What every agronomist needs to know about soil microbiology

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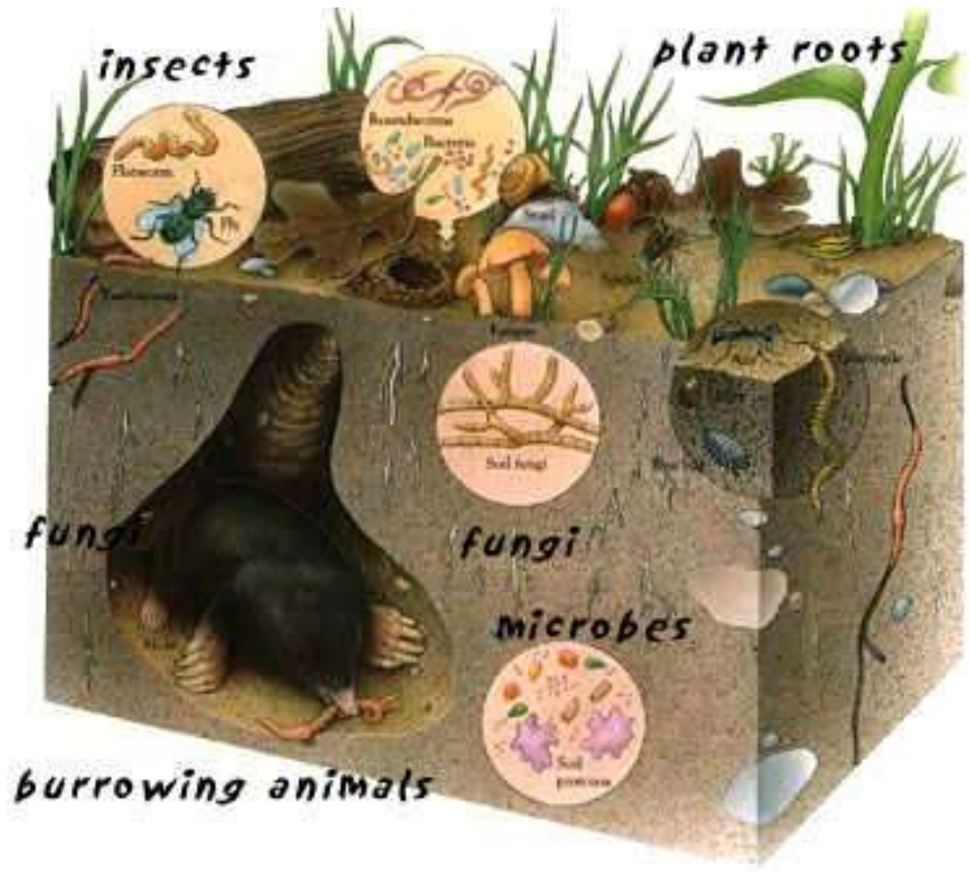

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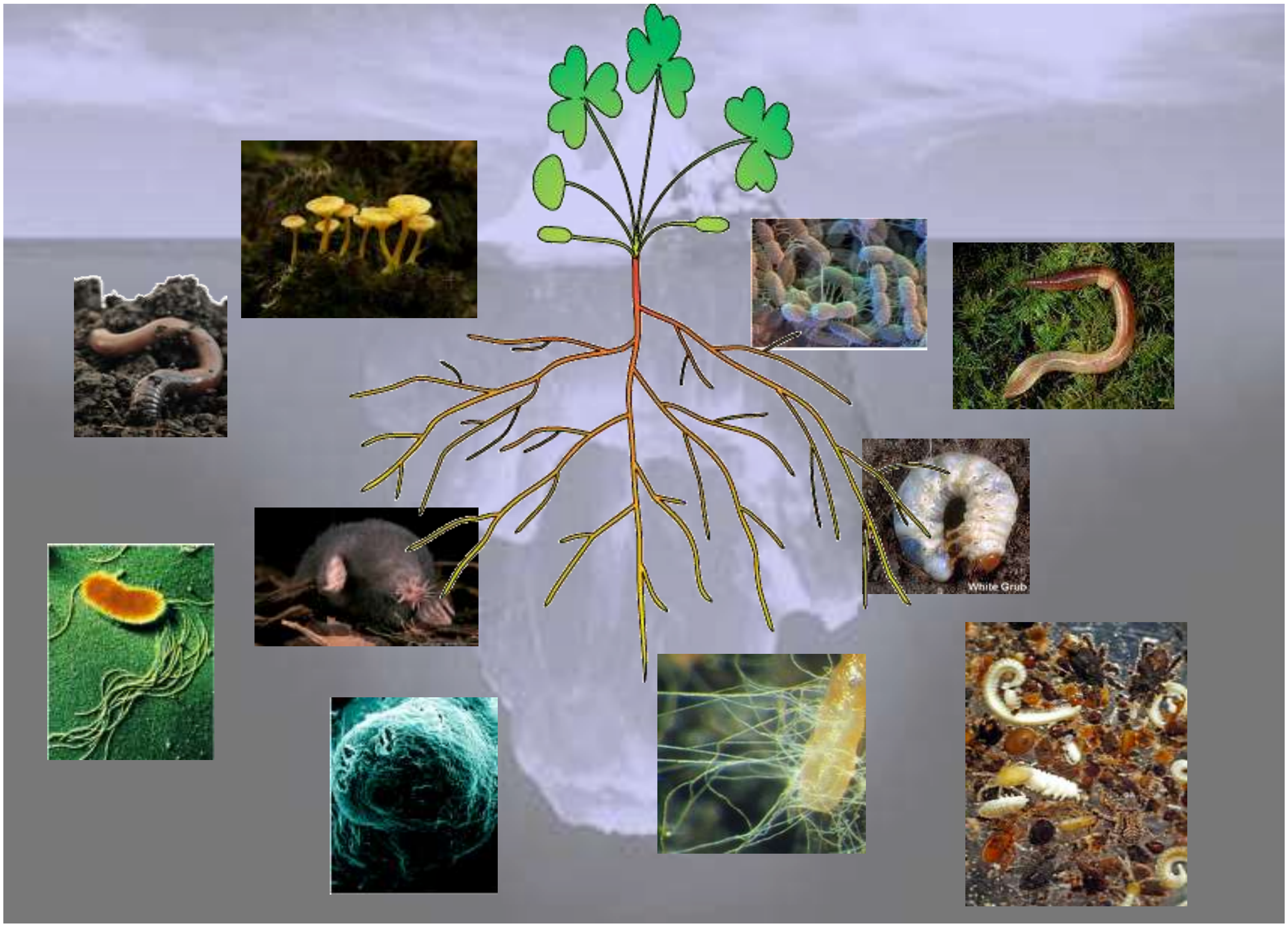
Outline

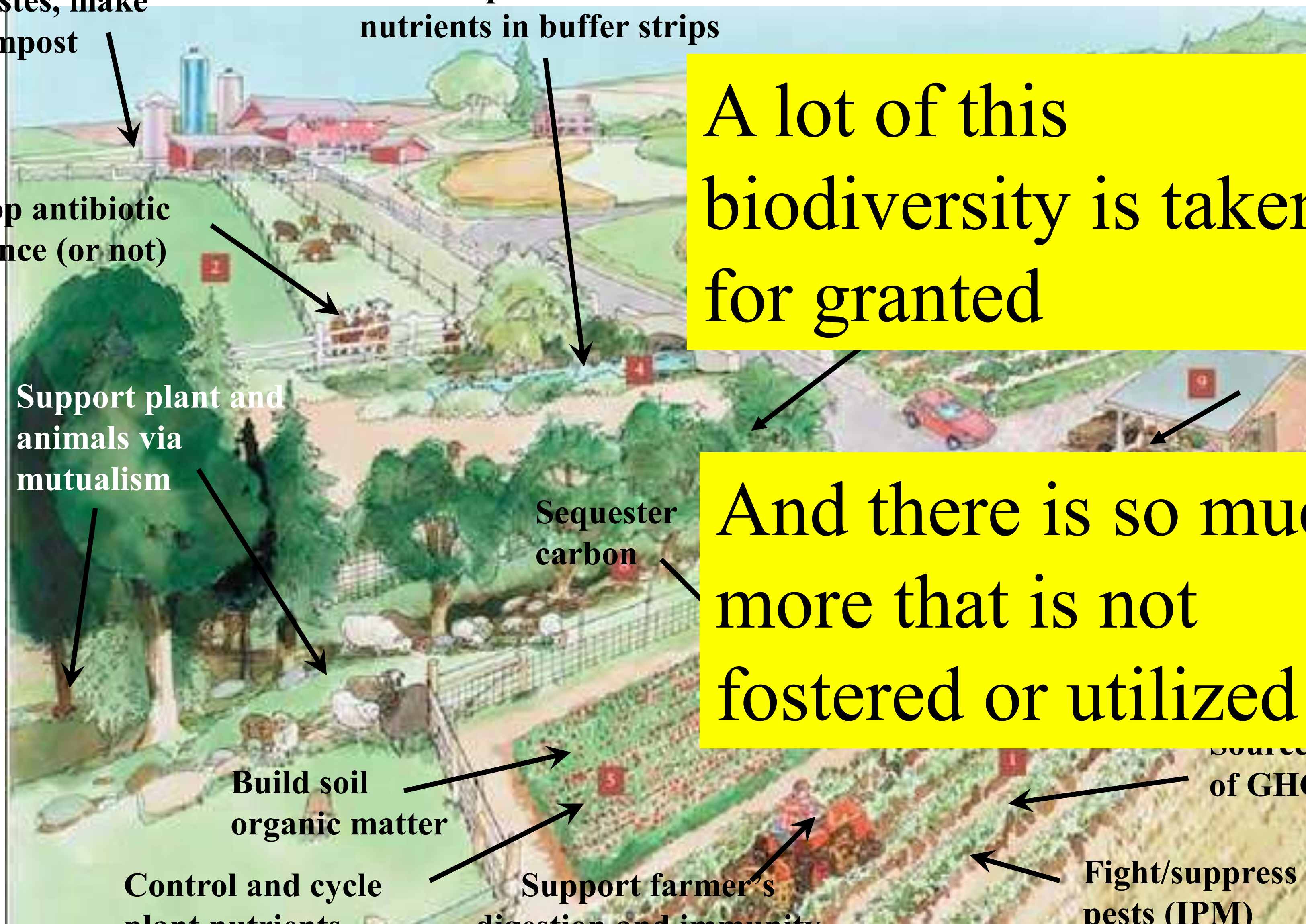
- **Role of soil microbes in agroecosystems**
  - **Biodiversity**
  - **Obstacles**
- **Key roles**
  - **Microbes and nitrogen cycling**
  - **Microbes and soil carbon**
  - **Microbes and soil structure**
- **Inoculation vs working with local talent**
- **What lies ahead—some examples**
  - **Compost impacts on biodiversity**
  - **Tillage and cover crops effects on biodiversity**
  - **Managing the rice microbiome**

Soil biodiversity: just as icebergs hide most of their mass below the surface...

...most ecosystems concentrate biomass and biodiversity below ground.



Agroecosystems host huge diversity of soil biology providing services (and disservices)



A lot of this biodiversity is taken for granted

And there is so much more that is not fostered or utilized

http://images.google.com/imgres?imgurl=http://www.sare.org/publications/explore/images/scenewide2.jpg

Agricultural soils can be chilly environment for microbes

Not enough carbon inputs: removal of large portion of plant biomass (not returning stubble) or simply not enough plant biomass *(organic carbon and microbial biomass increase when switch to organic)*

Physical disturbance from tillage (disturbs habitat and disrupts hyphal networks) and compaction from machinery

Bare soils during fallow periods—no C, no protection from heat, no water?

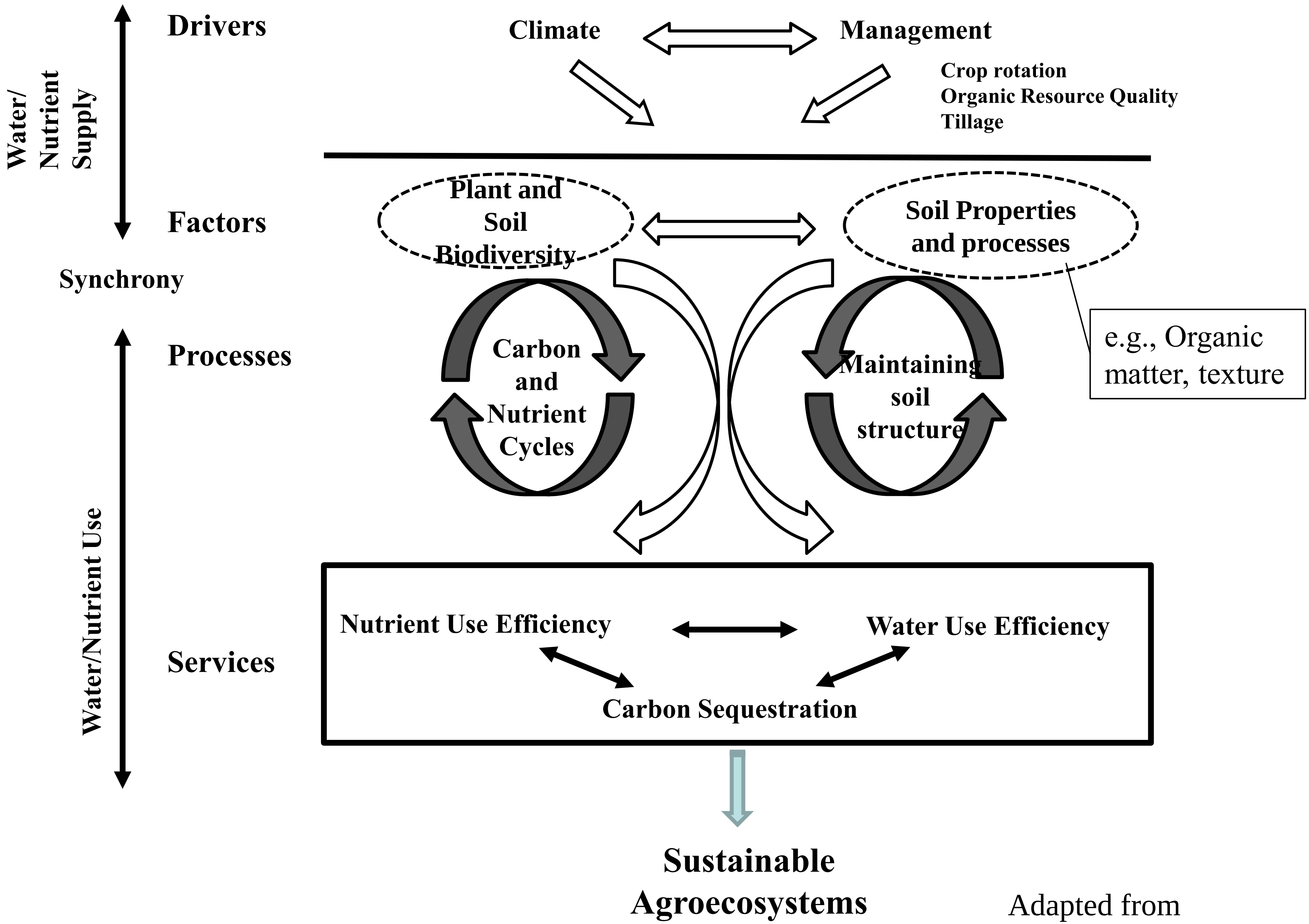
Agrichemicals decrease some groups –fungi, micro/macrofauna– and select others—e.g., some bacteria that degrade chemical or "bloom" after application

Fertilizer concentrations too high for symbiotic organisms w/plants.

Many recommended agricultural practices are:

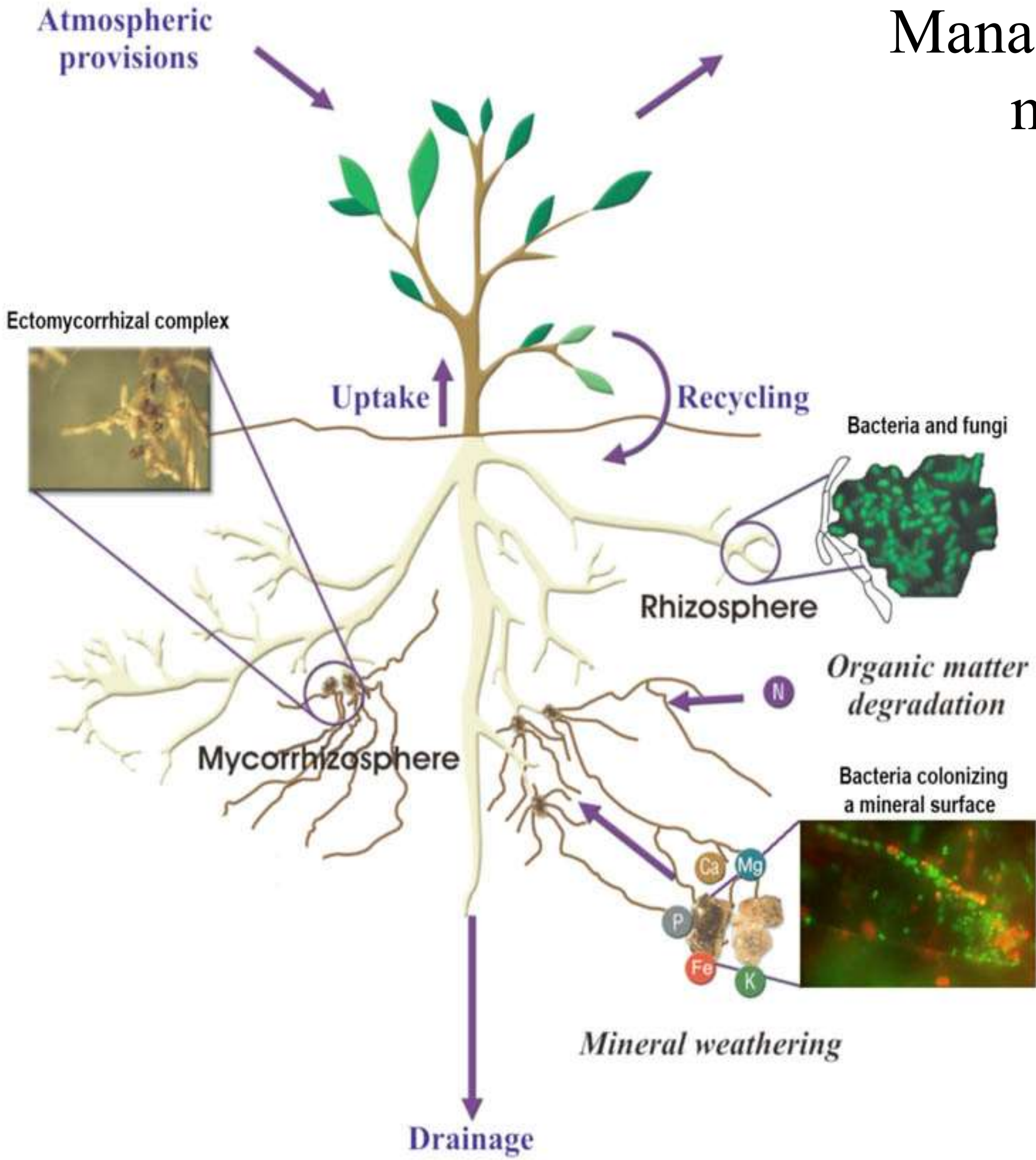
- cook book, maybe sometimes based on rapid test
- targeting single issues rather than systems oriented: address symptoms not underlying causes
- Have only short term perspective (that season)

Microbes tightly coupled with plants and soil: can't decouple biodiversity from soil



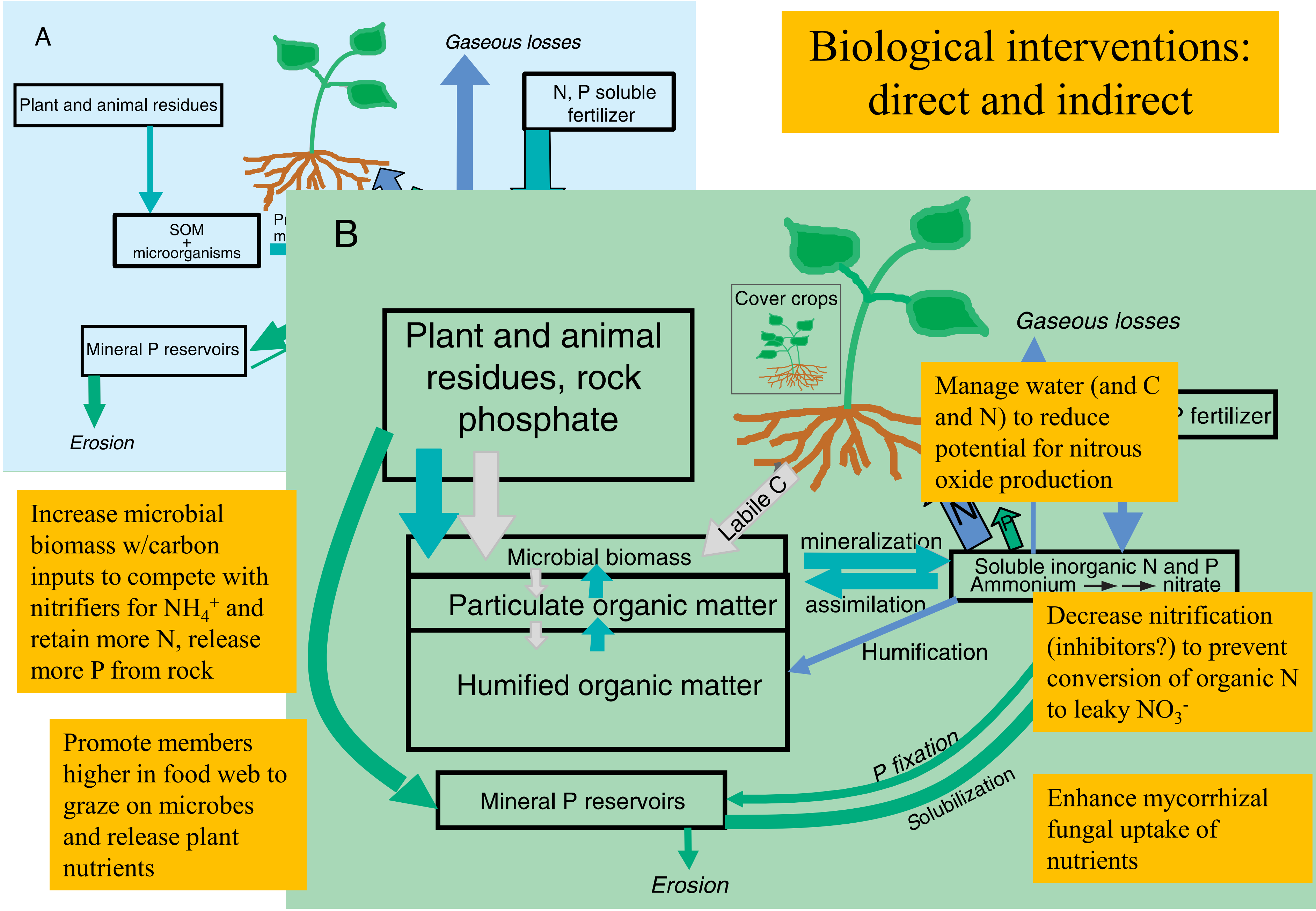
Adapted from
Brussaard et al. 2007

NUTRIENT CYCLING
Managing the N cycle means managing microbes



- Plant N use efficiency often low, <50% of N added is taken up into plants immediately
- Uptake is regulated by relationships between soil microorganisms and plants. Large amount of fertilizer, NO MATTER WHAT INITIAL FORM, goes through microbes before plant gets it.

Biological interventions: direct and indirect



Increase microbial biomass w/carbon inputs to compete with nitrifiers for NH_4^+ and retain more N, release more P from rock

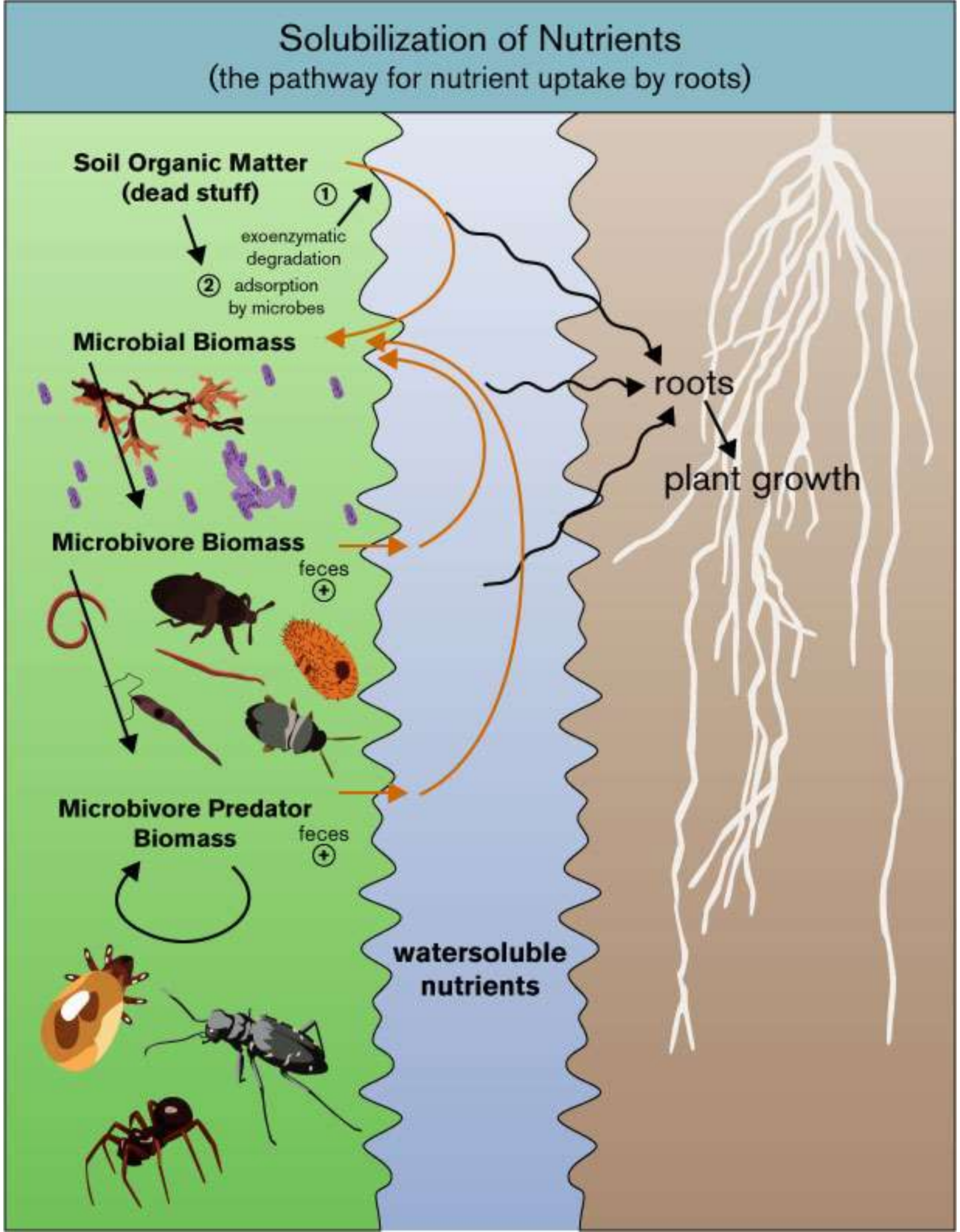
Promote members higher in food web to graze on microbes and release plant nutrients

Manage water (and C and N) to reduce potential for nitrous oxide production

Decrease nitrification (inhibitors?) to prevent conversion of organic N to leaky NO_3^-

Enhance mycorrhizal fungal uptake of nutrients

Drinkwater, Laurie E., and S. S. Snapp. "Nutrients in agroecosystems: rethinking the management paradigm." *Advances in Agronomy* 92 (2007): 163-186.

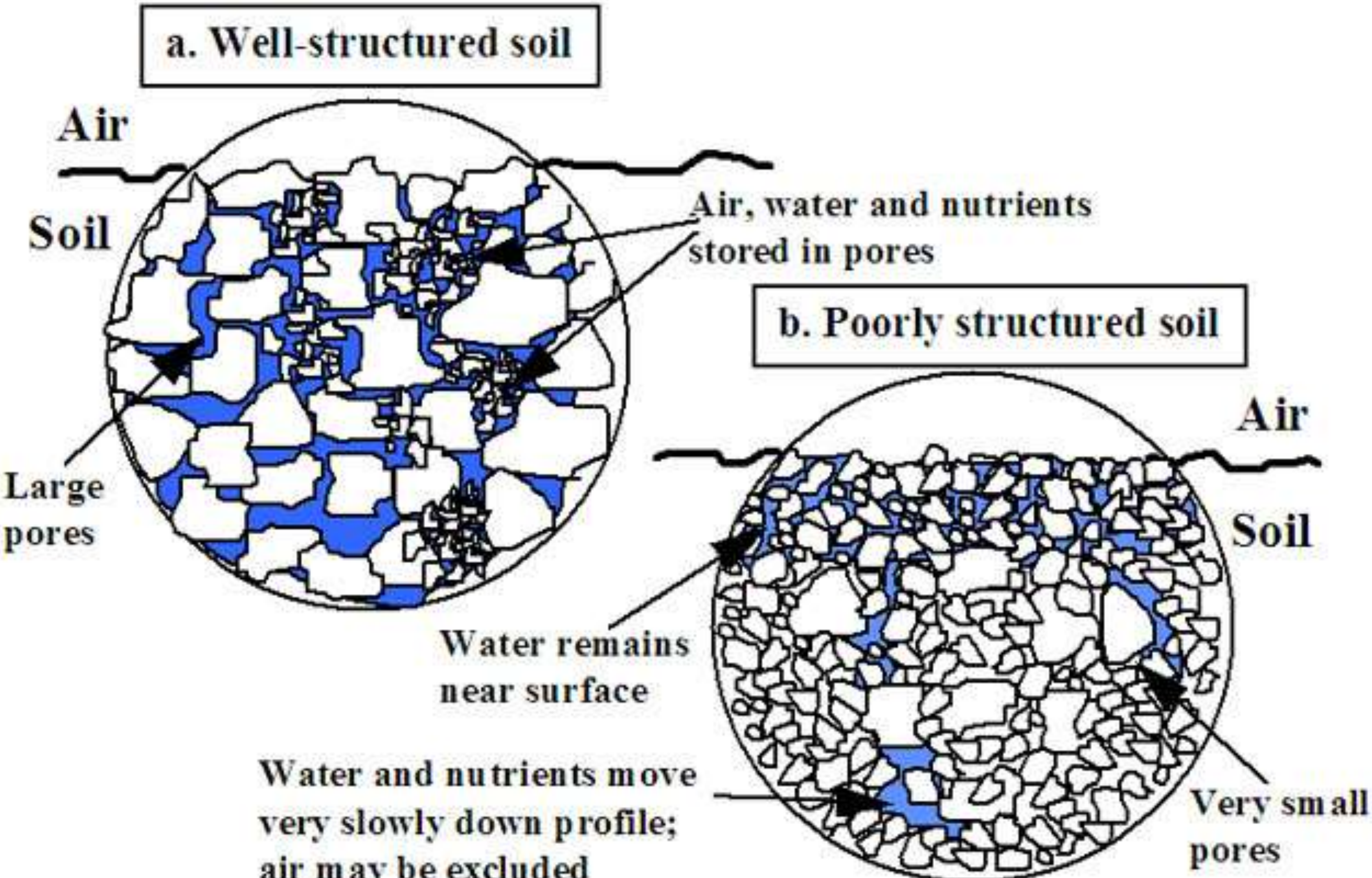


Promote members higher in food web to graze on microbes and release plant nutrients

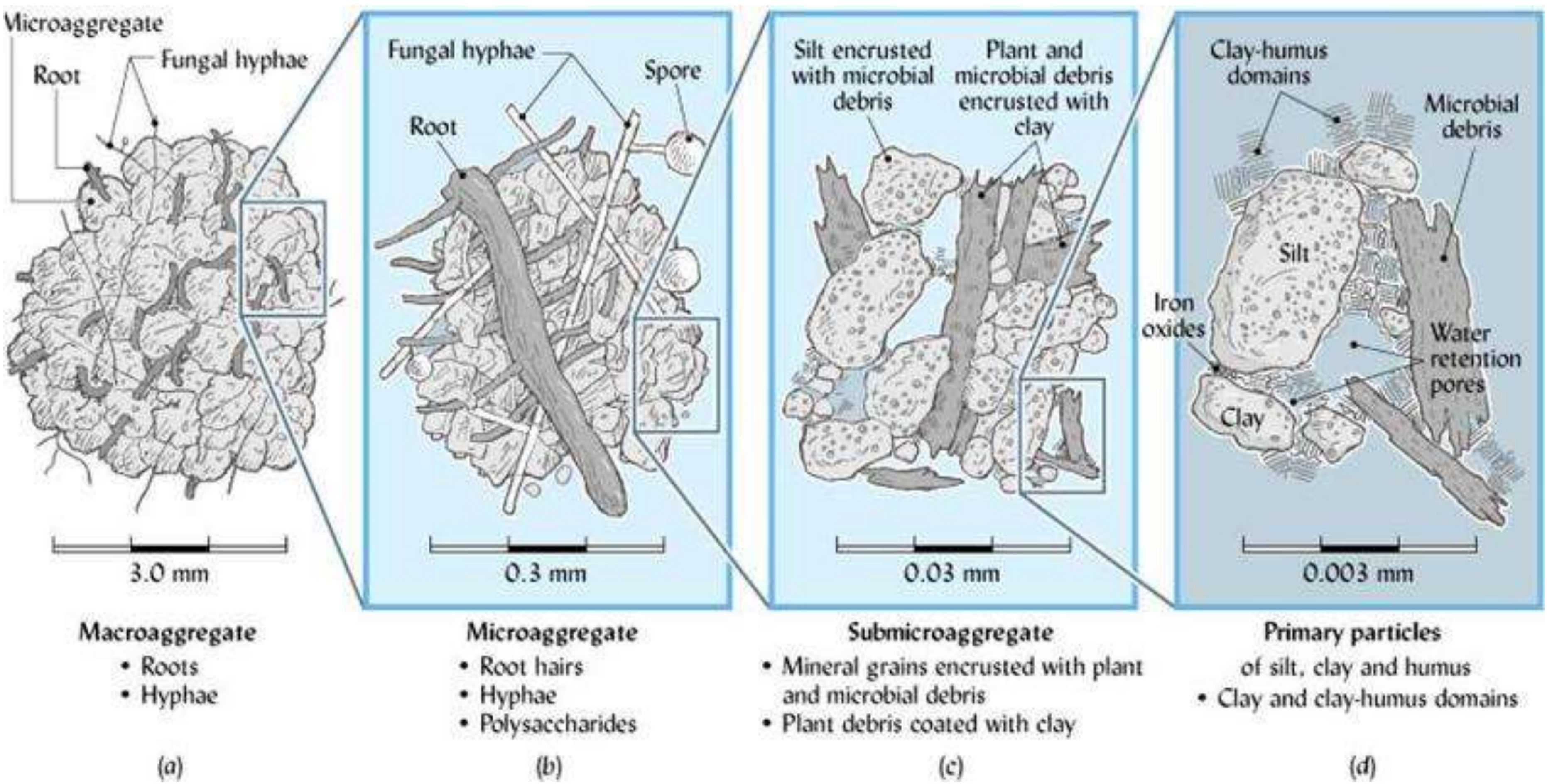
Also to speed up decomposition of residues that might get in way of operations

SOIL STRUCTURE

Implications of soil structure for water movement and gas exchange

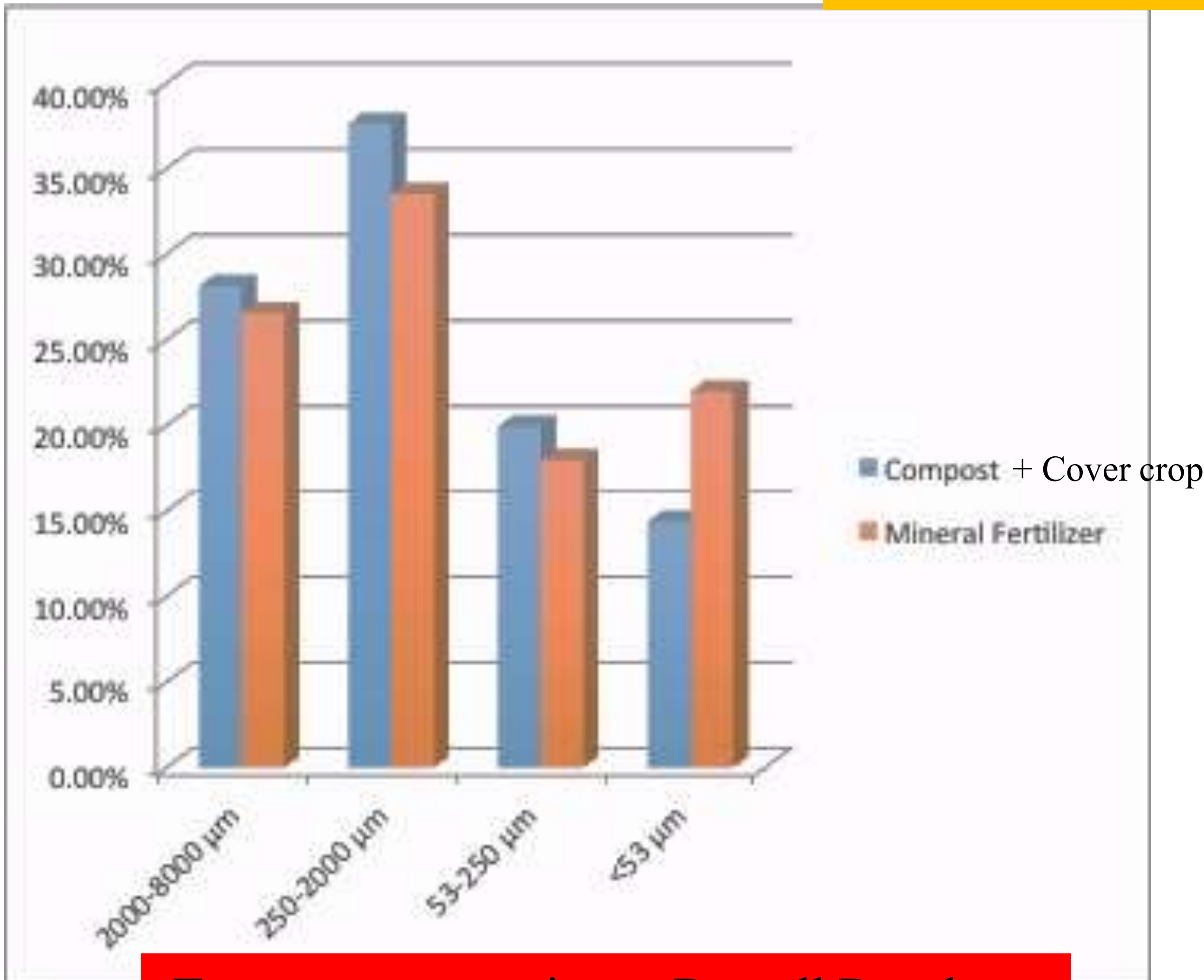


Role of organic matter and microbes in creating aggregate structure: fueled by carbon inputs



Higher organic matter inputs → higher microbial activity → better soil structure

- *More medium size aggregates*
- *Less unconsolidated material*
- *Much less slaking (disintegration)*



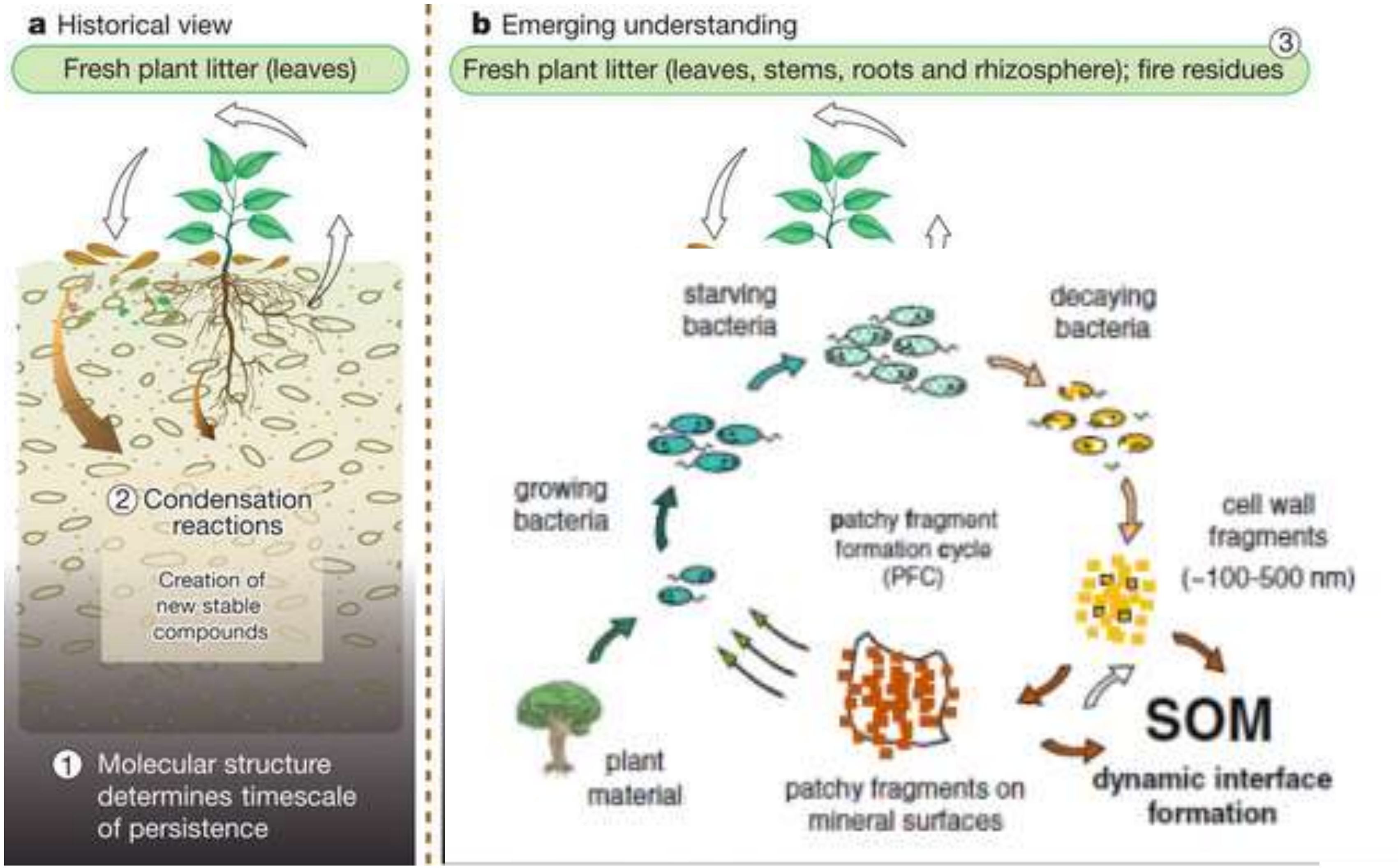
Tomato-corn rotation at Russell Ranch

Better soil structure→ greater infiltration and percolation rates.

Huge impacts on furrow irrigation management

Soil organic matter (SOM) formation

Microbes are enzymatic drivers and also "feedstock" for SOM formation



Persistence of soil organic matter as an ecosystem property (2011) Schmidt et al. Nature 478, 49–56

In general: management practices to manage microbes in soil

- Manipulate what they eat: C/N ratio of organics, degradability, physical availability, electron acceptors (e.g. oxygen), other nutrients, specific enzyme co-factors (?)

- Manipulate their environment: water and oxygen content, pH, “architecture”: stratified vs mixed layers in soil

- Add other soil amendments: biochar, calcium, signaling compounds?

- Inhibit/select for specific microbial groups? *Nitrification inhibitors? Or through specific substrates?*

- Promote symbiotic relationships with plants that short-circuit some of the soil processes providing N

- What about inoculation with consortia, specific strains?

USDA NRCS
United States Department of Agriculture
Natural Resources Conservation Service

National Soil Health Initiative

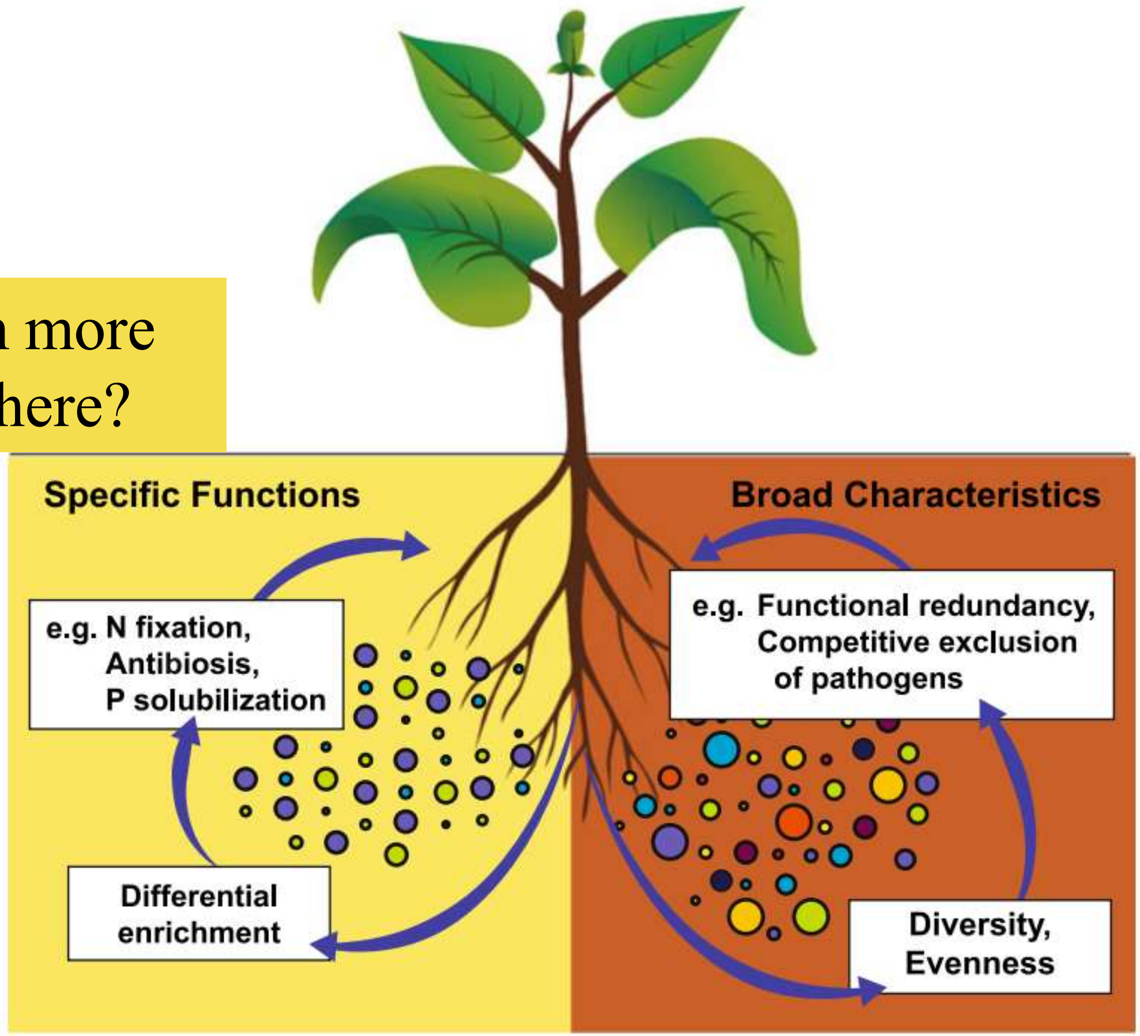
The Soil Health Roadmap to Productive, Sustainable Farming in the 21st Century and Beyond

Not surprisingly, many biologically friendly practices are similar or same as those recommended by soil health initiative

NRCS - HELPING PEOPLE HELP THE LAND

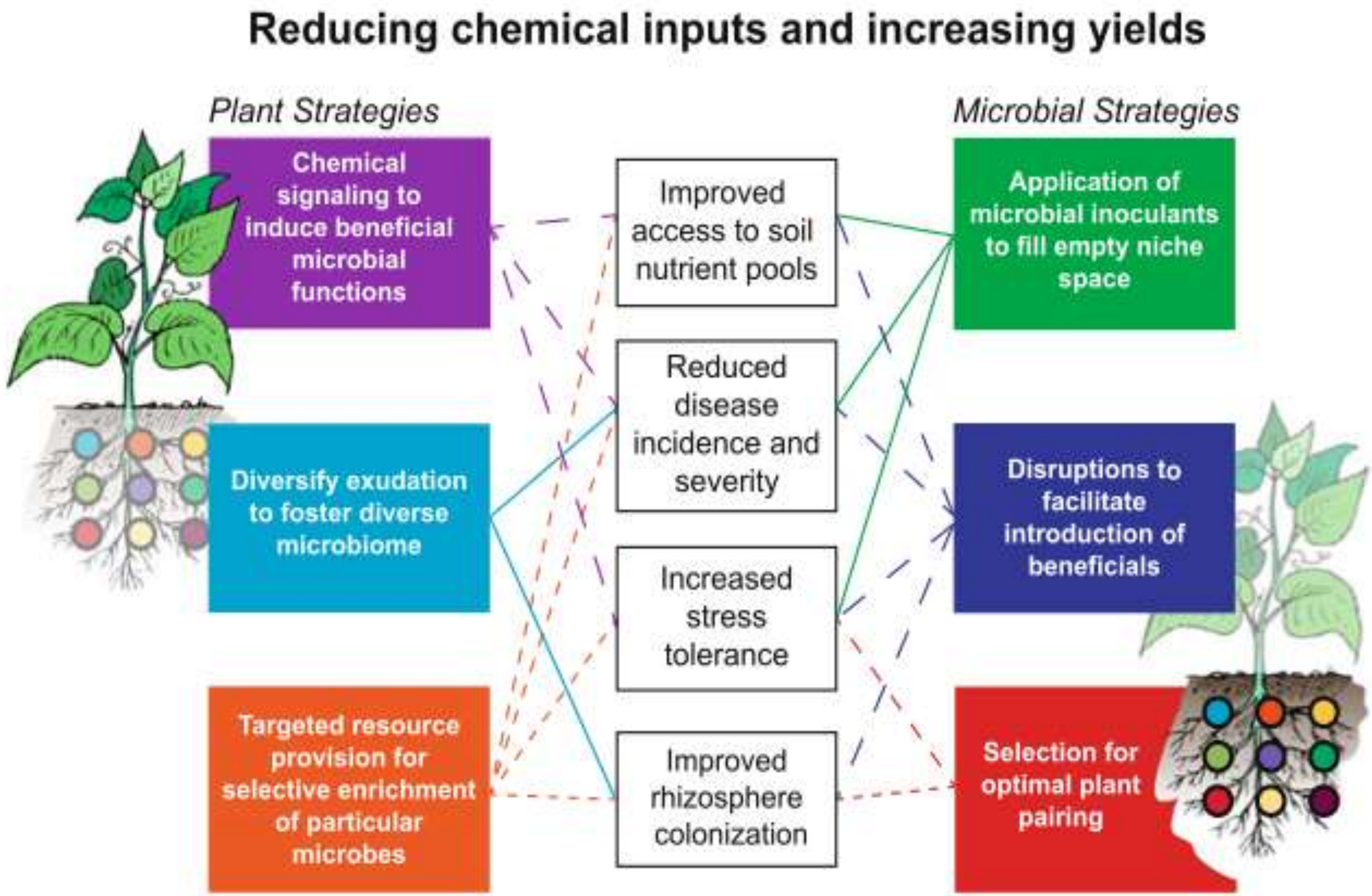
And inoculation??

Inoculation more promising here?



Bakker, M.G., Manter, D.K., Sheflin, A.M., Weir, T.L. and Vivanco, J.M., 2012. Harnessing the rhizosphere microbiome through plant breeding and agricultural management. *Plant and Soil*, *360*(1-2), pp.1-13.

Strategies to increase success of inoculation—in consort with plant



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WHY DOES INOCULATION OFTEN FAIL?

- Incomplete understanding of their abiotic requirements

- Incomplete understanding of their biotic requirements – may need to be added w/complementary organisms not present in community or whom they can't "find"

- Conditions not conducive to establishment at time of introduction (no rain, no food, etc.)

- Application method does not place inoculum into microhabitats where they'd thrive (e.g., need microaggregates, but added as aqueous slurry that quickly flows through preferential flow paths and macropores)

- Intense predation or competition by resident organisms (e.g., protozoa)

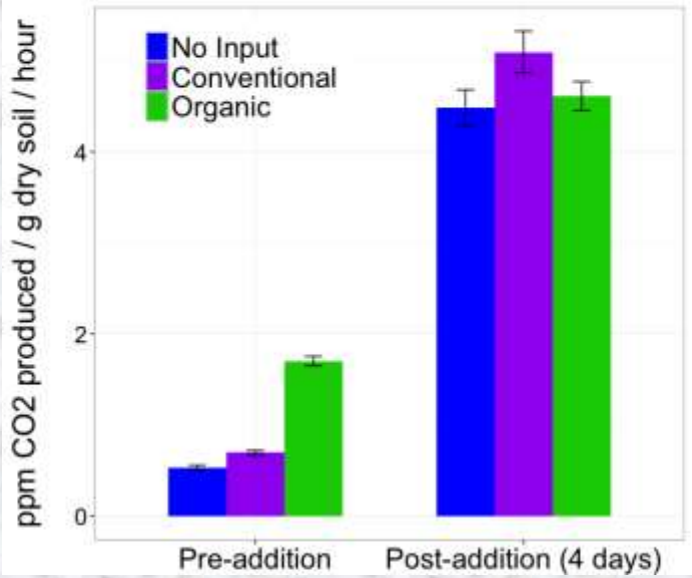
- Just adding inoculants is likely not successful first time--requires experimentation to get right doses, timing, placement

- Inoculum usually commercially produced under optimum conditions for growth—does this prepare them for what lies ahead?

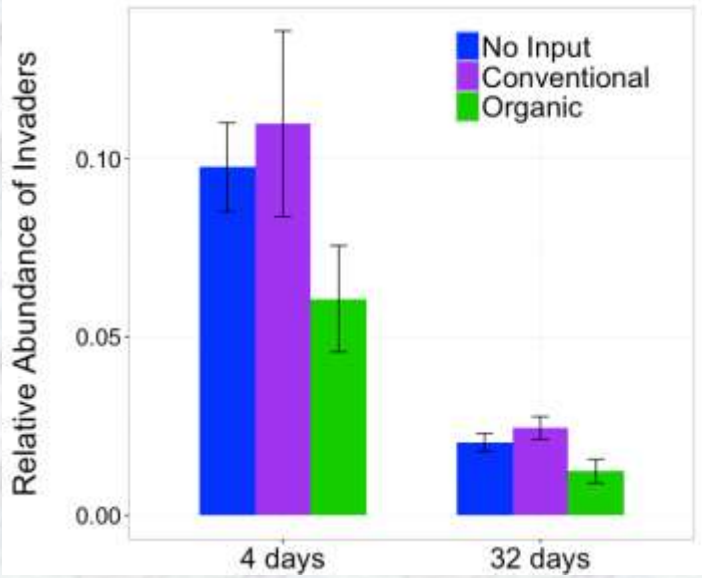
Microbial effects of adding compost to agricultural soils with different histories at Russell Ranch

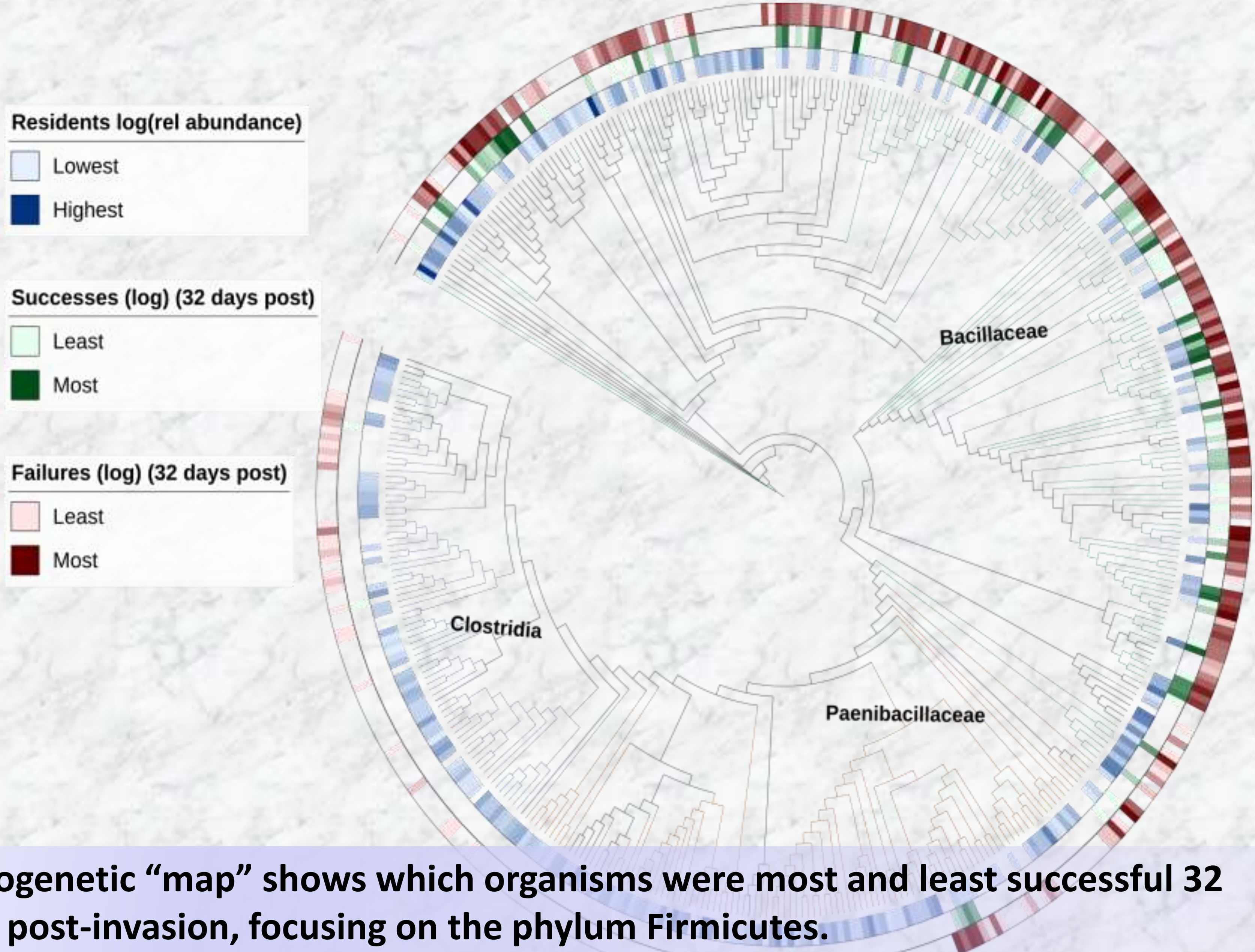
Kelly Gravuer and Kate Scow

- C-depleted soils are not limited in their ability to rapidly benefit from compost as a <u>substrate</u>



- **Compost-derived organisms establish** initially (4 d) but then dwindle away. Organic soil least colonized by compost organisms.





Phylogenetic "map" shows which organisms were most and least successful 32 days post-invasion, focusing on the phylum Firmicutes.
Actinobacteria, Gammaproteobacteria, Alphaproteobacteria were most successful invaders

Effects of cover crops and tillage on soil microbial communities

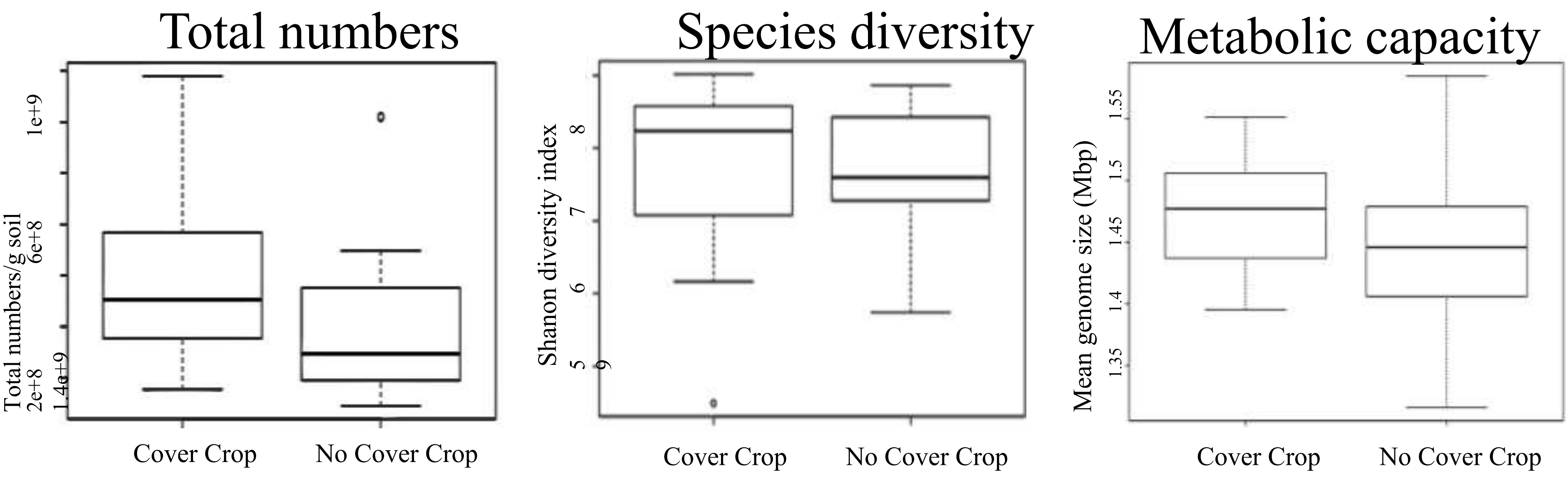
Rad Schmidt, Jeff Mitchell, Kate Scow

- Bacterial community dynamics are driven by C inputs
  - cover crops increase availability and diversity of C
  - select for communities with moderate growth-rate bacteria with wider metabolic capacities

- Fungal community dynamics are driven by disturbance
  - tillage redistributes plant matter and breaks fungal hyphae
  - no-till selects for communities with more symbiotic fungi and fewer saprophytes

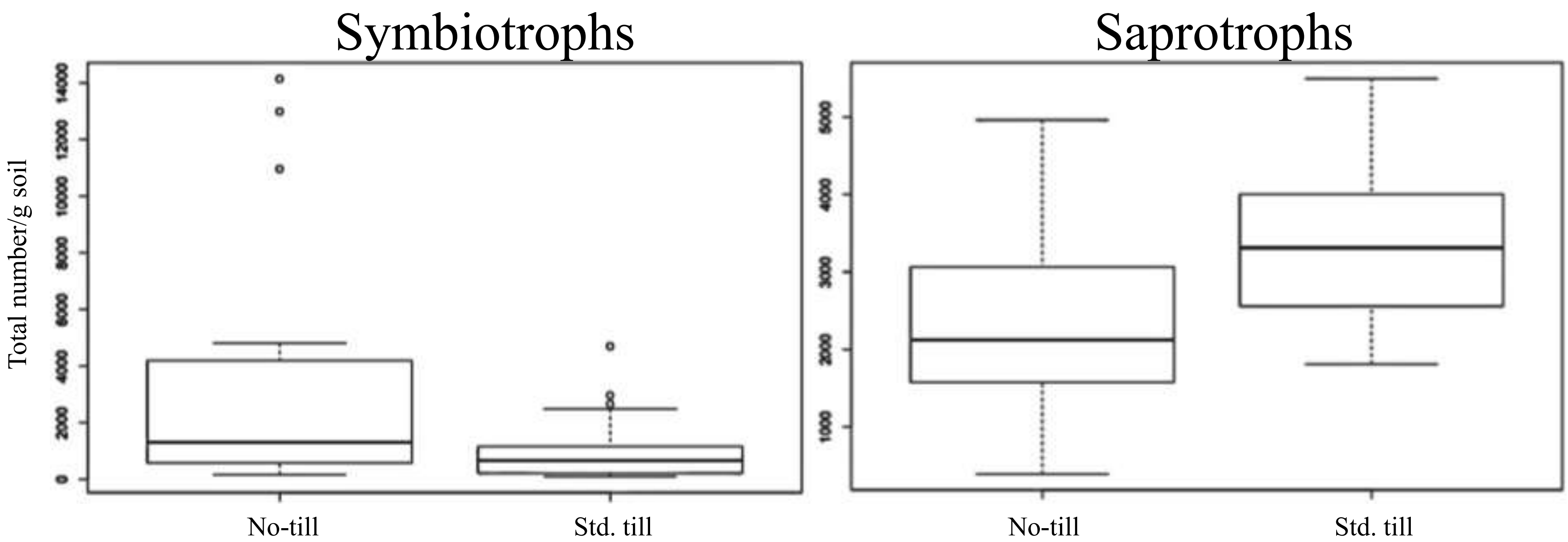
Bacteria respond strongly to cover crops, less to tillage

- Cover cropping leads to:
  - higher bacterial biomass
  - higher diversity
  - organisms with larger genomes and therefore greater metabolic capacities.



Fungi respond to tillage, less to cover crops

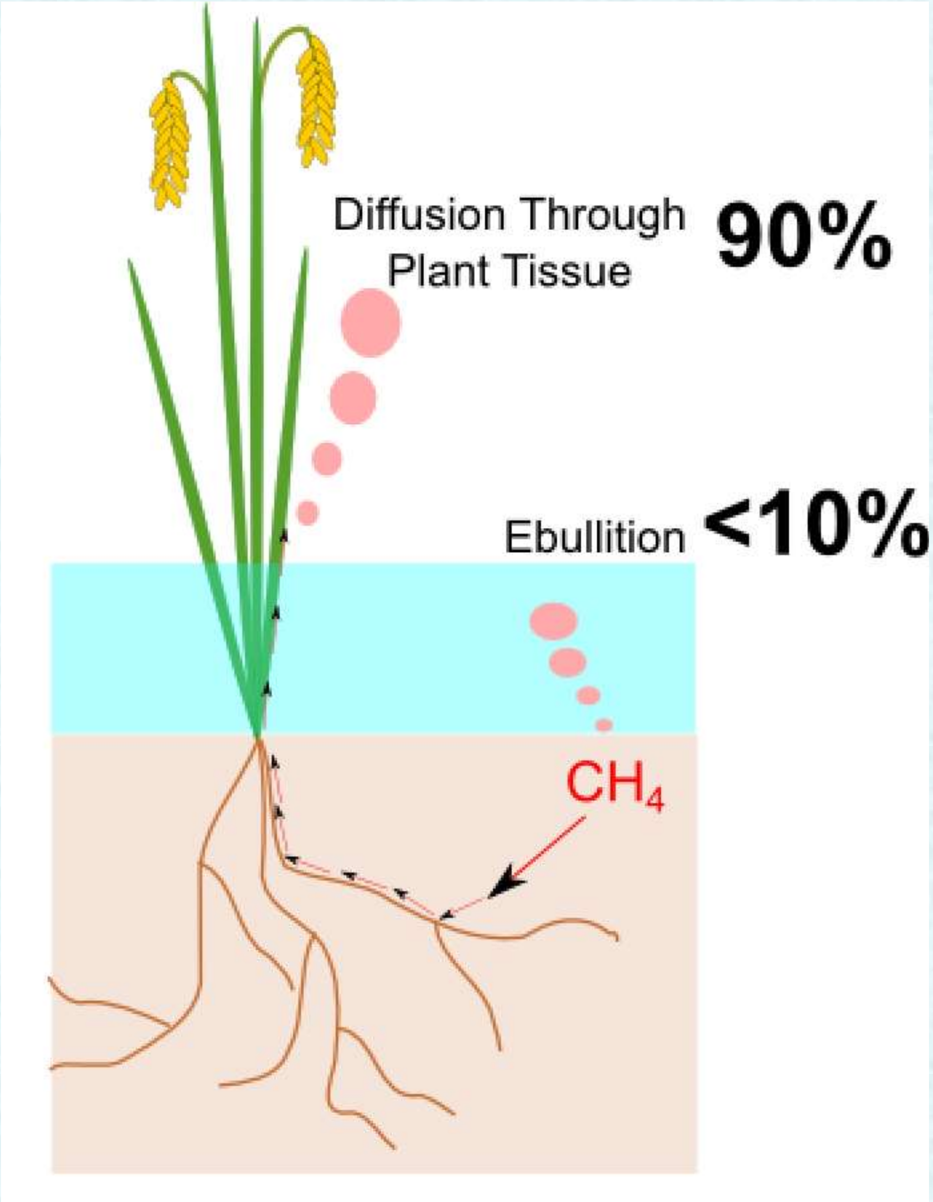
- Three life strategies – Symbiotrophs, Saprotrophs, Pathotrophs
- No-till leads to
  - Higher nunbers of mutually beneficial fungi (Symbiotrophs)
  - Lower numbers of fungi that break down organic matter (Saprotrophs)
  - No significant difference in pathogenic fungi (Pathotrophs)



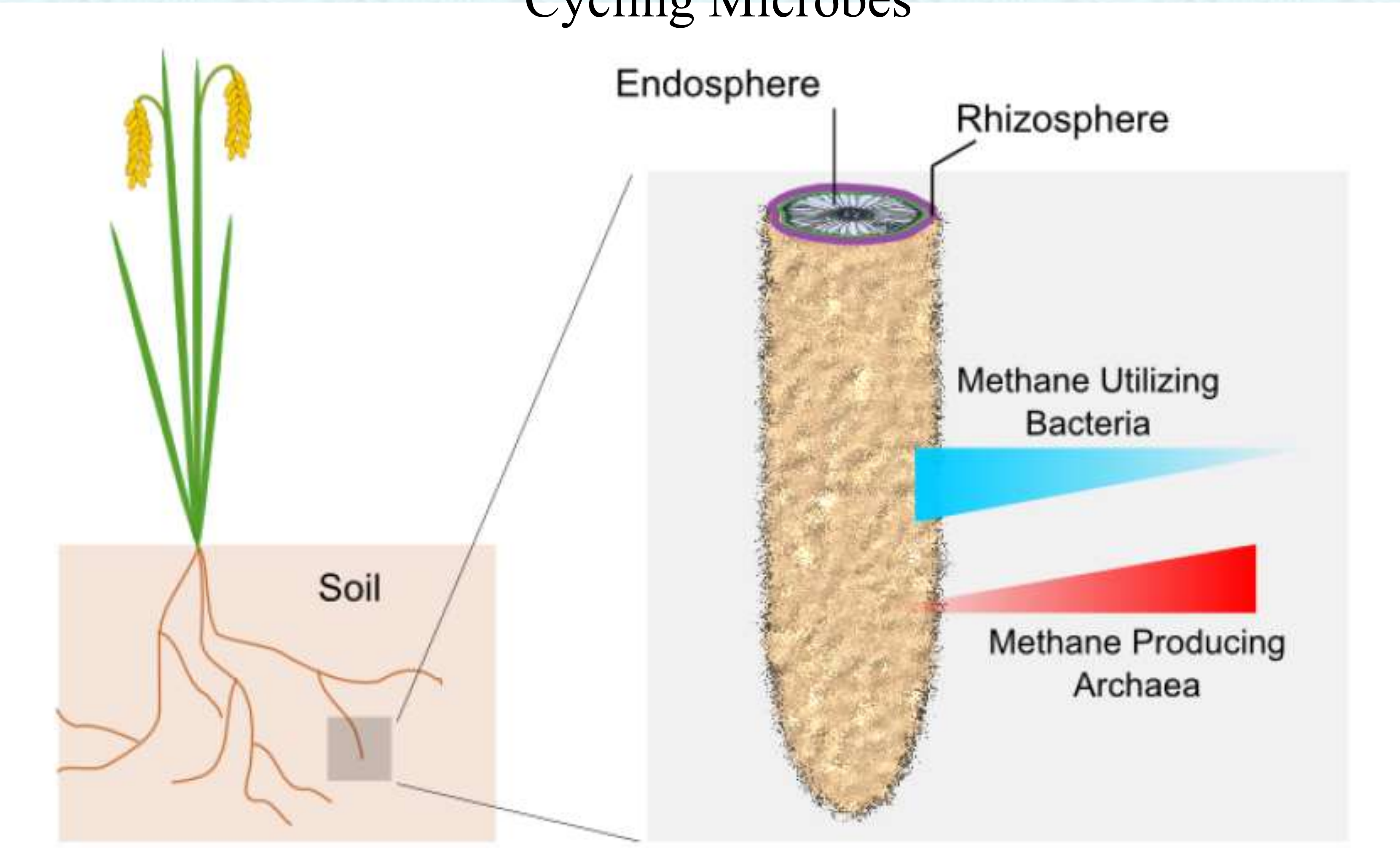
Harnessing the Microbiome of Rice

Joseph Edwards and Venkatesan Sundaresan

- Rice cultivation emits ~50 Million Tons of Methane every year
  - ~15% of Anthropogenic CH_4 emissions
  - CH_4 is 30X more potent than CO_2 as a greenhouse gas
- Warm, waterlogged soils are ideal for methane producing microbes
  - Methane producing microbes use decaying rice roots and root exudates for energy
  - Most CH4 is emitted through the plant itself



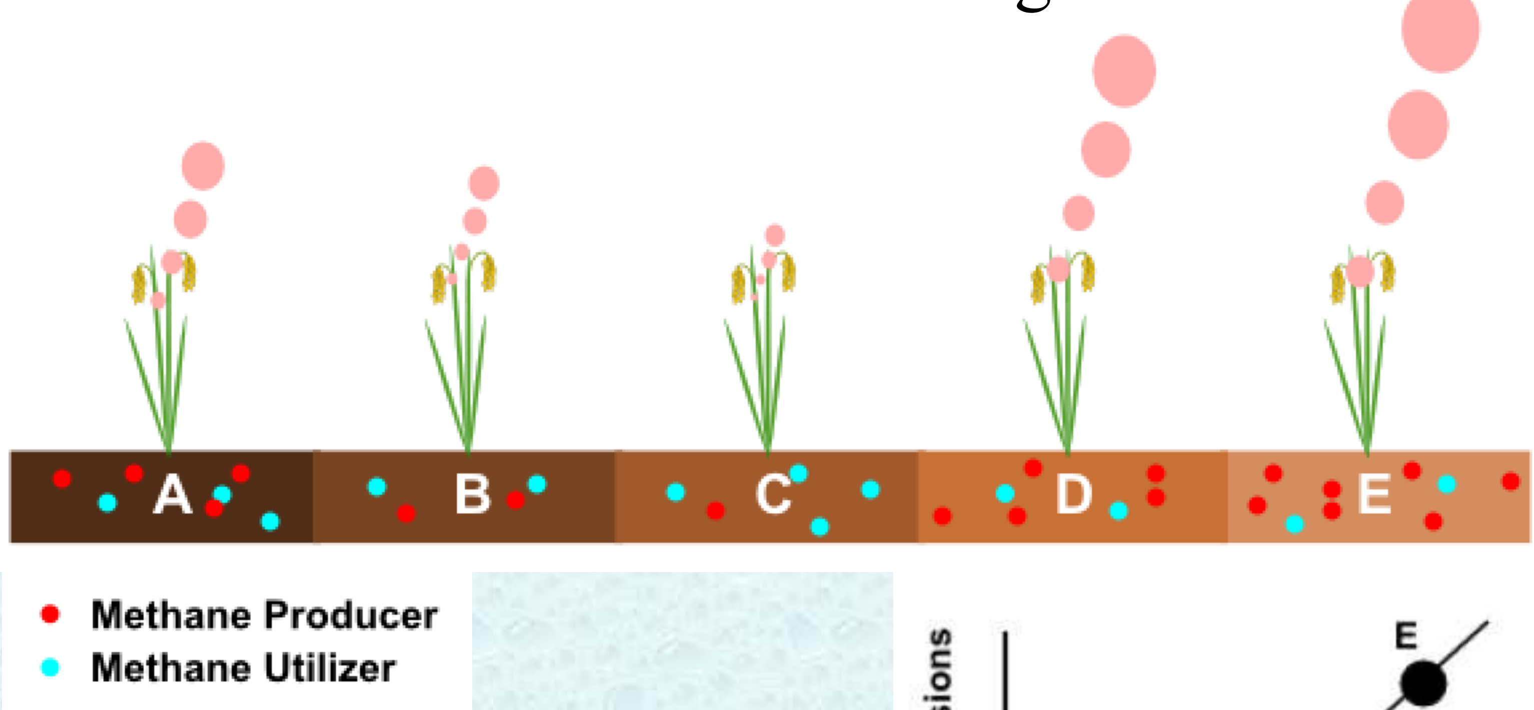
Rhizospheric Compartments Host Different Abundances of Methane Cycling Microbes

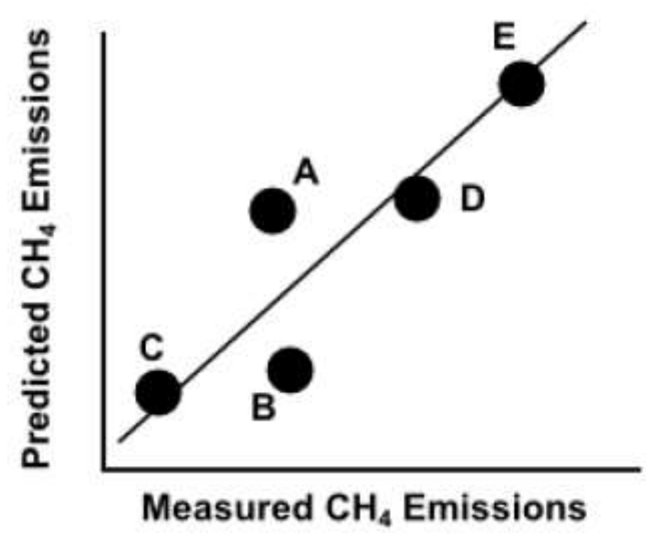


Methane utilizing microbes live in areas around and inside the roots where oxygen is prevalent

- Slightly mitigate CH4 emissions from the rice plant
- How can we increase methane utilizing microbes while reducing methane producing microbes?

Can we sequence microbial communities from soil and roots to predict CH4 emissions from rice fields and advise farmers how to mitigate?





Challenges and benefits in managing soil biology rather than relying only on chemically based systems

- Much of what we think of as “soil” processes are actually biological processes.
-
- “Indirect” management practices often more fruitful than direct manipulation of biology—though future holds promise as we learn more

- Everything is connected
  - Challenging because can’t isolate specific factors
  - Good in that can manage for multiple benefits
  - Important to evaluate trade-offs and identify indicators

Challenges and benefits in managing soil biology rather than relying only on chemically based systems (2)

- Takes time to invest in system w/eye on future (not just current growing season) to get it to where the positive benefits are substantial and consistent: much needed for managing soil biology

- Resistance/resilience of agroecosystems is largely due to its biological communities: need to figure out how to harness

- May not have quick fixes to problems (e.g., chemicals in organic or more biological system)—so need to design resilience into system—our expanding knowledge of microbial communities will help

Is use of subsurface drip irrigation substantially shrinking volume of agricultural soil that is biologically active? Are potential trade-offs and synergies of using drip being considered sufficiently?

Questions?

Figure 1. Dripline installed underground.

http://www.nytimes.com/2013/05/12/opinion/sunday/the-hidden-world-of-soil-under-our-feet.html?hp&_r=0

NEED TO CONNECT PUBLIC WITH AGRICULTURE'S BELOW GROUND "YIELDS"

State and county fairs give a prize for the biggest pumpkin…..

How about a prize for soil with greatest biomass or biodiversity?