Healthy soils for productive and sustainable agriculture: Evidence and barriers

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Joseph Bellacera, *Fields of Light #2*
www.josephbellacera.com

California agricultural production

- Highest agricultural crop value in U.S. for >50 consecutive years (~17% of total U.S. output)
- 2016: Farms and ranches received over $46 billion for their output
- More than 400 agricultural products
- 1/3 of the country’s vegetables, 2/3 of the country’s fruits and nuts
- 76,700 farms and ranches, 3M jobs in whole agricultural value chain

California Agricultural Statistics Review 2016-2017

Some major sustainability challenges for California agriculture

- Adapting to reduced water availability
  - Reduced snowpack
  - Groundwater regulation
  - Competition with urban users
- Reducing water pollution
- Mitigating climate change

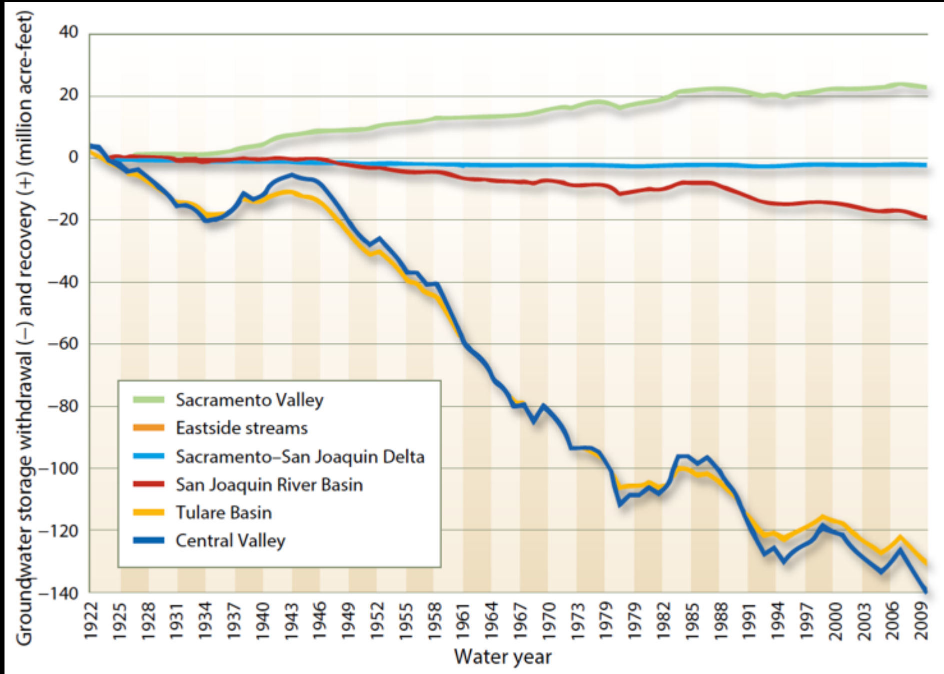


Fig. 1. Changes in groundwater storage in the California Central Valley (dark blue) and its subregions from 1922 to 2009 (adapted from Brush 2014). The largest depletions have occurred in the Tulare Lake Basin, which includes the southern part of the Central Valley from Fresno to Bakersfield.

Harter 2015, *California Agriculture*

How do we enhance food production while addressing environmental challenges and improving livelihoods – as climate changes?

This presentation

- Soil health: What is it and what is its role in meeting major challenges while sustaining agricultural production?
- How do healthy soils provide multiple ecosystem services in California?
- What are the strategies, barriers, and potential for building soil health in California?
- What are the implications for policy?

Soil

"The ecstatic skin of the Earth"

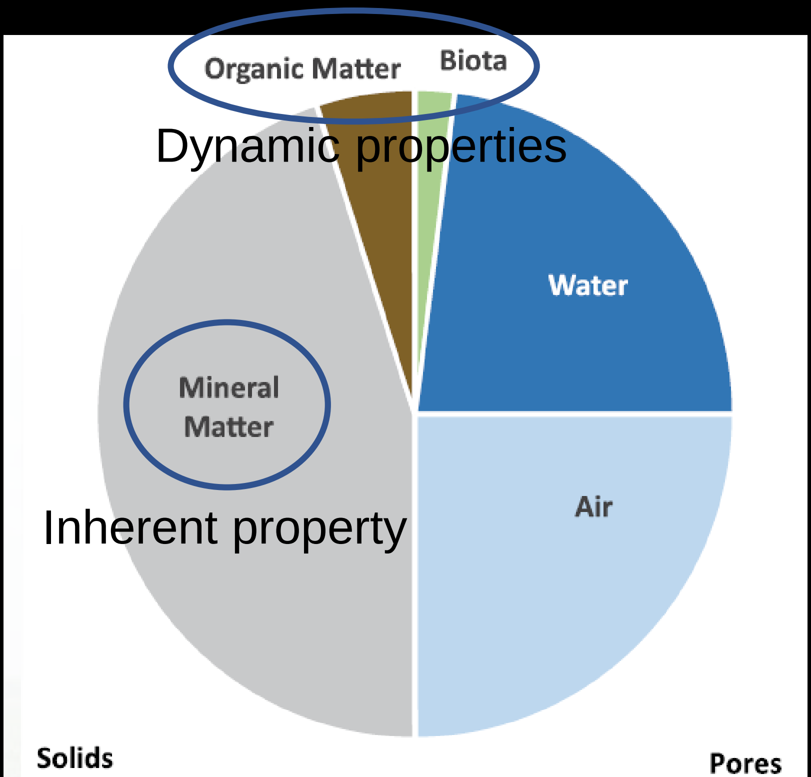
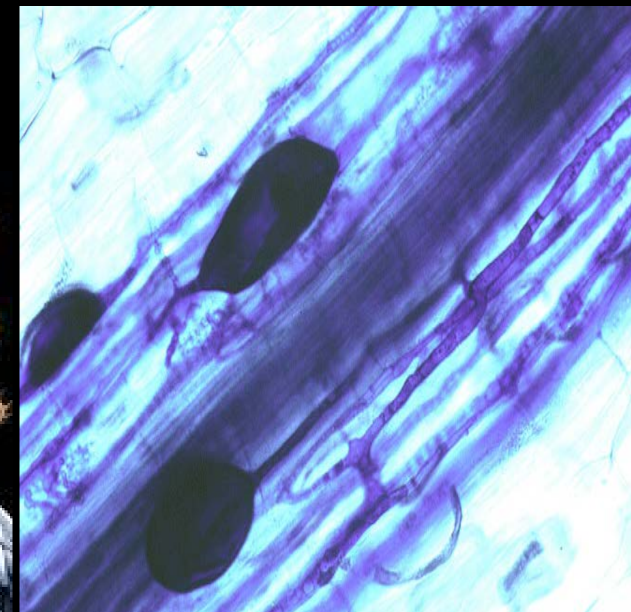


FIGURE 1.02 Distribution of solids and pores in soil. Solids are minerals, organic matter and living organisms, or biota. Pores are filled with water, air, and biota.

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

Soil organic matter

- Relict of every living thing that entered soil
- Food for all soil life
- About half is carbon
- With soil life, supports critical soil functions

Easy to lose and hard to restore

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.

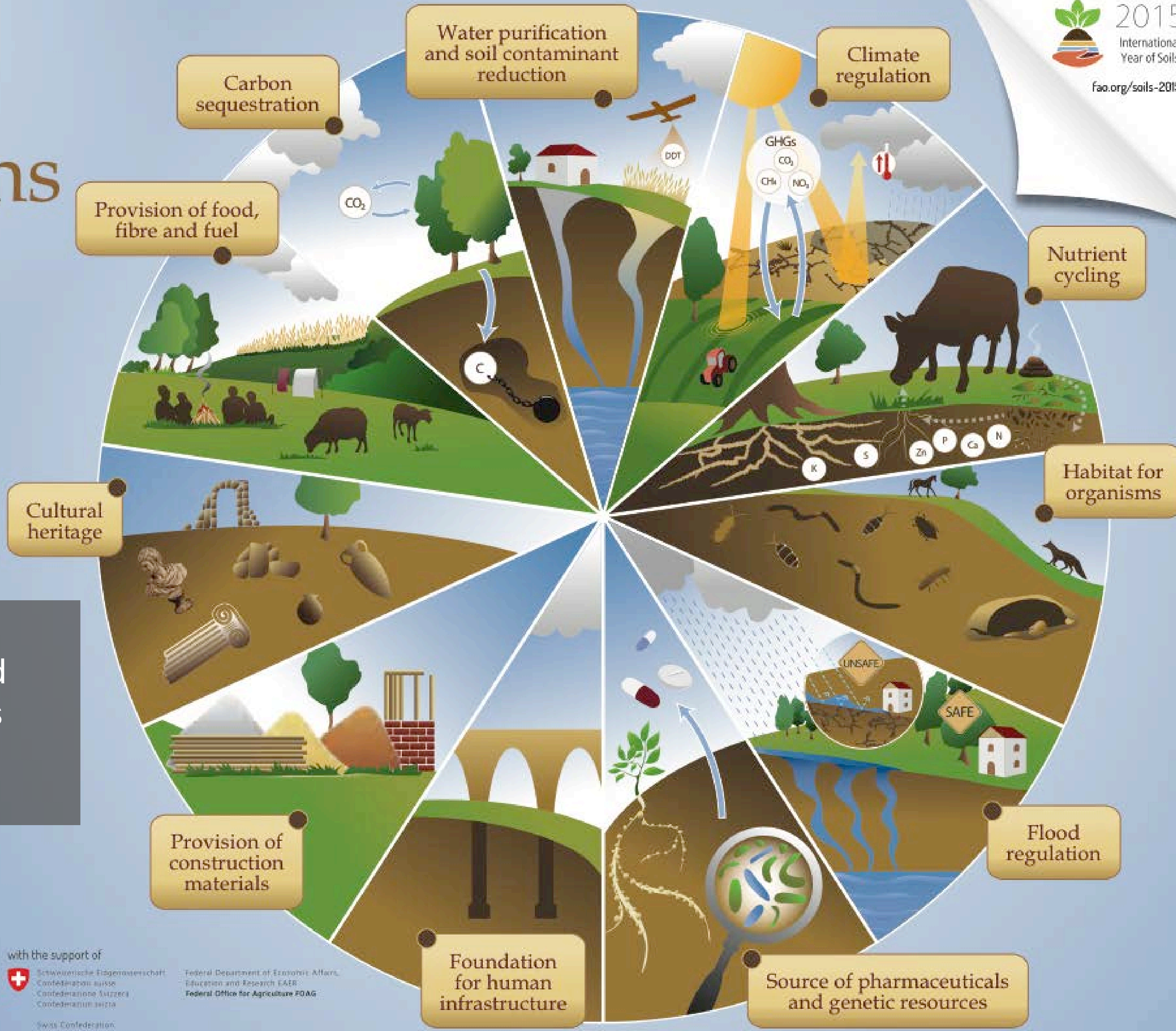
*Oxford English Dictionary

Soil functions

Soils deliver ecosystem services that enable life on Earth

2015 International Year of Soils

fao.org/soils-2015



Ecosystem services: The many and varied benefits that humans freely gain from the natural environment

Food and Agriculture Organization of the United Nations

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Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
Federal Office for Agriculture FOAG

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*

Healthy soils and multiple ecosystem services on California farms

Nitrate in drinking water wells often exceeds health standards

- ~250,000 people in Tulare Basin and Salinas Valley at risk for nitrate contamination of drinking water – linked to certain cancers and infant health problems
- 96% of nitrate in groundwater comes from croplands
- Disproportionately affects low income communities

EPA standard: <45 mg L^{-1} NO_3^-

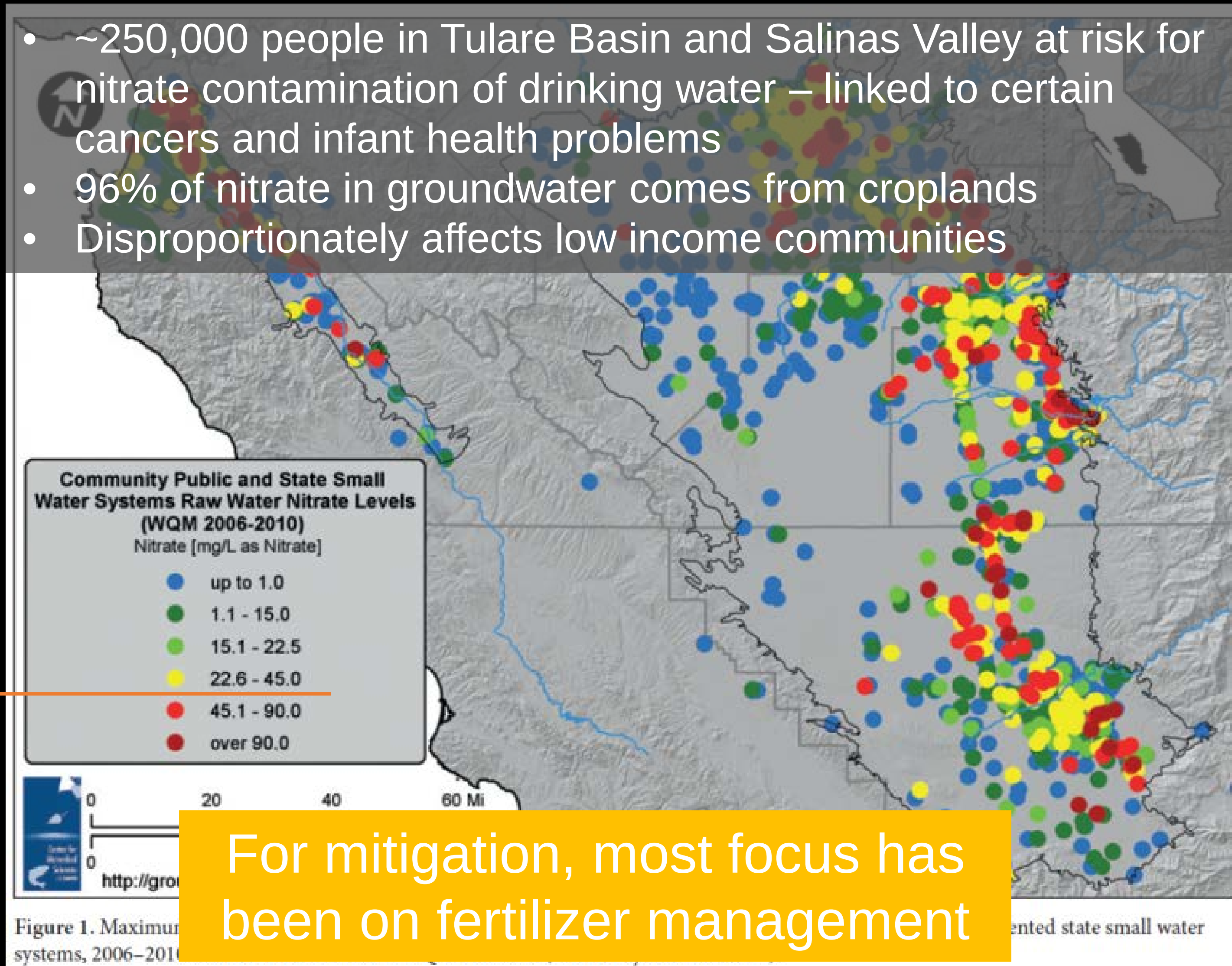


Figure 1. Maximum … ented state small water systems, 2006–201…

For mitigation, most focus has been on fertilizer management

Harter *et al.*, 2012: *Assessing Nitrate in California's Drinking Water*

Participatory research with innovative farmers

- Can farmers create healthy soils that minimize potential for nitrogen losses while maintaining high productivity?

Bowles et al. 2015, *PLoS ONE*

Jim and Deborah Durst
Durst Organic Growers

Frank Muller
Muller Ranch

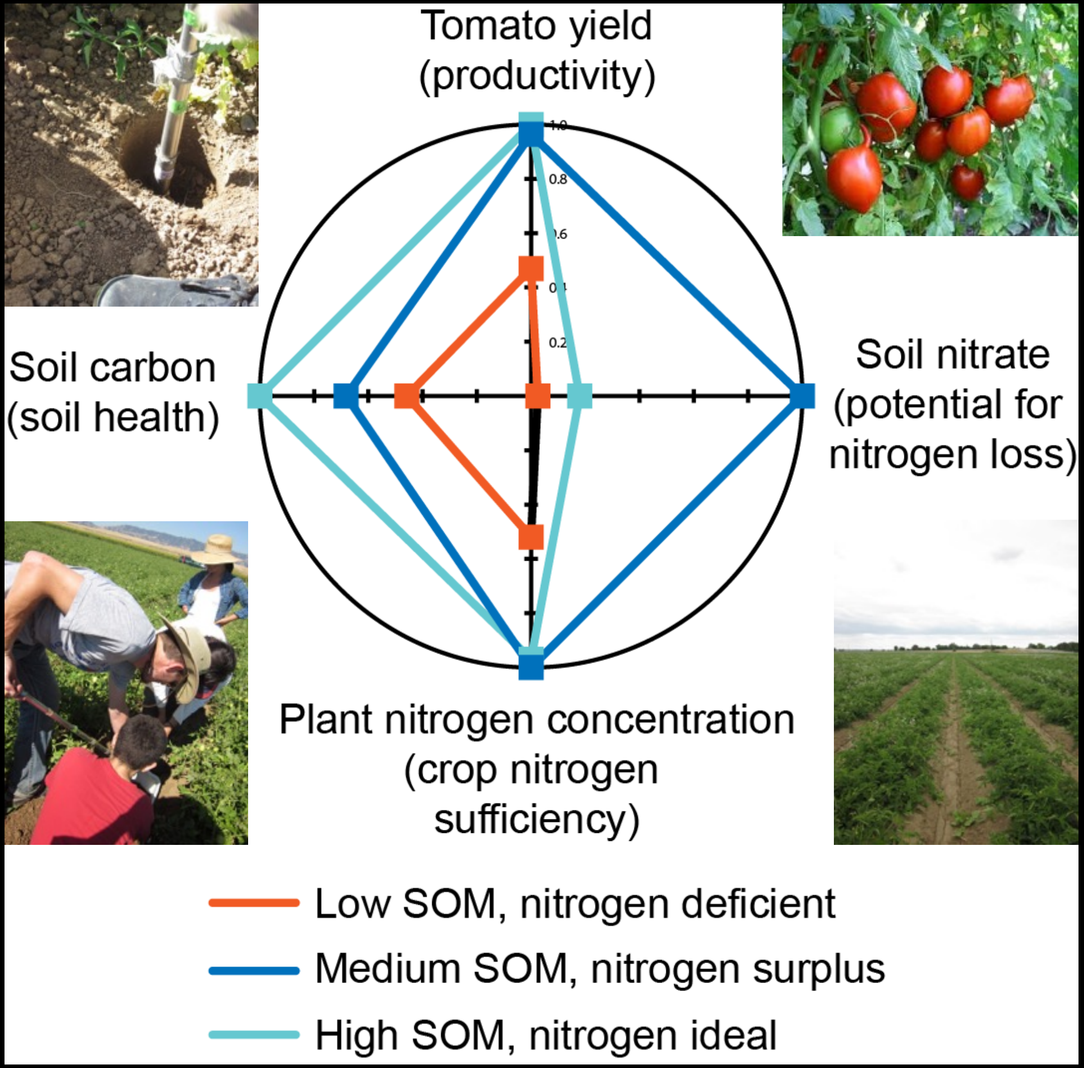
Andrew Brait et al.
Full Belly Farm

Thaddeus Barsotti and family
Capay Organic

13 farm sites in Yolo Co.

Reduced tradeoffs with high soil organic matter (SOM)

- 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

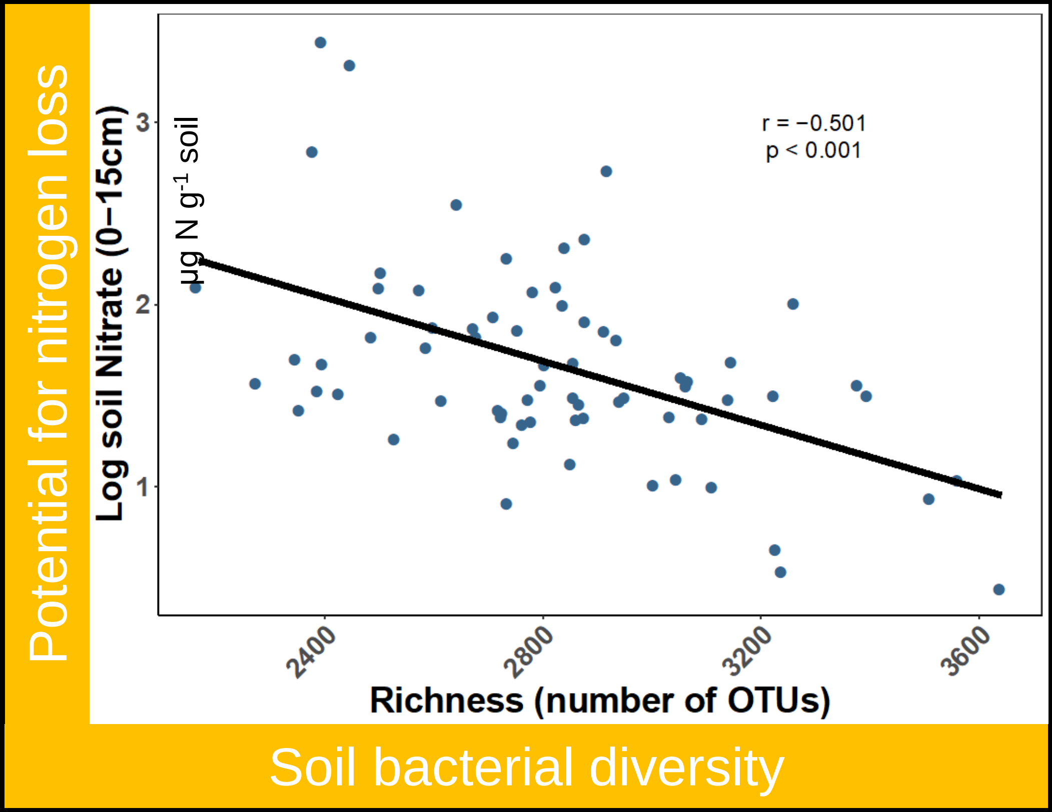


*Graph shows relative levels for each variable

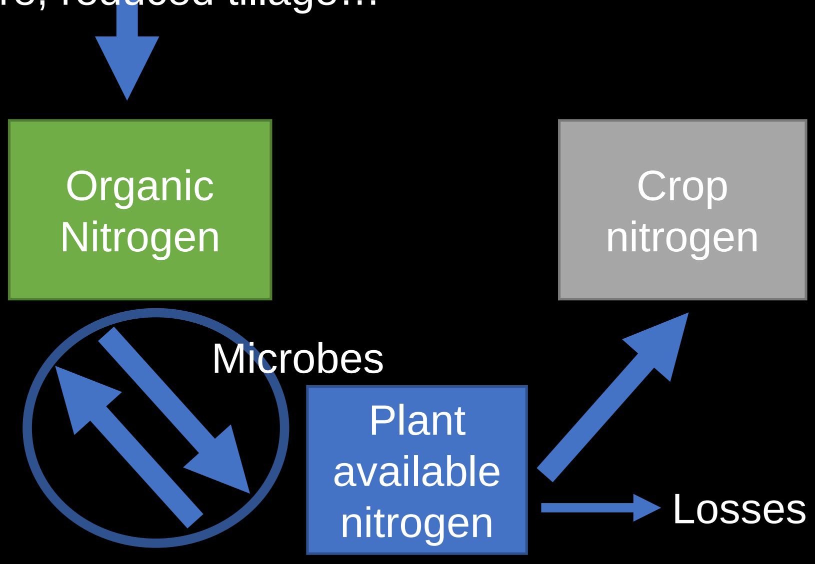
Bowles *et al.*, 2014; *Soil Biology and Biochemistry*
Bowles *et al.*, 2015; *Plos One*

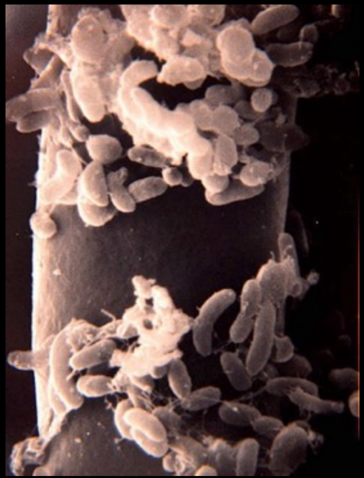
Diverse soil microbes

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



Cover crops, compost, manure, reduced tillage…

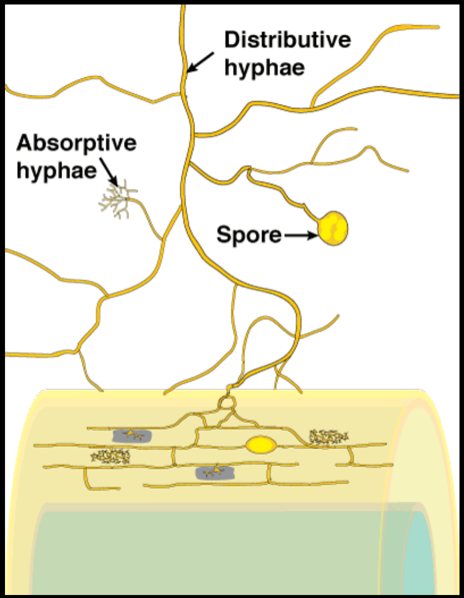




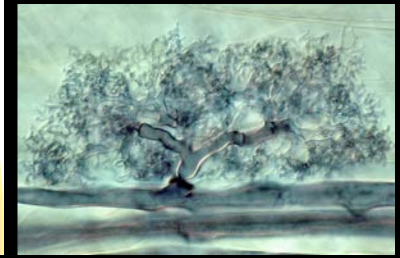
Jordan Sayre and Jorge Rodrigues, UC Davis

Root symbionts 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



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*

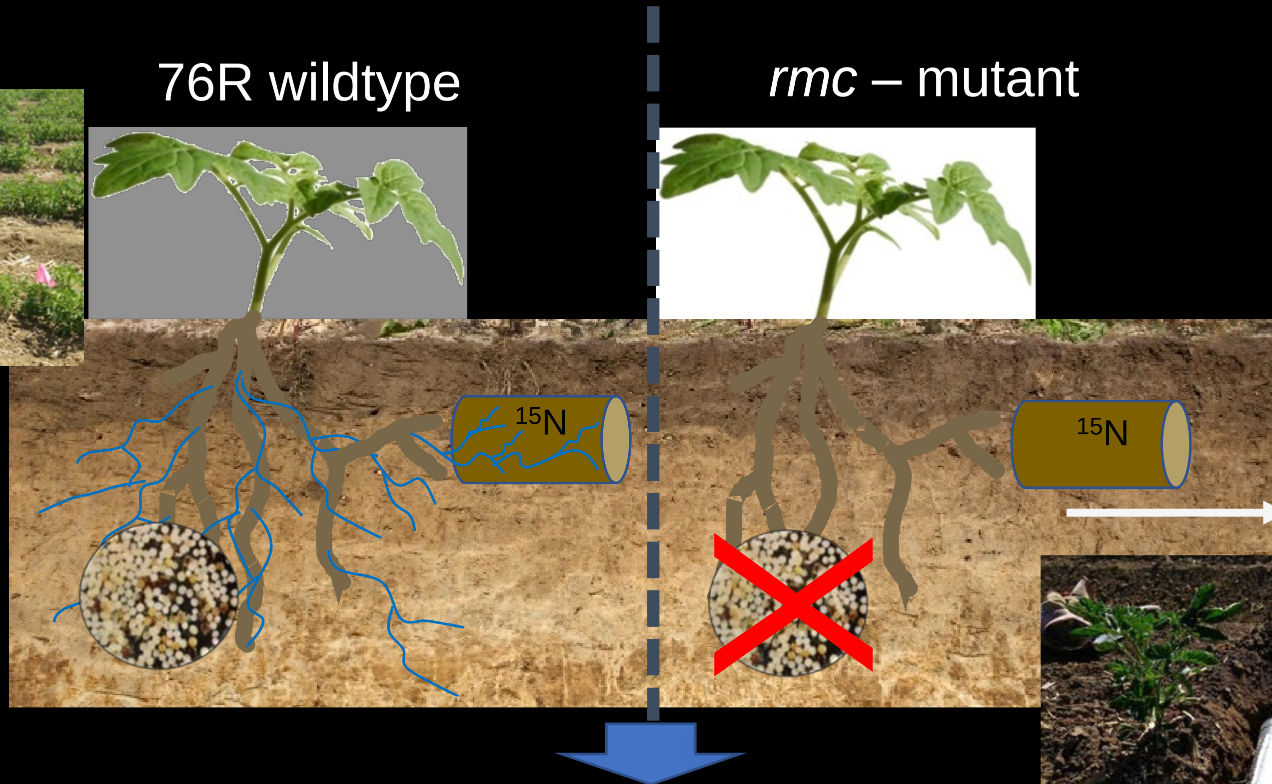
AMF and long-term agricultural management – yield and (N uptake)

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.

AMF and long-term agricultural management – yield and (N uptake)

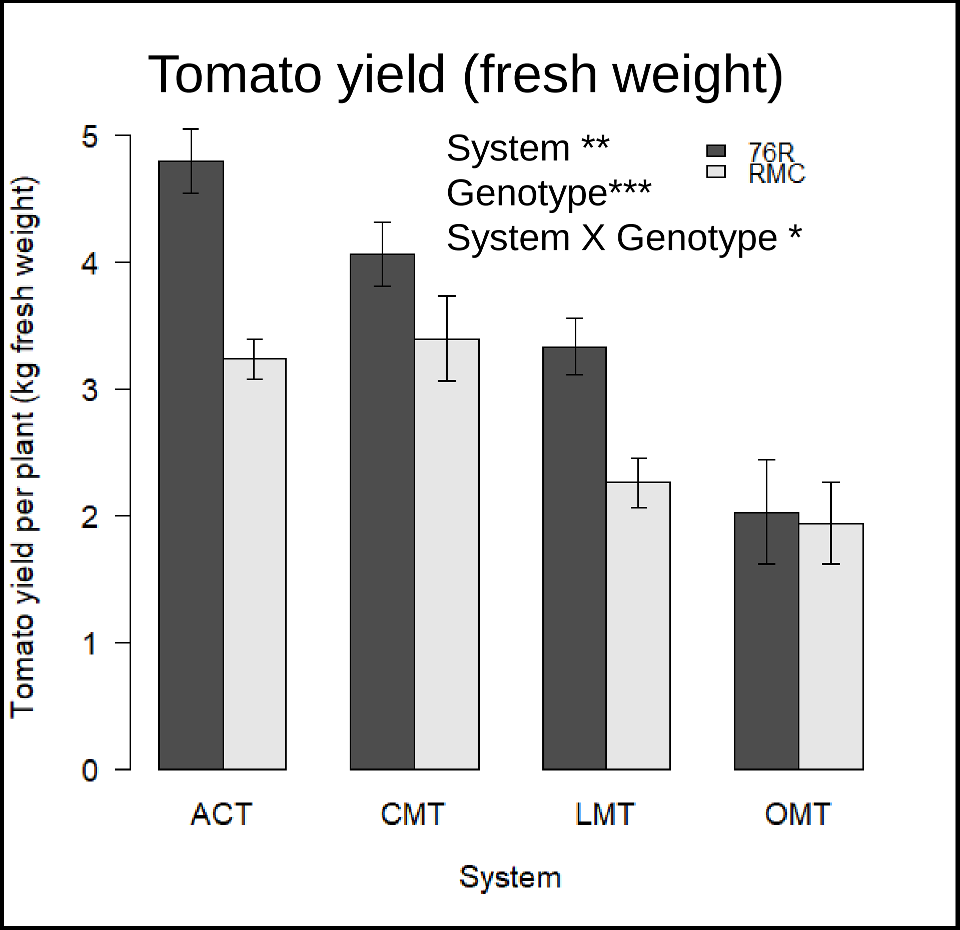


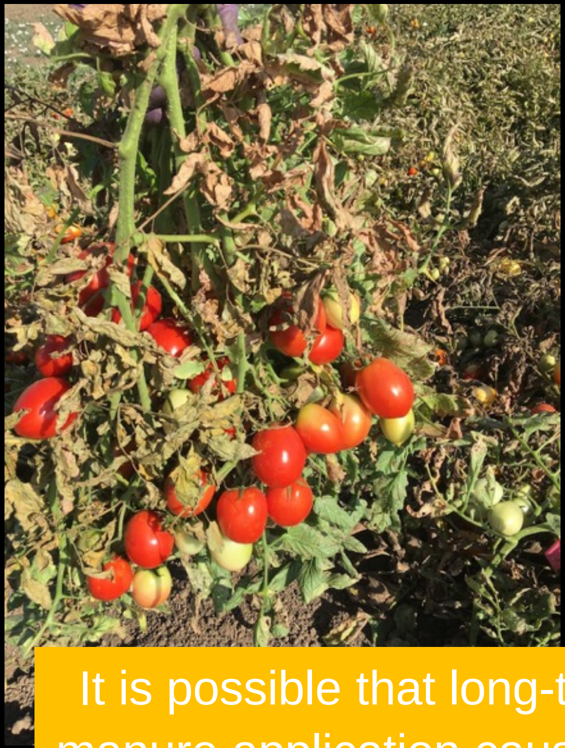
Field soil mixed with ^{15}N labeled plant litter

Ingrowth cores

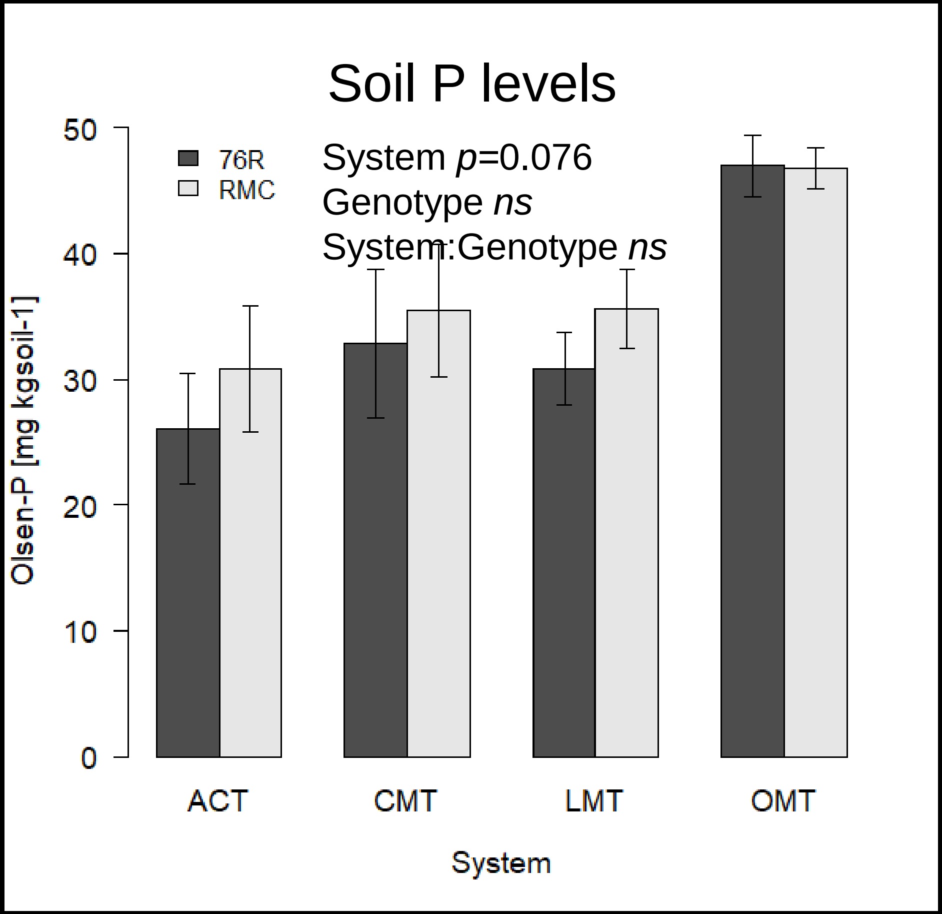
- Tomato biomass, yield and nutrition
- N mobilization and uptake from cover-crop litter
- Soil fauna community and ^{15}N uptake
- Microbial/ AMF communities

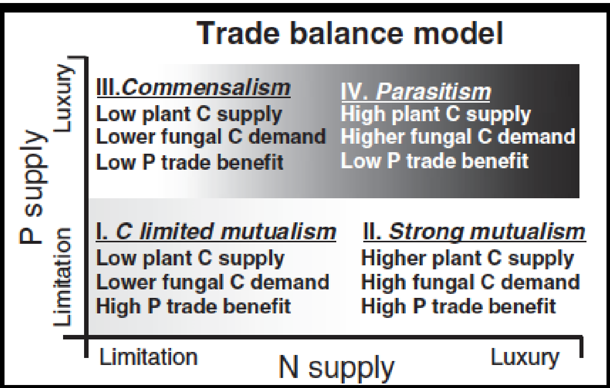
AMF and long-term agricultural management – yield and (N uptake)





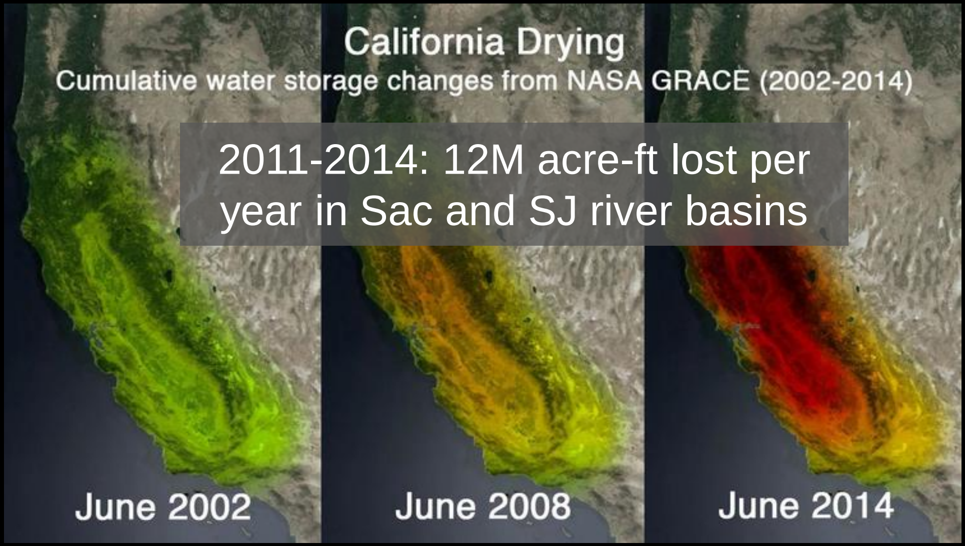
It is possible that long-term manure application caused P to build up, leading to decreased AM benefits



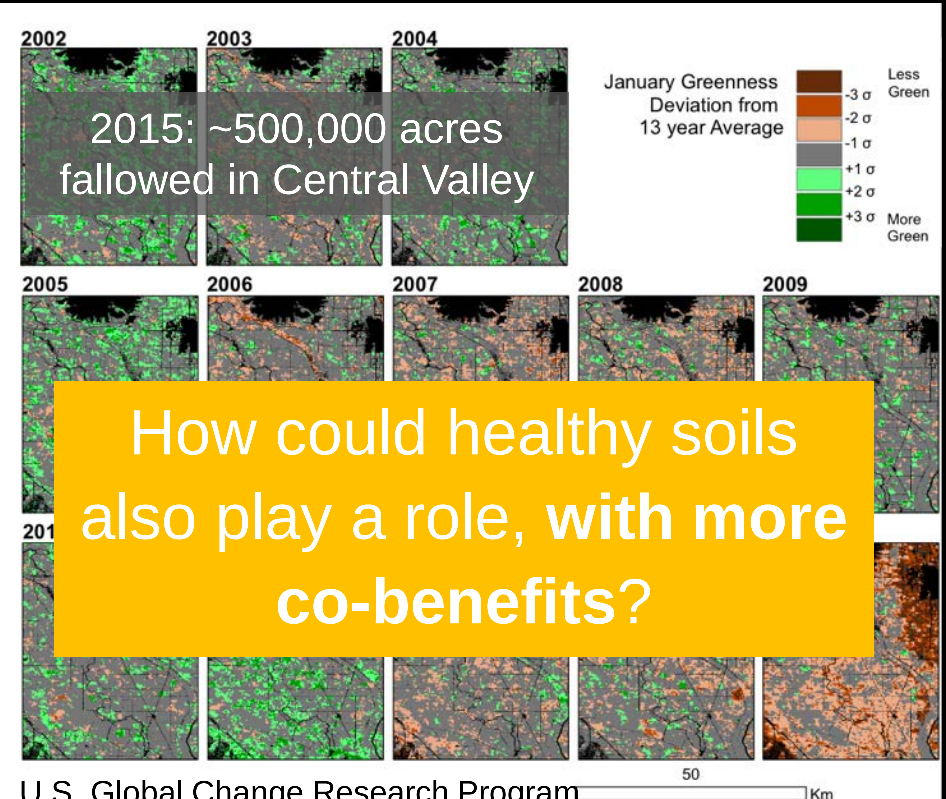


Drought and California agriculture

- Undesirable responses to drought include:
  - Unsustainable groundwater extraction
  - Fallowing
- Farmers adapt by:
  - Switching crops
  - More efficient irrigation technologies
  - Renting/buying land with more water available



2011-2014: 12M acre-ft lost per year in Sac and SJ river basins



2015: ~500,000 acres fallowed in Central Valley

How could healthy soils also play a role, **with more co-benefits**?

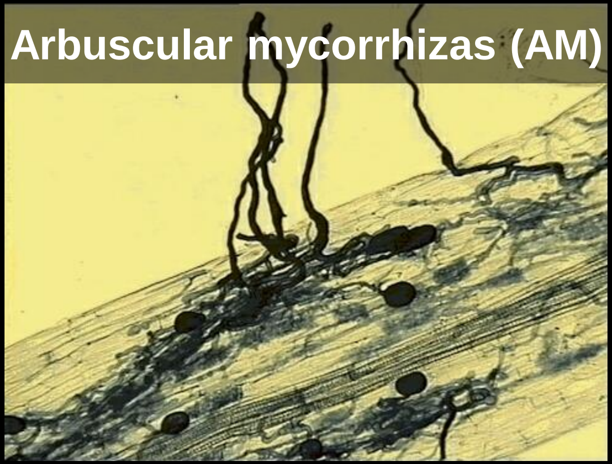
U.S. Global Change Research Program

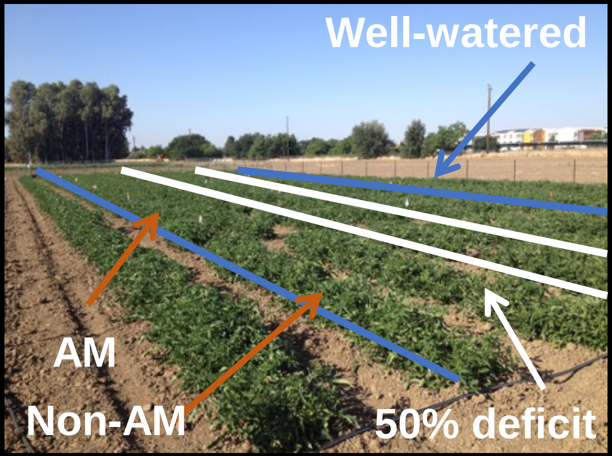
Root microbial symbionts increase crop water use efficiency

- 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



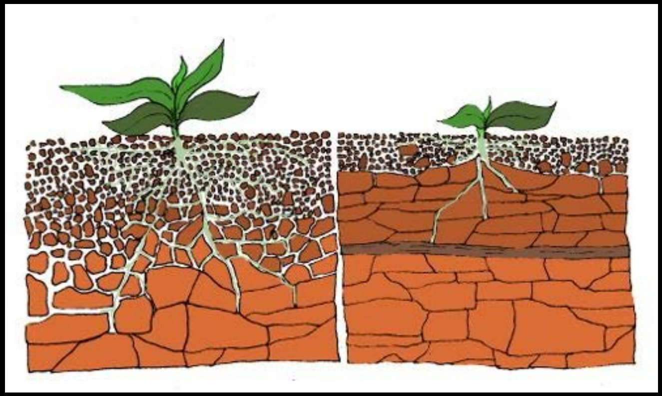


Bowles *et al.*, 2016; *Science of the Total Environment*

Smart soil management increases water availability

- Field trials in San Joaquin Valley
  - Cover crops/no-till vs. standard practice:
    - Improved soil structure
    - Increased soil carbon content ~30%
    - Increased infiltration rates nearly 4-fold
  - Retaining crop residue on soil surface:
    - Reduced summer evaporative losses by ~4 inches

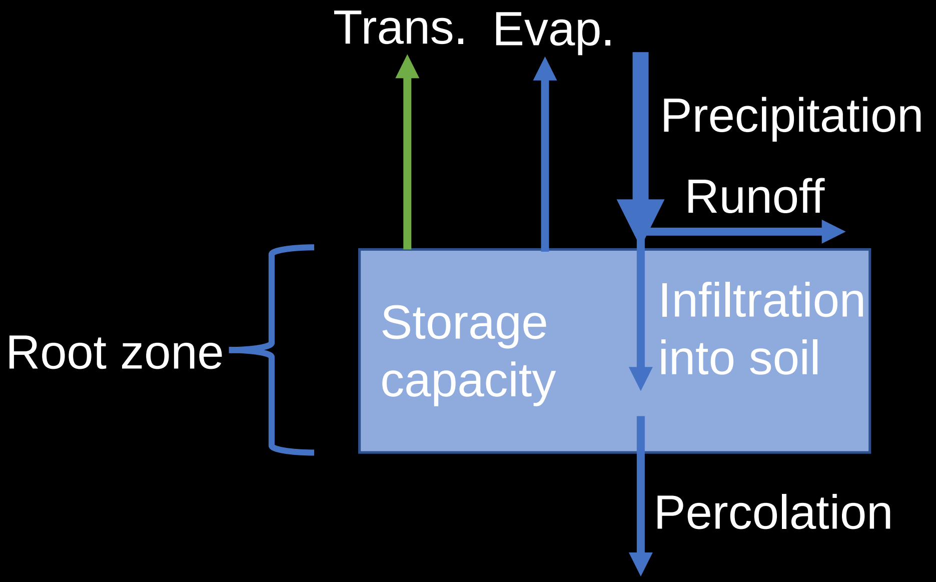
<u>Well-structured</u> <u>Poorly-structured</u>



Jeff Mitchell, *California Agriculture*

Conservation tillage allows growers to plant directly into fields that contain residue from prior crops. *Above*, tomatoes are transplanted into cover crop residues (triticale, rye and pea) in Five Points.

Mitchell *et al.*, 2017; *Soil & Tillage Research*
Mitchell *et al.*, 2012; *California Agriculture*



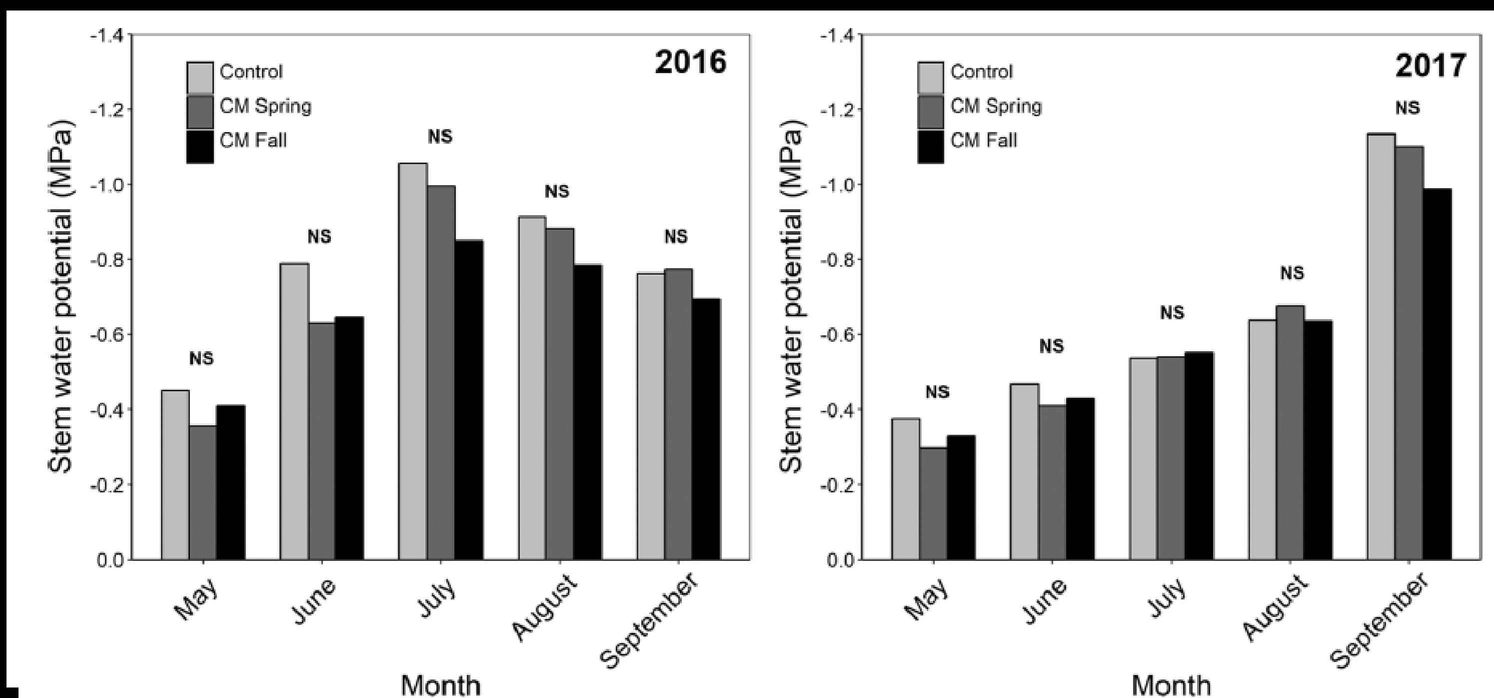
What other information do we need?

Example: Very limited quantitative data on impacts of increasing soil water holding capacity in irrigated systems

Impact of organic matter amendments on soil and tree water status in a California orchard

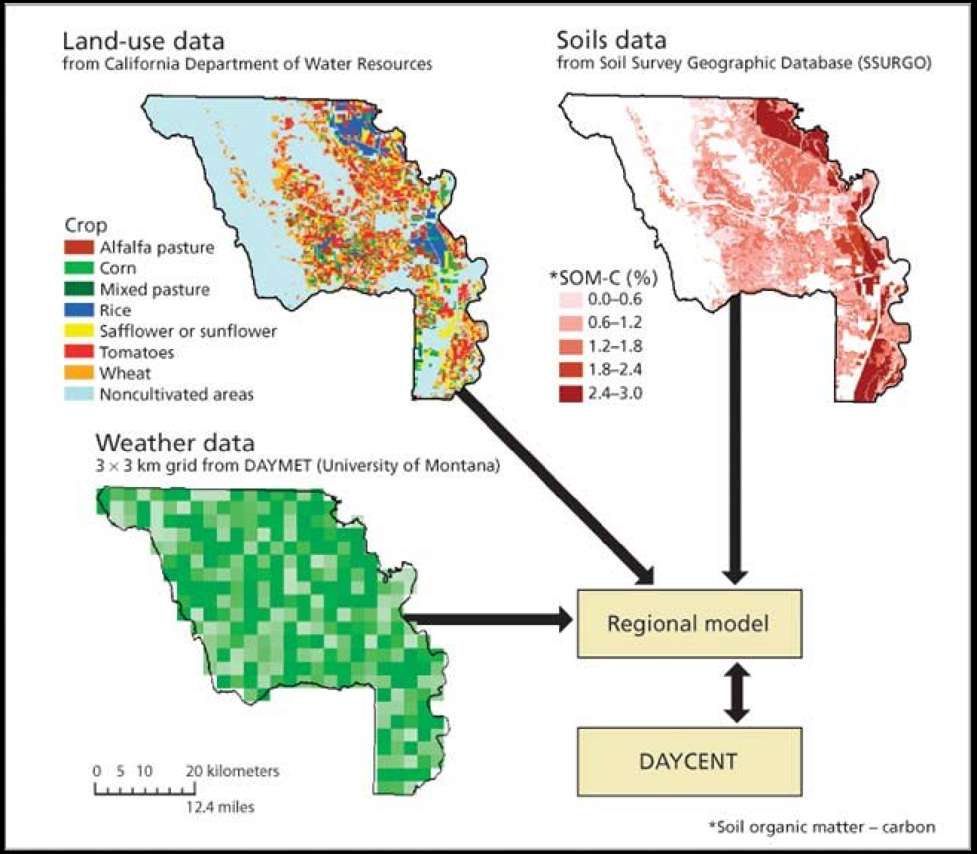
Hannah C. Lepsch, Patrick H. Brown, Caitlin A. Peterson, Amélie C.M. Gaudin, Sat Darshan S. Khalsa*

Department of Plant Sciences, University of California Davis, One Shields Ave. Davis, CA 95616 United States



Soil already recognized for climate change mitigation potential

- Incorporated into California's 2017 Climate Change Scoping Plan
- Practices that build healthy soils can remove CO_2 from atmosphere and store in soils, and reduce GHG emissions from nitrous oxide and fuel (up to ~1.2 metric tons CO_2-e/acre/yr combined total)
- State wants 5X as many acres in soil conservation practices by 2030 as current to achieve climate goals



De Gryze *et al.*, 2009,*California Agriculture*

Building soil health in California: Practices, Barriers, and Potential

Many studies on improving soil health

- Soil life
  - Worldwide “meta-analysis”: Cover cropping and reduced tillage each increased AM by 30%
  - Long-term trial in Salinas: Greater cover cropping frequency increased biomass of microbes ~2-fold and abundance of soil animals
- Soil organic matter
  - Long-term trial in San Joaquin: Combining cover crops and reduced tillage increased soil carbon by 29%
  - Long-term trial in Davis: Organic management increased soil carbon 33% in 10 years
- Many, many other studies
  - Elimination of soil fungicides and fumigants
  - Compost and manure amendments
  - Crop rotation diversity
  - Reducing synthetic fertilizers

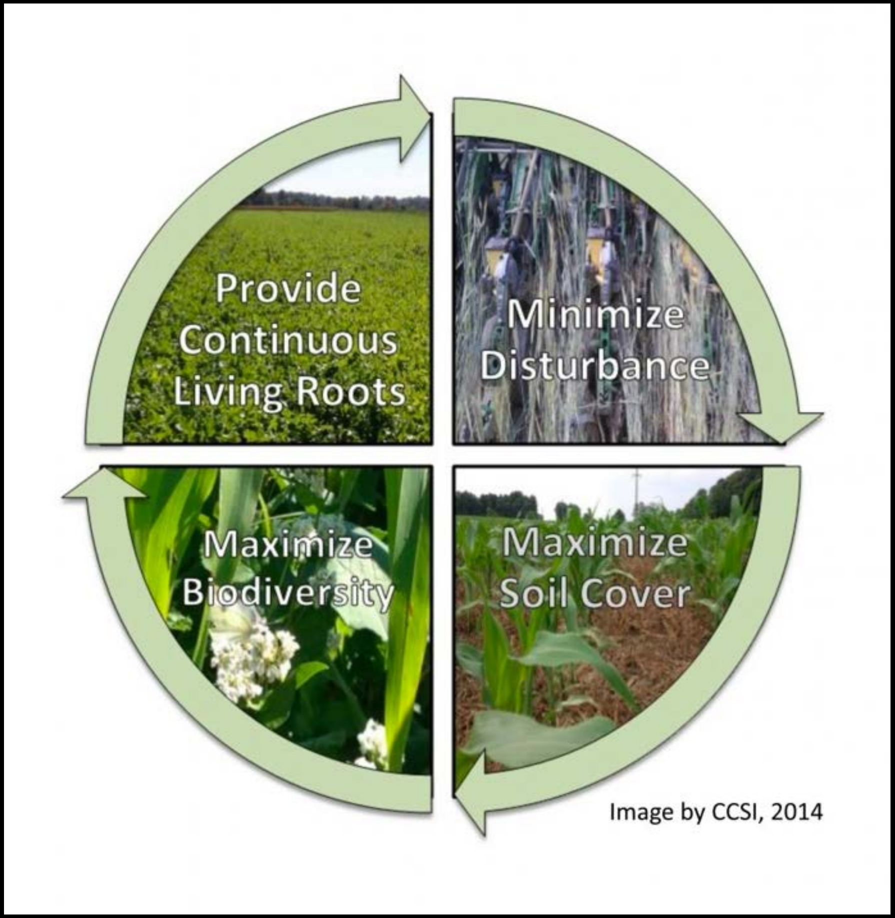
California Agriculture Systems Innovation

California Agriculture

Bowles *et al.*, 2017; *Journal of Applied Ecology*
Brennan and Acosta-Martinez, 2017; *Soil Biology and Biochemistry*
Mitchell *et al.*, 2015; *Agronomy Journal*
Kong *et al.*, 2005; *Soil Science Society of America Journal*

We know the principles for improving soil health

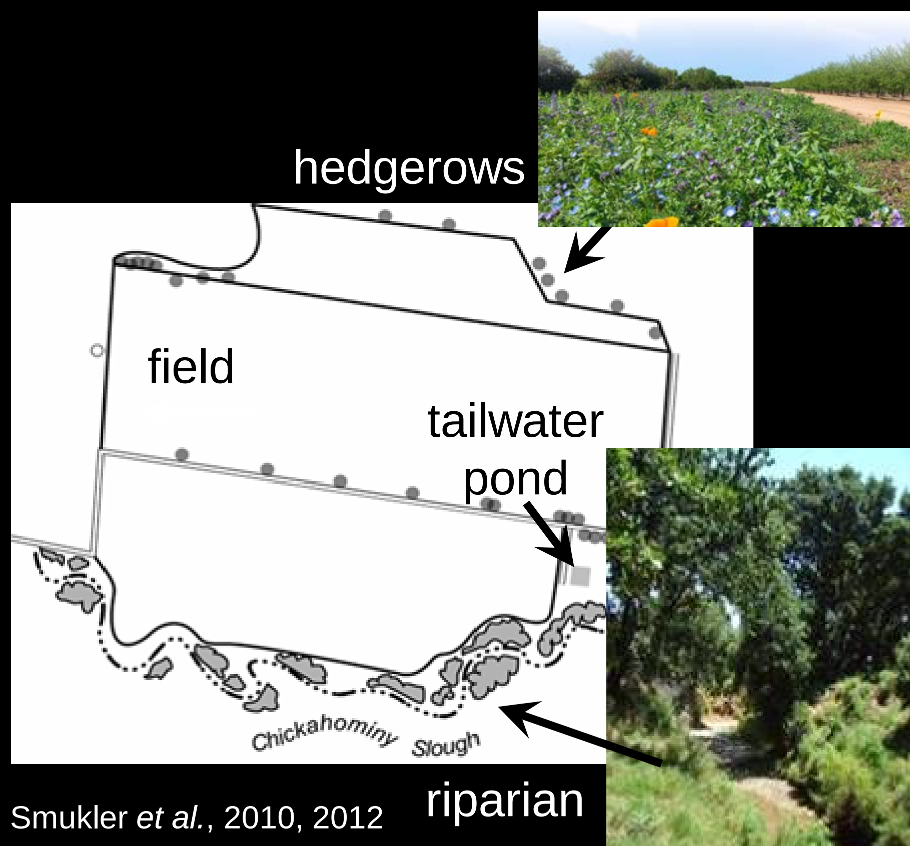
Within production fields



We know the principles for improving soil health

Surrounding production fields

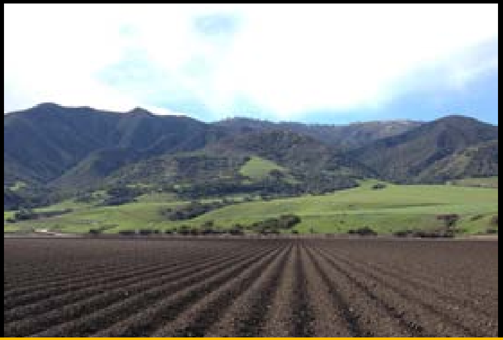
“Perennialize” landscapes



Smukler *et al.*, 2010, 2012

But adoption rates are low in California

- <5% of vegetable land in Salinas Valley is cover cropped
- <5% of annual cropland in California in “conservation agriculture”
- Low adoption of perennial cover around fields, and declining dramatically in some regions (Salinas)



Predominant management practices in California jeopardize soil health and its functions – bad for farmers and the rest of society

Brennan 2017; *HortTech*
Mitchell *et al.*, 2016; *California Agriculture*
Karp *et al.*, 2015; *P.N.A.S.*

Studying barriers and motivations

- *Promoting Soil Health Innovations: Barriers, Motivations, Enabling Conditions*
- Two phases:
  - Statewide survey of extension and industry professionals – UCCE, NRCS, RCD, CCAs, PCAs (completed)
  - Interviews with farmers in selected regions/crops (in progress)
- Expected outcomes:
  - Relative importance of different barriers
  - Recommendations for improving adoption of soil health practices



Project team: Alastair Iles, Claire Kremen, Joanna Ory, Tim Bowles

BERKELEY FOOD INSTITUTE UC BERKELEY

Preliminary survey results

- 143 responses, 36% response rate
  - Thanks to the UCCE, RCD, and NRCS personnel who completed the survey and helped spread the word
- 5 most important practices for managing soil health in crop and rangelands: 1) cover cropping, 2) rotational grazing, 3) reduced tillage, 4) diverse crop rotations, and 5) riparian herbaceous cover
- Barriers identified with cover cropping:
  - Cost of land
  - Interrupted spring planting
  - Cover crop residue as “foreign material”
  - Adequate water
  - Frost damage in orchards
- 17% of TA providers do not recommend cover cropping

Examples of multiple, interacting barriers

- Technical
  - Cover crops in almond orchards conflict with nut harvest
- Knowledge
  - Farmers unsure how to implement reduced tillage practices in intensive organic vegetable production
- Economic
  - Challenges balancing known, market-based adoption costs with less-certain, long-term non-market benefits
- Policy
  - Food safety regulations directly conflict with use of compost, manure, and perennial vegetation
- Supply chains
  - Cannery incentives for early tomato plantings impinge on cover crop use

Interviews with growers confirm TA provider survey

- Example: Cost of land
  - "Can I tell the landlord, hey, don't charge me this year because I'm going to grow a cover crop?" – Organic grower
  - "How can I make that land pay for itself in the fastest time?" – Organic grower
  - "I would like to do more cover cropping. Right now we cover crop around 10% of our acres, around 100 acres in total. The main reason we don't do more is the high rent and need to access the fields for planting. They need the beds prepped and ready for planting." – Conventional grower

Benefits of soil health management cut across state programs

Only program with an explicit focus on soils

State program	Goal
Healthy Soils Program	Sequester carbon, reduce GHG, and improve soil health
State Water Efficiency and Enhan… Progra…	Save water and …
Sustai… Ground… Manag… (SGMA)	…ater …d … balance
Irrigated Lands Regulatory Program (ILRP)	Improve surface and groundwater quality

Incorporating soil health and soil management into multiple programs could produce cross-cutting, amplified benefits

Positive benefits of soil health-promoting management practices

Programs can be silo-ed with respect to goals and approaches

Recommendations

- Support participatory, applied research
- Develop communities of practice among farmers and researchers
- Reduce adoption costs and offset opportunity costs with incentive programs
- Support research to quantify non-market benefits
- Improve buy-in from supply chains
- Incorporate healthy soils/soil management into multiple programs and policies

If you want to live a long and healthy life, what do you do?

Invest in your healthy early and often. The same goes for soil.

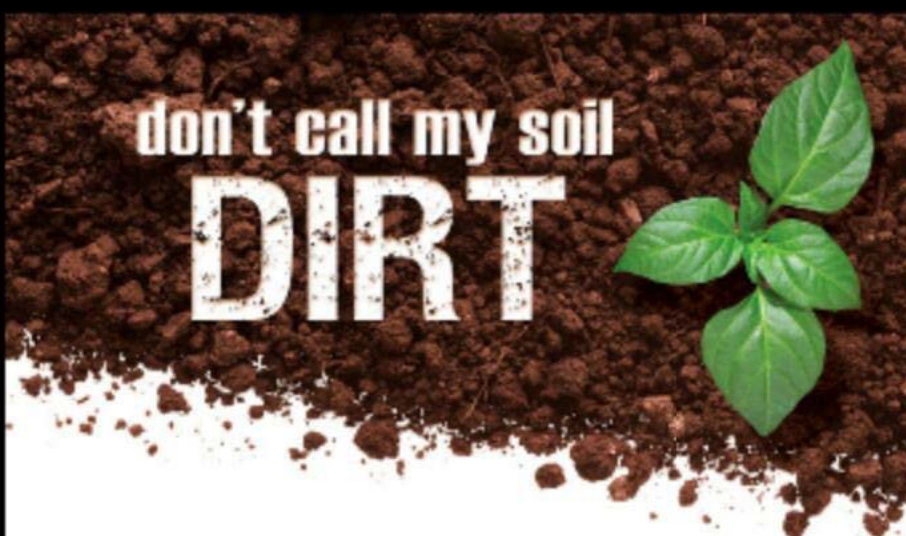
Some parting wisdom

- “Remember to look up at the stars and not down at your feet…” – Stephen Hawking
- “Remember to look up at the stars and ~~not down at~~ beneath your feet…” – Anonymous

The Land Institute

Thank you!

- Yolo Co. farmers
- Louise Jackson (UC Davis Emerita)
- Berkeley Food Institute faculty and staff, especially Nina Ichikawa (UC Berkeley)
- Bowles Lab members
- Contact: timothy.bowles@berkeley.edu



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