

# Life Underground: partnering with soil microbial communities on the farm



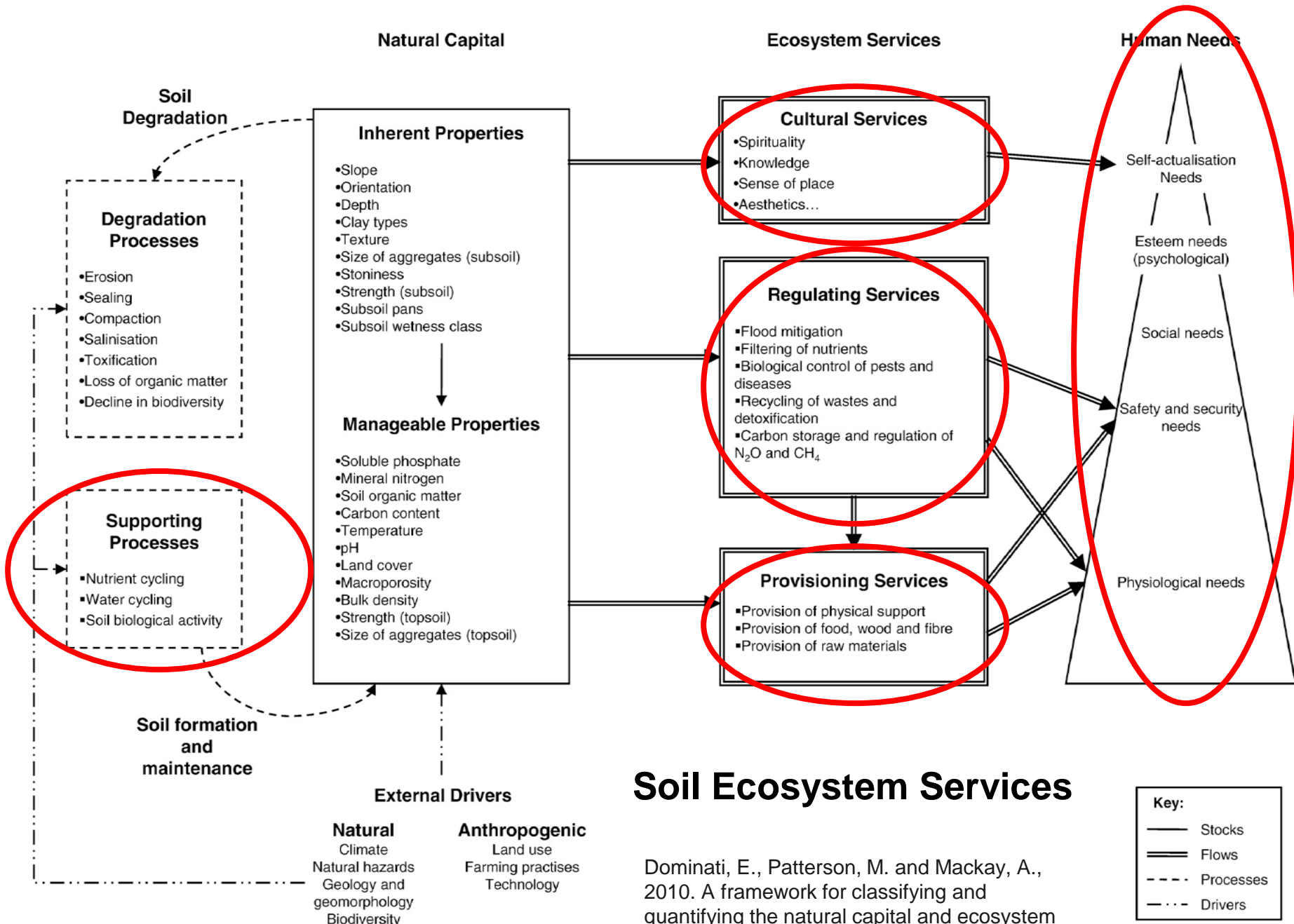
Kate Scow

Dept of Land, Air and Water Resources  
Russell Ranch Sustainable Ag Facility  
Agricultural Sustainability Institute



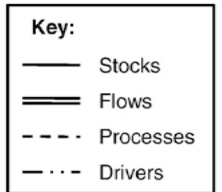
# Outline

- **Soil ecosystem services and soil health**
- **Role of soil biology in ecosystems (w/focus on agriculture)**
- **Key roles**
  - **Microbes and soil structure**
  - **Microbes and soil carbon**
  - **Microbes and nitrogen cycling**
- **Management impacts and ways to enhance soil biology**
- **Examples**
  - **Assessing Soil Health—Russell Ranch**
  - **Tillage and cover crops effects on biodiversity—Five Points**
- **Microbial inoculants**
- **Conclusions**



## Soil Ecosystem Services

Dominati, E., Patterson, M. and Mackay, A., 2010. A framework for classifying and quantifying the natural capital and ecosystem services of soils. *Ecological Economics*, 69(9), pp.1858-1868.



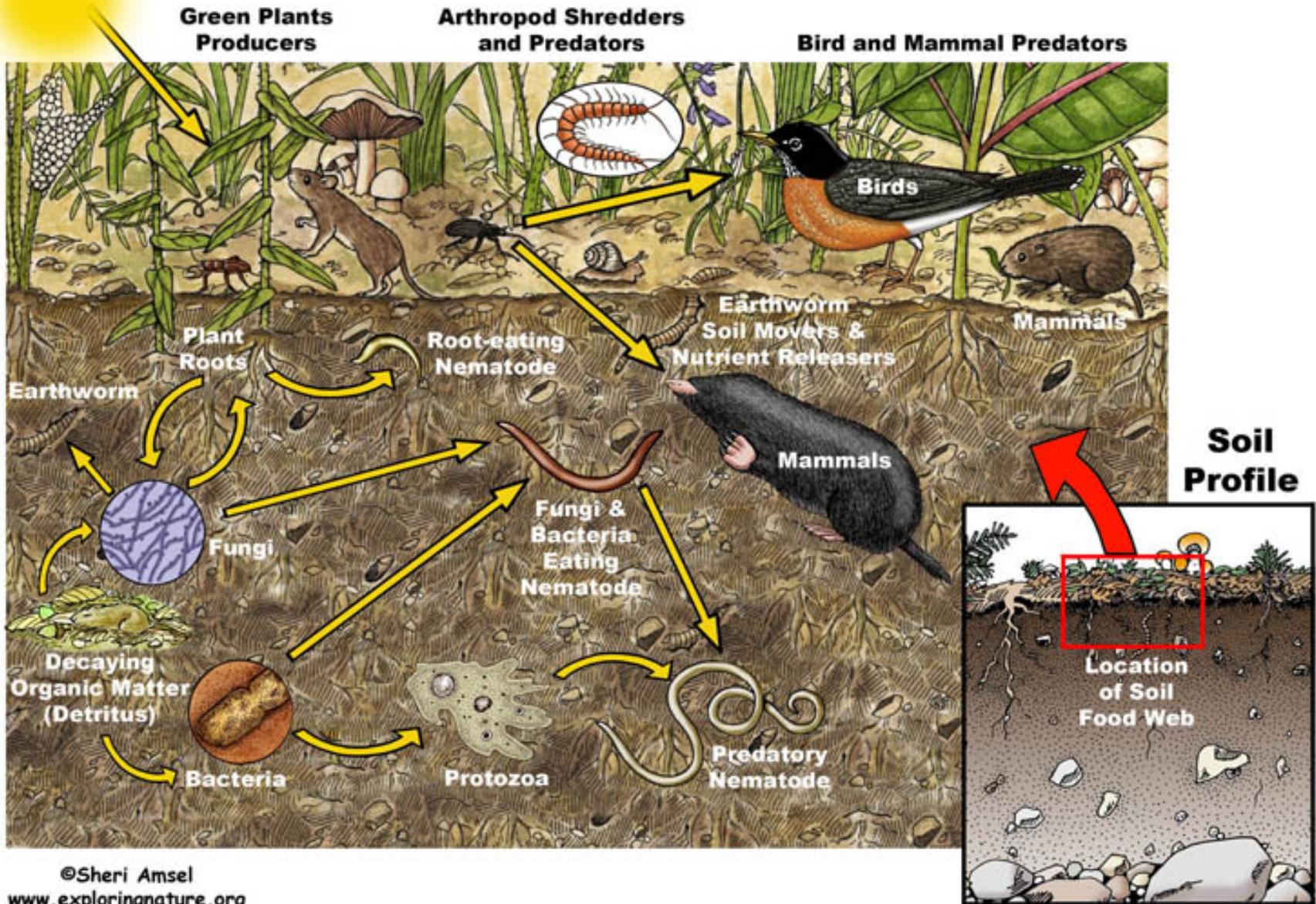
# Soil health—what is it

The continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans (and microbes!)

Healthy soil provides:

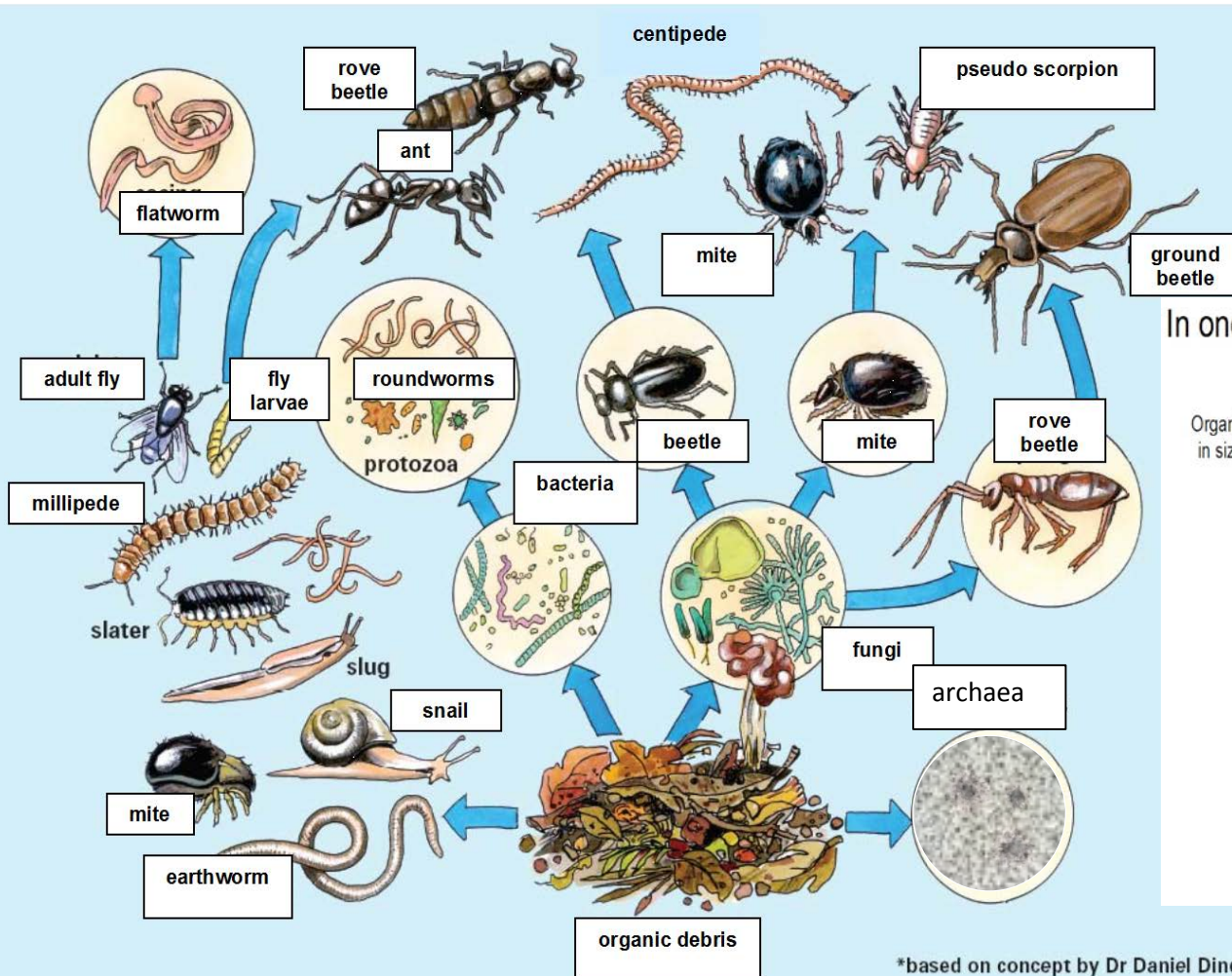
- Nutrient cycling
- Water (infiltration and availability)
- Filtering and buffering
- Physical stability and support
- Habitat for biodiversity

# Soil food web: creators and beneficiaries of soil health



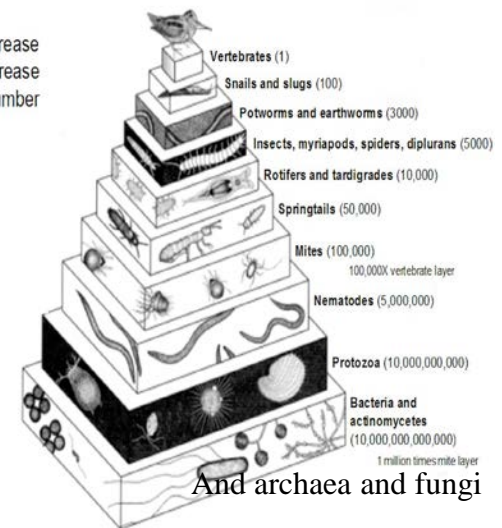
Soil is one of most diverse microbial habitats: Thousands of “species” can be detected in gram of soil. Most not yet identified nor their function(s) known.

Microbes include: **Bacteria, Archaea, and Fungi**. Of bacteria and archaea, ~1500 different taxa detected in CA cropping systems.



In one square meter of soil...

Organisms decrease in size and increase in number



And archaea and fungi

\*based on concept by Dr Daniel Dindal





Soil structure and soil biology



Soil organic matter (SOM) formation by microbes

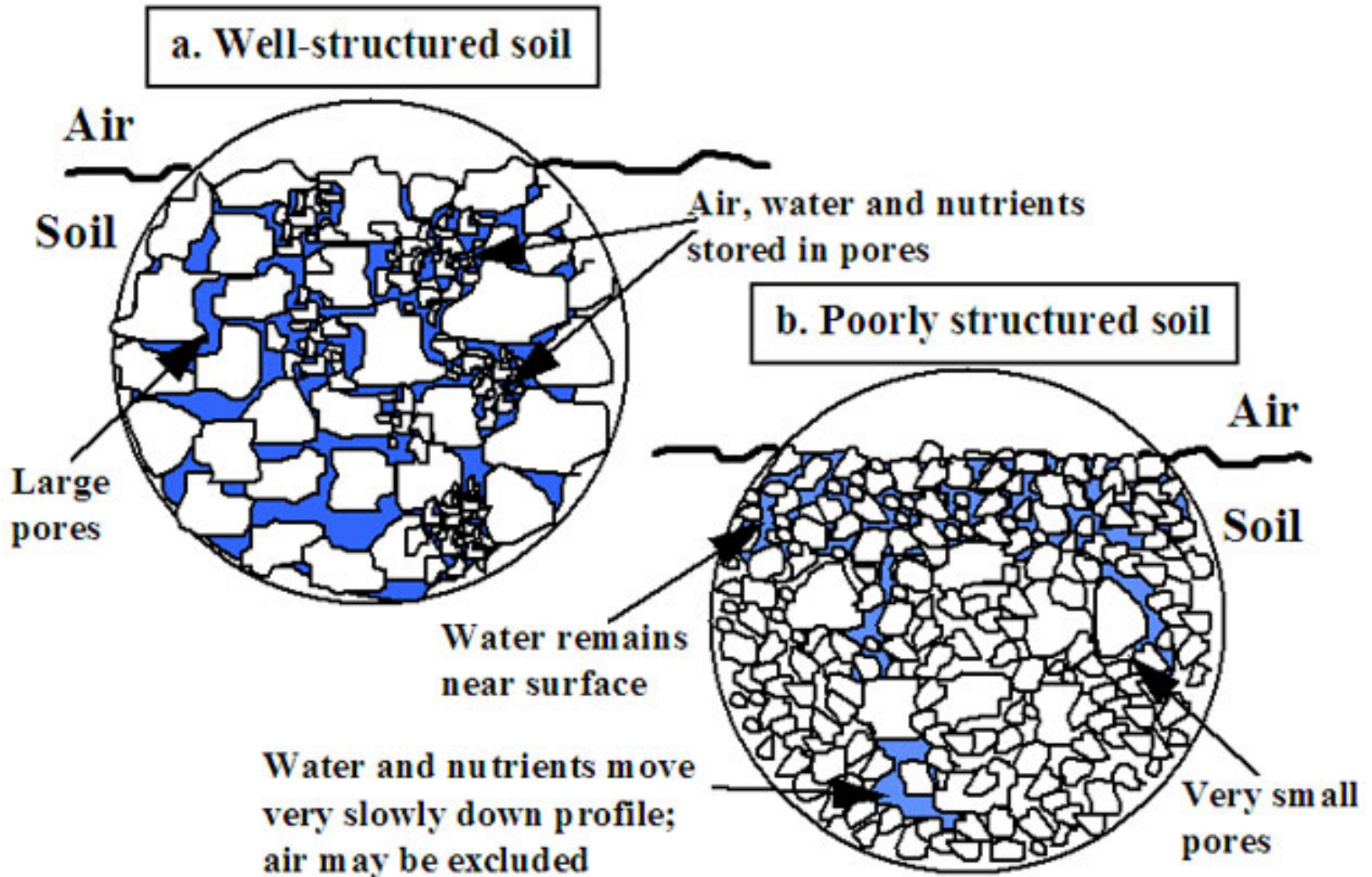


Managing the N cycle is managing microbes

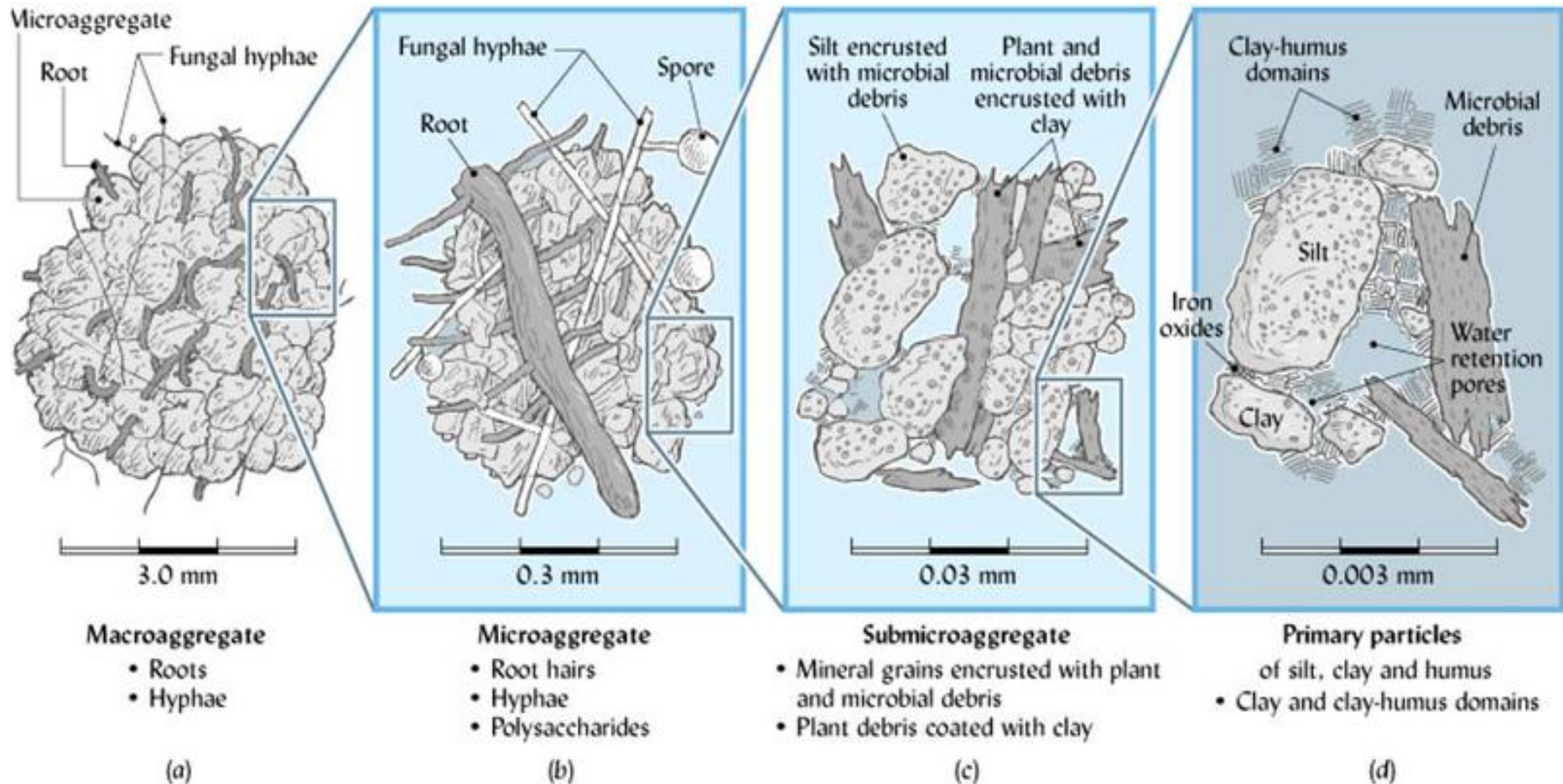


WINTER 2017

# Soil structure and soil biology



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





Organic

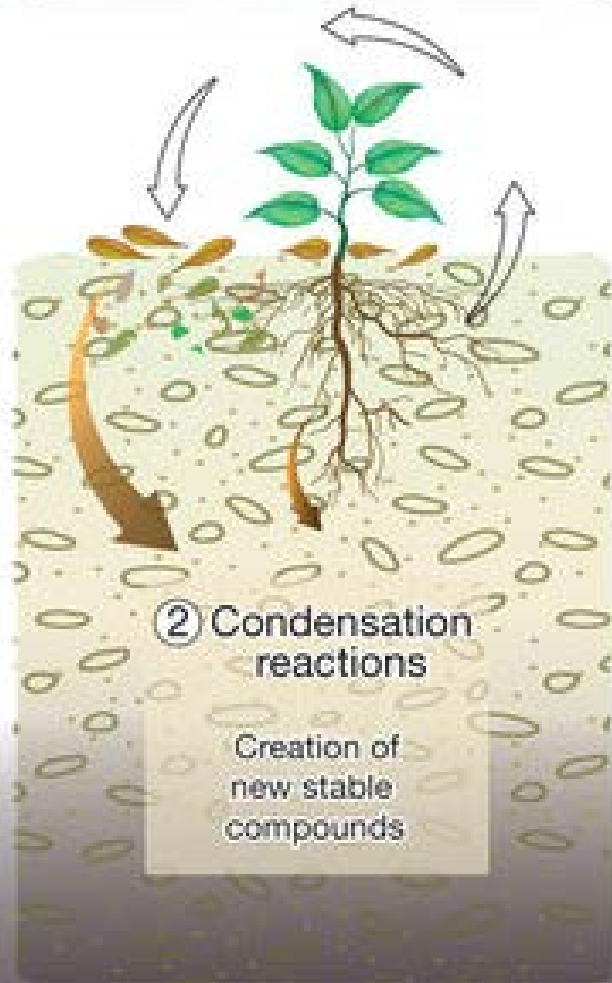


Conventional



Soil organic matter (SOM) formation

Fresh plant litter (leaves)

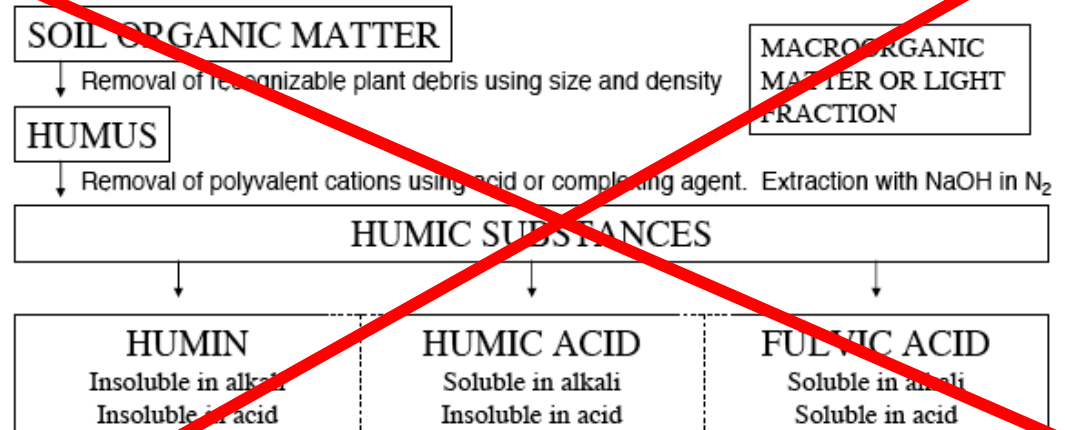


② Condensation reactions

Creation of new stable compounds

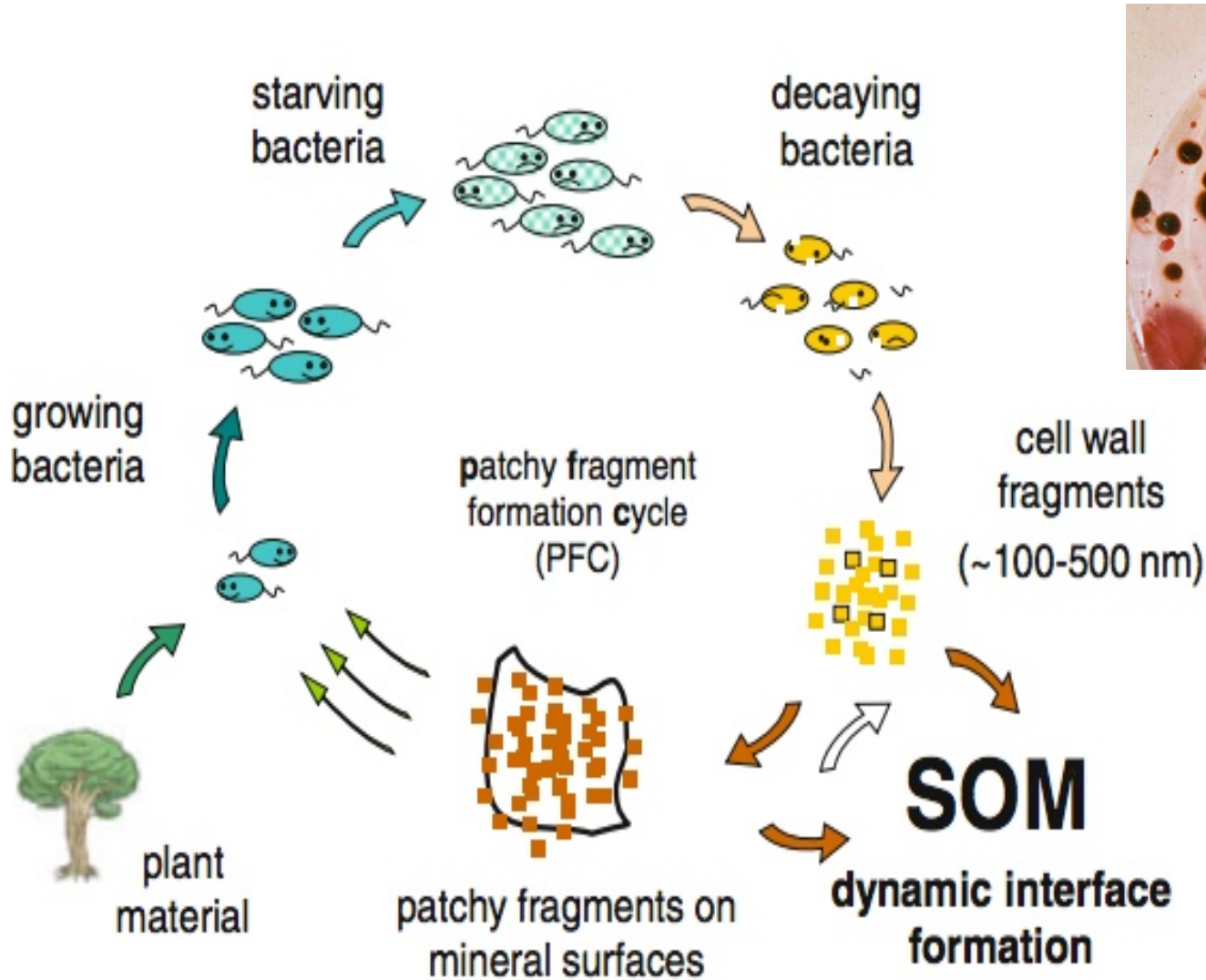
① Molecular structure determines timescale of persistence

## Historical view



# Soil organic matter formation: (STEP 1) Transformation of plant residues into microbial cells and by-products

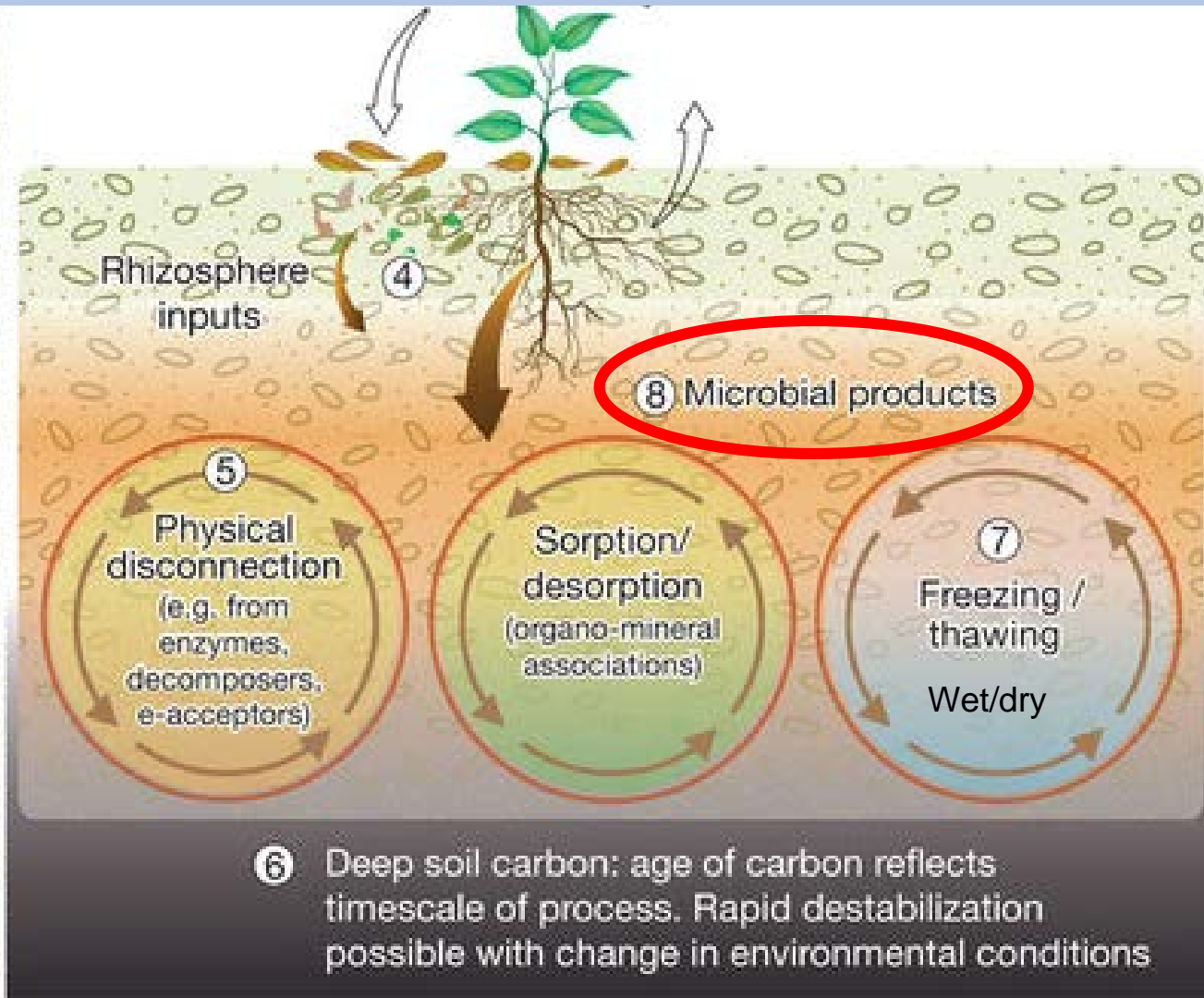
Microbes are enzymatic drivers and “feedstock” for SOM formation



*e.g., Fungal colonies have cell wall components that are precursors to SOM*

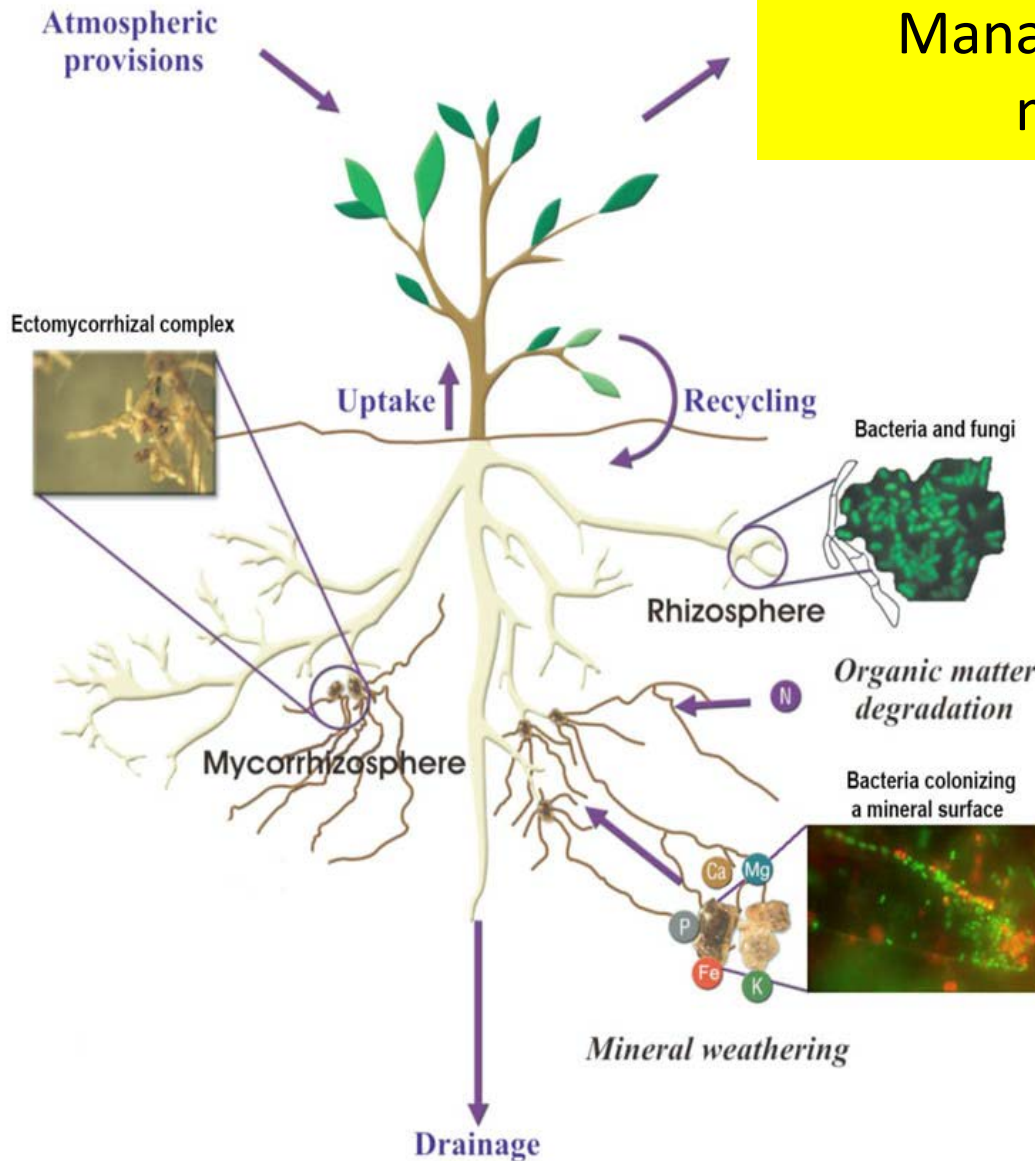
Anja Miltner et al, (2012) SOM genesis: microbial biomass as a significant source. *Biogeochemistry*, 111, 41–55.

## Soil organic matter formation:(STEP 2) stabilization of organic material in soil



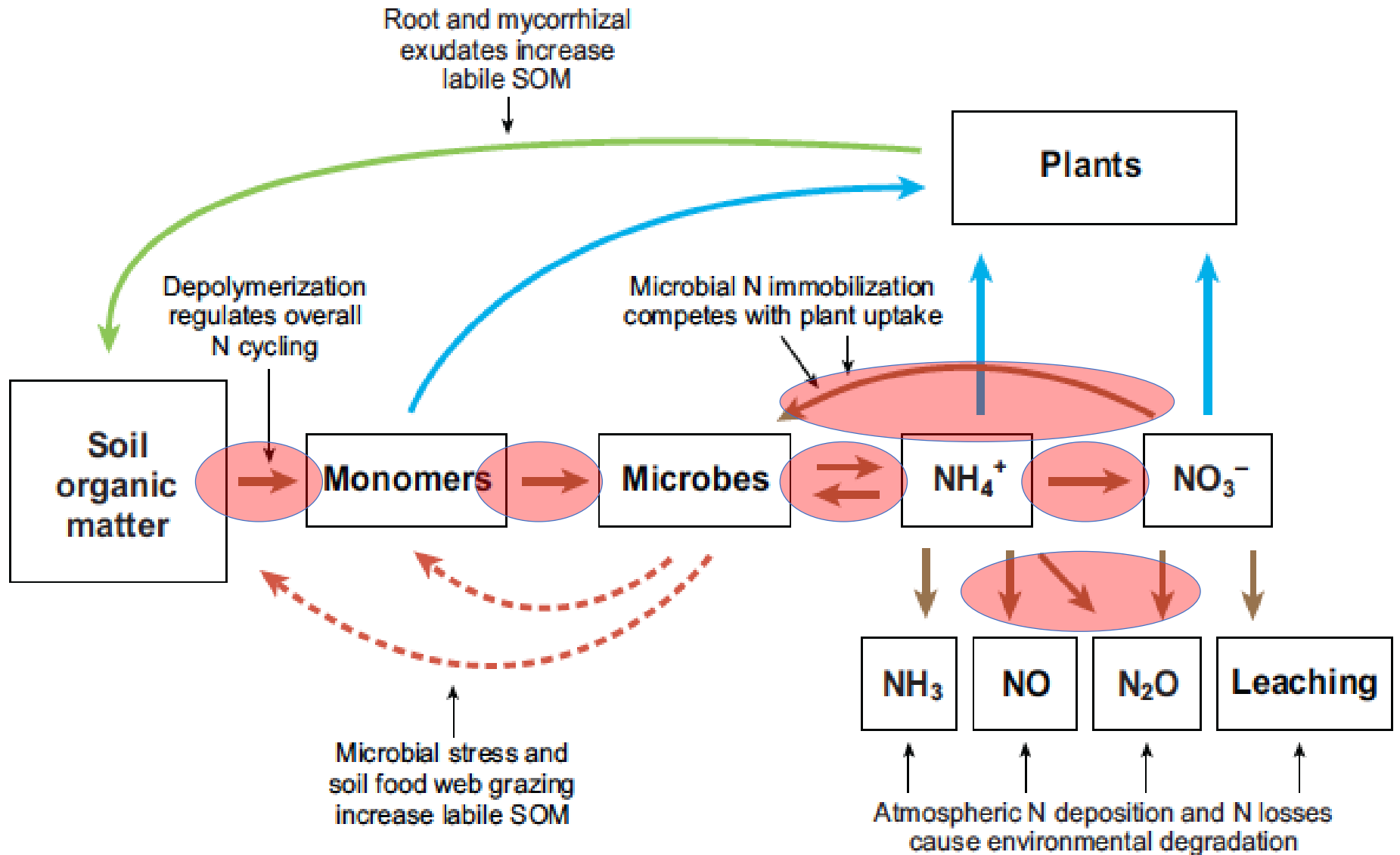
# NUTRIENT CYCLING

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 portion of nutrients, NO MATTER WHAT INITIAL FORM, goes through microbes before plant gets it.

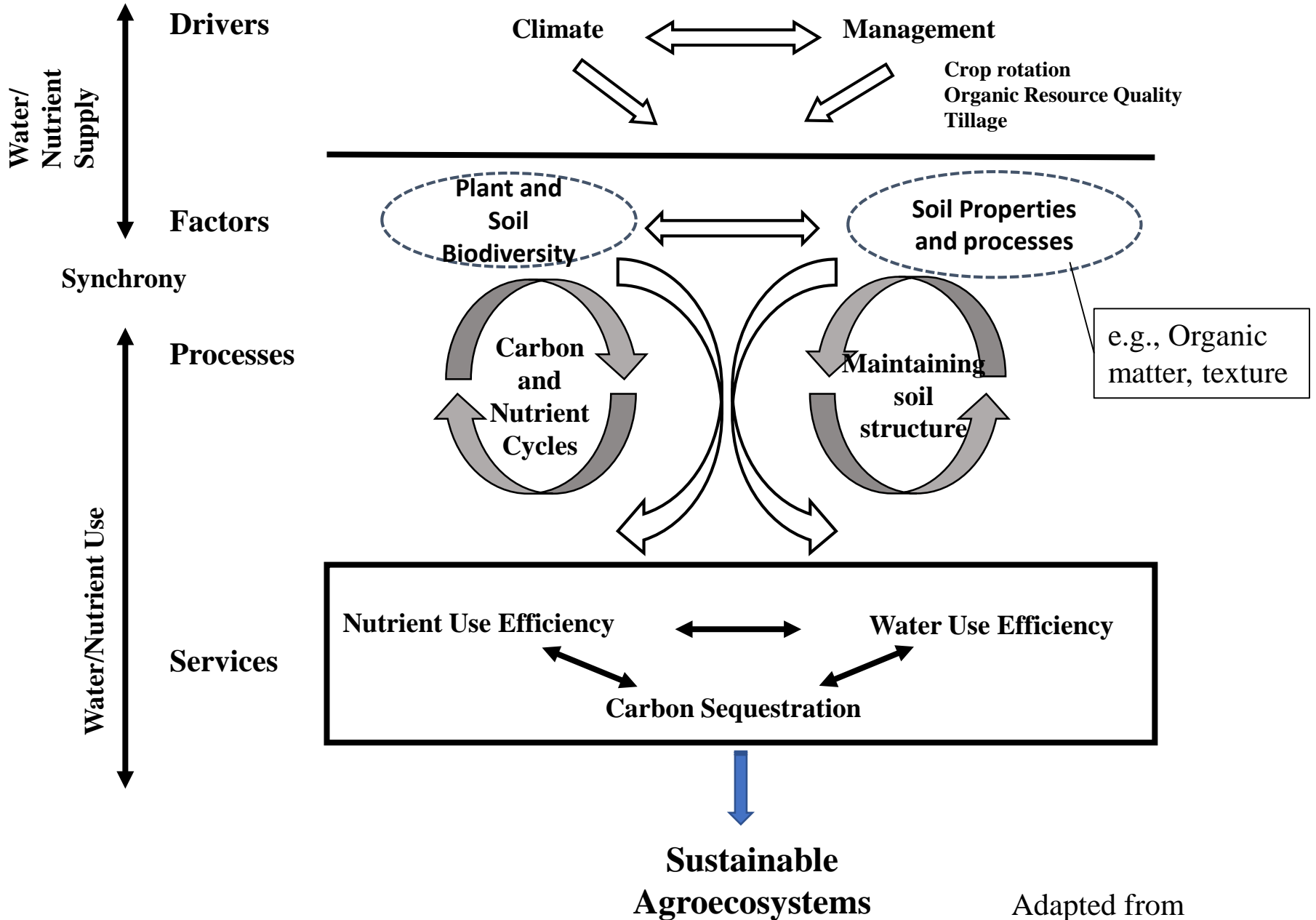
# Managing the N cycle means managing microbes



(diagram from Jackson et al., 2008 (Ann Rev Plant Biol 59))

Shaded circles show microbial processes or influences

*EVERYTHING IS CONNECTED!! Microbes tightly coupled with plants and soil*



## 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

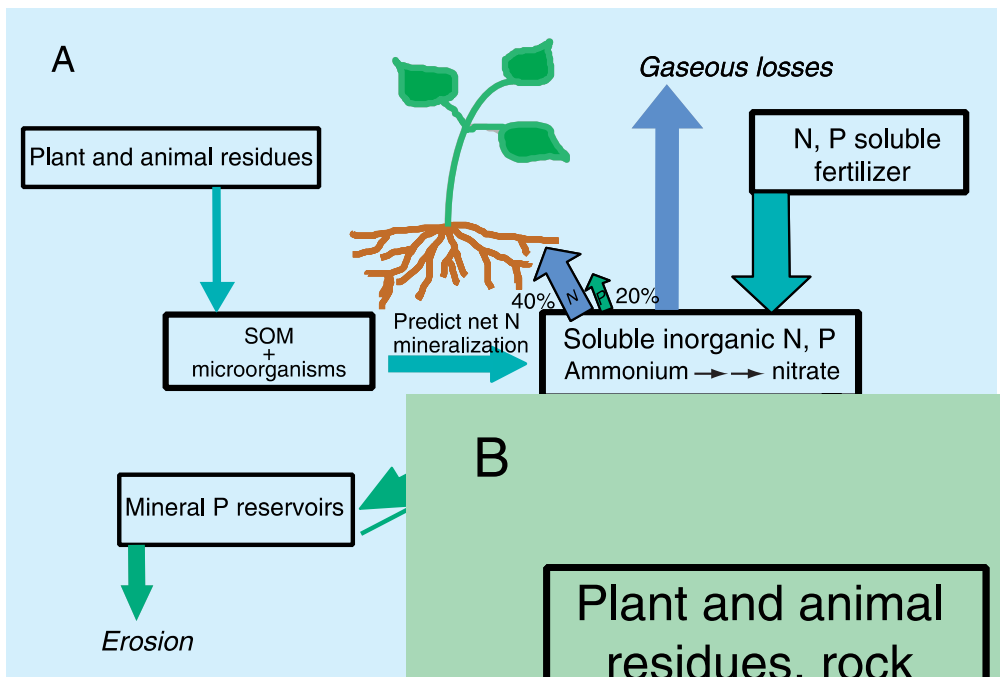
Fertilizer concentrations too high for symbiotic organisms w/plants.

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)

In general: management practices to manage microbes in soil--

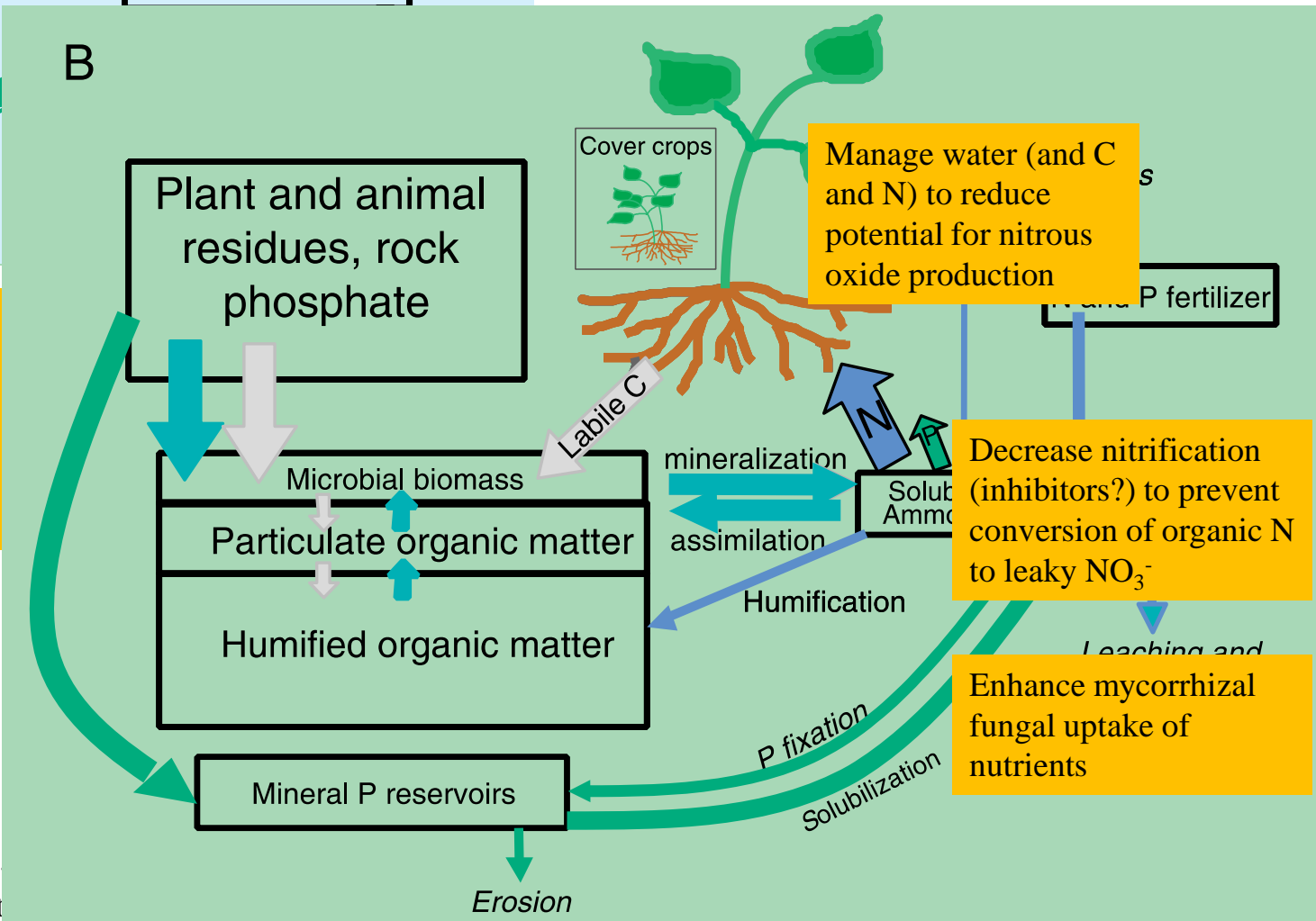
- Manipulate what they eat: C/N ratio of organics, degradability, physical availability, electron acceptors (e.g. oxygen), other nutrients, specific enzyme co-factors (?)
- Manipulate their environment: water and oxygen content, pH, “architecture”: stratified vs mixed layers in soil
- Add other soil 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?



Biological interventions: direct and indirect

Increase microbial biomass w/carbon inputs to compete with nitrifiers for  $\text{NH}_4^+$  and retain more N, release more P from rock

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



Drinkwater, Laurie E management paradigm

# Managing for soil health is same as managing soil biology

- Feed the soil
- Minimize disturbance
- Maximize diversity of plants in rotation
- Cover crops
- Keeping living roots present as much as possible
- Keep covered (plants and residues)
- Reduce chemical use
- Create favorable habitat for soil food web

## CASE STUDY

Impacts of Management on Soil Microbial Communities:  
how to measure?

Tillage and cover crops impacts on soil community  
composition and function

# CASE STUDY of Soil Microbial Analysis

## Conservation / Standard Tillage Comparison Study

Tomato-cotton rotation--14 years



Till + cover crop

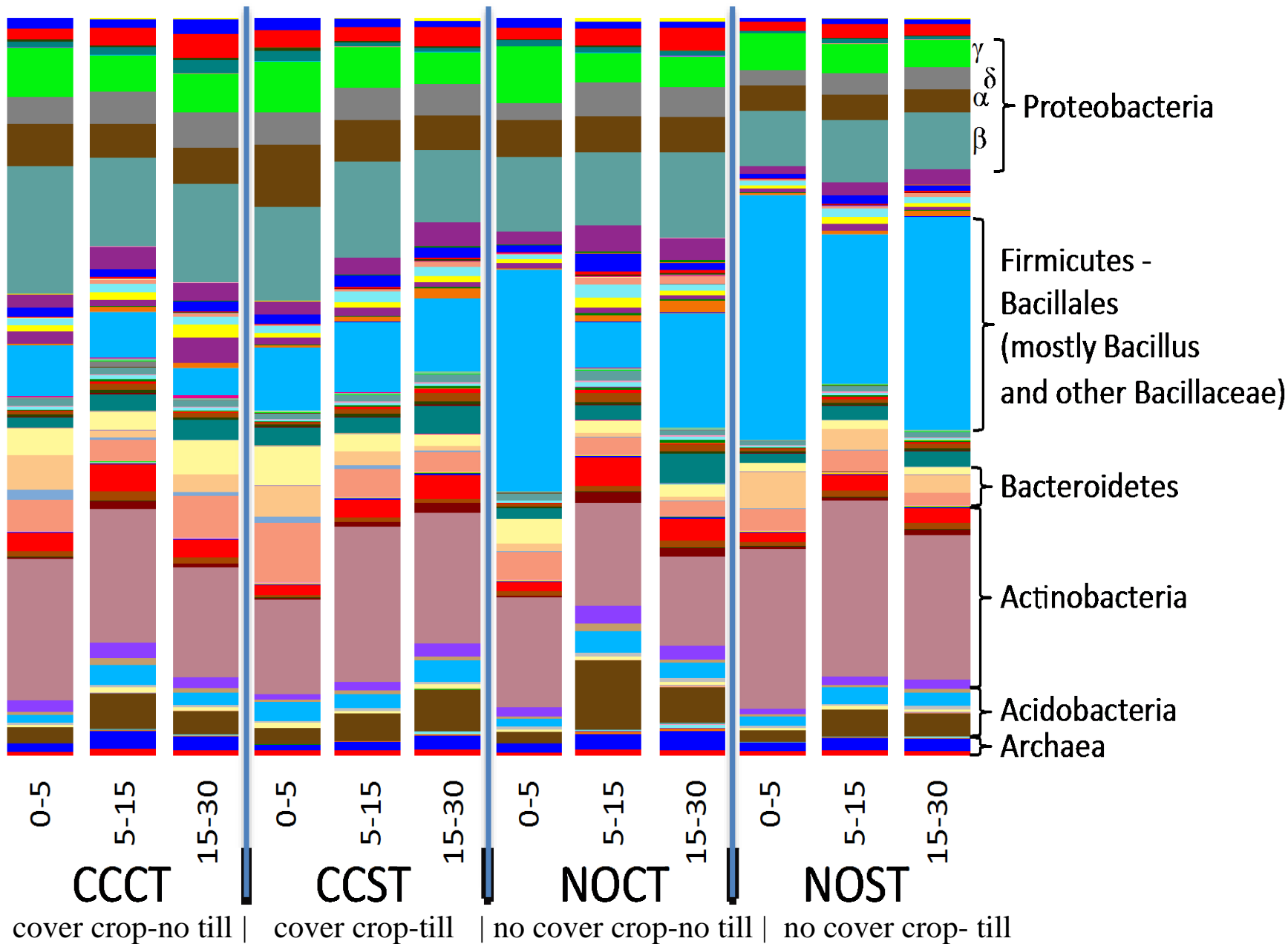
No till + cover crop

Till no cover crop

No till no cover crop

NRI CT Project Field Fall 2007  
Jeff Mitchell

# Microbial Community Composition (Illumina sequencing)



# Alternative: Functional Trait Assessment

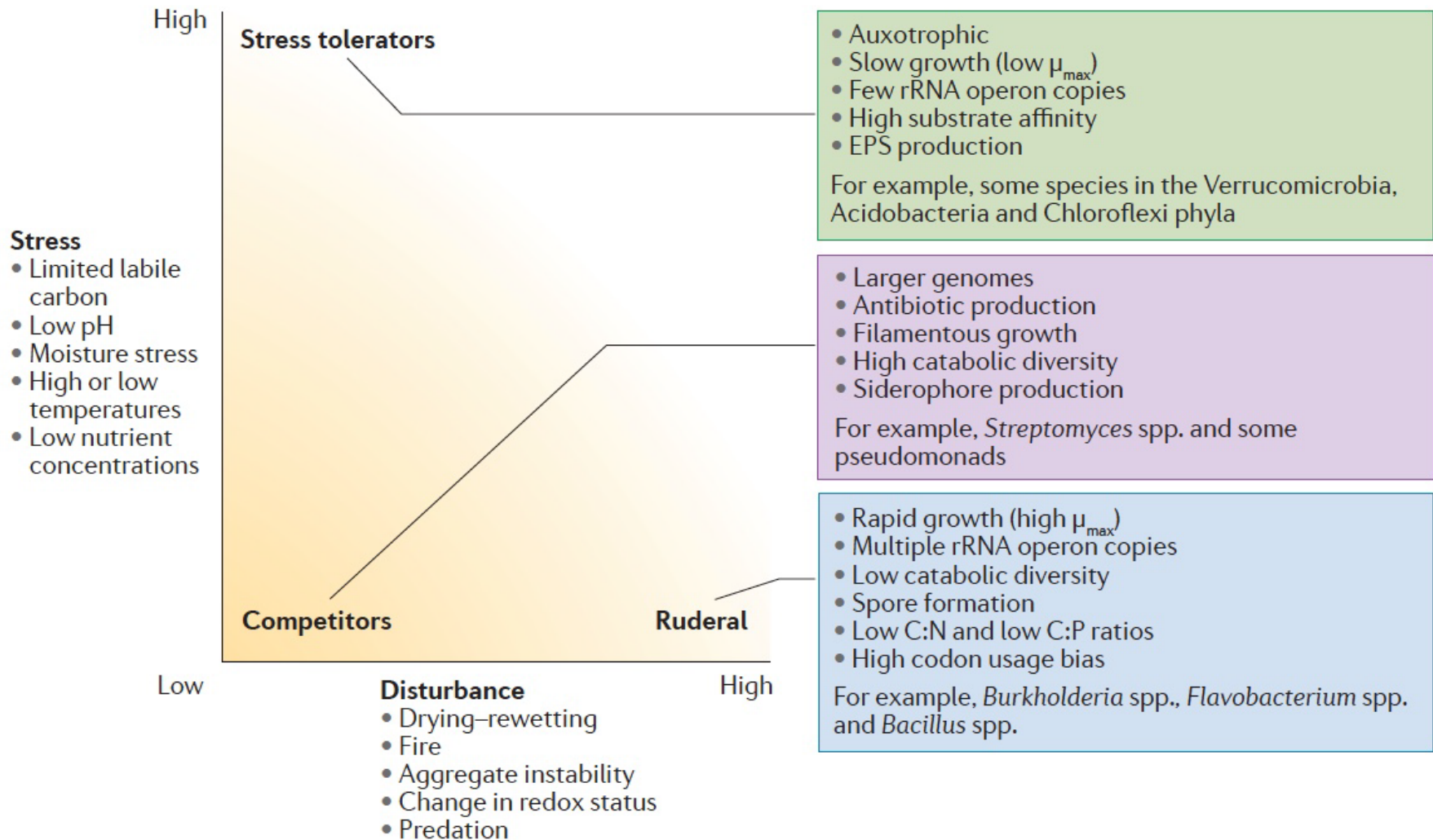
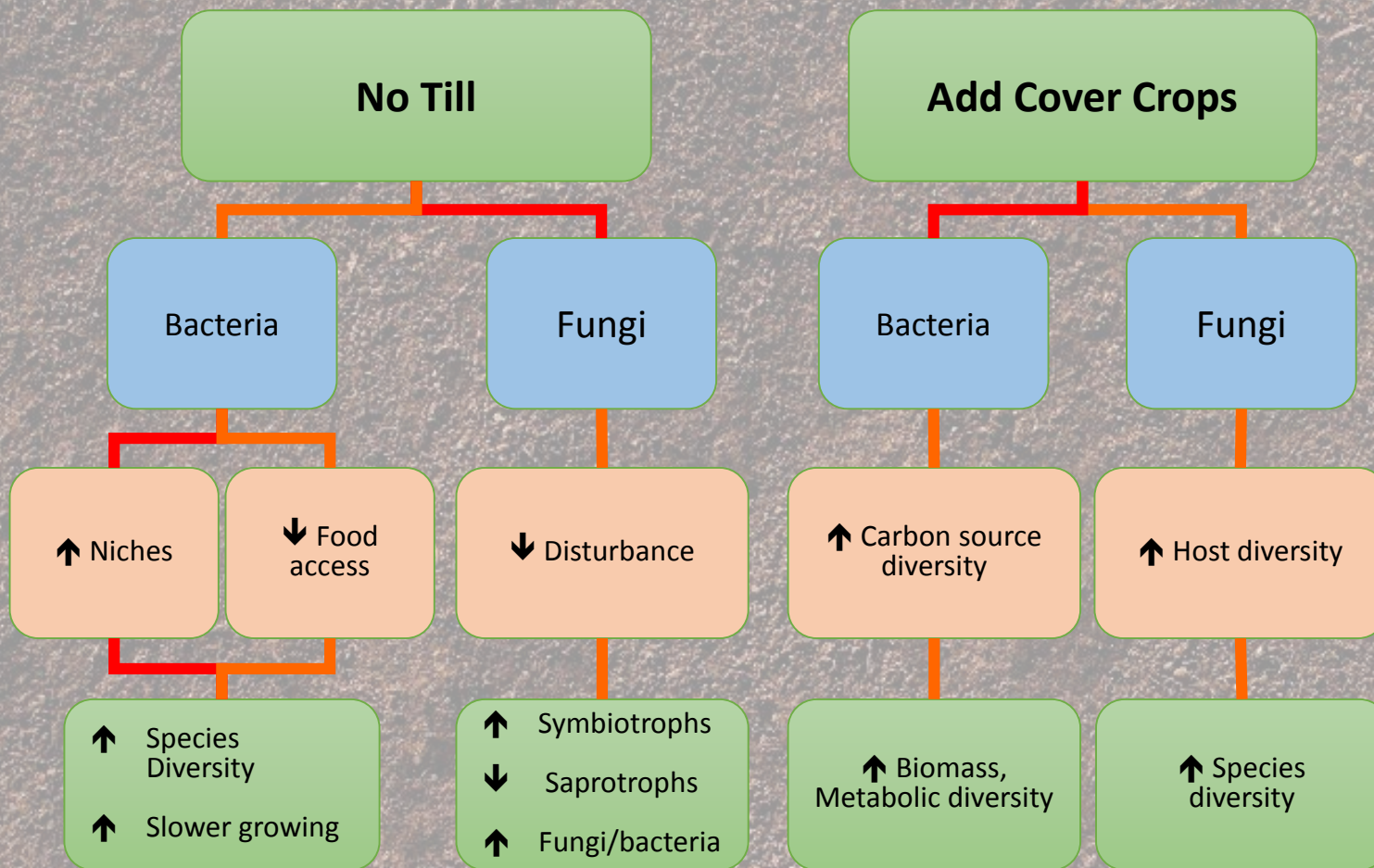
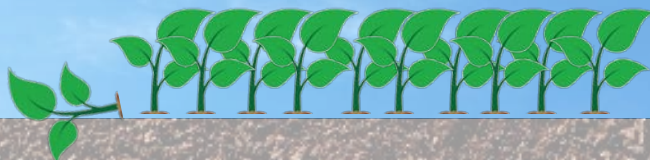


Figure 6 | Grime's competitor–stress tolerator–ruderal framework applied to soil bacterial heterotrophs

# Functional Trait Assessment of Tillage/Cover Crop experiment

*Cover crops increase soil carbon and plant diversity*

*Reduced tillage preserves soil structure, decreases mixing of soil with residue, nutrients released more slowly*



## Summary of analyses

Functional trait rather than phylogenetic analysis provides insight on interrelationships between habitat and microbial communities

with feedback for soil health

Still don't know who built the soil structure and stored the carbon

would this info be helpful?

how would we use that information?

Scale of investigation (physical is this case) may miss some insights

how scale down in measurement?

then scale back up in meaning?

## CASE STUDY

Impacts of Management on Soil Microbial Communities:  
how to measure?

Soil Health Assessment Indices

# CORNELL SOIL HEALTH ASSESSMENT

Measured Soil Textural Class: **silt loam**

Sand: **2%** - Silt: **83%** - Clay: **15%**

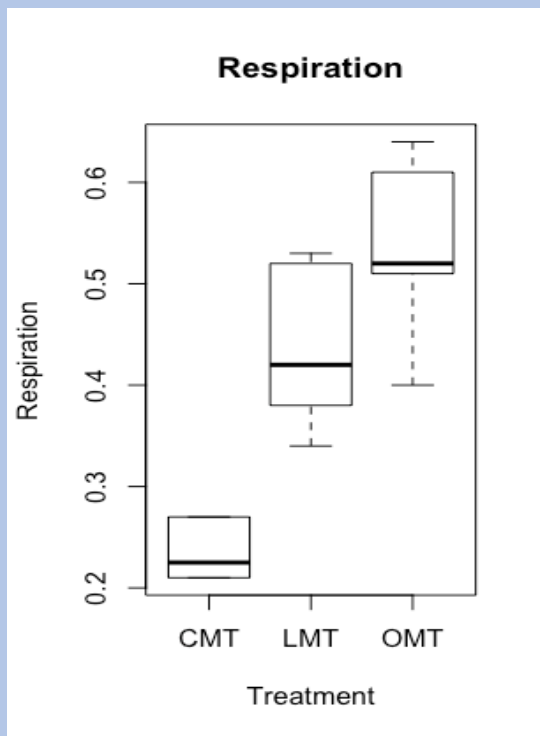
Group	Indicator	Value	Rating	Constraints
<i>physical</i>	Available Water Capacity	<b>0.14</b>	<b>37</b>	
<i>physical</i>	Surface Hardness	<b>260</b>	<b>12</b>	<b>Rooting, Water Transmission</b>
<i>physical</i>	Subsurface Hardness	<b>340</b>	<b>35</b>	
<i>physical</i>	Aggregate Stability	<b>15.7</b>	<b>19</b>	<b>Aeration, Infiltration, Rooting, Crusting, Sealing, Erosion, Runoff</b>
<i>biological</i>	Organic Matter	<b>2.5</b>	<b>28</b>	
<i>biological</i>	ACE Soil Protein Index	<b>5.1</b>	<b>25</b>	
<i>biological</i>	Soil Respiration	<b>0.5</b>	<b>40</b>	
<i>biological</i>	Active Carbon	<b>288</b>	<b>12</b>	<b>Energy Source for Soil Biota</b>
<i>chemical</i>	Soil pH	<b>6.5</b>	<b>100</b>	
<i>chemical</i>	Extractable Phosphorus	<b>20.0</b>	<b>100</b>	
<i>chemical</i>	Extractable Potassium	<b>150.6</b>	<b>100</b>	
<i>chemical</i>	Minor Elements Mg: 131.0 / Fe: 1.2 / Mn: 12.9 / Zn: 0.3		<b>100</b>	

Overall Quality Score: **51 / Medium**

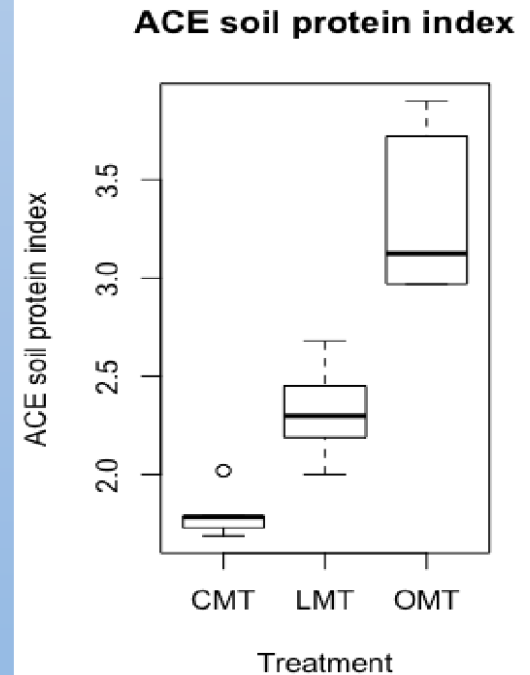
# Russell Ranch Sustainable Agriculture Facility—Century Experiment

*23 out of 100 years, tomato-corn rotation*

tomato



Organic Matter



Comparing conventional (**CMT**); hybrid(conv + cover crop) (**LMT**); organic (**OMT**)

## Summary: Soil Health Indicators--*microbial*

What are we completely missing that is essential?

- microbial biomass?
- diversity?—functional, phylogenetic?
- the taxa involved in what we already value for soil health?

Microbes are often dynamic and reactive; not as stable as some other indicators.

- responses to perturbations may be most revealing about a soil's health—RESILIENCE!!! how do we capture this?

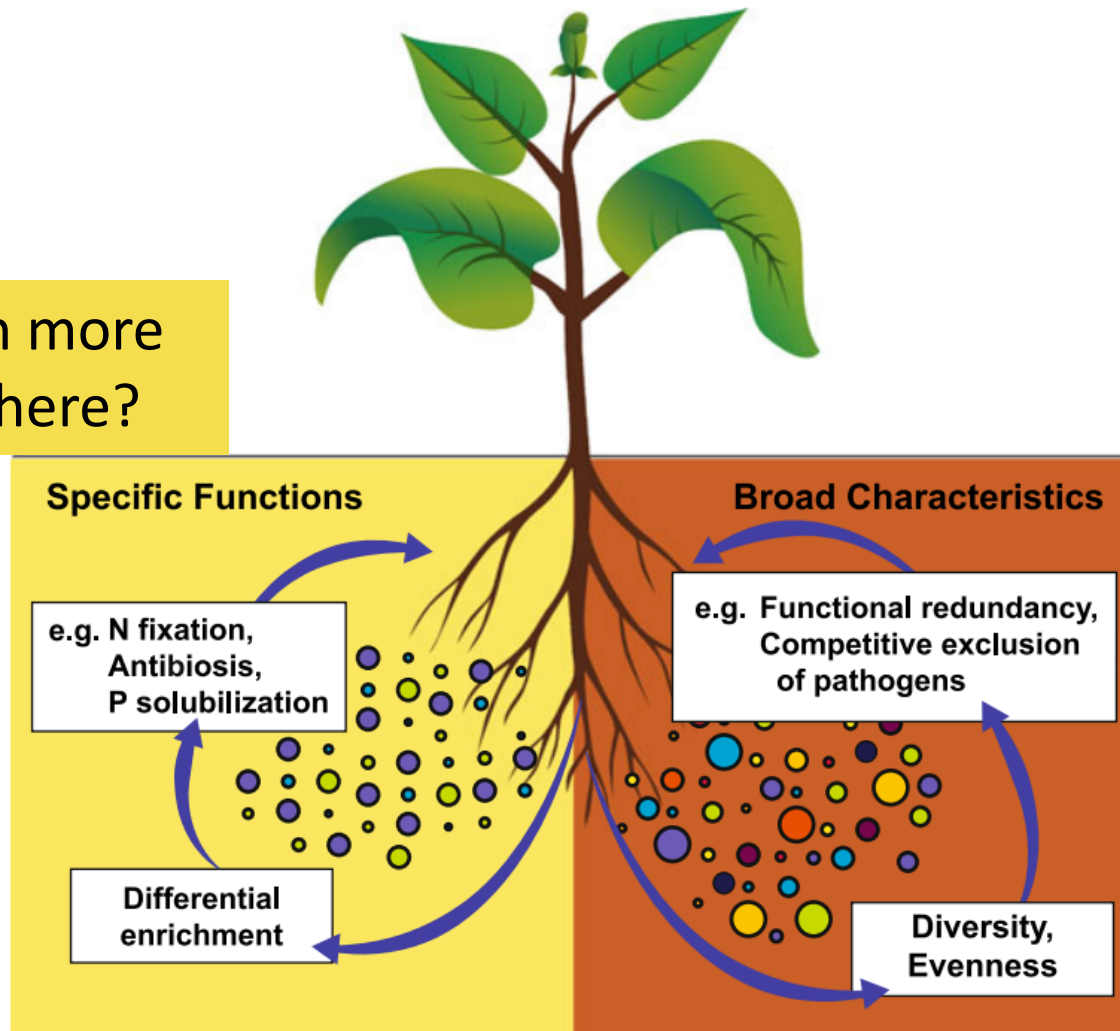
How do we defend extra cost, work, complexity?

What can be done by farmers/how important is that?

- how good are the proxies (e.g., fauna)?

# What about microbial inoculants??

Inoculation more promising here?

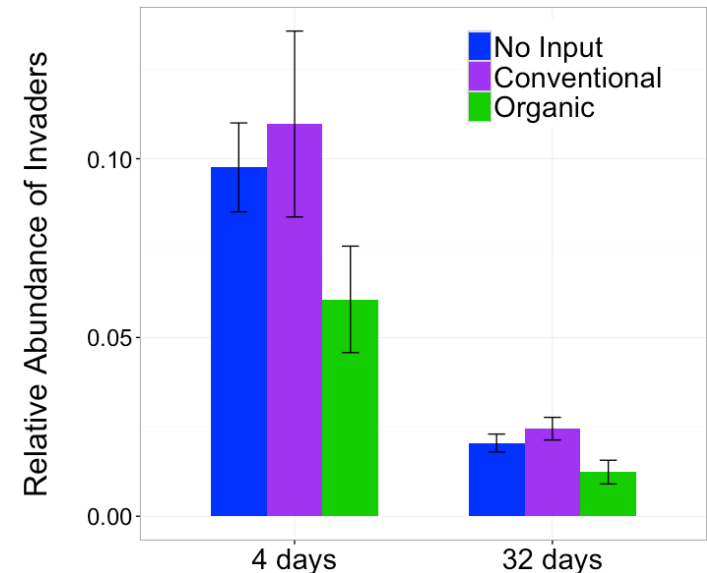
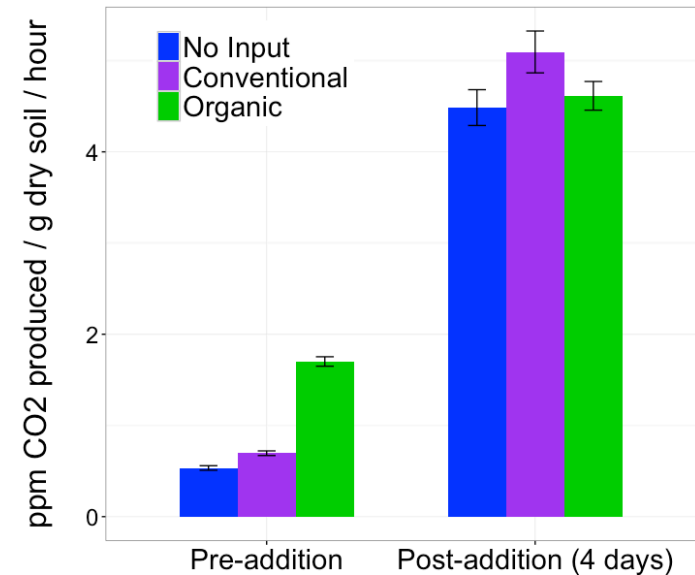


Bakker, M.G., Manter, D.K., Sheflin, A.M., Weir, T.L. and Vivanco, J.M., 2012. Harnessing the rhizosphere microbiome through plant breeding and agricultural management. *Plant and Soil*, 360(1-2), pp.1-13.

# Microbial effects of adding compost to agricultural soils with different histories at Russell Ranch: *no input vs conventional vs organic*

- C-depleted soils are not limited in their ability to rapidly benefit from compost as a substrate
- **Compost-derived organisms establish** initially (4 d) but then dwindle away. Organic soil least colonized by compost organisms.

Kelly Gravuer



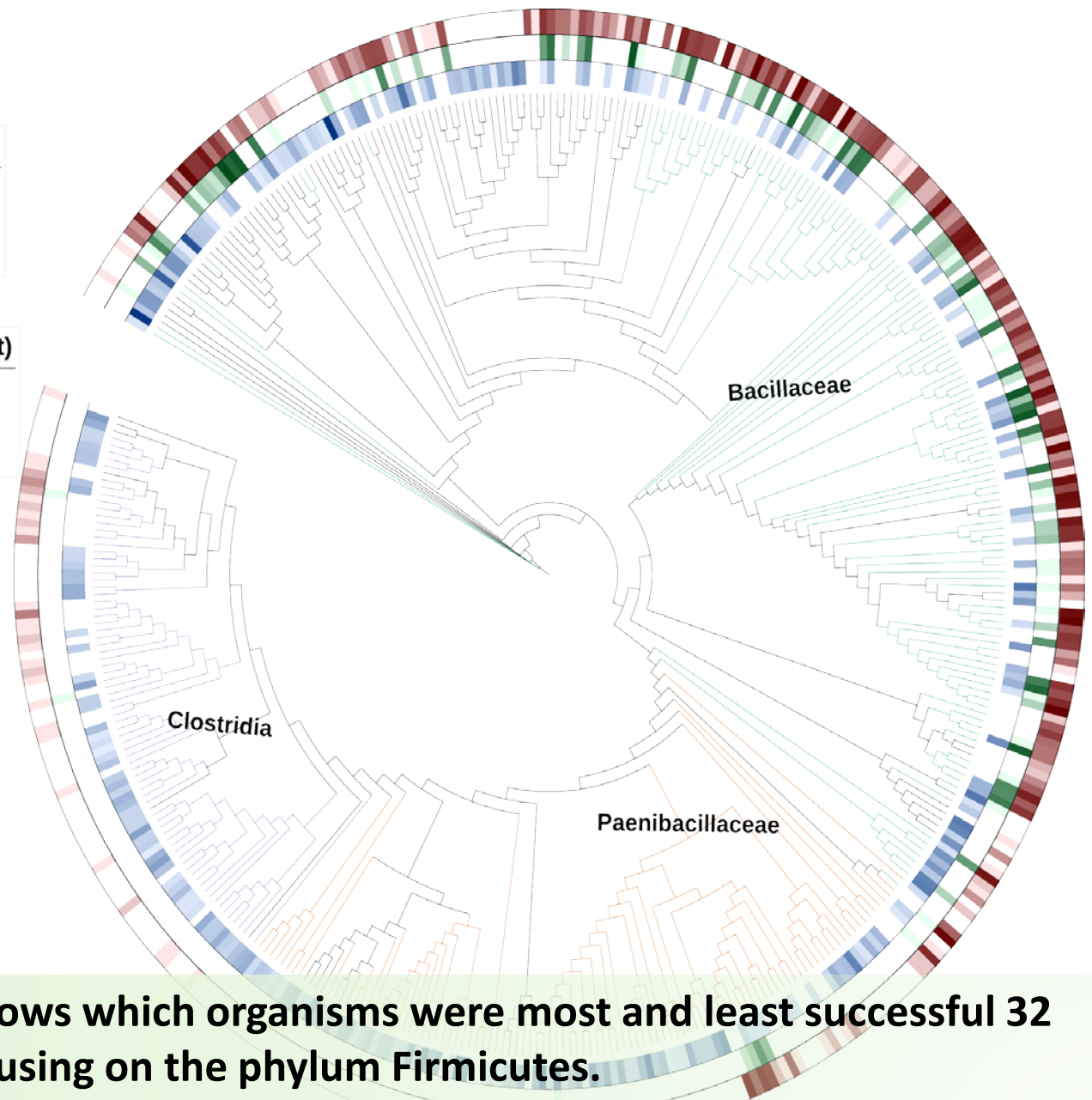
**Residents log(rel abundance)**



**Successes (log) (32 days post)**



**Failures (log) (32 days post)**

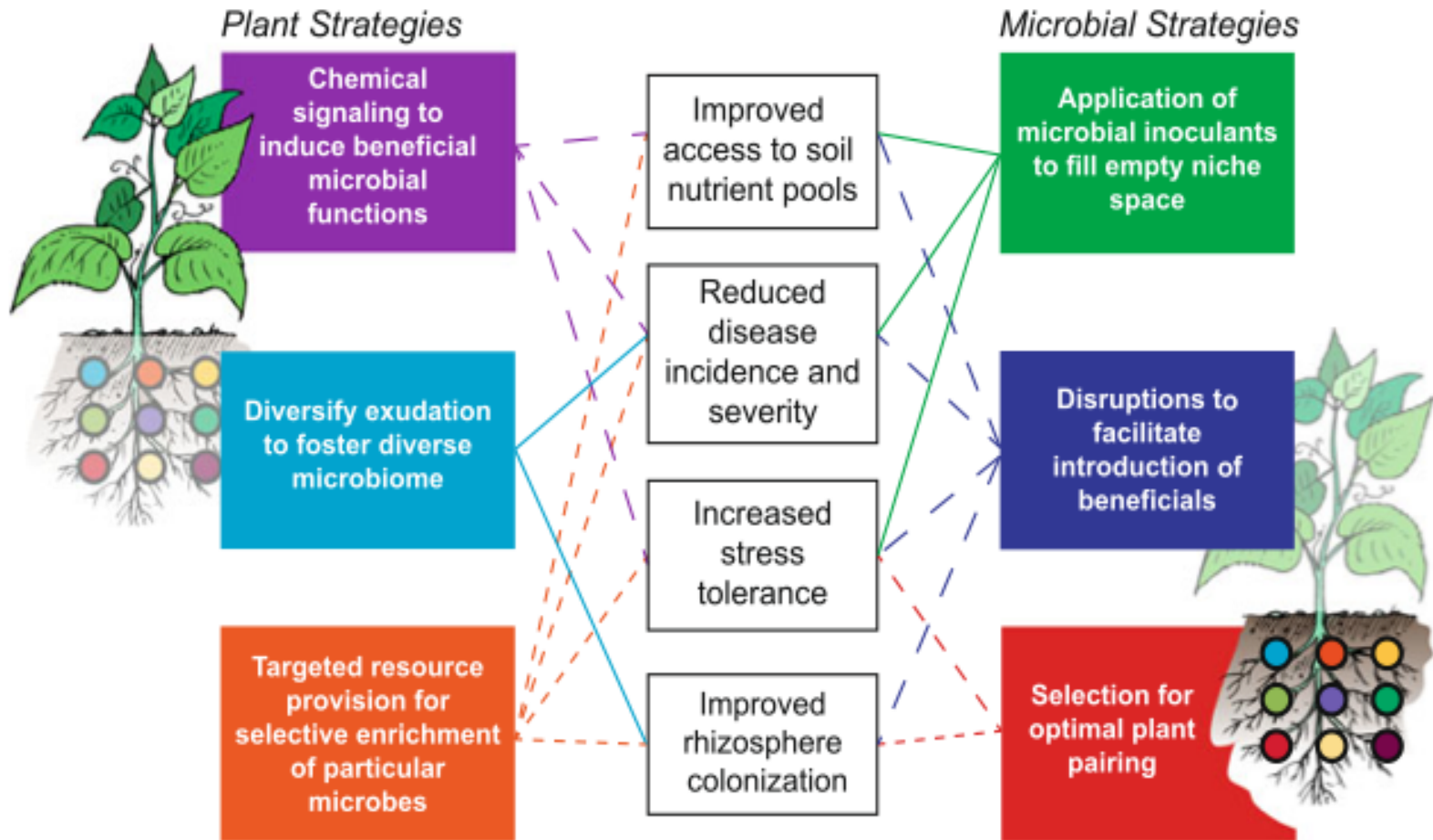


**Phylogenetic “map” shows which organisms were most and least successful 32 days post-invasion, focusing on the phylum Firmicutes.**

**Actinobacteria, Gammaproteobacteria, Alphaproteobacteria were most successful invaders**

# Strategies to increase success of inoculation—in consort with plant

## Reducing chemical inputs and increasing yields



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.

## *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?

# 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

## Scott Park's pearls

Do not disturb your soil biology.....get out of their way: feed them, be respectful of their “house” —and don't do too much-don't plant too densely, don't put in too much water, or too much fertilizer

You need to smell and listen to the sound of the soil, taste the soil too, get all your senses involved.

You have to make a long term investment and it will take time. But NOT managing the soil leads to problems downstream that will require greater and greater inputs

“Take care of the soil and everything else will follow”



Parting thought: 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?

Kate Scow

[kmscow@ucdavis.edu](mailto:kmscow@ucdavis.edu)

*Thanks: College of Ag and Environmental Sciences at UC Davis, USDA AFRI, UC ANR Catalyst, USDA NRCS, Ag Sustainability Institute, Scott Park, Israel Herrera and RR staff, Scow lab*



**Figure 1. Dripline installed underground.**