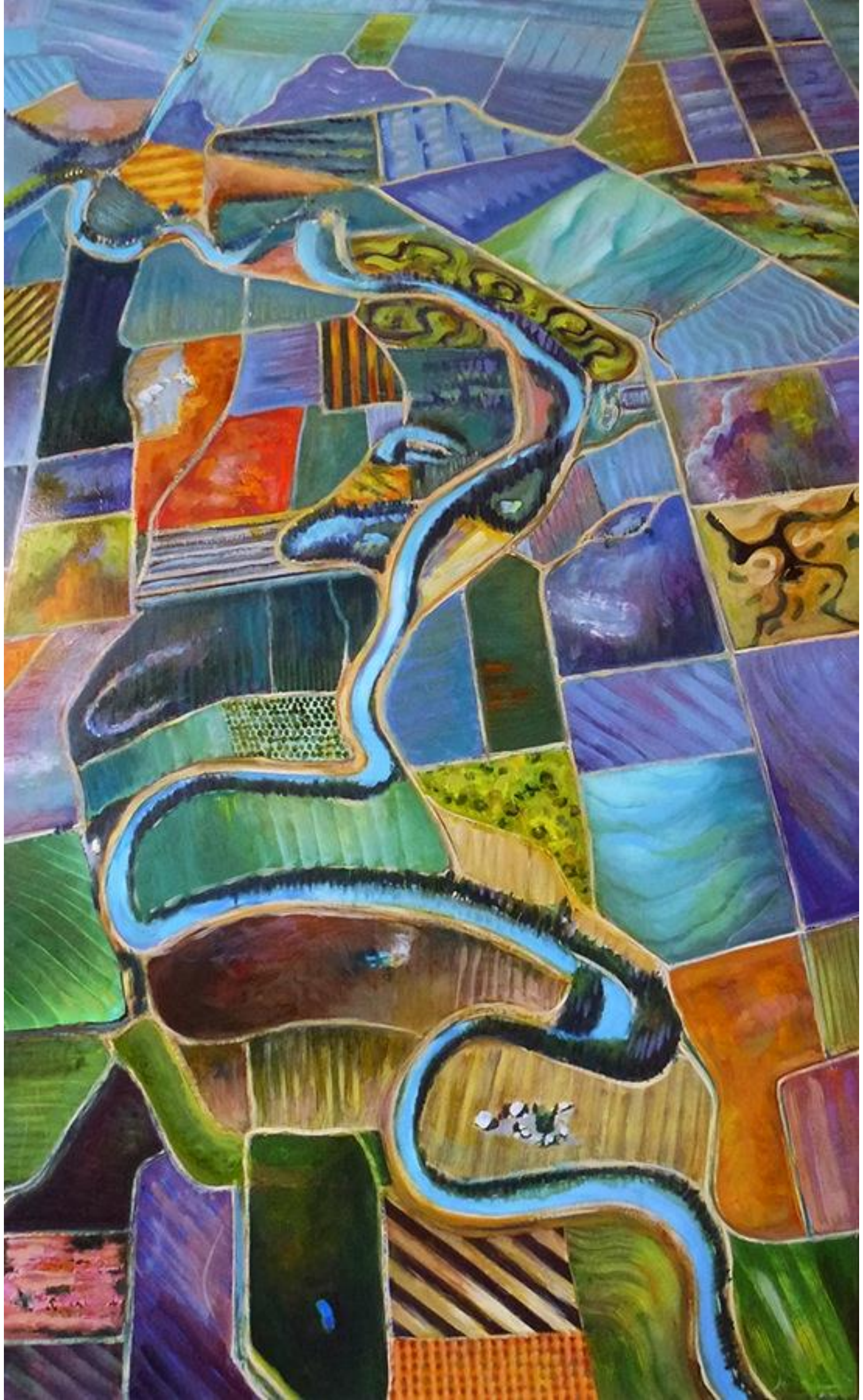
Soil microbes and plant nitrogen nutrition

Tim Bowles

Assistant Professor of Agroecology & Sustainable Agricultural Systems



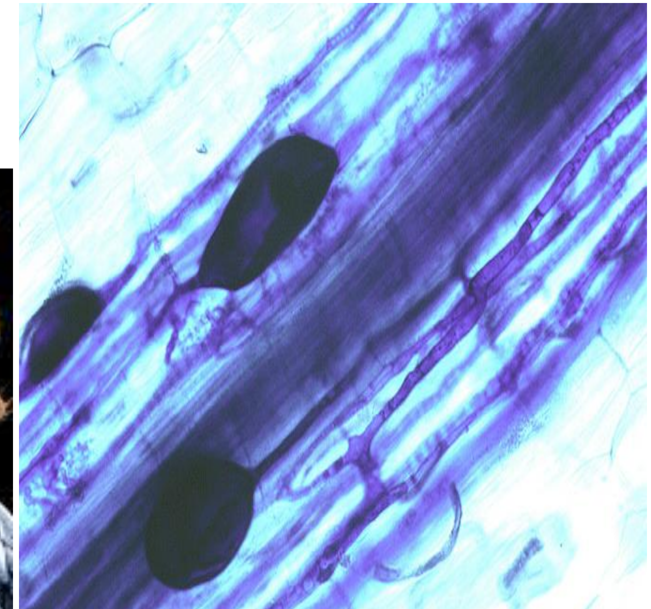
Joseph Bellacera, *Over Yolo #2*
www.josephbellacera.com

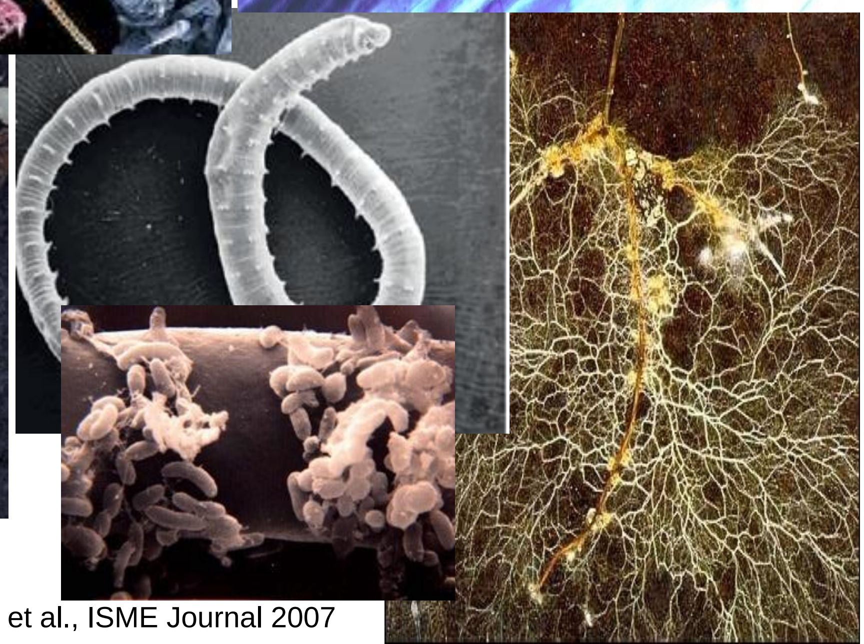
Learning goals

1. Describe the linkage between soil health and soil fertility.
2. Understand soil nitrogen cycling as highly dynamic.
3. Interpret soil test results from healthy soils with highly active microbes.

Soil life

1g of soil contains: 10^9 bacteria, 6,000 – 50,000 bacterial species and up to 200m fungal hyphae

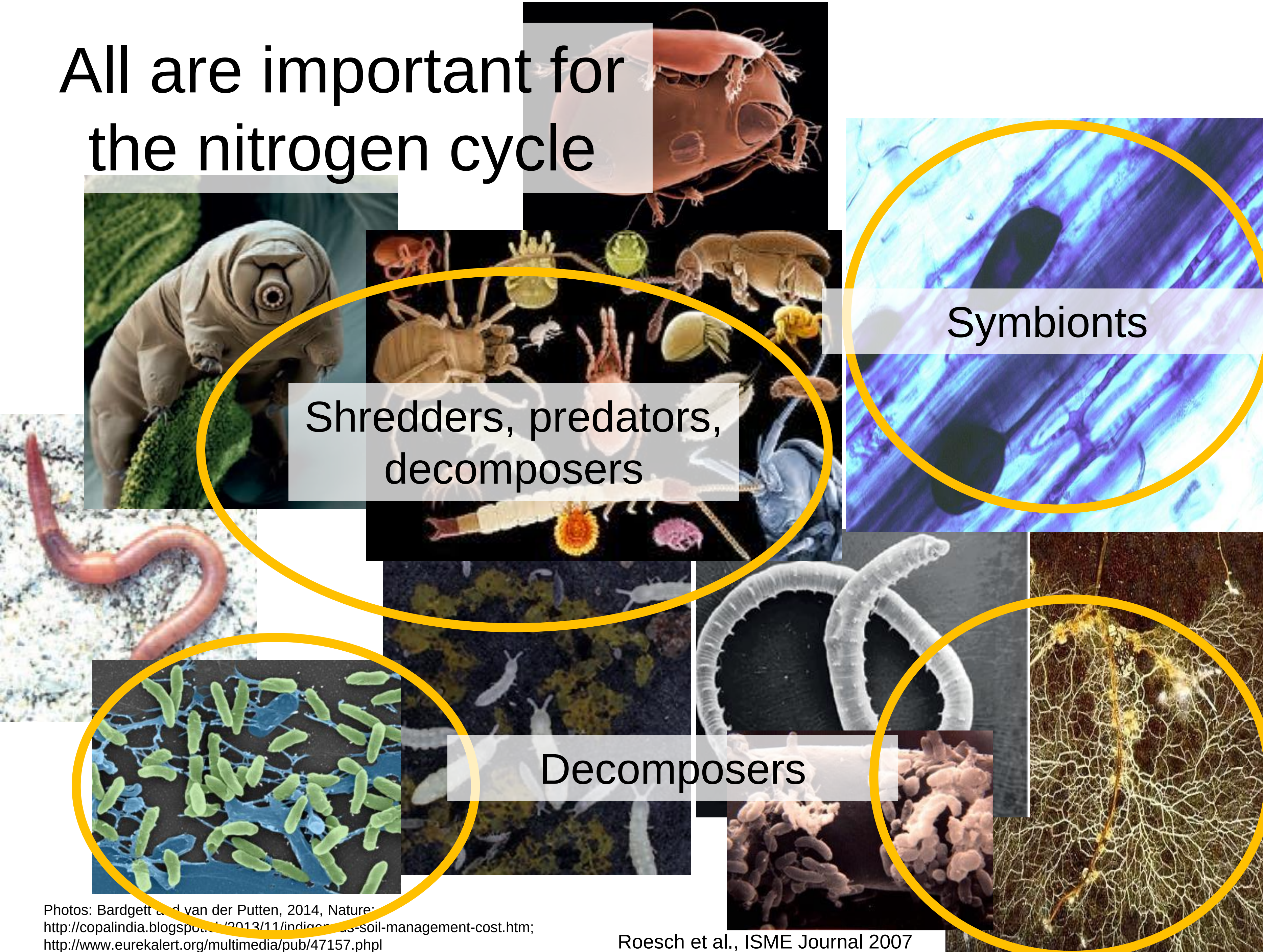




Photos: Bardgett and van der Putten, 2014, Nature;
http://copalindia.blogspot.ch/2013/11/indigenous-soil-management-cost.htm;
http://www.eurekalert.org/multimedia/pub/47157.phpl

Roesch et al., ISME Journal 2007

All are important for the nitrogen cycle



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Roesch et al., ISME Journal 2007

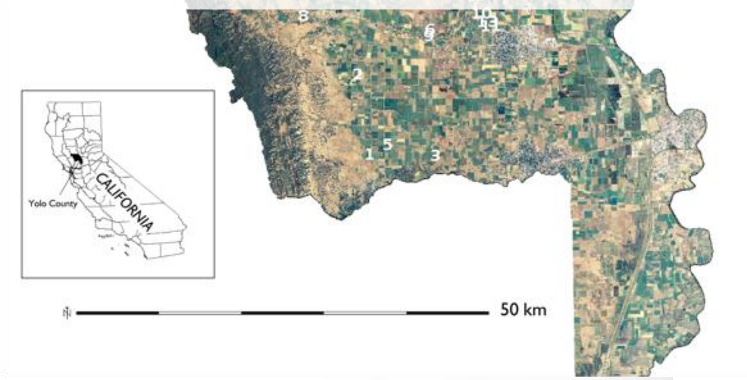
Today we'll focus on…

Photos: Bardgett and van der Putten, 2014, Nature; http://copalindia.blogspot.../2013/11/indigenous-soil-management-cost.htm; http://www.eurekalert.org/multimedia/pub/47157.phpl

Roesch et al., ISME Journal 2007

A soil fertility puzzle

13 organic tomato fields intensively monitored over a growing season



Bowles et al (2015) *Plos One*

	Mean soil nitrate (0-6 in, g NO_3^--N/kg soil)		
Field group #	Transplant	Flowering	Harvest
1	5.8	0.2	4.0
2	6.7	16.4	6.2
3	1.8	2.9	4.7

Bustamante and Hartz (2015) suggest 10-15 mg N kg^{-1} soil post-transplant as "action threshold" for organic processing tomatoes

Based only on this information, which groups of fields do you think showed nitrogen deficiency and reduced yields?

A soil fertility puzzle

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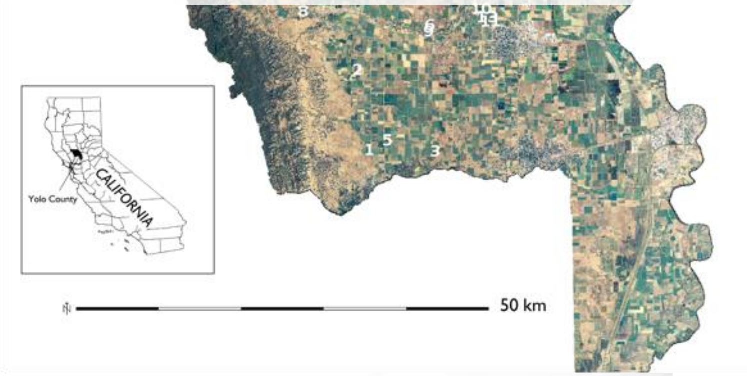

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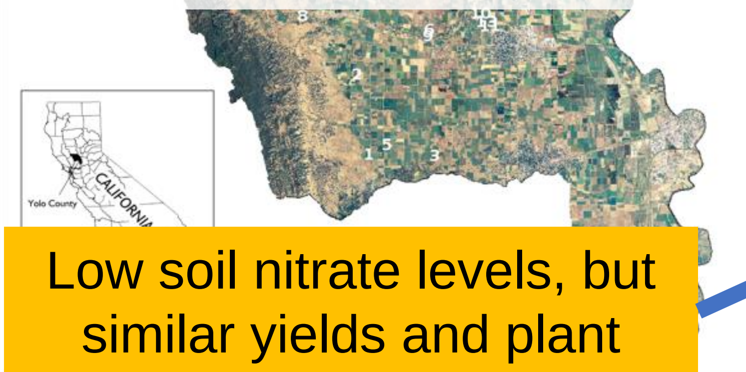
Field group #	**Plant nitrogen (%) @ flowering**	**Yield (US tons/acre)**
1	1.7	20.2
2	3.3	41.5
3	3.2	43.0

A soil fertility puzzle

13 organic tomato fields intensively monitored over a growing season



Low soil nitrate levels, but similar yields and plant nitrogen: *Sufficient nitrogen and less potential for nitrogen losses*

Bowles et al (2015) *Plos One*

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What's going on?

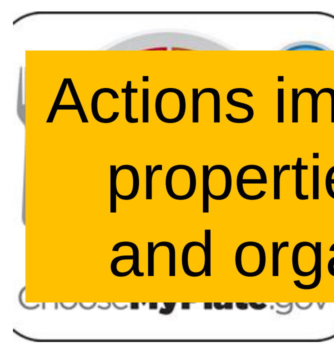
We need to understand linkages between soil health and soil fertility

The health metaphor

- Our health:
  - **Parents** (genes) ×
  - **Environment** ×
  - **Actions** (Diet, exercise)
- Soil health:
  - **Parents** (rocks) ×
  - **Environment** ×
  - **Actions** (Agricultural management)
- Health* (n) - Soundness of body; that condition in which its **functions** are duly and efficiently discharged

Us

Soil



Actions impact dynamic properties – soil life and organic matter.

*Oxford English Dictionary

Soil health defined

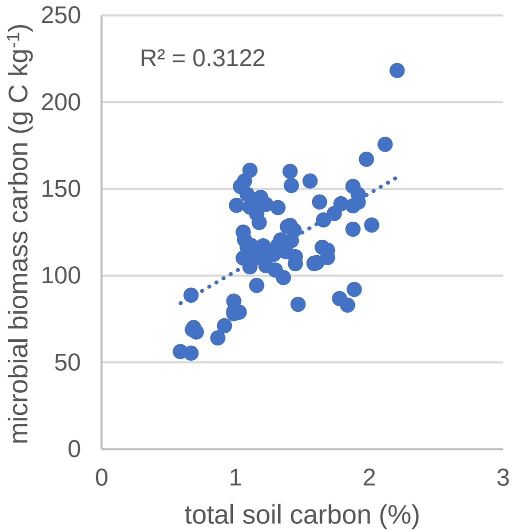
- "A healthy agricultural soil is one that is capable of **supporting the production of food and fiber**, to a level and with a quality sufficient to meet human requirements, **together with continued delivery of other ecosystem services** that are essential for maintenance of the quality of life for humans and the conservation of biodiversity."
- "Soil health is the degree to which **dynamic properties** have been managed for optimum function within the constraints of the soil's **inherent properties**."

Kibblewhite *et al.*, 2008; *Proc Roy Soc B*
Moebius-Clune *et al.*, 2006*; Comprehensive Assessment of Soil Health*

Soil organic matter and organic matter inputs are ~half carbon: Energy for microbes

- OM inputs like…

The more soil carbon, the greater the biomass of microbes:

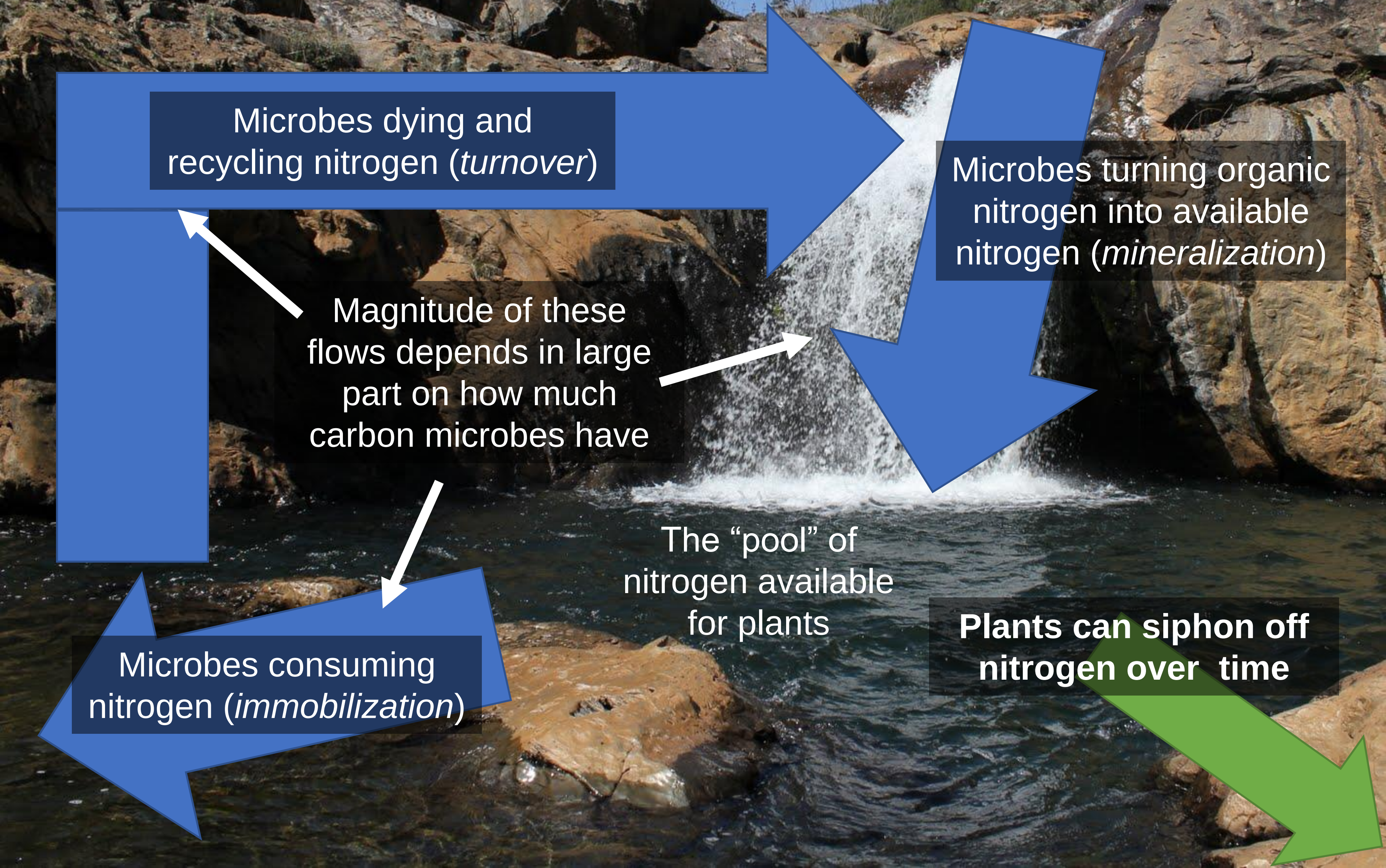


Data are from the same 13 fields. Microbial biomass measured at tomato flowering

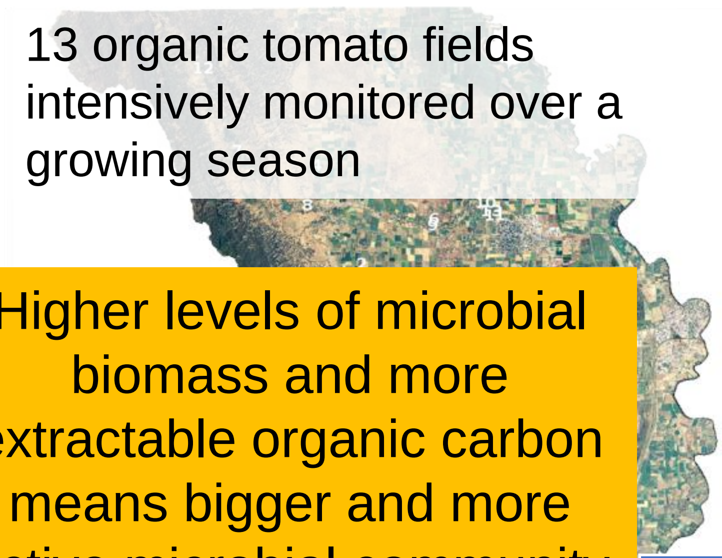
When microbes have carbon available, they will look for nitrogen

- Nitrogen is a nutrient for microbes – builds proteins, DNA, etc
- Microbes *mineralize* nitrogen from organic matter (soil or cover crops, compost, etc) – convert it into forms that microbes and plants can use, first amino acids, then ammonium, and then nitrate
- We typically think that only nitrogen beyond what microbes require is available for crops.

But we should think of soil nitrogen cycling more like this… Dynamic!



A soil fertility puzzle



13 organic tomato fields intensively monitored over a growing season

Higher levels of microbial biomass and more extractable organic carbon means bigger and more active microbial community

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Field group #	Transplant	Flowering	Harvest
1	5.8	0.2	4.0
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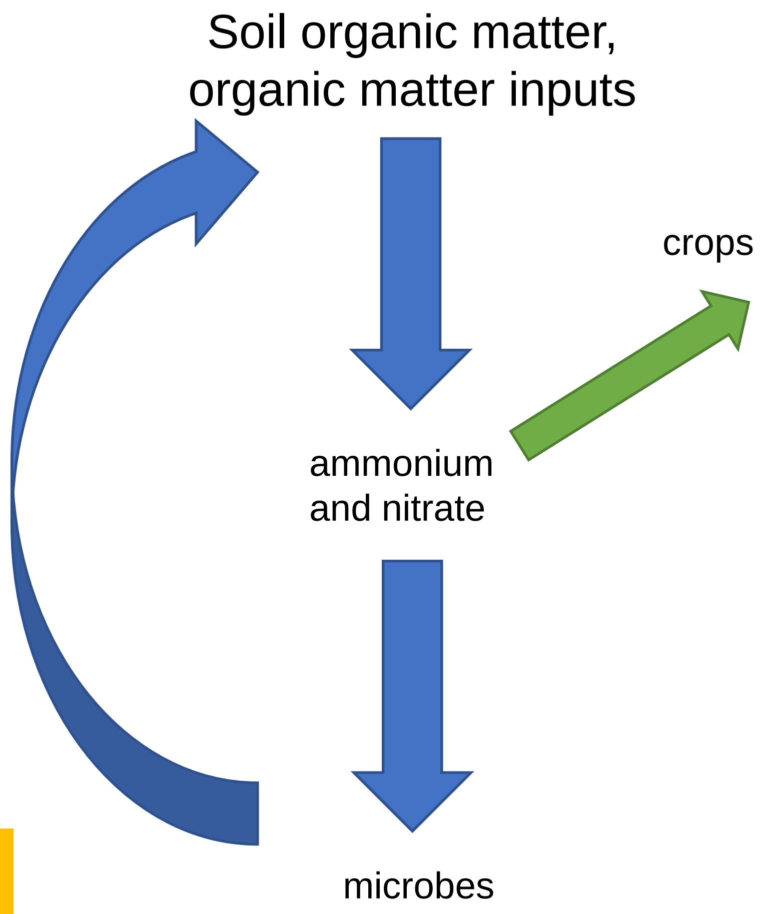
Field group #	Total soil carbon (%)	Microbial biomass carbon (g C kg^{-1})	"Extractable" organic carbon (g C kg^{-1})
1	0.8	72	28
2	1.2	124	42
3	1.8	130	70

Bowles et al (2015) *Plos One*

How can soil nitrogen cycling change as soil health improves?

1. More carbon for microbes means more abundant and active microbes
2. These leads to greater *flows* of nitrogen, but *pools* may not build up, if flows to microbes and/or plants are high
3. Plants are good competitors for nitrogen over time – they can siphon off nitrogen as it flows



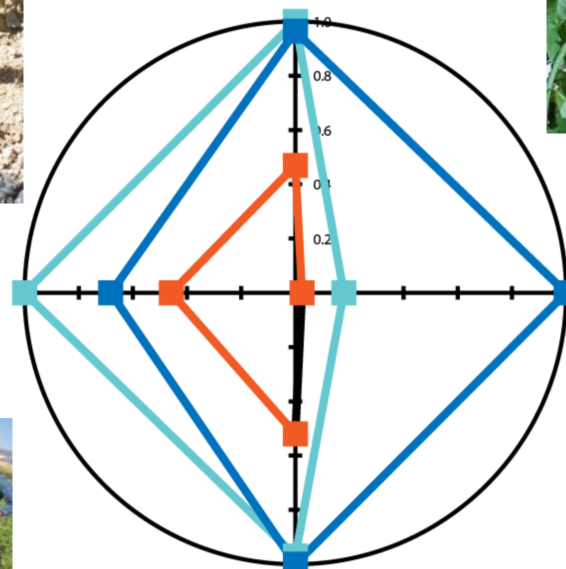
The challenge for fertility management is that flows are difficult to measure

What does this mean for soil fertility management?

- Monitoring soil nitrate is still an essential part of organic soil fertility management
- Measuring low soil nitrate can mean:
  - There is not going to be enough nitrogen available to meet crop demand – take action
  - OR, microbes are very active, and nitrate is not building up but flows may be enough to meet crop demand
- How to differentiate?
  - Low soil nitrate levels but crops that seem to have plenty of nitrogen (but this could also depend on irrigation if nitrate is being flushed below root zone)
  - Soil organic matter that is high for your area and soil type
  - Adding an additional measurement of active carbon and/or microbial activity

Healthy soils may optimize nutrient cycling

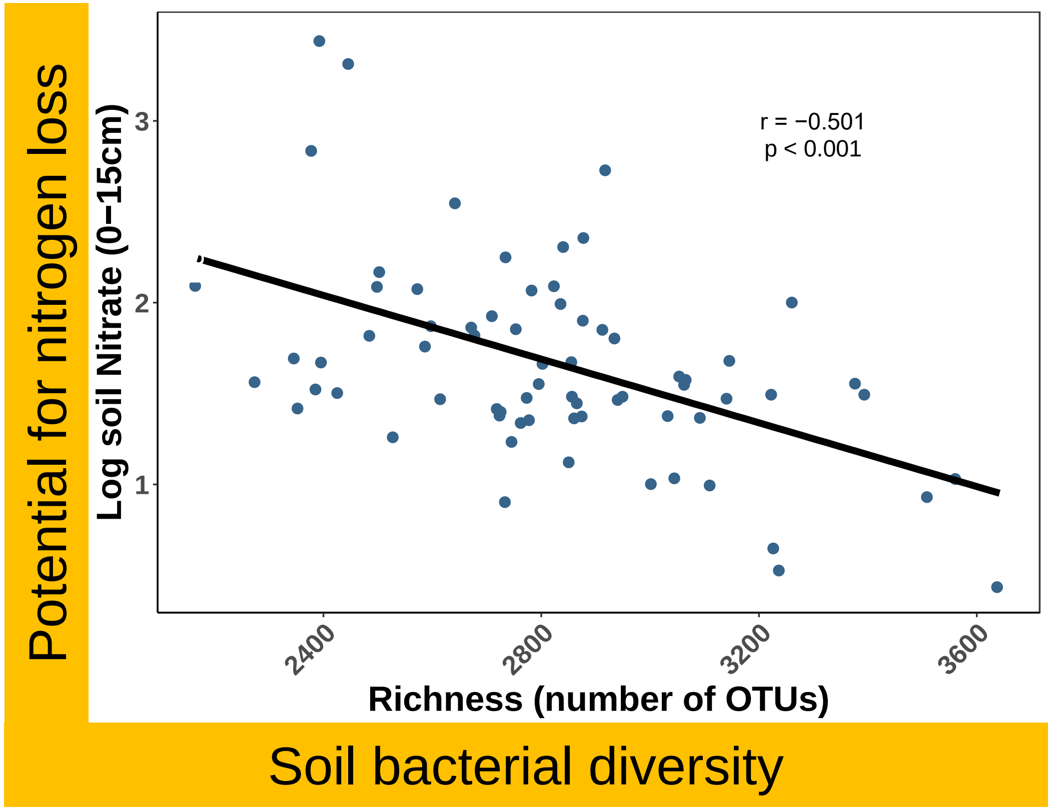
- High SOM
  - Tomato yields similar to Yolo Co. average
  - Some potential for nitrogen losses
- Medium SOM
  - Tomato yields similar to Yolo Co. average
  - Highest potential for nitrogen losses
- Low SOM
  - Low tomato yields
  - Low potential for nitrogen losses

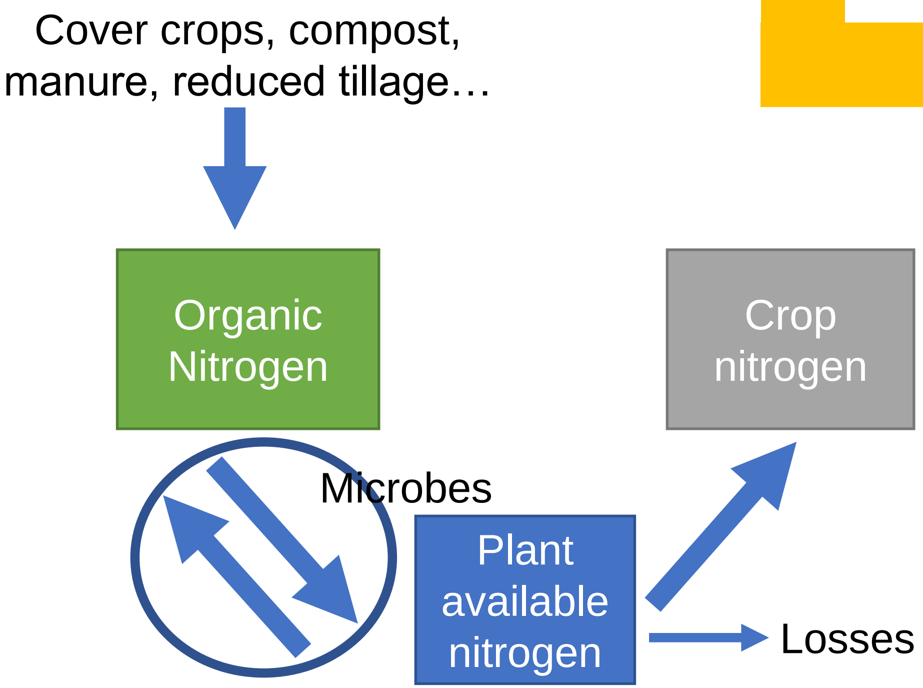


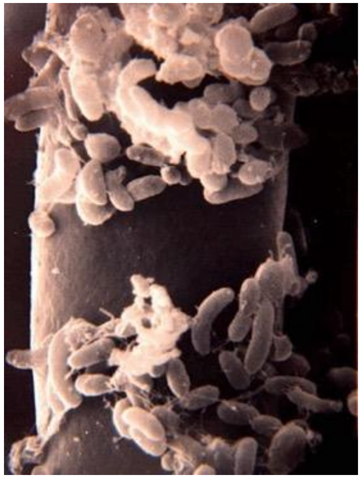
Bowles *et al.*, 2014; *Soil Biology and Biochemistry*
Bowles *et al.*, 2015; *Plos One*

Diverse soil microbes

- Farms with greater soil microbial diversity had high tomato production, *and* reduced potential for nitrogen losses





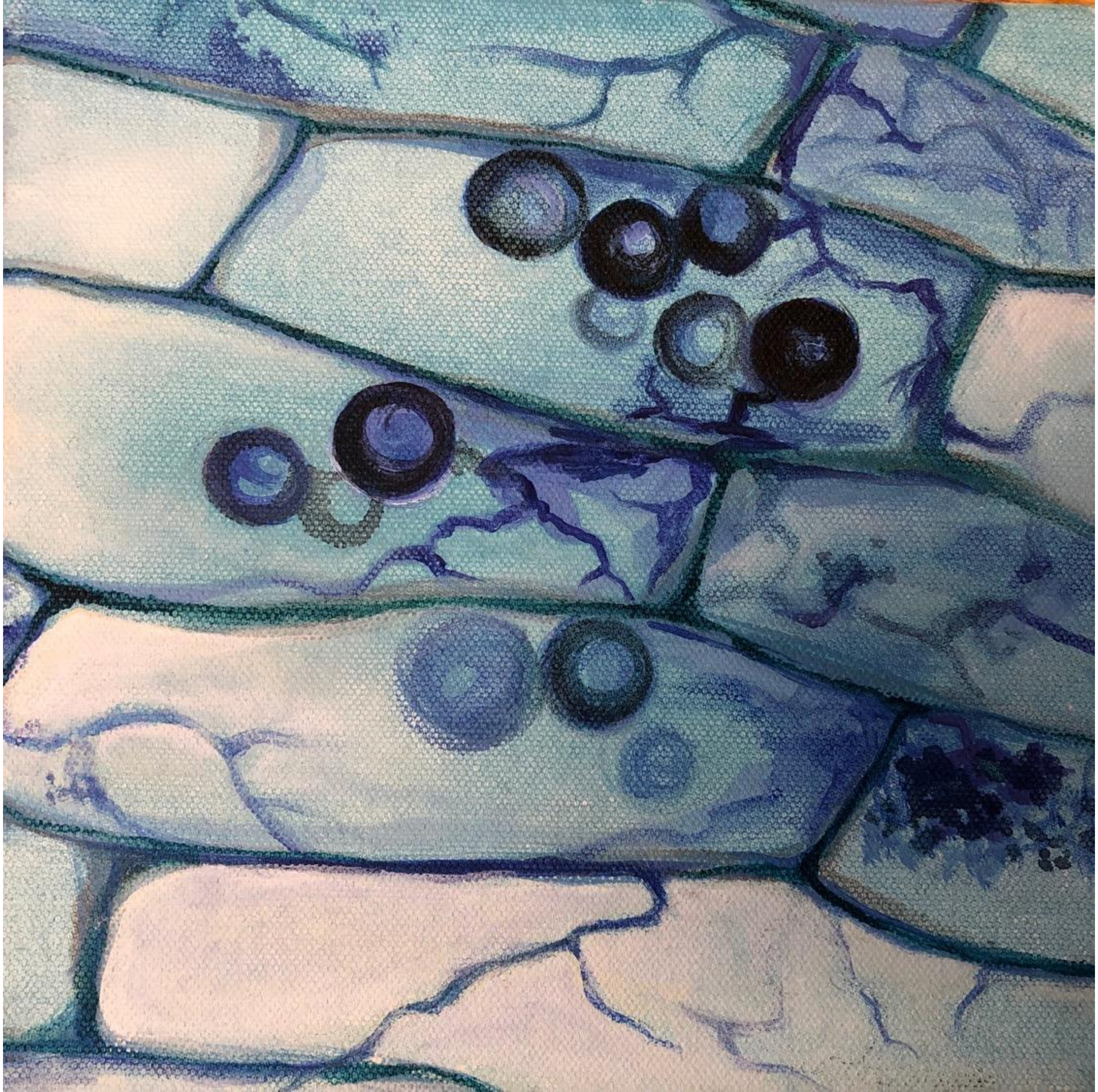


Jordan Sayre and Jorge Rodrigues, UC Davis

Some key messages

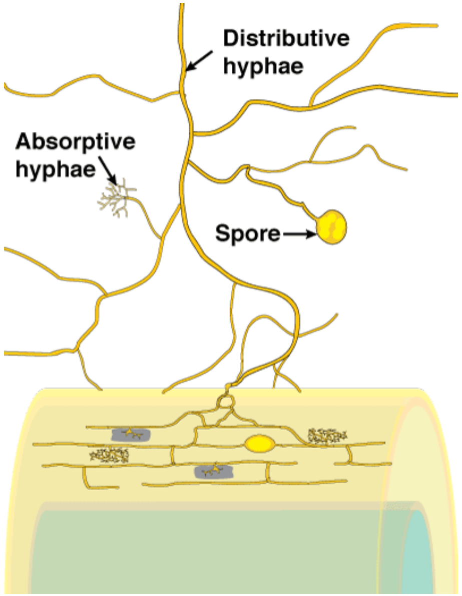
- Farms can produce well with “tight” N cycling
  - Tight N cycling associated with higher total C and N (SOM)
  - Very low SOM contributes to N deficiency
  - Of course, management plays a big role too:
    - Short term: Using highly-labile organic N inputs like guano contributes to higher soil NO_3^- and N excess, especially when SOM is lower
    - Longer term: Combination of organic matter inputs with relatively small inputs of labile organic N may be best to build SOM and tight N cycling
- Assessing N cycling on your farm may require more than one type of measurement
  - Unfortunately, commercial testing labs do not routinely offer tests for “active” carbon
  - Work is currently underway to validate new potential measurements
  - Cornell Soil Health test is one that contains both traditional measures of soil fertility like nitrate, as well as ones that indicate microbial activity

Photo courtesy Patrick Baur

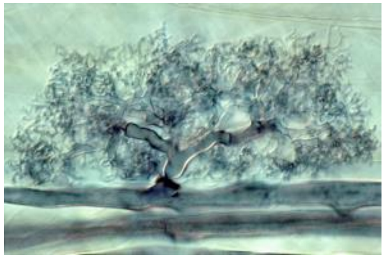


Root symbionts can increase nitrogen uptake

- On California farms with healthy soils:
  - AM increased crop uptake of nitrogen, including nitrate (most susceptible to loss)
- Other experiments show:
  - AM can reduce nitrate leaching
  - AM can reduce nitrous oxide emissions (potent GHG)



Arbuscular mycorrhizas (AM): Association between plant roots and soil fungi, present in ~80% of plants



Durst Organic Growers, Esparto, CA

Louise Jackson
UC Davis

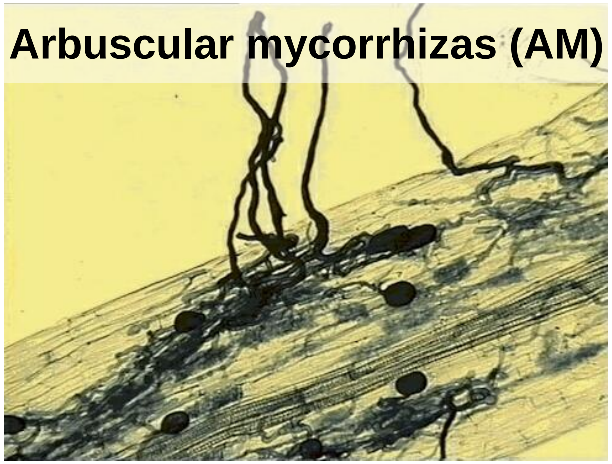
Cavagnaro *et al.*, 2012; *Plant Soil*
Bender *et al.*, 2014; *ISME Journal*
Bowles *et al.*, 2016; *Science of the Total Envir.*
Cavagnaro *et al.*, 2015; *Trends in Ecol. and Evol.*
Lazcano *et al.*, 2014; *Soil Biology and Biochemistry*

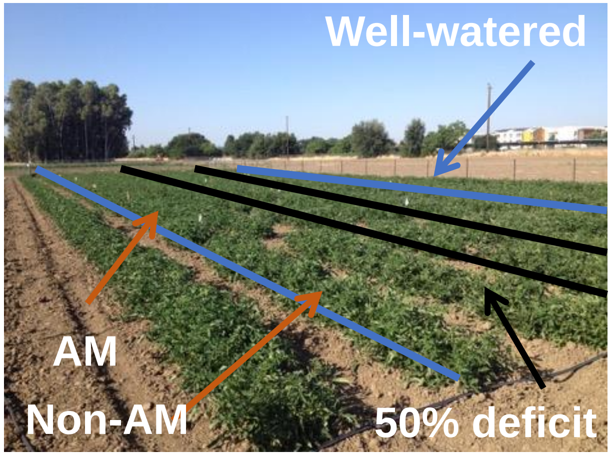
AM can increase crop water use efficiency

- Field trial in Davis, CA
- AM and non-AM tomatoes
- 50% deficit irrigation
- Higher water use efficiency (WUE) in plants associated with AM fungi:

Crop WUE (Mg yield ha^{-1} cm^{-1} water applied)		
	100% irrigation	50% irrigation
AM+	2.46	3.72
Without AM	1.85	2.94

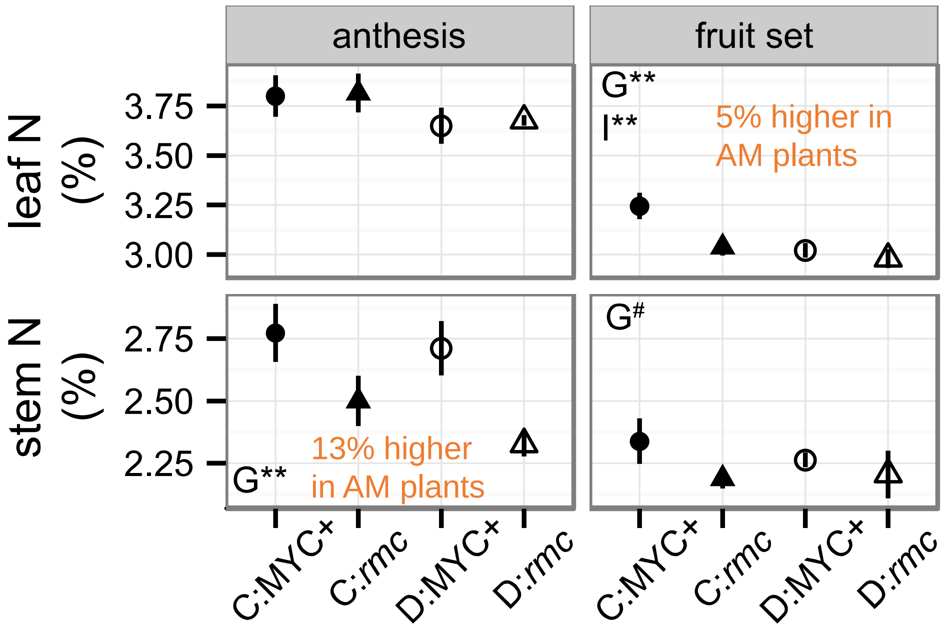
- More crop yield per drop





Bowles *et al.*, 2017; *Science of the Total Environment*

AM tomatoes: slightly higher N concentration



- Plants were slightly below the "critical N concentration" - minimum N concentration for maximum plant growth
- AM tomatoes at times had higher photosynthetic rates – especially during heat or moisture stress

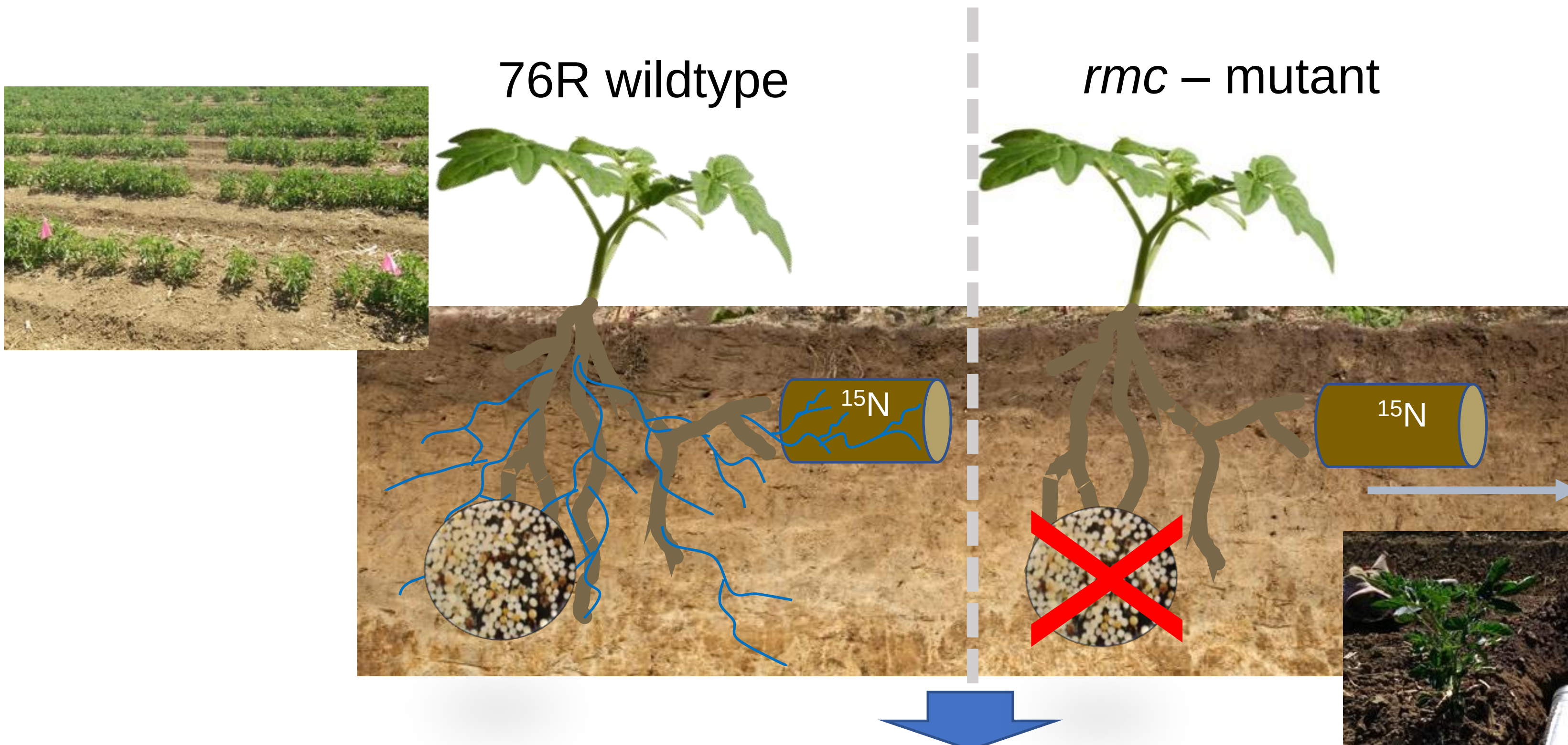
AMF and long-term agricultural management

Century experiment, Russel Ranch, Davis, CA

Long term comparison of different cropping systems for 25 years

Franz Bender
UC Berkeley

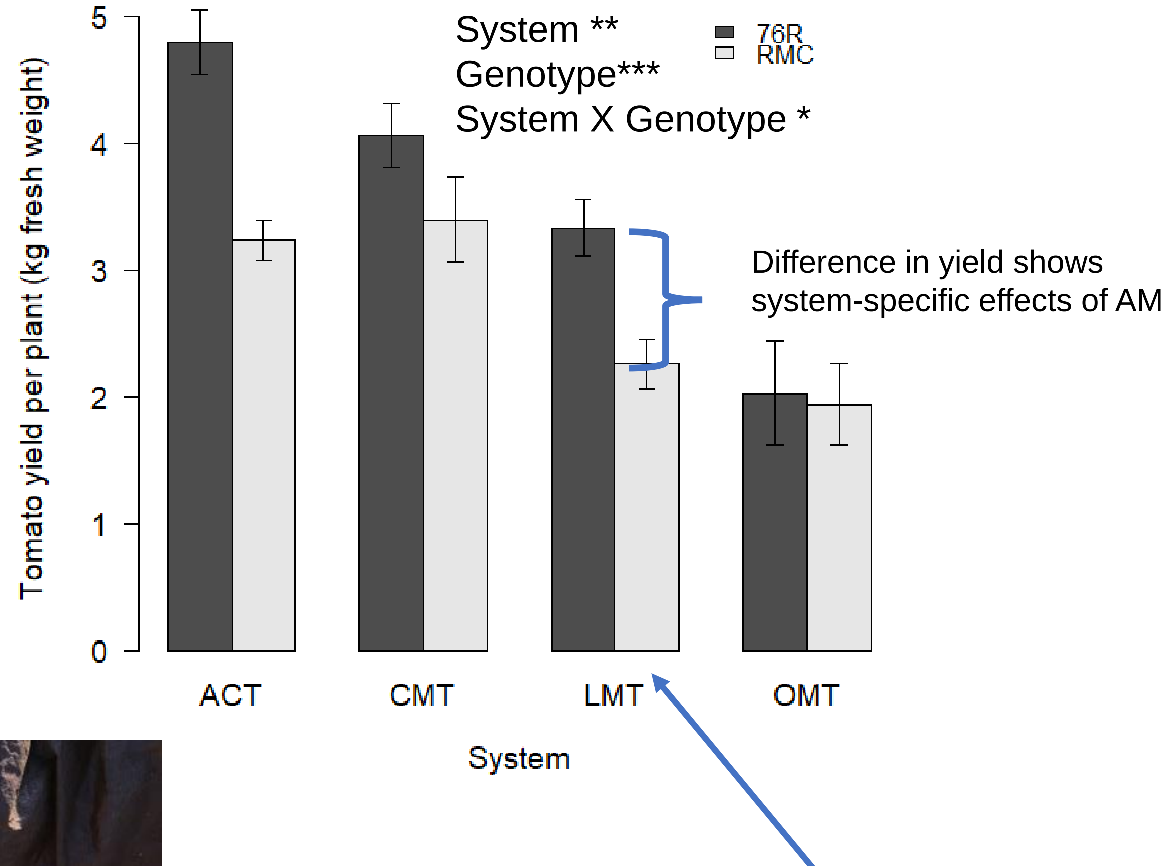
System	Cash crop rotation	Winter cover-crops	Fertilization	Plant protection
ACT	Alf.-Alf.-/Corn/Tomato	yes	synthetic	Conv.
CMT	Corn/Tomato	no	synthetic	Conv.
LMT	Corn/Tomato	yes	red. synthetic	Conv.
OMT	Corn/Tomato	yes	organic	Org.




Ingrowth cores

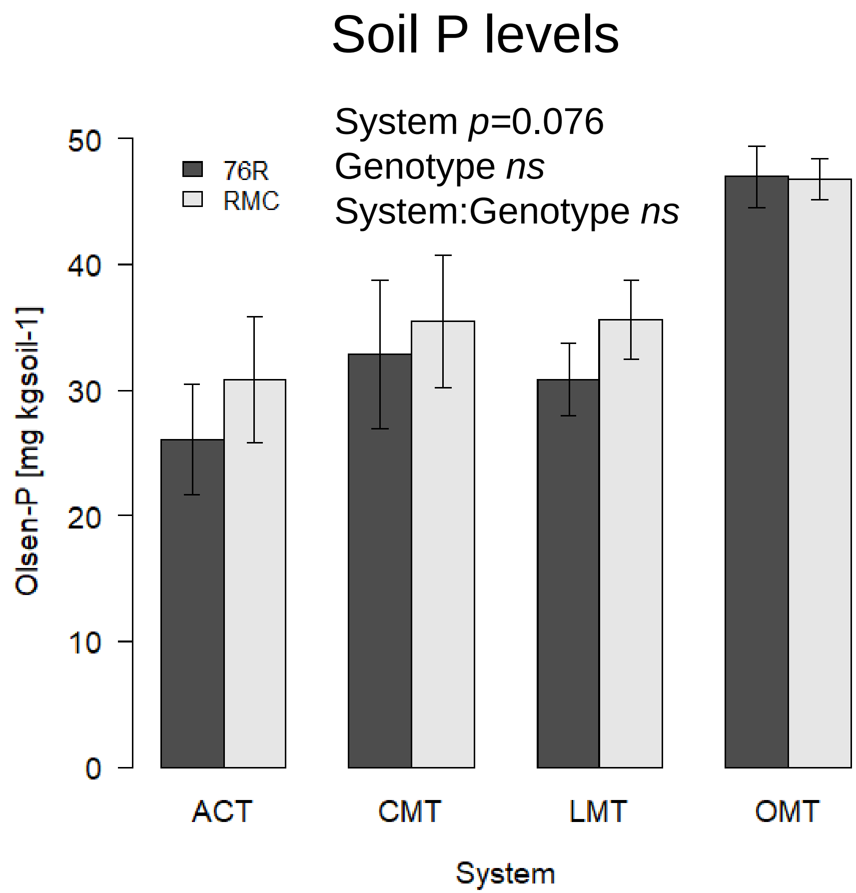
- Tomato biomass, yield and nutrition
- N mobilization and uptake from cover-crop litter
- Soil fauna community and ^{15}N uptake
- Microbial/ AMF communities

Tomato yield (fresh weight)



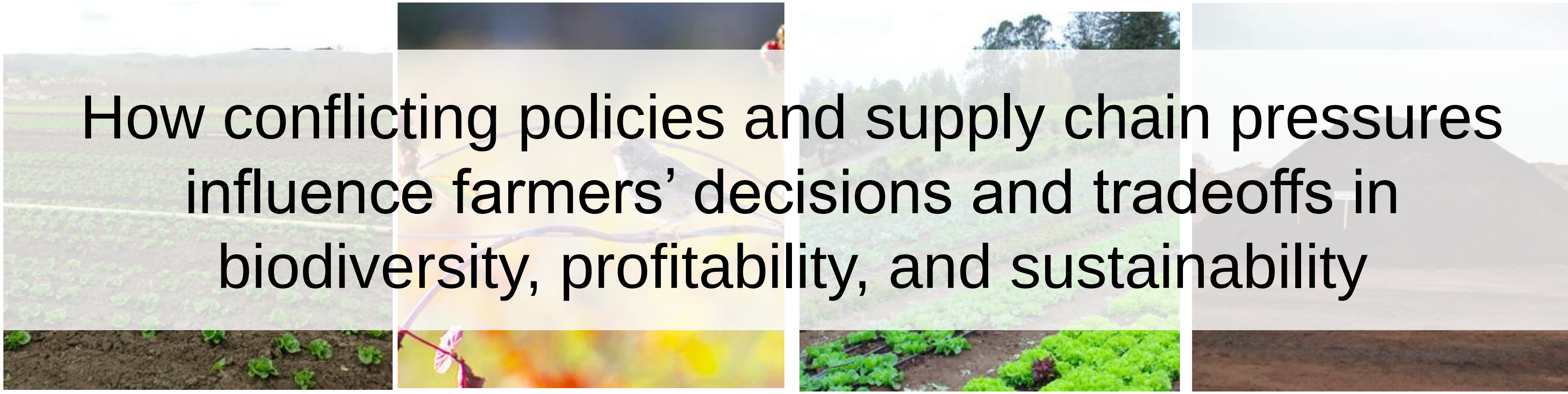
Dark bars = AM tomatoes
Light bars = reduced AM tomatoes

AM provide no benefit in the organic system in this study! Surprised? I was.



Due to years of composted manure application (high N:P ratio), P has built up in organic soils. When P is high, mycorrhizas can be a “cost” to the plant

New research in organic leafy green production in the Central Coast



How conflicting policies and supply chain pressures influence farmers’ decisions and tradeoffs in biodiversity, profitability, and sustainability

Funded by

NSF

Project team	Expertise
Tim Bowles	Agroecology and soils
Claire Kremen	Biodiversity and conservation
Alastair Iles	Policy and social science
Danny Karp	Community ecology and conservation
Carl Boettiger	Modeling
Federico Castillo	Agricultural economics
Liz Carlisle	Social science
Nina Ichikawa	Policy

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Influences on farmers' decisions

Question 1

Diversification practices in lettuce production

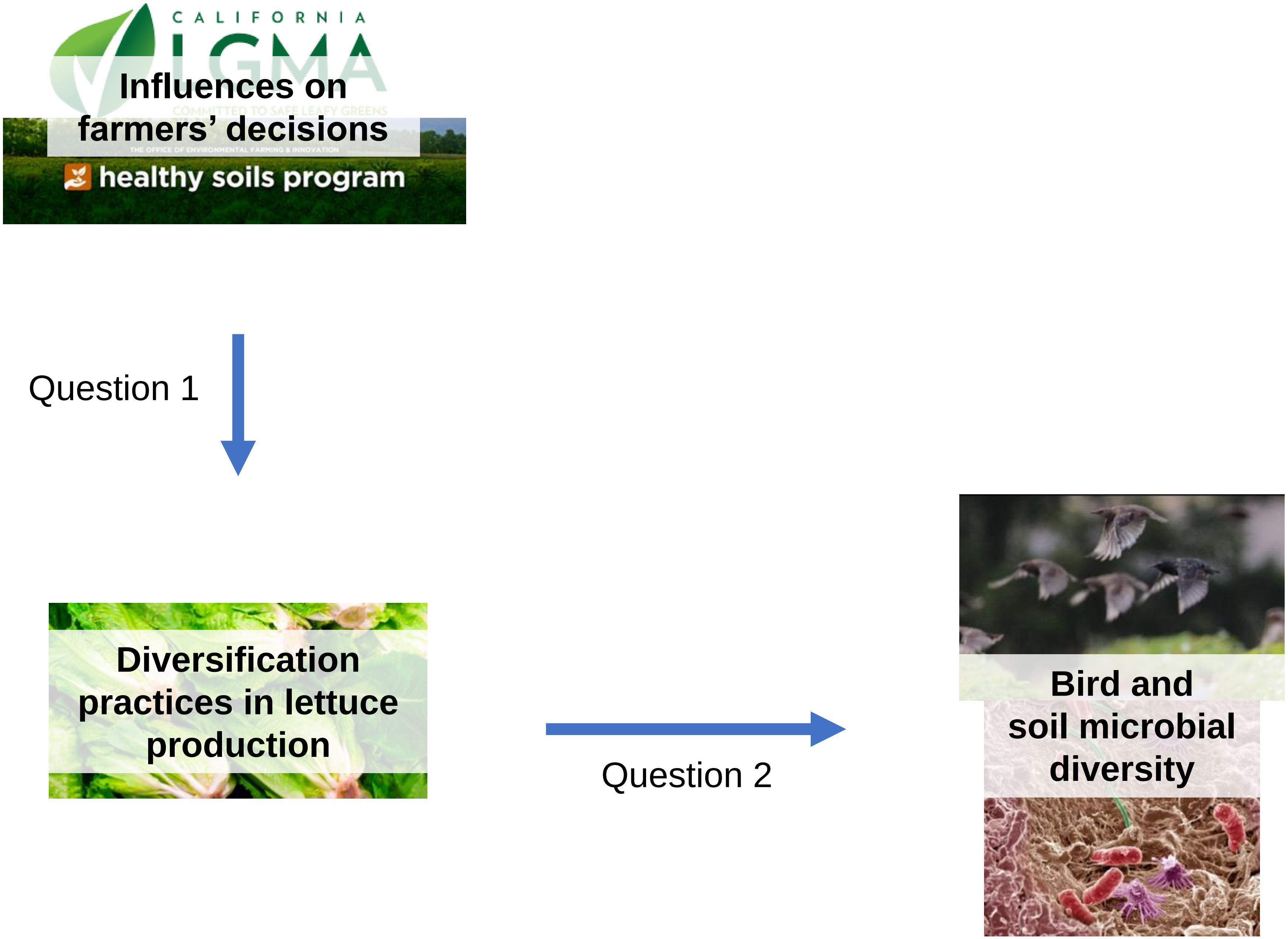
Diversification Practices

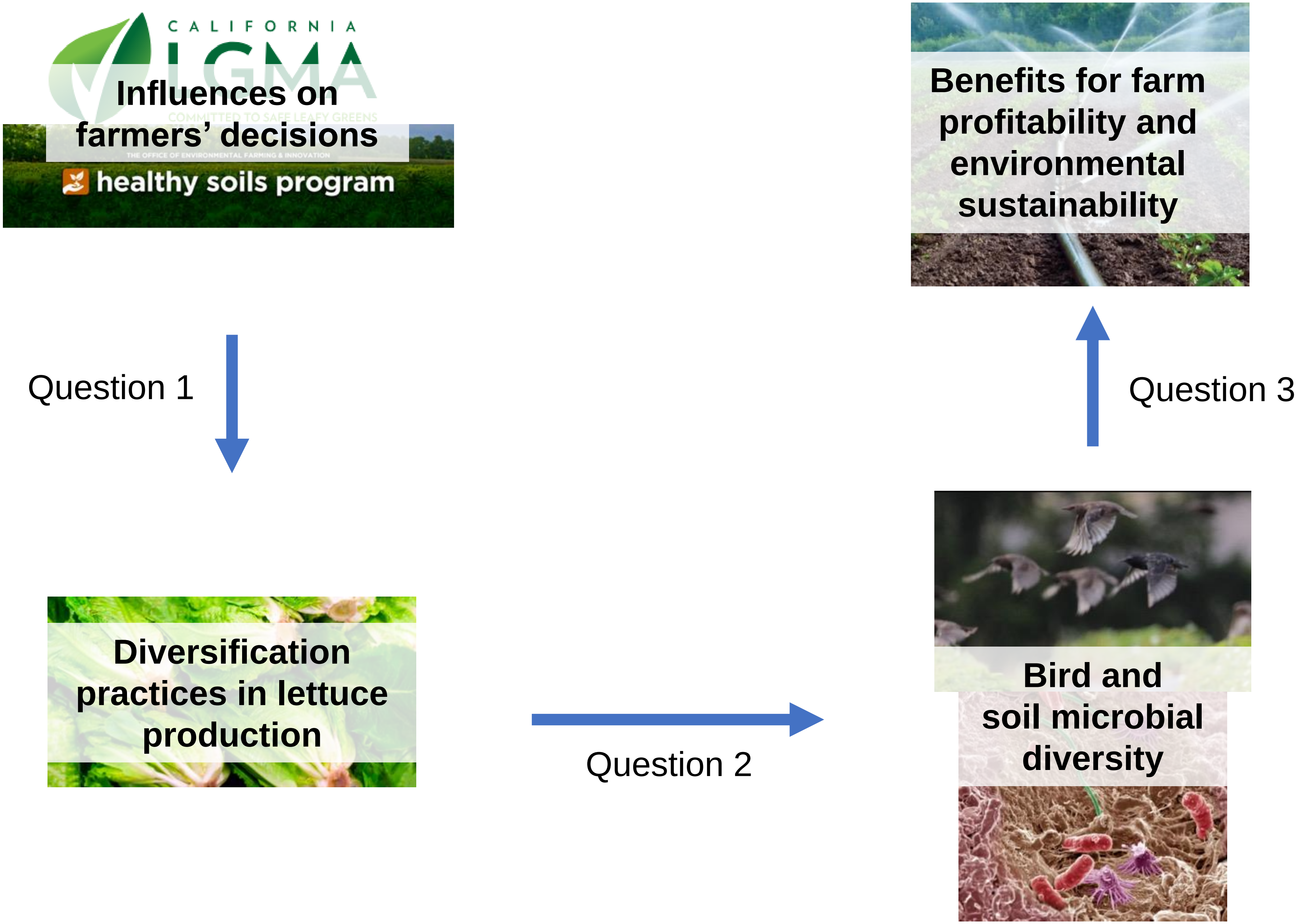
Crop Diversity
- Intercropping
- Crop rotation
- Cover cropping

Non-crop Diversity
- Hedgerows
- Flower strips
- Windblocks
- Riparian buffers
- Retention ponds

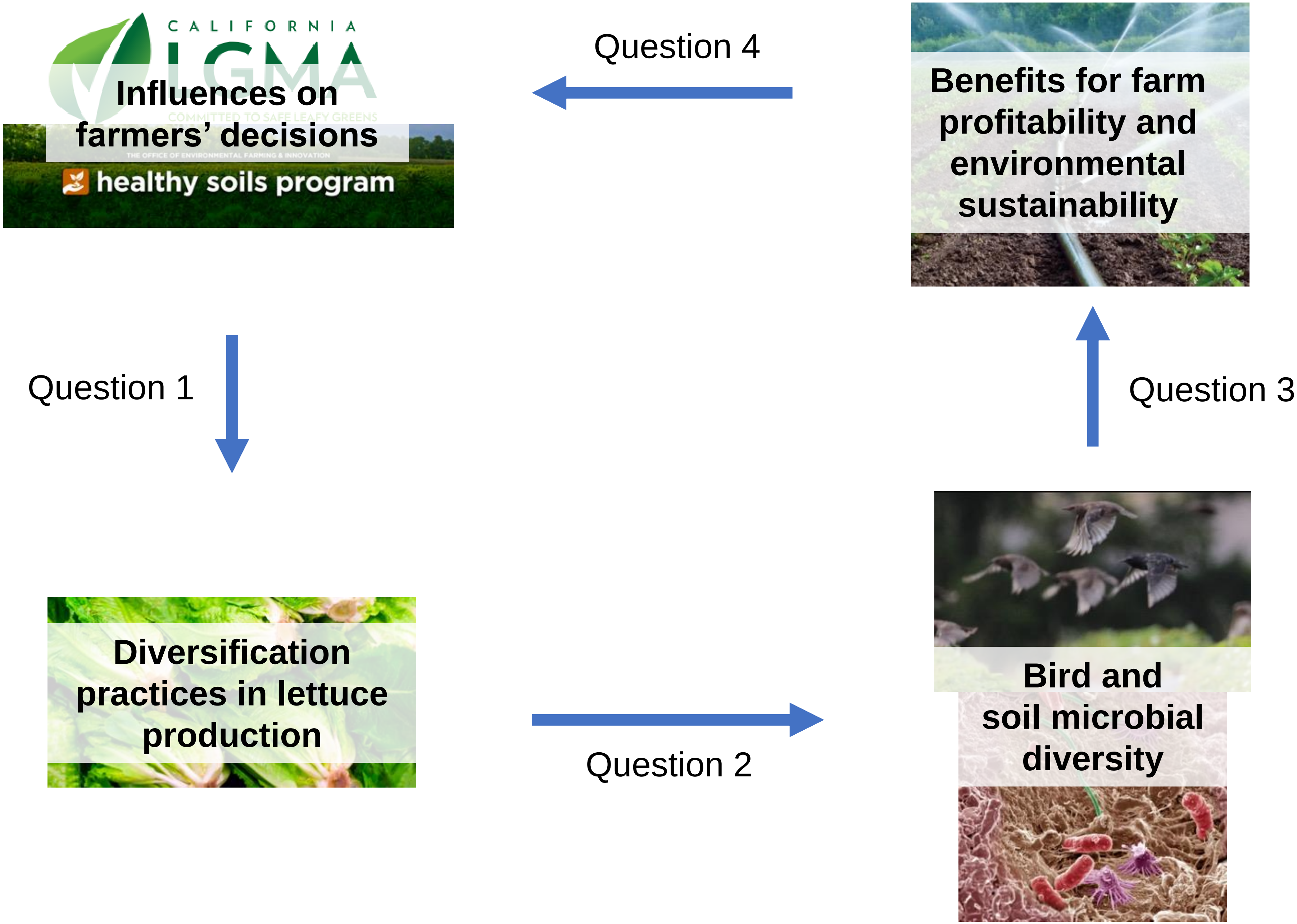
Organic Matter Additions
- Mulch
- Compost
- Green manure

Alternative Tillage
- Reduce tillage
- Permanent beds
- No-till


CALIFORNIA
LGMA
COMMITTED TO SAFE LEAFY GREENS
Influences on farmers' decisions
THE OFFICE OF ENVIRONMENTAL FARMING & INNOVATION
healthy soils program
Question 1
Diversification practices in lettuce production
Question 2
Bird and soil microbial diversity



CALIFORNIA
Influences on farmers' decisions
healthy soils program
Question 1
Diversification practices in lettuce production
Question 2
Bird and soil microbial diversity
Question 3
Benefits for farm profitability and environmental sustainability


CALIFORNIA LGMA
Influences on farmers' decisions
healthy soils program
Question 4
Benefits for farm profitability and environmental sustainability
Question 1
Question 3
Diversification practices in lettuce production
Question 2
Bird and soil microbial diversity

Timeline: January 2019–September 2021

	2019				2020			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Talk to potential participants								
Field studies								
Individual interviews & focus groups								
Advisory group meeting								

(Yr 2021 for results analyses and sharing)

Interested in participating or more information? Please see me after this session, email me at timothy.bowles@berkeley.edu, or call at 510-642-5277

Thank you!

- Acknowledgements to collaborators and co-authors

    Louise Jackson, Tim Cavagnaro, Felipe Barrios-Masias, Eli Carlisle, Franz Bender

- Lab and field technicians

    Vi Truong, Malina Loeher, Julian Marquez, Rebecca Stonor, Lindsey Guan, Anna Barcellos

- Funding

    USDA and NSF

USDA

United States Department of Agriculture
National Institute of Food and Agriculture

Bowles lab