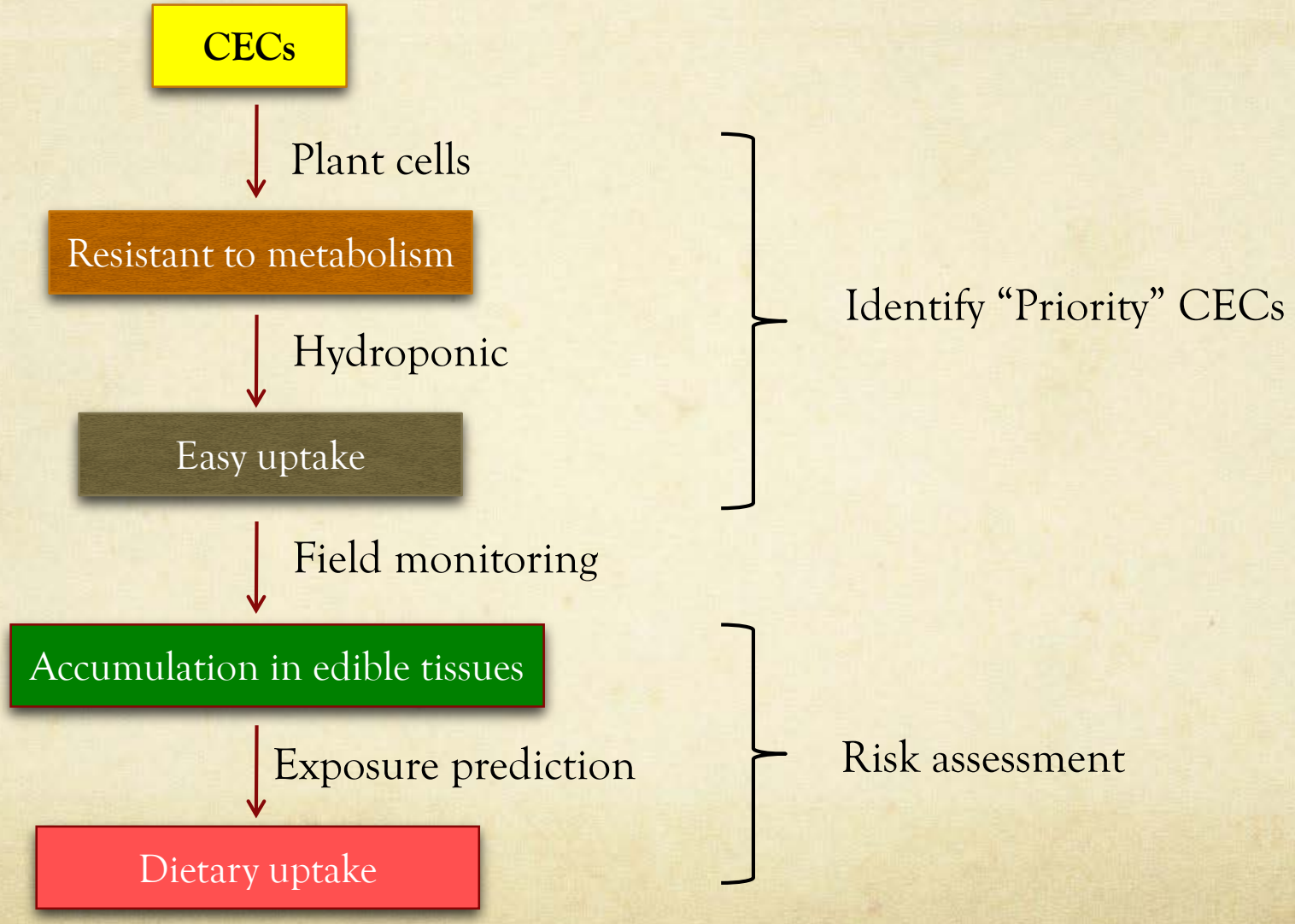
Metabolism in plant

Translocation from root Leaves/fruits

Uptake into root

Sorption & transformations in soil - availability

Tiered Approach



Project Objectives

① Controlled experiments to screen "priority" CECs
   a) Plant cells
   b) Hydroponic

② Effects on terrestrial insects

③ Field studies to understand actual risks

④ Outreach to stakeholders

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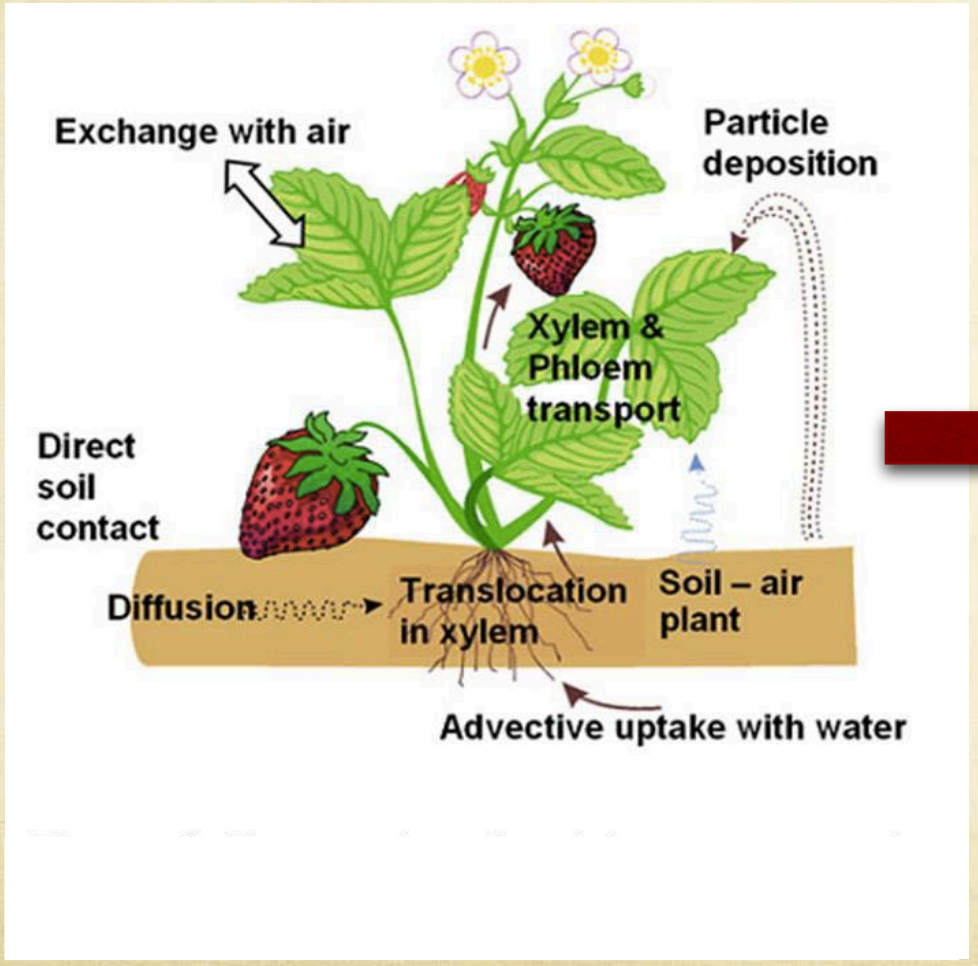
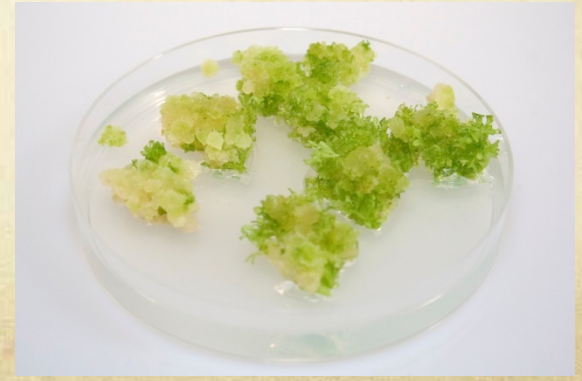
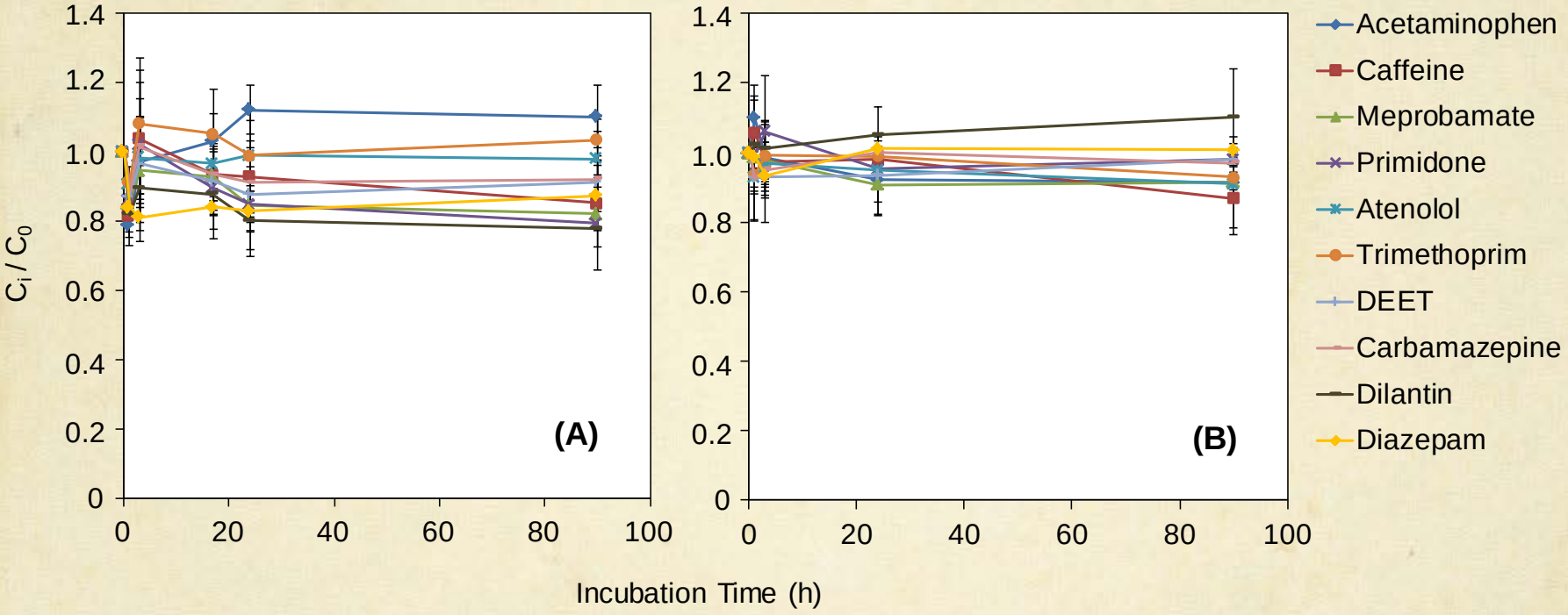
Controlled Experiments:

- Plant cells as a rapid screening tool



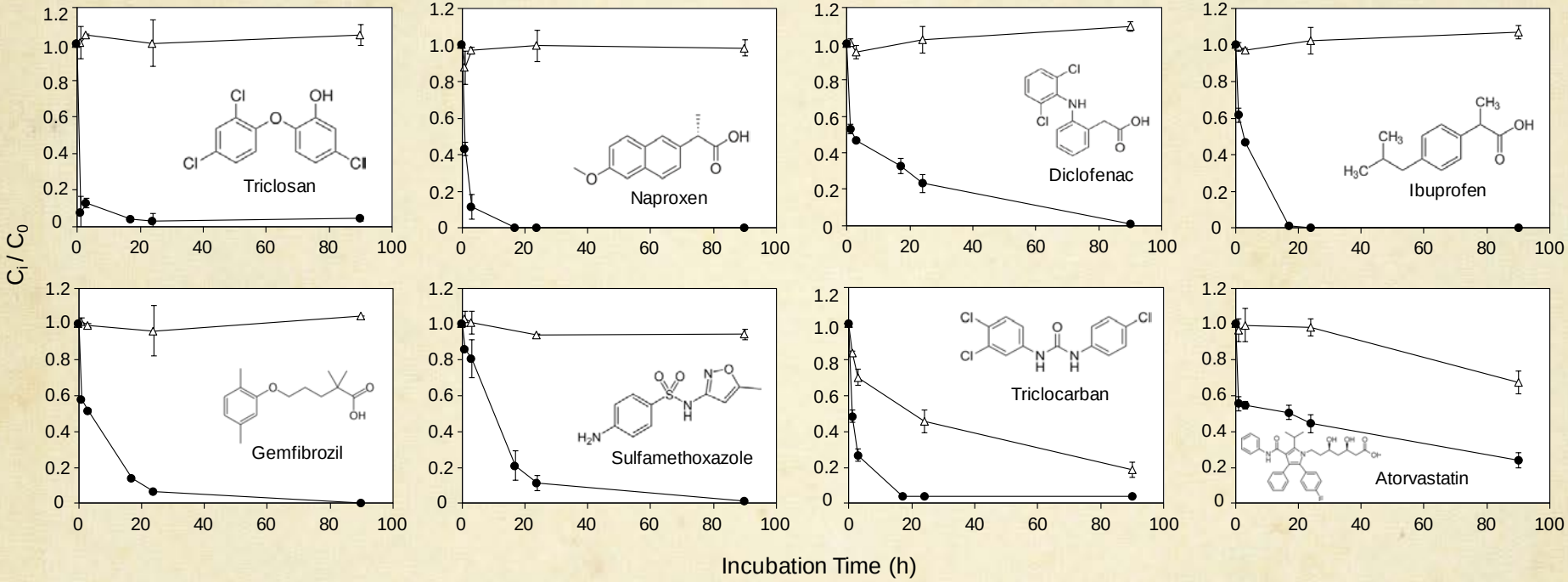


Screening of 18 CECs in Carrot Cells



10 of 18 PPCPs were relatively stable in carrot cell suspensions

Stability in Cell Suspensions



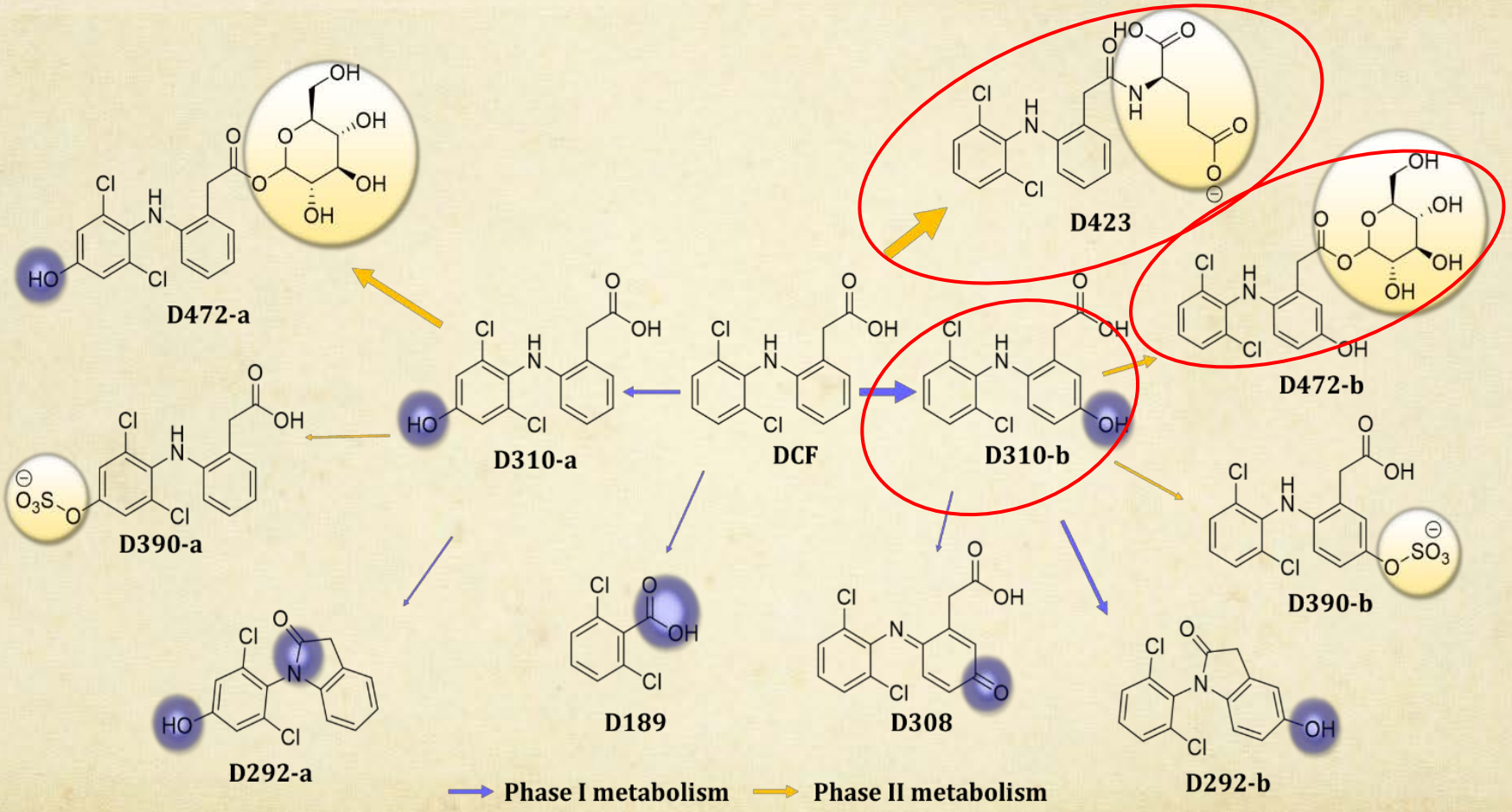
8 of 18 PPCPs were rapidly transformed !

Estimated Half-life (h)

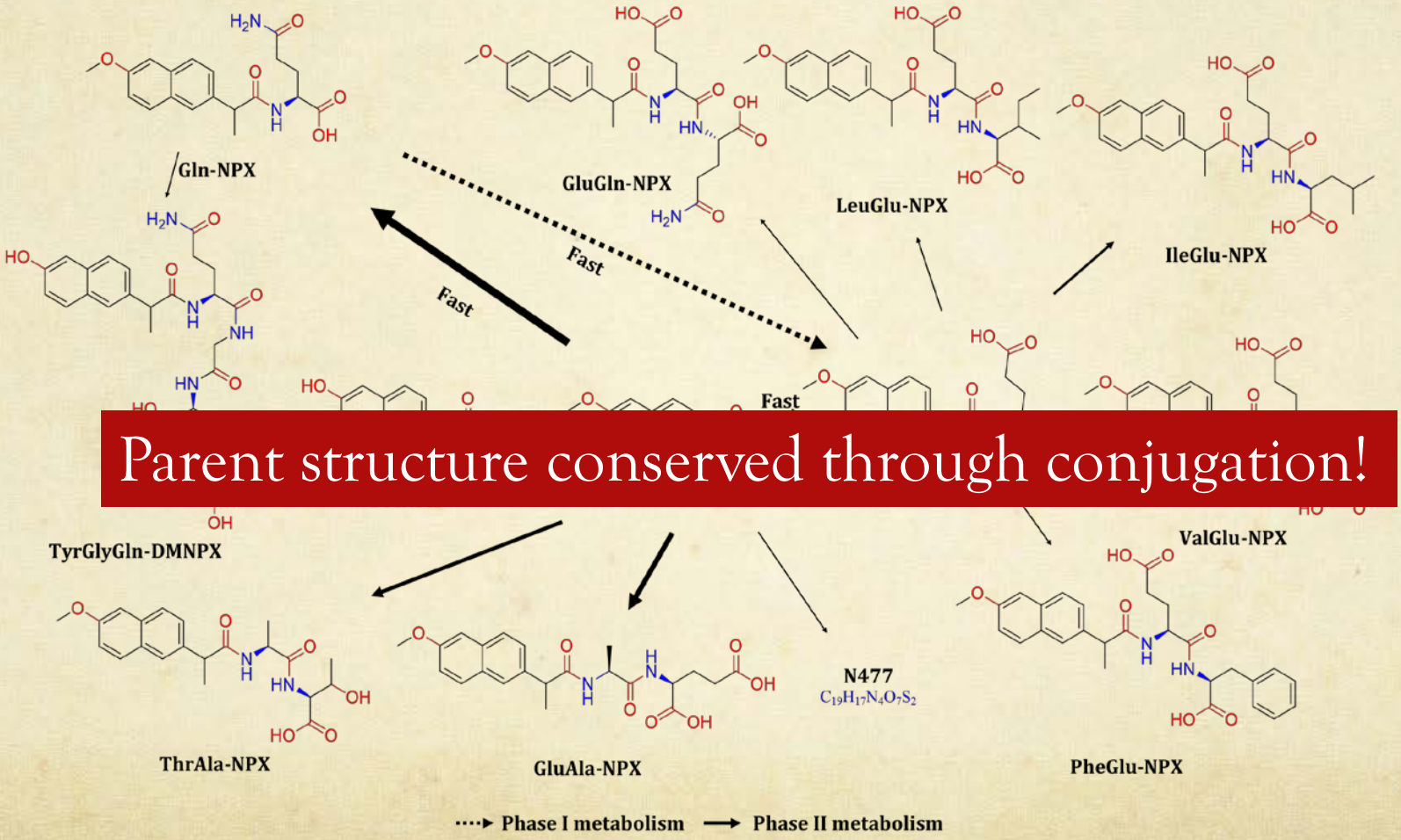
Recalcitrant compounds	Dissipative Compounds	$t_{1/2}$ (hour)
Acetaminophen	Triclosan	0.2
Caffeine	Naproxen	0.8
Meprobamate	Triclocarban	1.1
Primidone	Diclofenac	1.4
Atenolol	Ibuprofen	2.2
Trimethoprim	Gemfibrozil	2.8
DEET	Sulfamethoxazole	7.7
Carbamazepine	Atorvastatin	17
Dilantin		
Diazepam		

Rapidly transformed

Diclofenac metabolism in *Arabidopsis* Cells

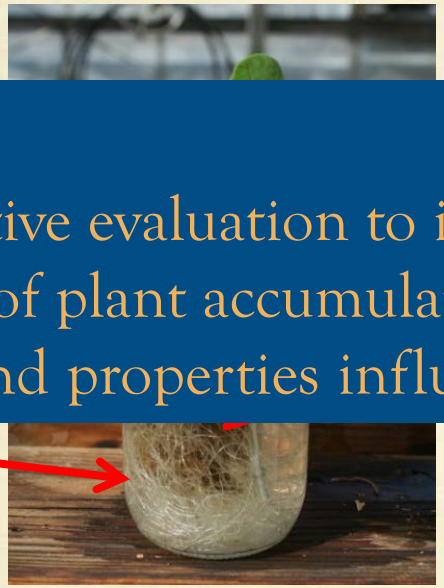


Naproxen Metabolism in *Arabidopsis* Cells



Parent structure conserved through conjugation!

Controlled Experiments:
Hydroponic Cultivation



Tube

Glass jar (450 ml)

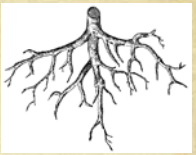
Spinach

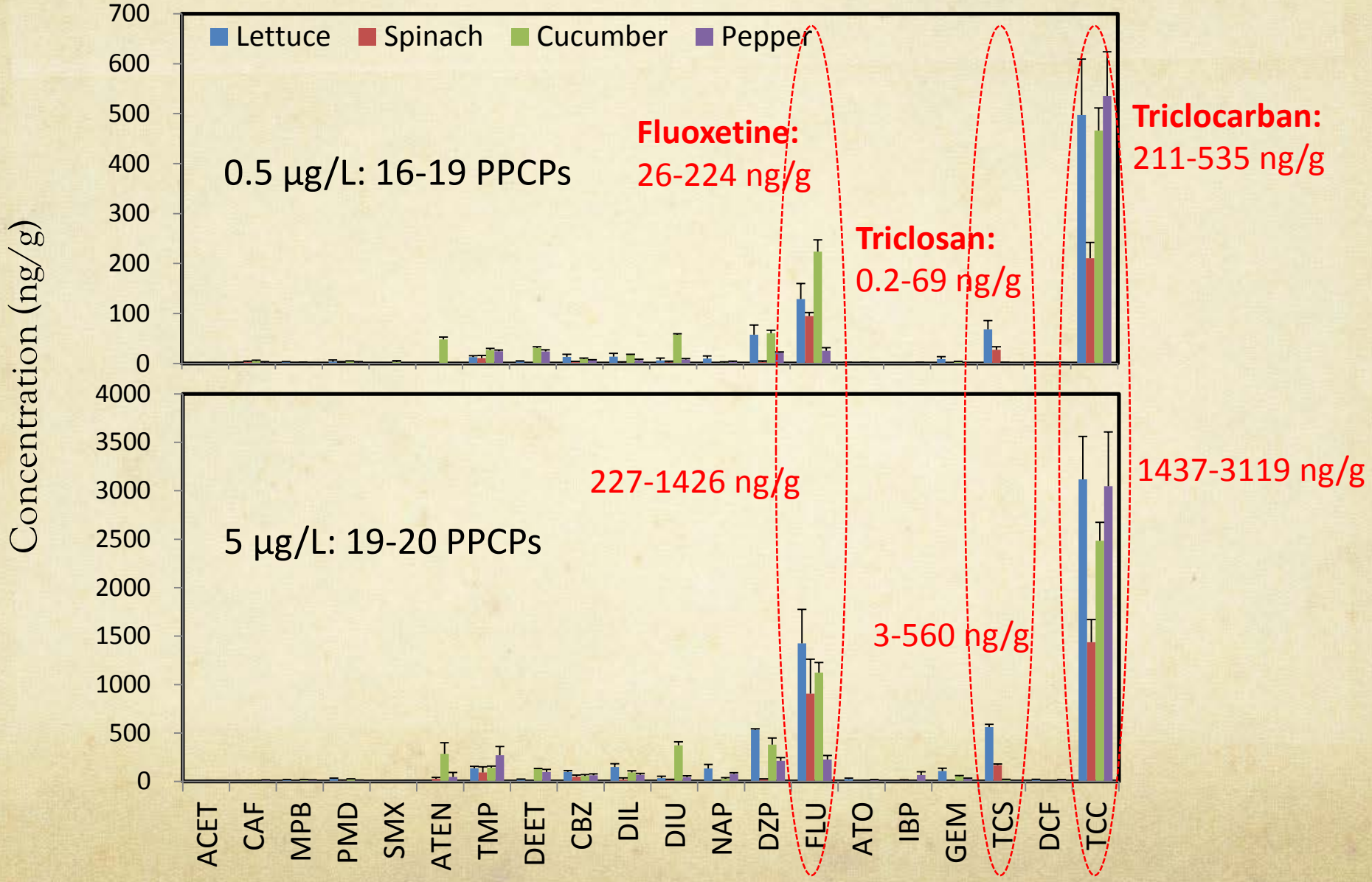
Goals:

1. Comparative evaluation to identify compounds with high potential of plant accumulation
2. Understand properties influencing plant uptake

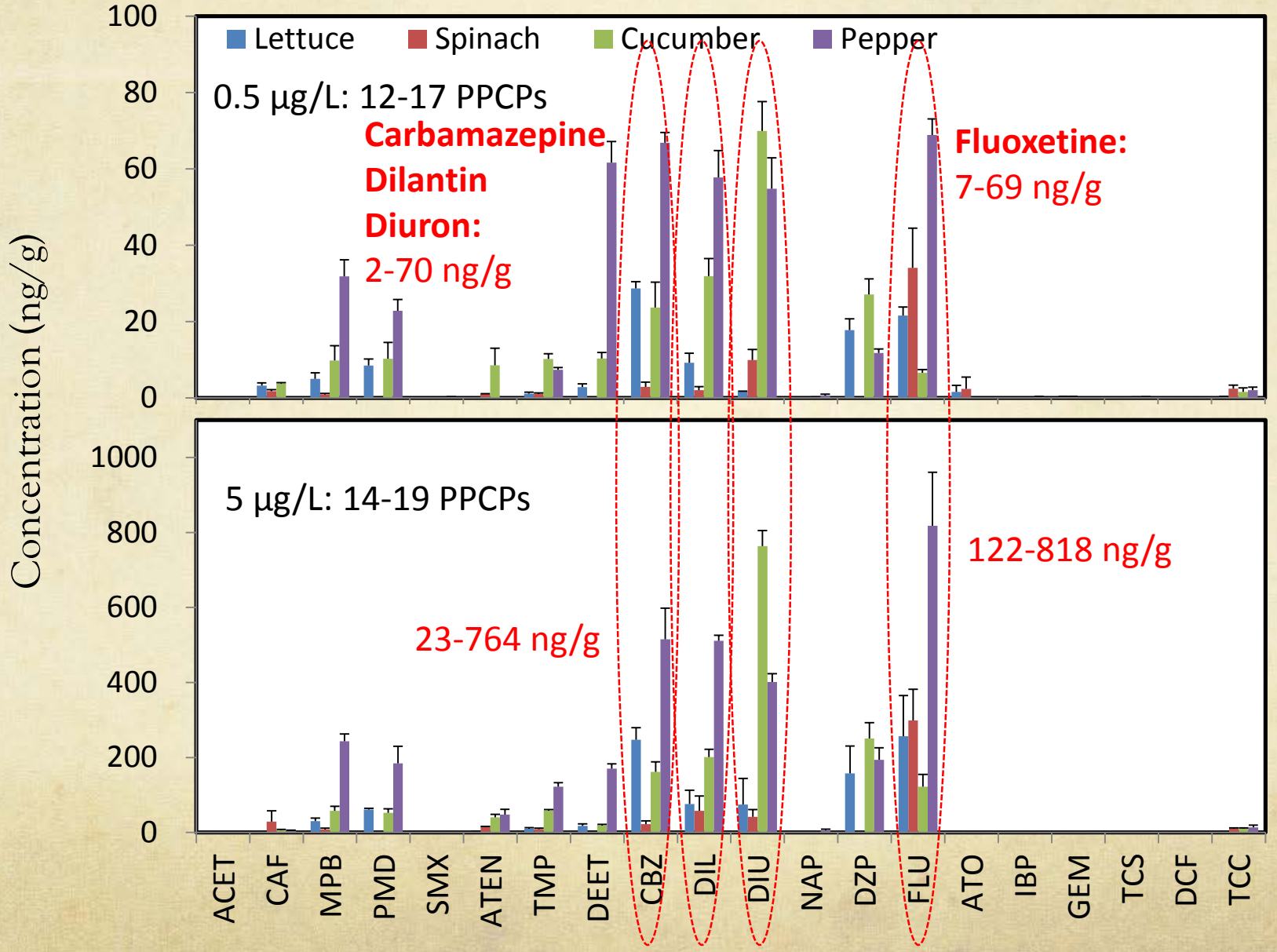
- **Spiked concentration: 0.5 µg/L, 5 µg/L**
- **Growth period: 21 d; nutrient solution changed every 3 d**

Results - Accumulation of PPCPs in root



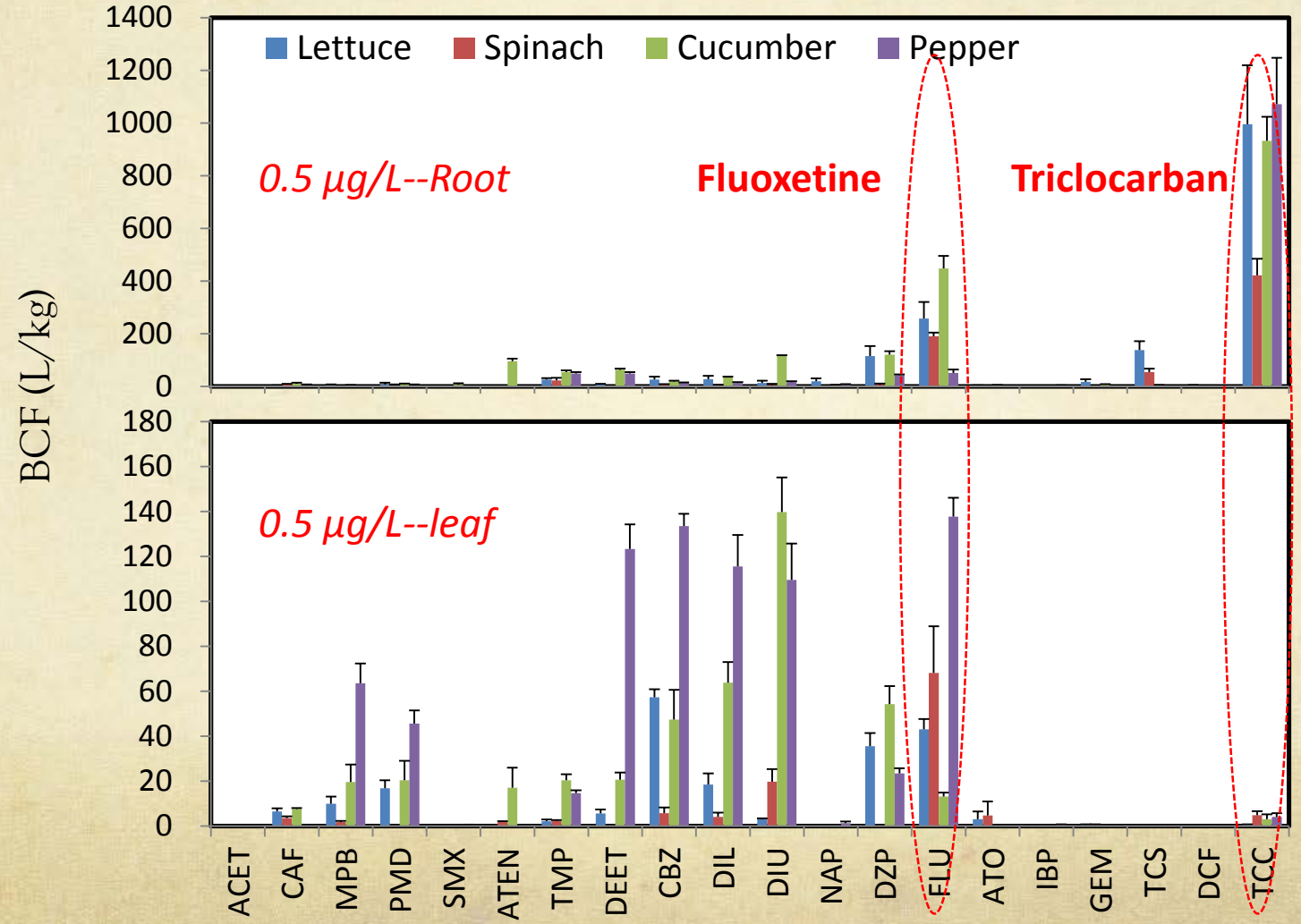


Accumulation of PPCPs in leaf/stem



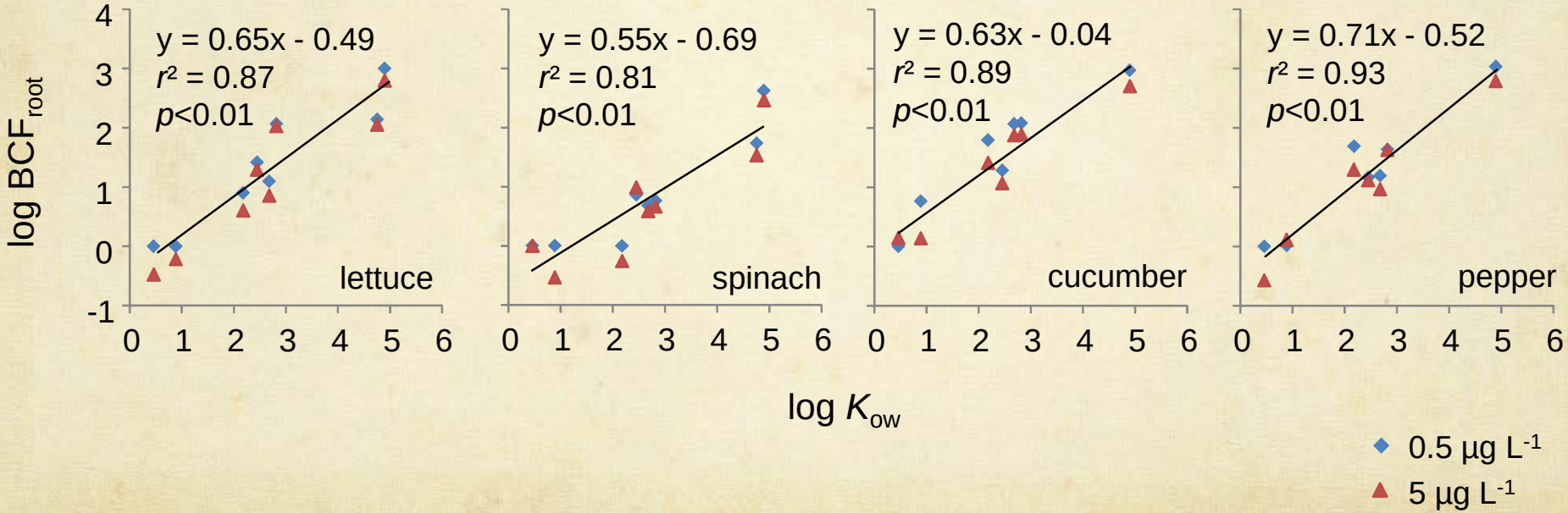
Bioconcentration factor of PPCPs in plant tissue

$$\text{Bioconcentration factor (BCF)} = \frac{C_{\text{plant tissue}}\ (\mu g/kg)}{C_{\text{nutrient solution}}\ (\mu g/L)}$$



Trends & Patterns

- Understand properties driving uptake or translocation



Effects of PPCPs on Important Insects

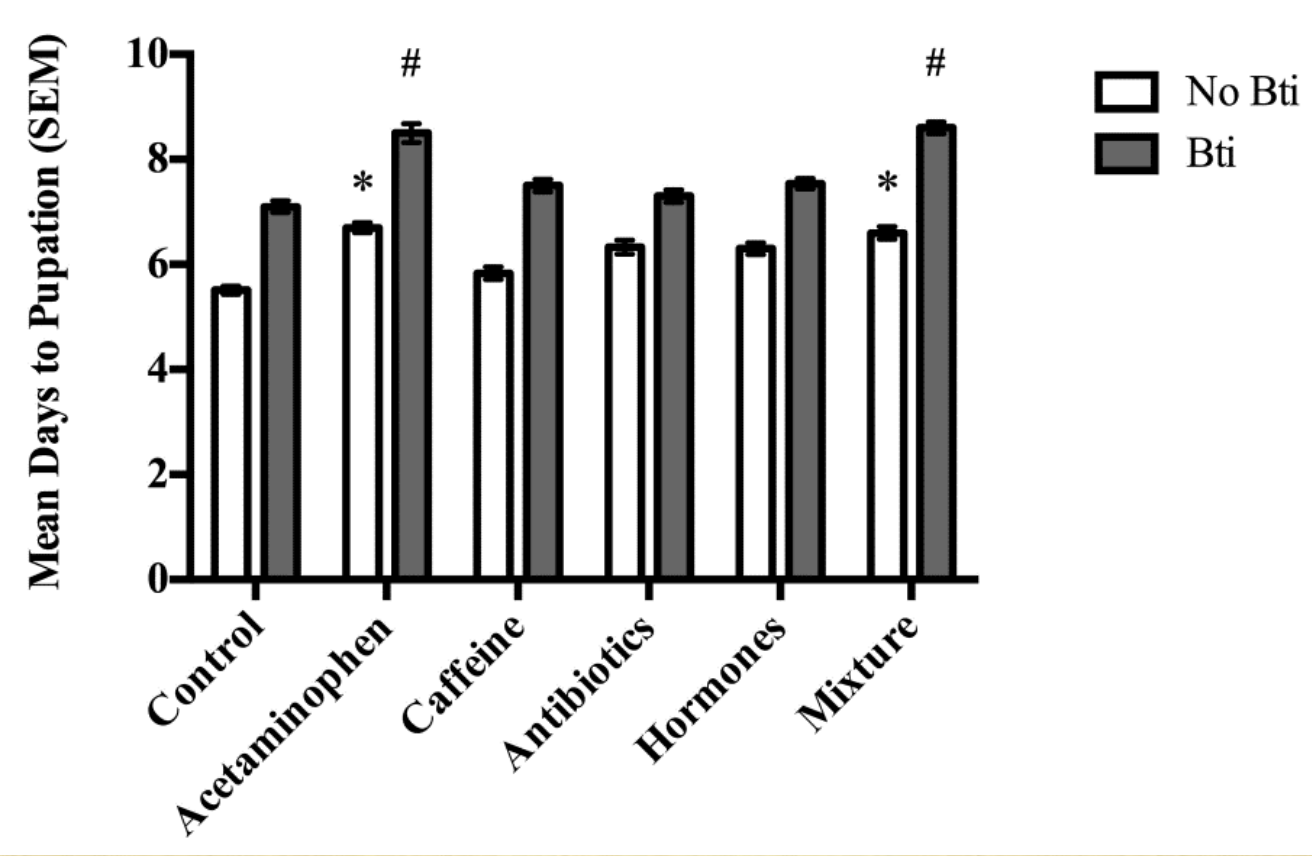
- Can PPCPs affect insects at environmentally relevant concentrations ?
- Does the effect of PPCPs vary by the feeding ecology of insects ?
- Four insect species:
  - Filter feeder (medically important mosquito)
  - Chewing insect (agricultural pest)
  - Phloem feeder (agricultural pest)
  - Detritivore (ecologically and medically important fly)

- *Culex quinquefasciatus* (Say)
  - Filter feeders
  - Aquatic larvae, terrestrial adults
  - West Nile Virus, Equine Encephalitis and possibly Zika virus

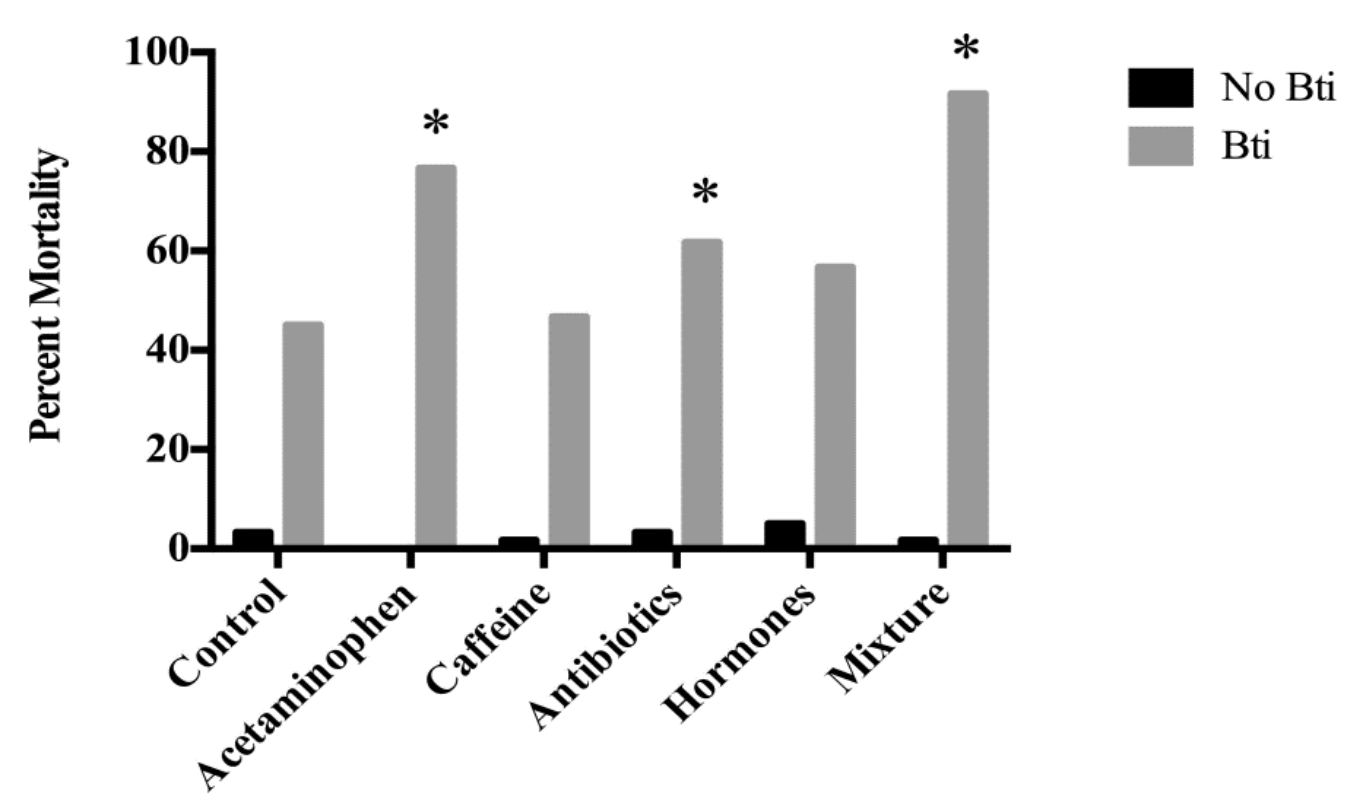
- *Trichoplusia ni* (Hübner)
  - Cabbage looper
  - Major pest of cole and solanaceous crops
  - Ranges from Canada to Mexico

- *Myzus persicae* (Sulzer)
  - Green peach aphid
  - A top agriculturally important aphid
  - Vector for over 100 plant viruses

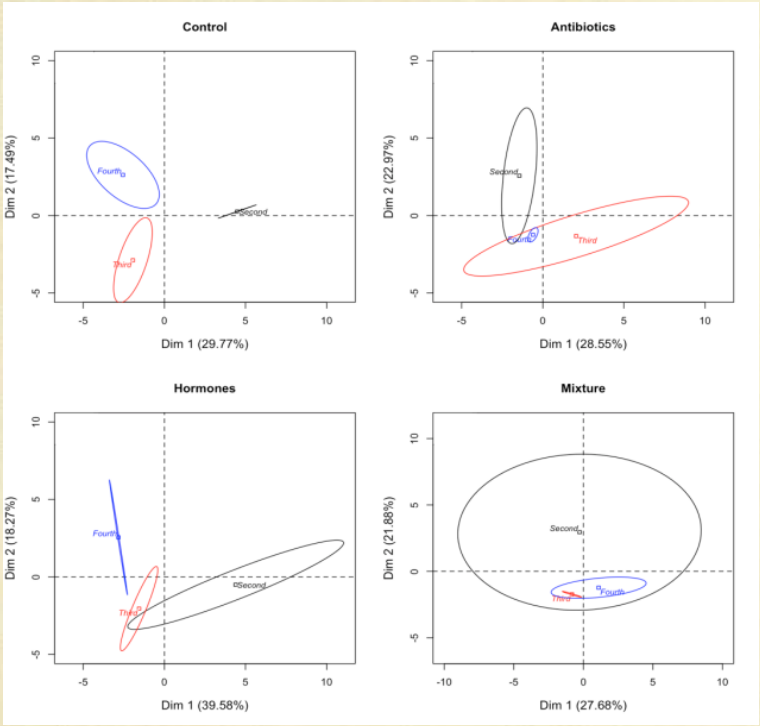
PPCPs extended mosquito developmental time

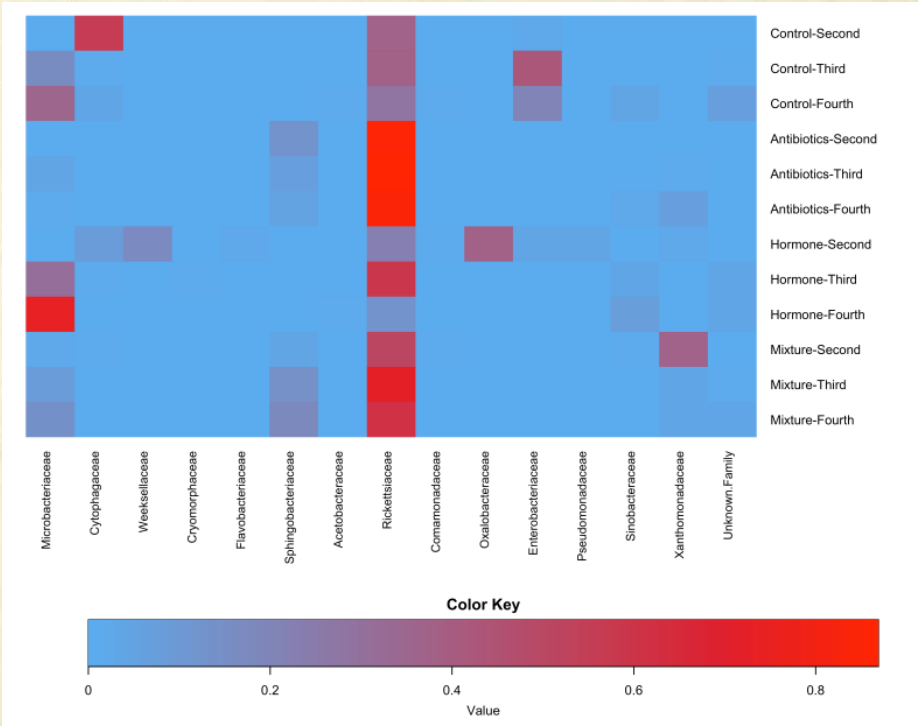


PPCPs enhanced mortality by *Bacillus thuringiensis (Bt)*



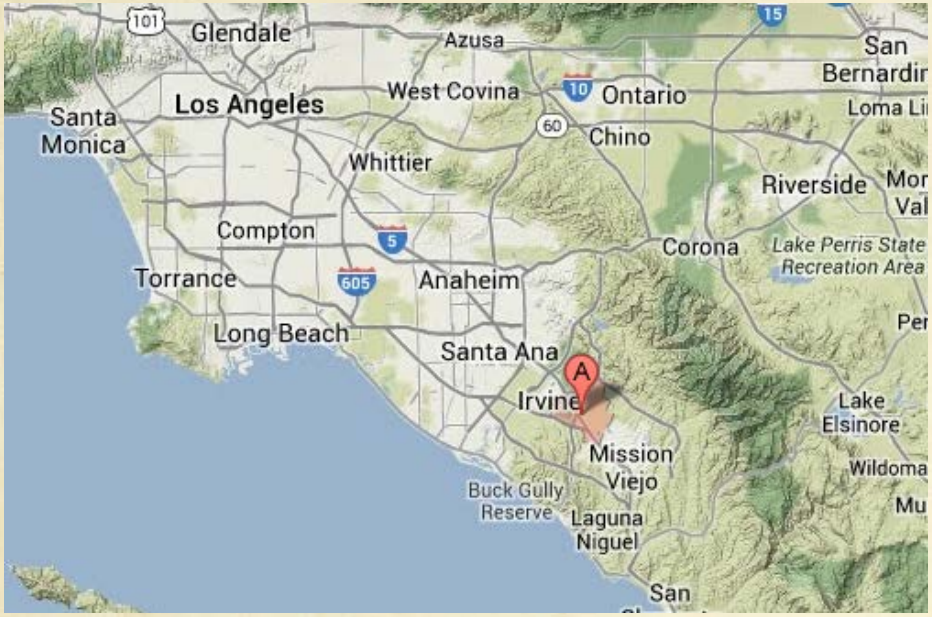
PPCPs changed the Mosquito Microbiome





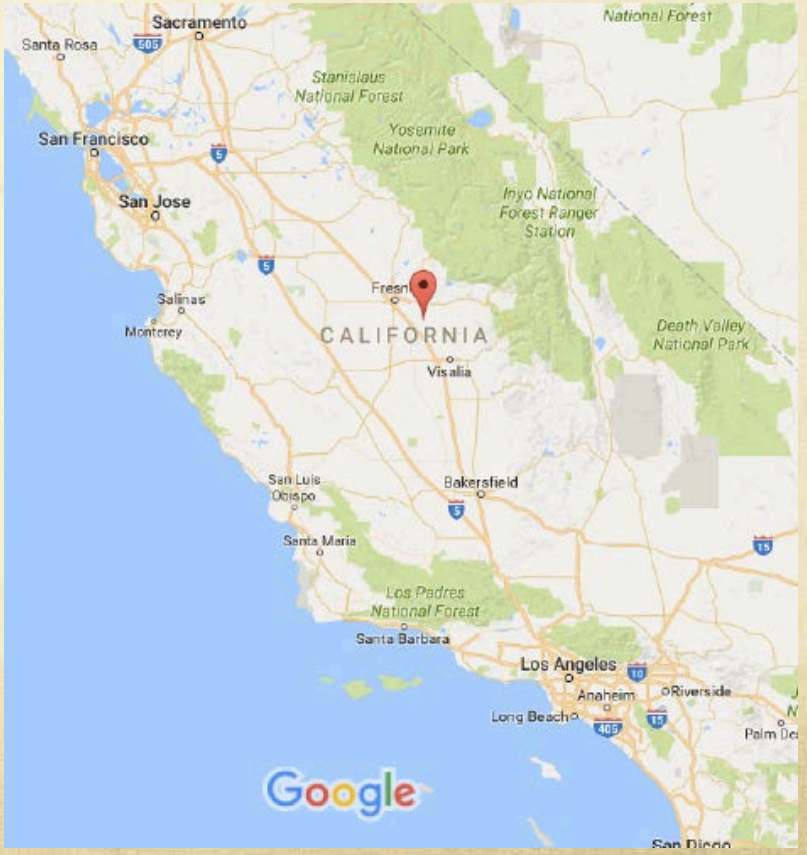
Field Evaluation

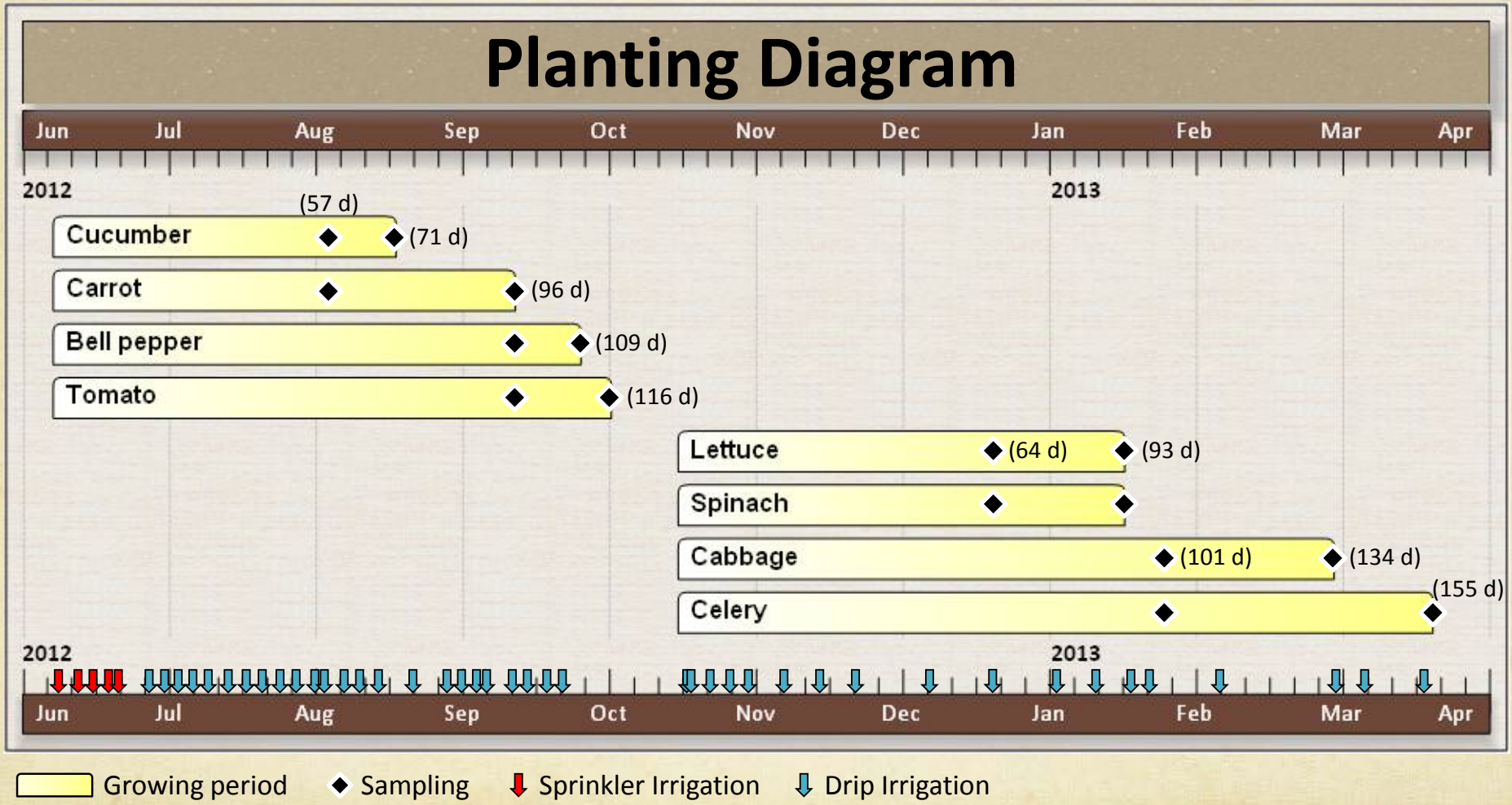
Two Field Sites



Irvine, Southern CA

Fresno, Central CA




Planting Diagram
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
2012
2013
(57 d)
Cucumber
(71 d)
Carrot
(96 d)
Bell pepper
(109 d)
Tomato
(116 d)
Lettuce
(64 d)
(93 d)
Spinach
Cabbage
(101 d)
(134 d)
(155 d)
Celery
Growing period
Sampling
Sprinkler Irrigation
Drip Irrigation

PPCPs in vegetables/fruits

Root:

Leaf:

Fruit:

Stakeholder Outreach

- Regional water districts
- County extension offices
- USDA-ARS in Central Valley, CA

- Address public concerns
- Promote safe reuse of reclaim water

Anticipated Results & Impacts

- **New knowledge**
  - High risk CECs
  - Properties governing uptake and accumulation
  - Realistic levels and risks
- **Impacts:**
  - Public perception and awareness
  - Promotion of safe reuse

Funding $upport

United States Department of Agriculture
National Institute of Food and Agriculture