United States Department of Agriculture

Soil Biology
Links to Soil Health & Ecosystem Functionality

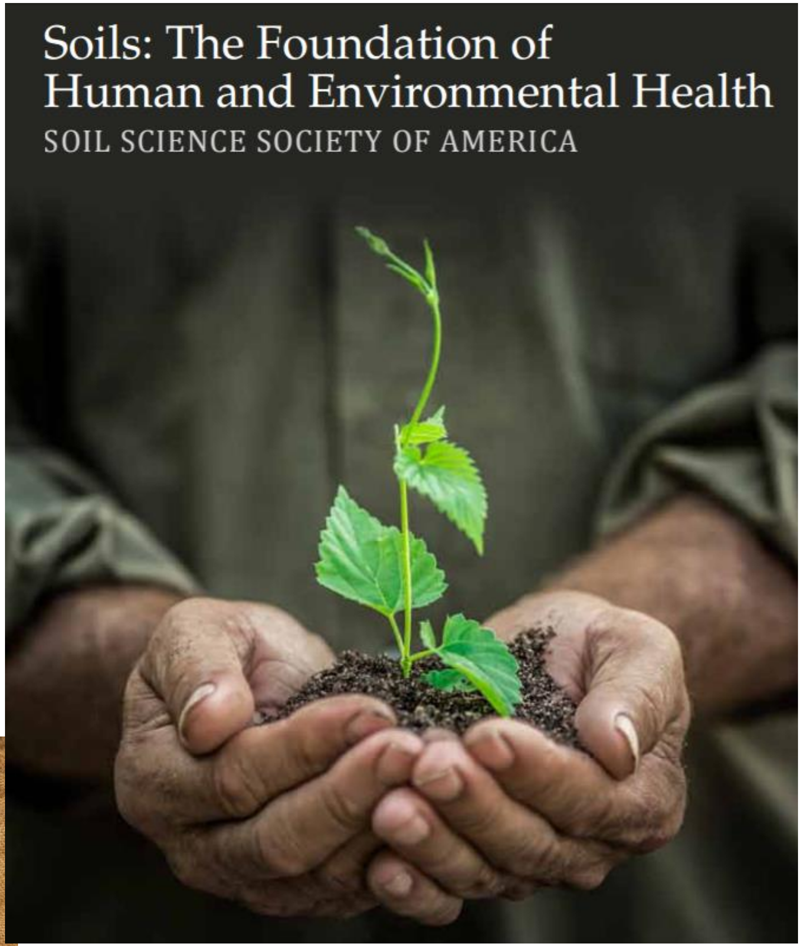
Jennifer Moore Kucera, Ph.D.
West Regional Soil Health Team Leader
NRCS Soil Health Division

Dec 8, 2017
National Cover Crop Conference, Indianapolis, IN

United States Department of Agriculture

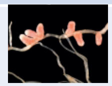
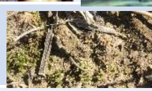
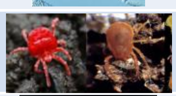
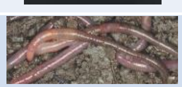
Soil Health

The continued capacity of a soil to function as a vital, living ecosystem that sustains plants, animals, and humans."



United States Department of Agriculture

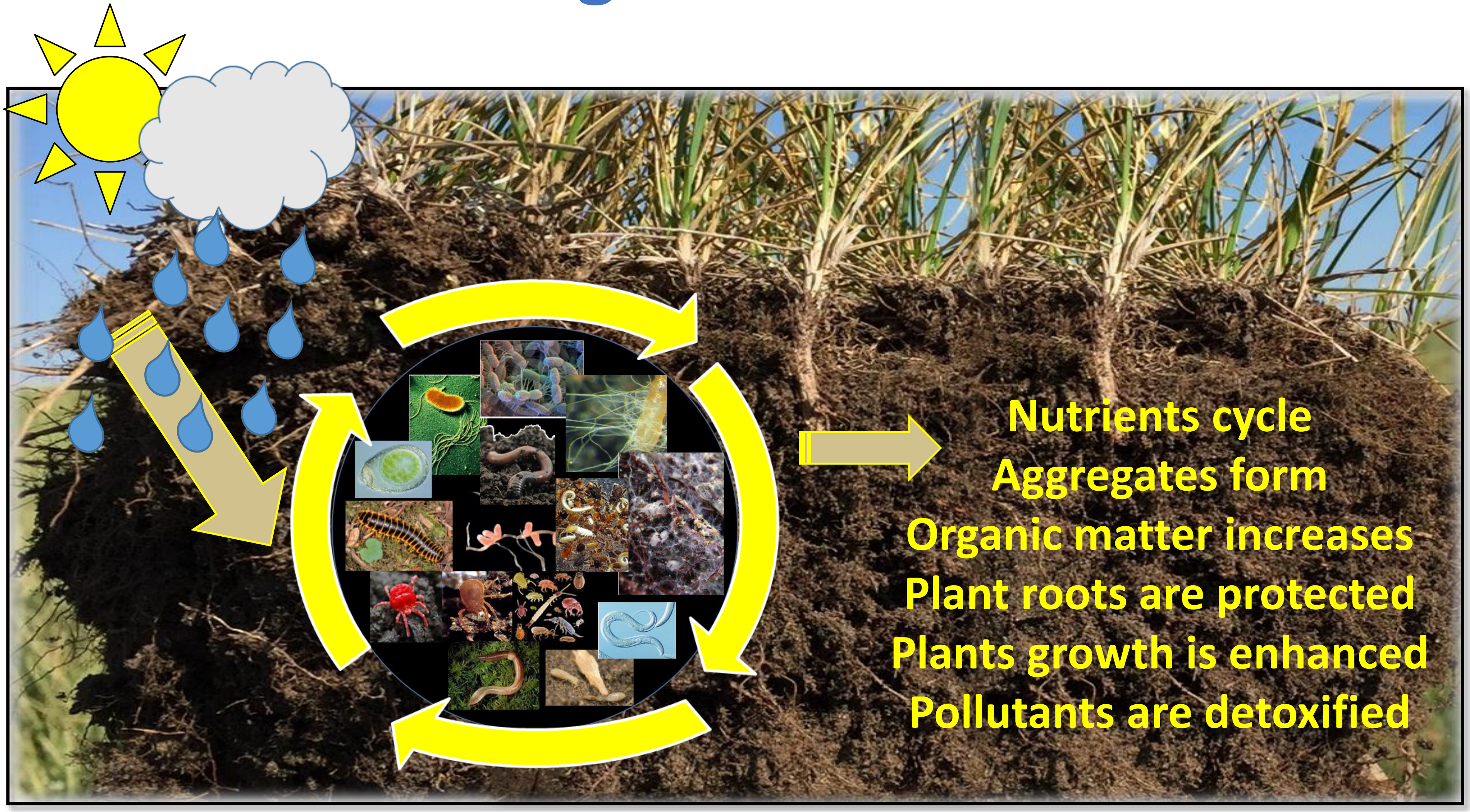
Life Belowground Supports Life Aboveground

Organisms	Number (per 10 ft^2)
Microorganisms	
Bacteria & Archaea  	100 trillion – 1 quadrillion
Actinobacteria 	1-10 trillion
Fungi  	1-10 million per 3 ft
Algae 	1-10 billion
Fauna	
Protists 	10 million – 100 billion
Nematodes 	100,000 – 10 million
Mites 	100 - 1 million
Collembola 	100 - 1 million
Earthworms 	10 - 100
Other fauna 	100-10,000

1 acre may house 10,000 - 30,000 lb of belowground biomass! Equivalent to 20-30 cows!

Sources: Weil & Brady, The Nature and Properties of Soil, 15e; Lindo, Kozlowski & Robinson (eds), Know Soil Know Life; Orgiazzi , Bardgett, Barrios et al. 2016. Global Soil Biodiversity Atlas

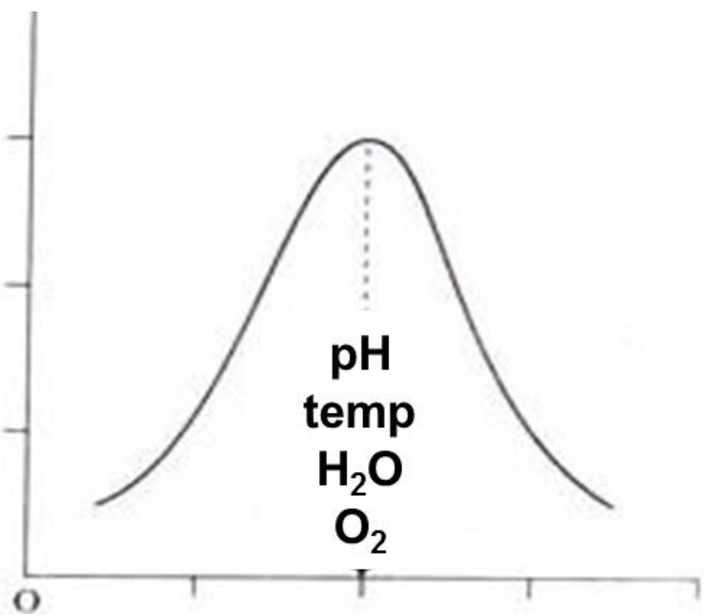
It Takes a Village To Make Soil Function



Soil photo source and slide design: Jennifer Moore-Kucera, USDA-NRCS-SHD; Soil organisms images from Orgiazzi , Bardgett, Barrios et al. 2016. Global Soil Biodiversity Atlas. Publications Office of the European Union.

Goldilocks, Sleeping Beauty, & Prince Charming

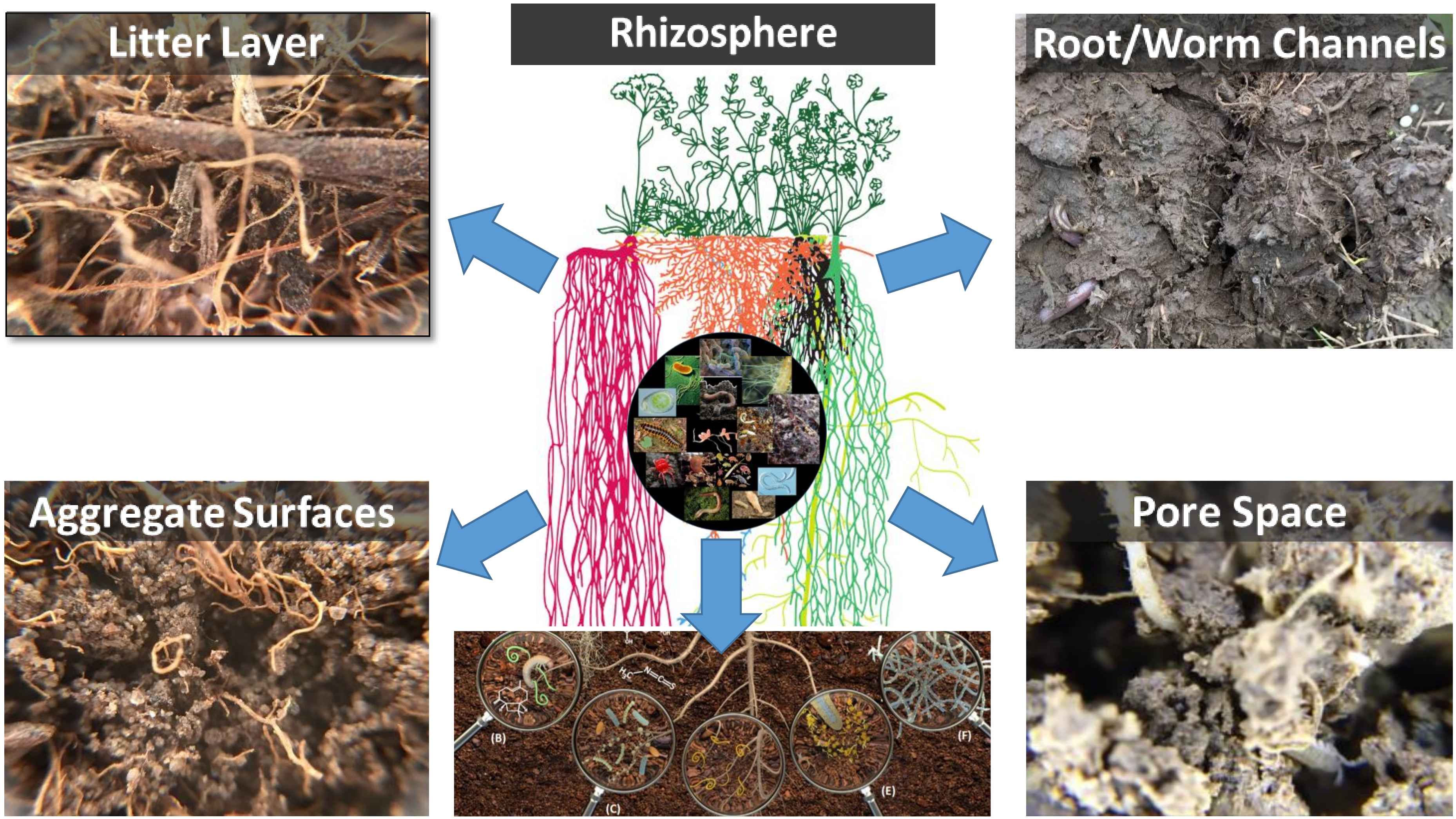
Carbon (food) is most limiting



- Most soil microbes are in a ‘resting’ phase
- Other organisms can help awaken soil microbes

- Biological hotspots exist…how to maximize through management?

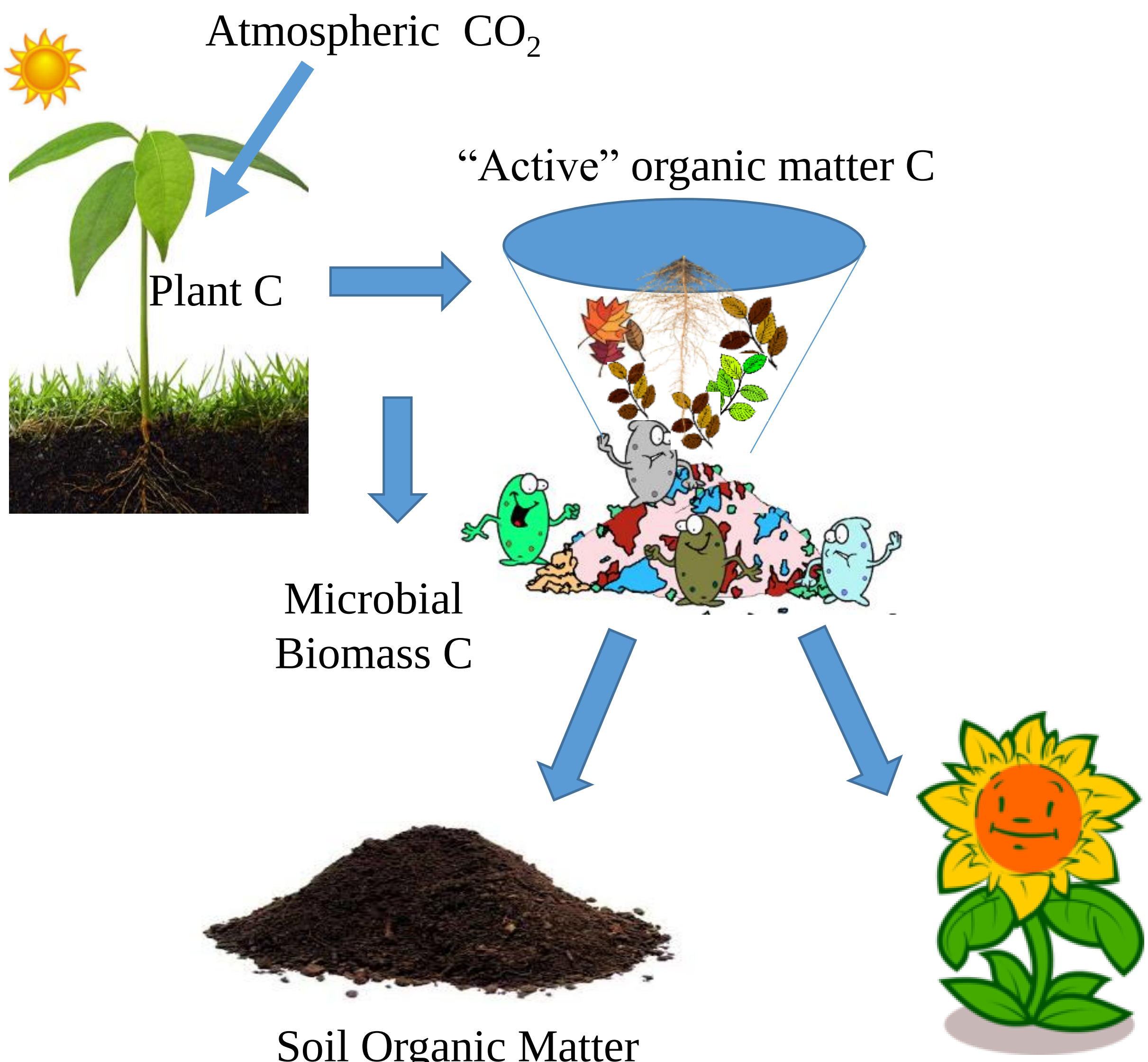
Biological Hot Spots to Optimize Function



Trends in Plant Science 2016 21, 256-265 DOI: (10.1016/j.tplants.2016.01.008)

Soil photos & slide design by J Moore-Kucera, NRCS-SHD

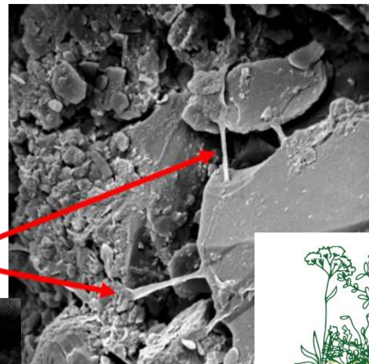
Continuous Flow of C Drives System

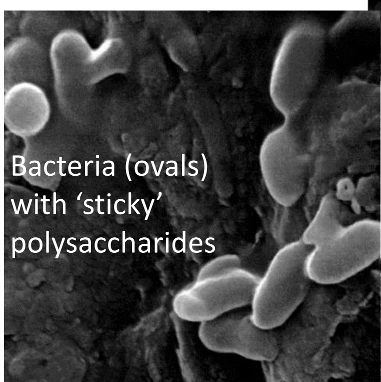


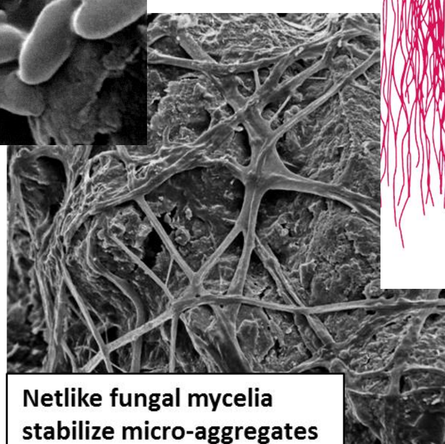
USDA
United States Department of Agriculture

Soil Aggregation is a Biological Process

Stabilization of soil structure by actinomycete (bacterial) filaments





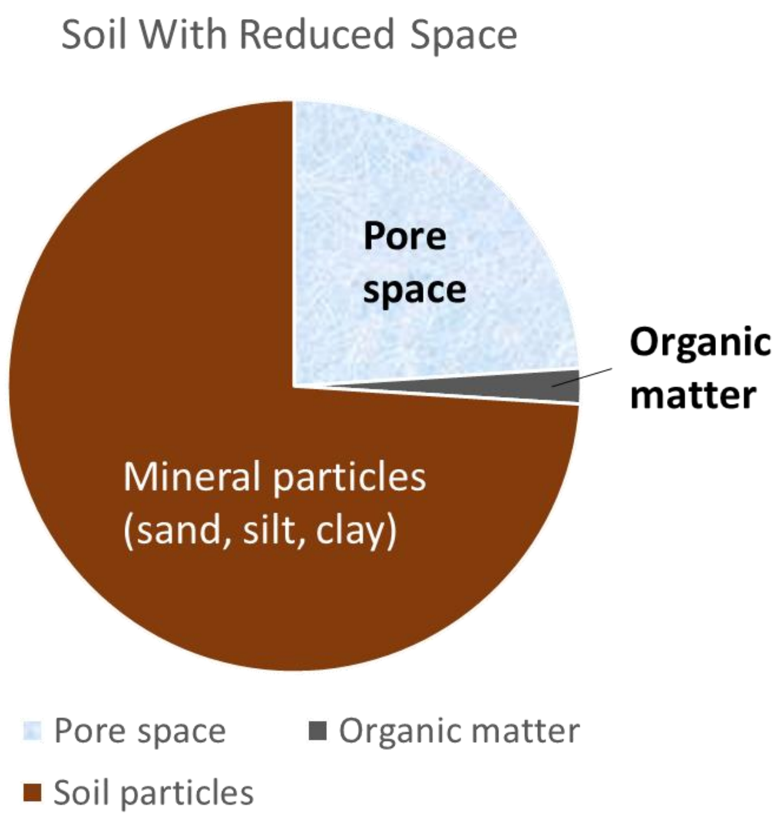


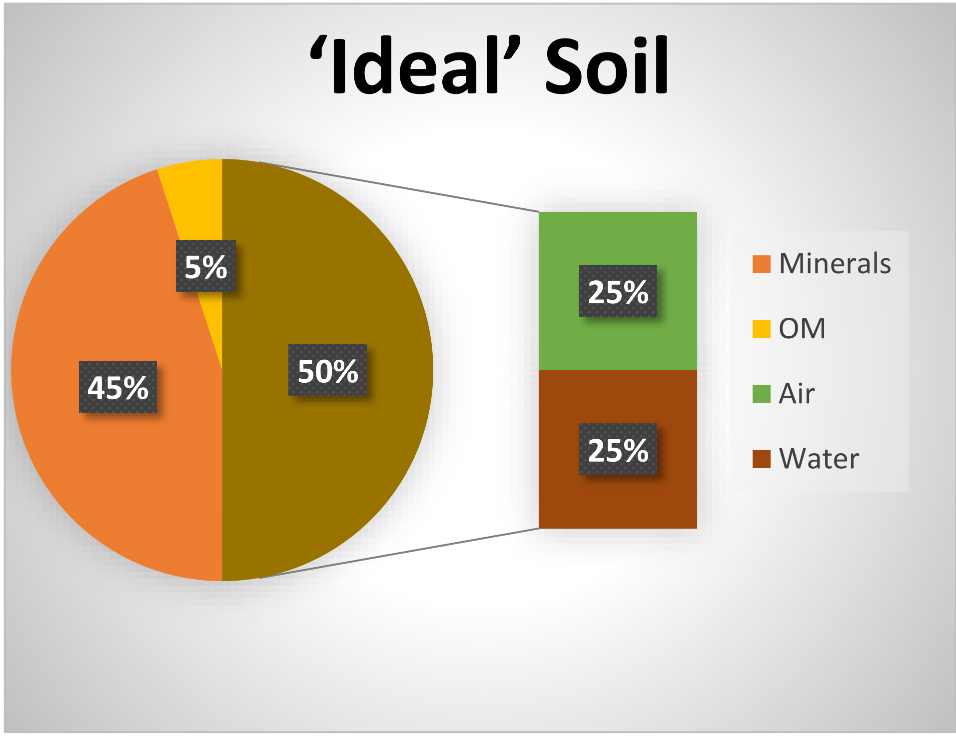
Netlike fungal mycelia stabilize micro-aggregates

- Aggregates resist erosion
- Ultimate home of microbes
- Creates pore space
- Large pores important for infiltration, drainage, aeration
- Small pores important for water storage and protection of organic matter and microbes

SEM photo source: Eickhorst, Thilo & Tippkoetter, Rolf. Micropedology – The hidden world of soils. University of Bremen, Germany. http://www.microped.uni-bremen.de

Barrios, 2007. Soil biota, ecosystem services and land productivity. Ecological Economics, 2:269-285.





- Infiltration slows
- Soils store less water
- Soils don't drain as easily
- Water, soil, and chemicals ($$$) run-off
- Plants drown

Manage Microbes – Manage Nutrients

- Majority of fertilizer, **no matter what initial form**, goes through microbes before plant gets it
- Soil microbial biomass accounts for:
  - 1-5% of total organic C
  - 2-6% of total organic N
  - ~3% of total organic P in arable soils
  - 5-24% of total organic P in grassland soils

Paul, 1984, Plant and Soil 76:275-285;
Brookes et al., 1984. Soil Biol Biochem, 16:169-175

USDA
United States Department of Agriculture

Optimize Biological Hot Spots → Optimize Nutrient Cycling & Availability

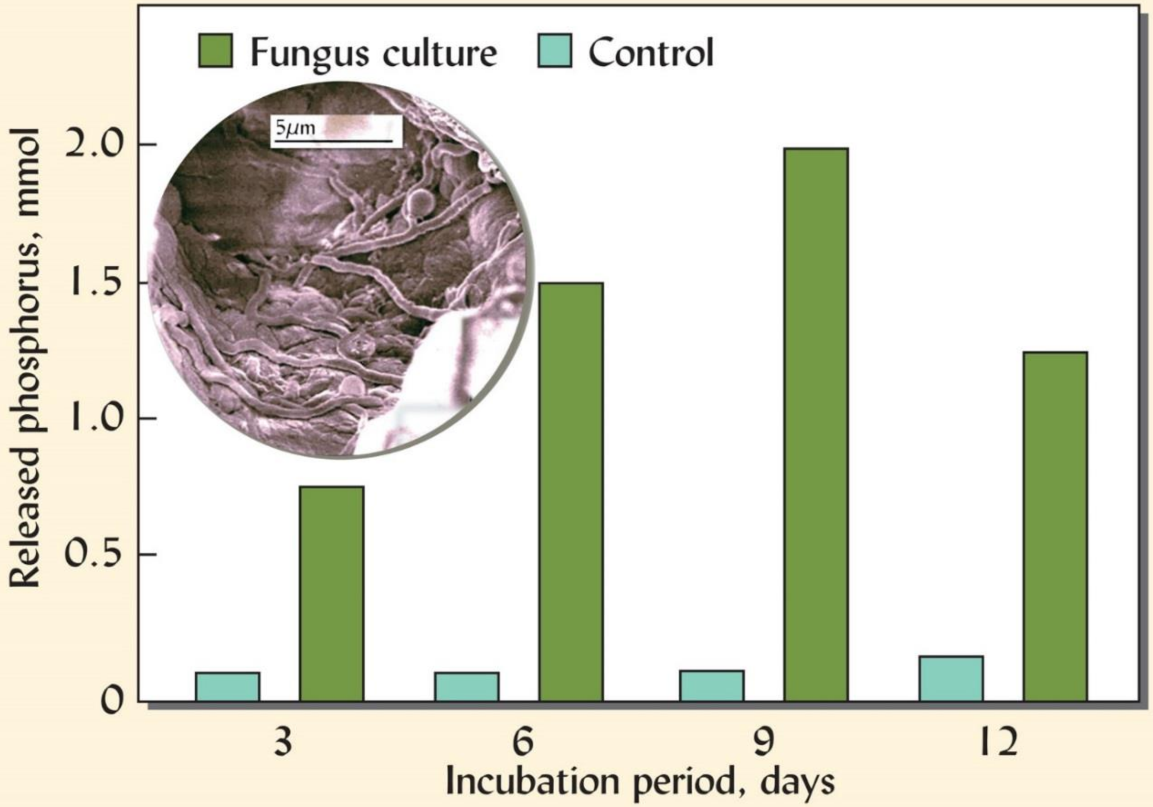
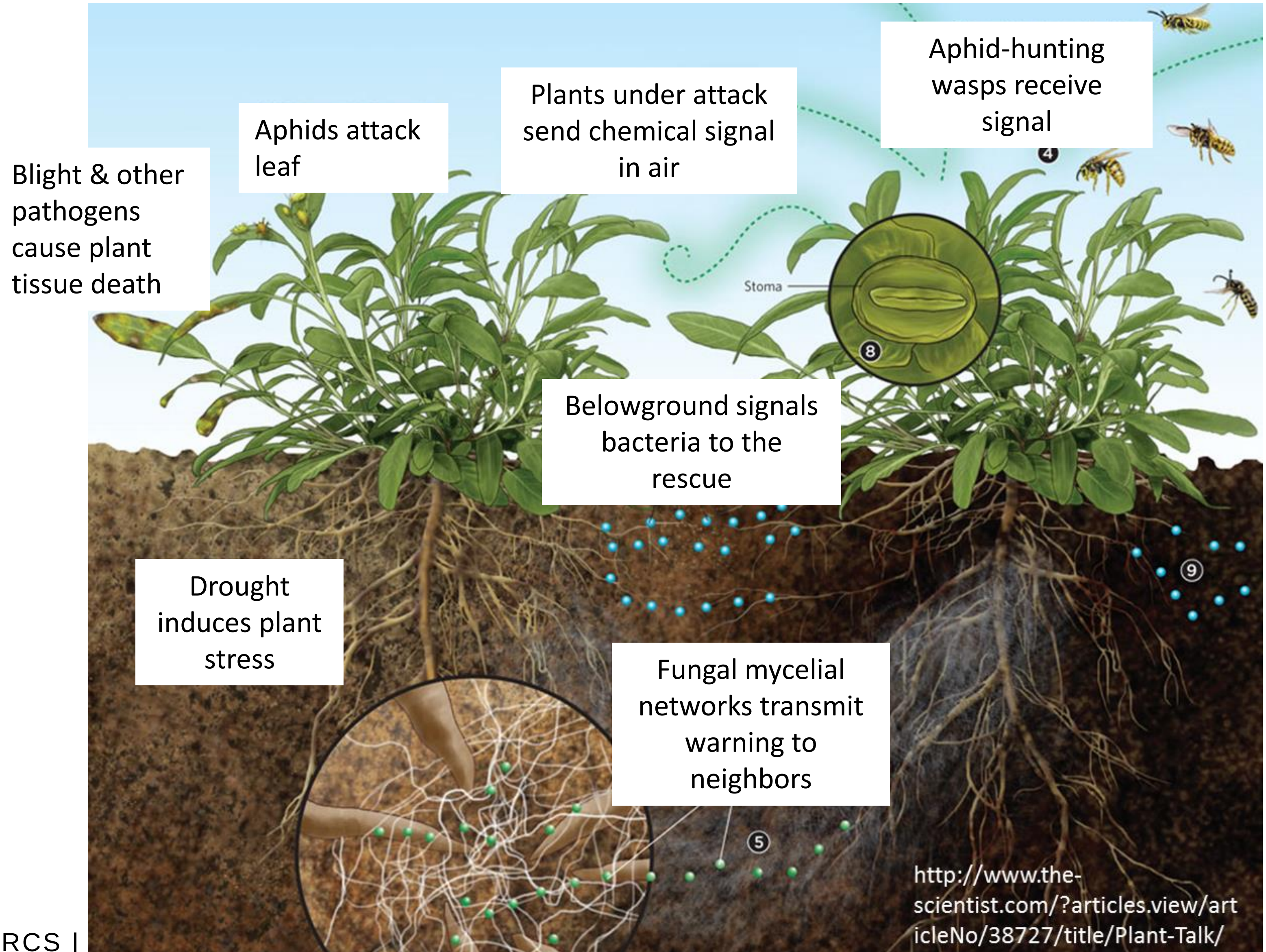


Image source: The Nature and Properties of Soils, 15e, Weil and Brady

Microbes release P from minerals

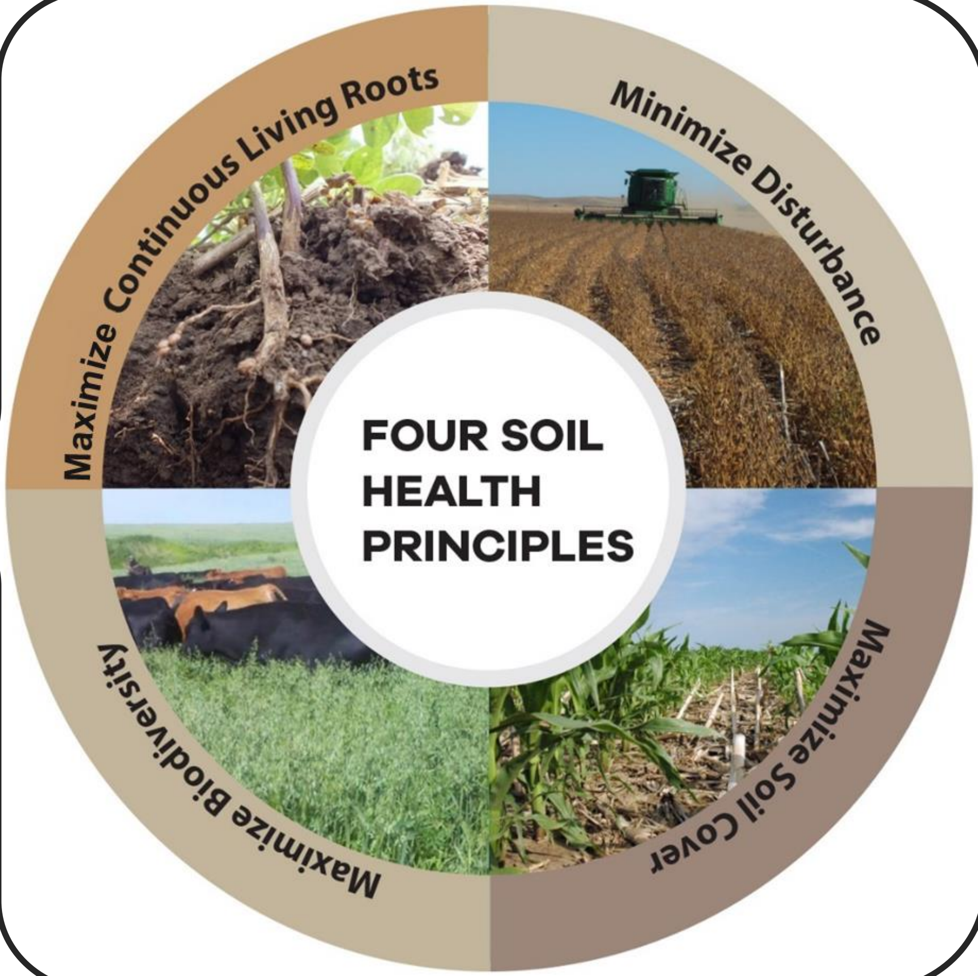
Plant Selection for Plant Protection?



Manage For Biological Hotspots

Soil Health Principles to Optimize Biological Hotspots and Function

Feed & Fuel Soil Biology



Protect Soil Aggregate & Organic Matter

United States Department of Agriculture

Soil Health Principles

Minimize Disturbance & Maximize Cover

- Maintain stable aggregates
- Reduce erosion and runoff risk
- Buffer temperature
- Reduce evaporation
- Maintain soil organic matter

USDA United States Department of Agriculture

Soil Health Principles

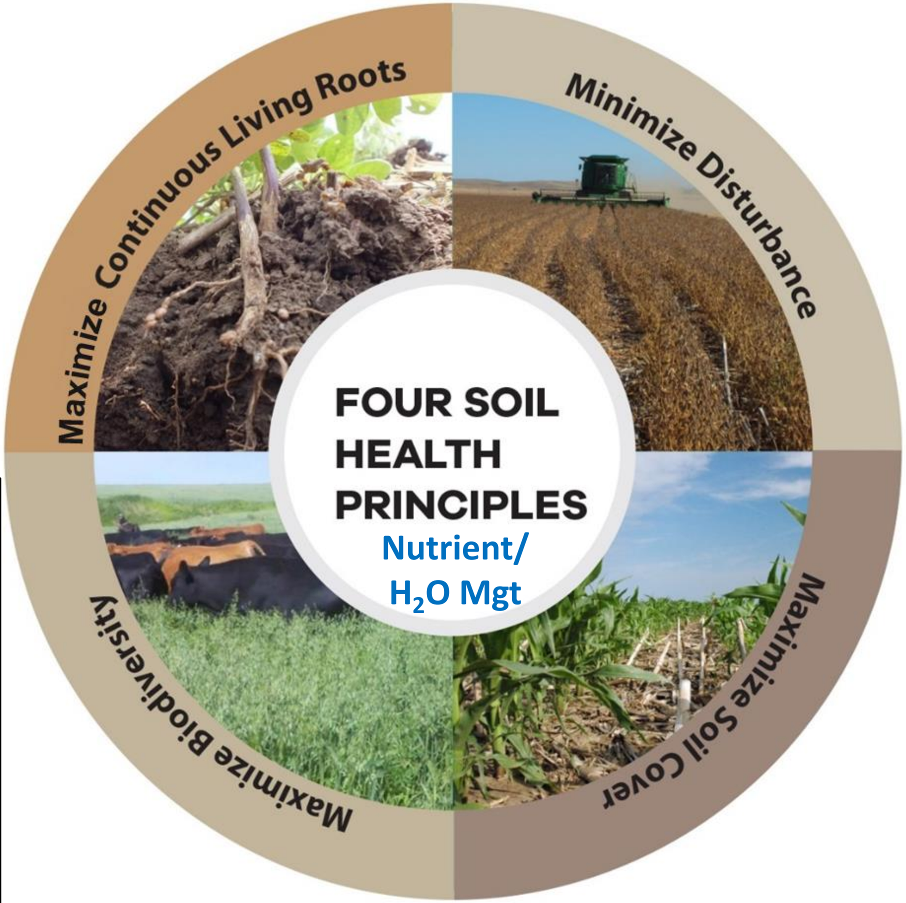
Maximize Biodiversity & Maximize Living Roots

- Break disease/pest cycles
- Stimulate/change belowground diversity
- Increase soil organic matter
- Increase nutrient cycling
- Enhance plant growth
- Increase predator & pollinator populations

United States Department of Agriculture

Practices that Feed & Protect

Crop Rotation
Cover Crop
Relay Crops
Forage & Biomass Planting
Perennial Crops



Reduced Tillage
Controlled Traffic
Avoid Tillage When Wet
No-till

Cover Crop
Crop Rotation
Rotational Grazing
IPM
Pollinator plantings
Organic fertilizers
Legumes in mix

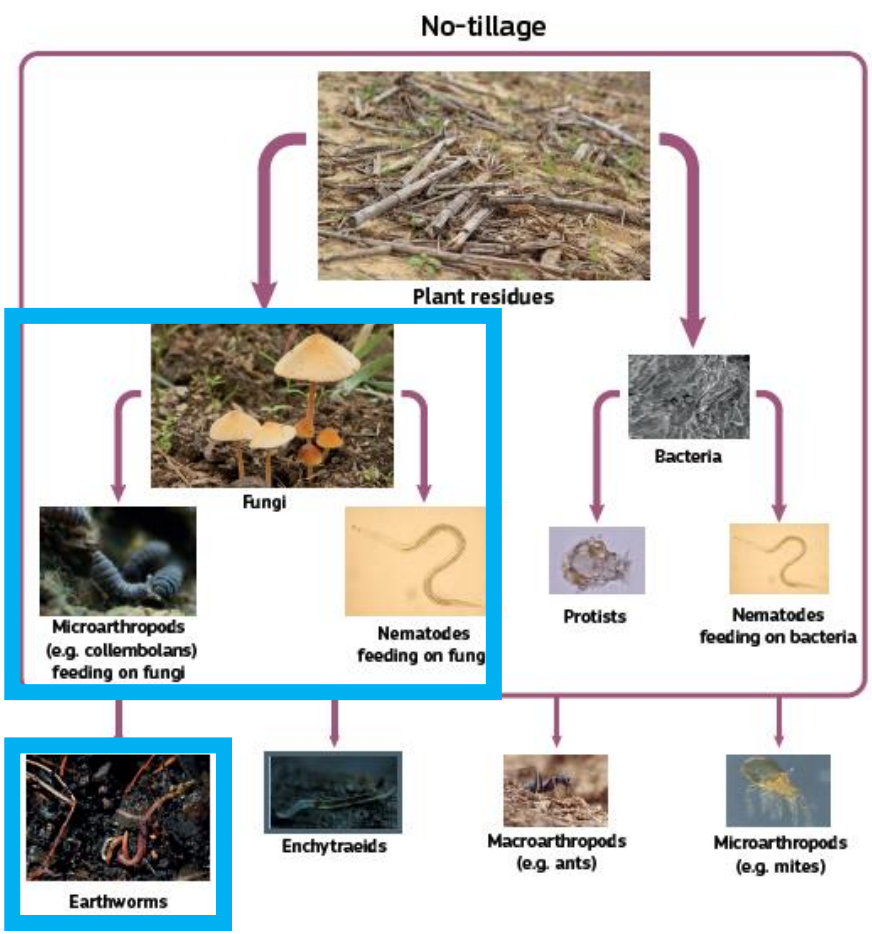
Cover Crop
Mulching
Reduced Tillage
Forage & Biomass Planting
Residue Retention

No-Till Favors:

Greater earthworm and mycorrhizal populations and nematodes shift to fungal feeders; greater overall biomass

Tillage Tends To Favor:

Increased bacteria & their predators (Protists & nematodes shift to bacterial-feeders); lower overall biomass



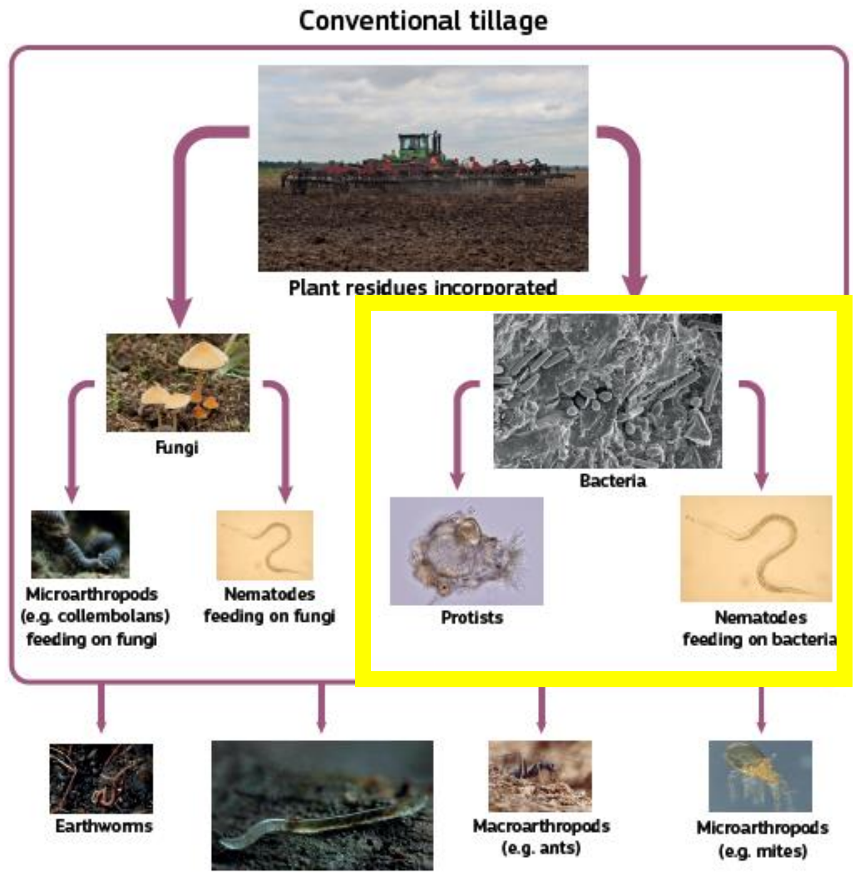
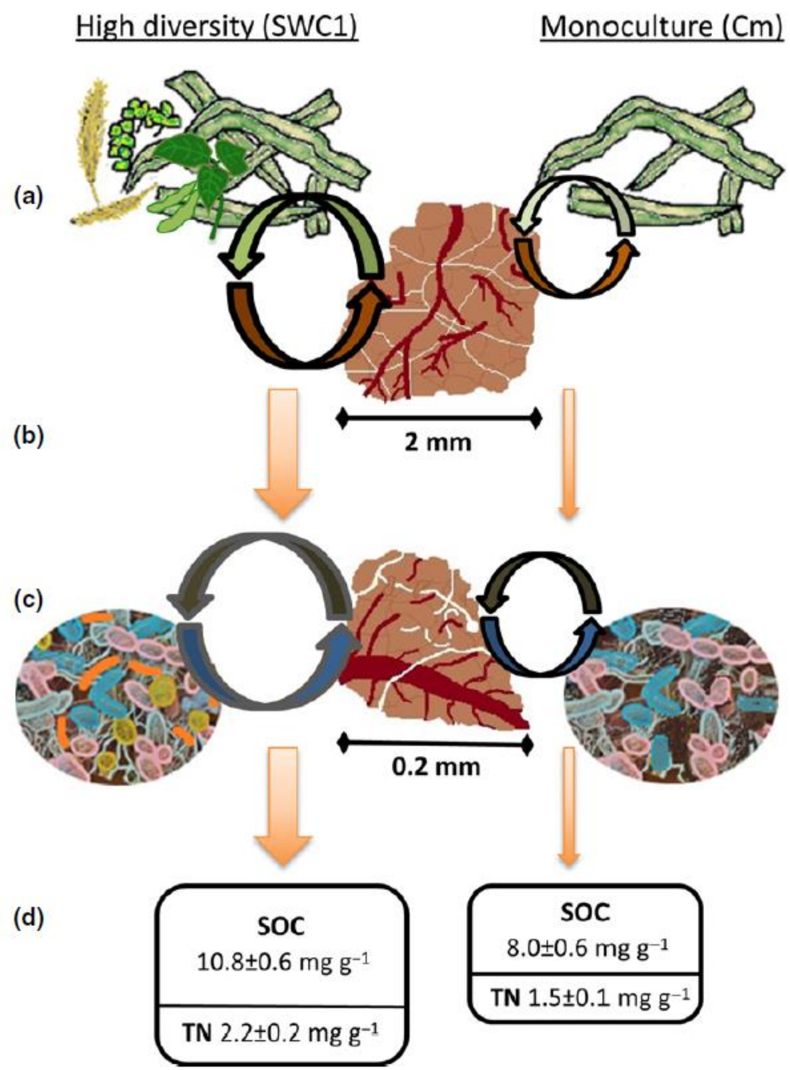
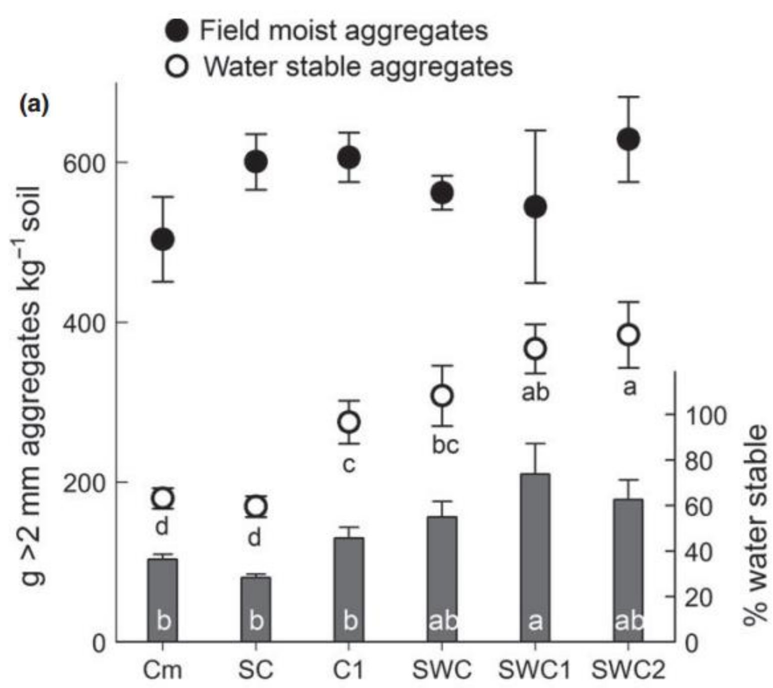


Photo source: (2016). Global Soil Biodiversity Atlas. A. Orgiazzi, R. D. Bardgett, E. Barrios et al. **176p.**

Crop Diversity Can Increase SOC

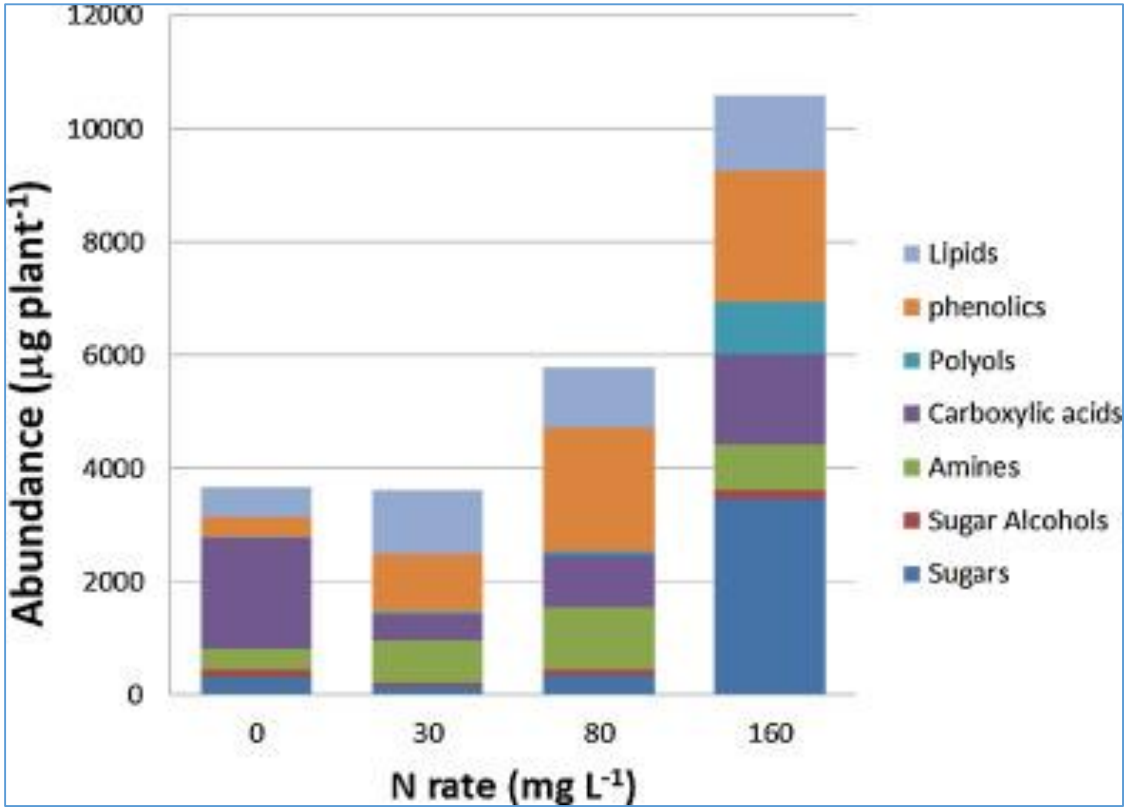




Cm – corn, monoculture
SC – soy, corn
C1 – corn w/ 1 cover
SWC – soy, wheat, corn
SWC1 – soy, wheat, corn w/ 1 cover
SWC2 – soy, wheat, corn w/ 2 cover

Tiemann et al., 2015. Ecol Letters 18:761-771.

N Fertilization Impacts Plant-Microbe Interactions



- N rate changed amount & composition of root exudates
- Increased microbial biomass and competition
- NUE decreased
- Fertilizer lost to microbes

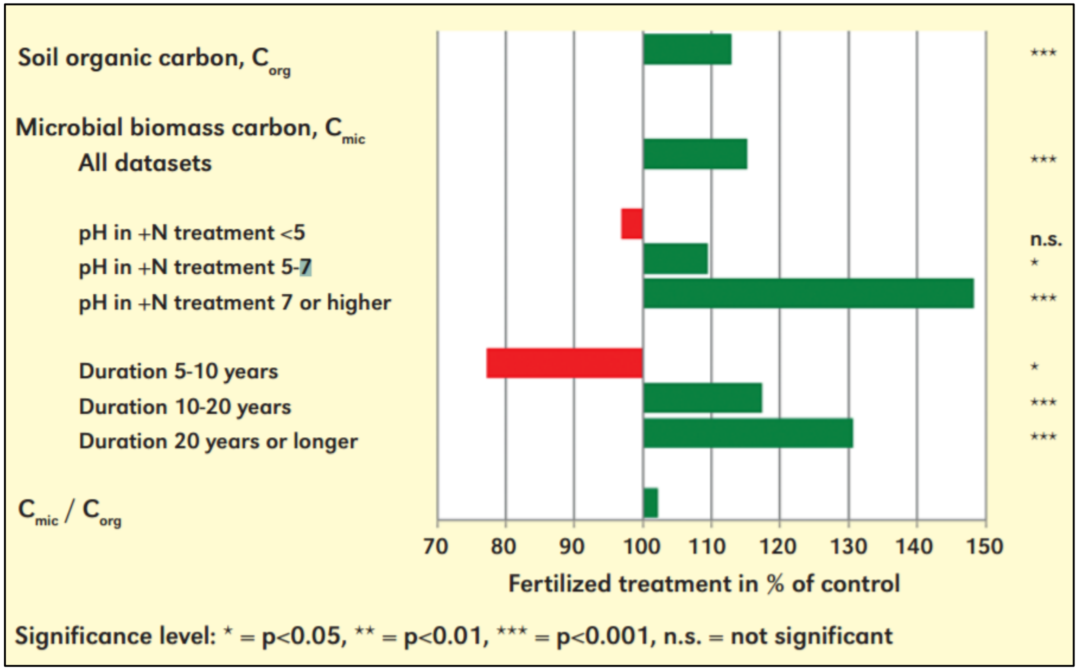
Zhu et al. 2016. Appl. Soil Ecol 107:324-333

Fertilization and Soil Microbes

- Increased SOC content 13% and microbial biomass 15%
- Urea and anhydrous tend to have negative impact (at least short-term)
- Unknown effects on community composition
- **Many fertilizer concentrations too high for symbiosis to work most efficiently**

Does Long-term Use of Mineral Fertilizers Affect the Soil Microbial Biomass?

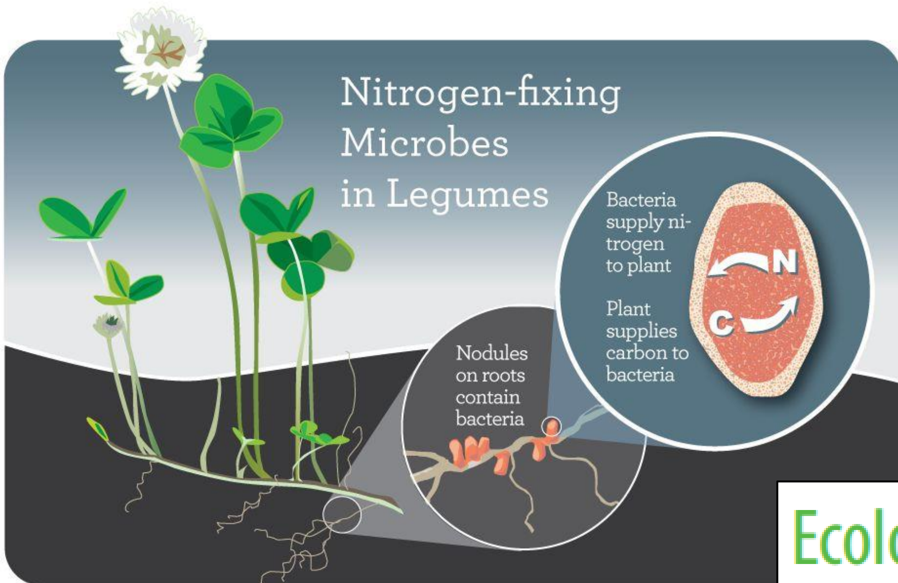
By Daniel Geisseler and Kate M. Scow



http://www.ipni.net/publication/bettercrops.nsf/0/2860E3614494E0D185257DAA00507C4F/$FILE/BC%202014-4%20p13.pdf

USDA
United States Department of Agriculture

Historical N Additions May Negatively Affect Nitrogen-Fixing Bacteria



https://news.illinois.edu/blog/view/6367/204407#image-2

doi:10.1111/evo.12594

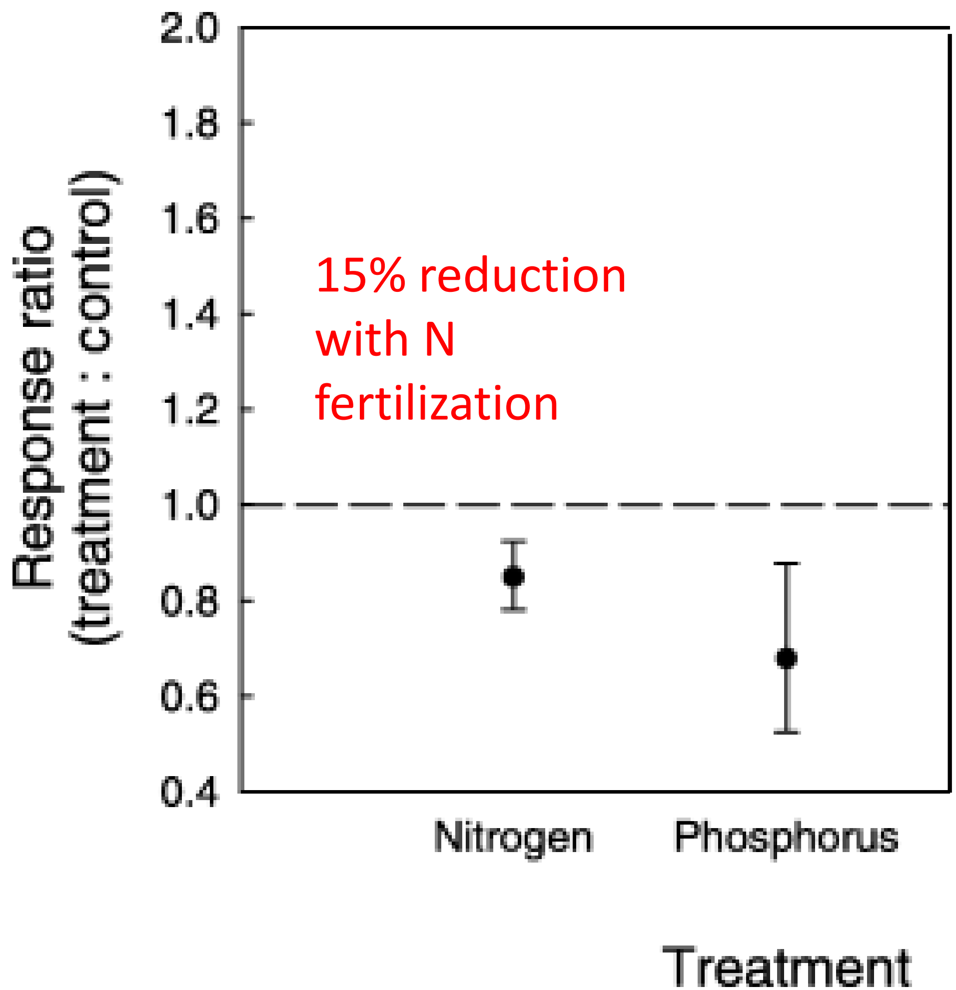
Long-term nitrogen addition causes the evolution of less-cooperative mutualists

Dylan J. Weese,[1,2,3] Katy D. Heath,[4] Bryn T. M. Dentinger,[5] and Jennifer A. Lau[2]
[1]*Department of Biology, St. Ambrose University, 518 West Locust St, Davenport, Iowa 52803*
[2]*Kellogg Biological Station and Department of Plant Biology, Michigan State University, 3700 E. Gull Lake Drive, Hickory Corners, Michigan 49060*
[3]*E-mail: weesedylanj@sau.edu*
[4]*Department of Plant Biology, University of Illinois, 192 Edward R. Madigan Lab, 1201 W. Gregory, Urbana, Illinois 61801*
[5]*Jodrell Laboratory, Royal Botanic Gardens, Kew, Richmond, Surrey, TW9 3DS, United Kingdom*

Ecological genomics of mutualism decline in nitrogen-fixing bacteria

Christie R. Klinger[1], Jennifer A. Lau[2] and Katy D. Heath[1]
[1]Department of Plant Biology, University of Illinois Urbana-Champaign, 505 South Goodwin Avenue, Urbana, IL 61801, USA
[2]W.K. Kellogg Biological Station and Department of Plant Biology, Michigan State University, East Lansing, MI, USA

Fertilization Reduces Mycorrhizal Fungi



15% reduction with N fertilization

32% reduction with P fertilization

Modified from Treseder (2004), New Phytologist, 164: 347–355

Cover Crops for Nutrient Traps

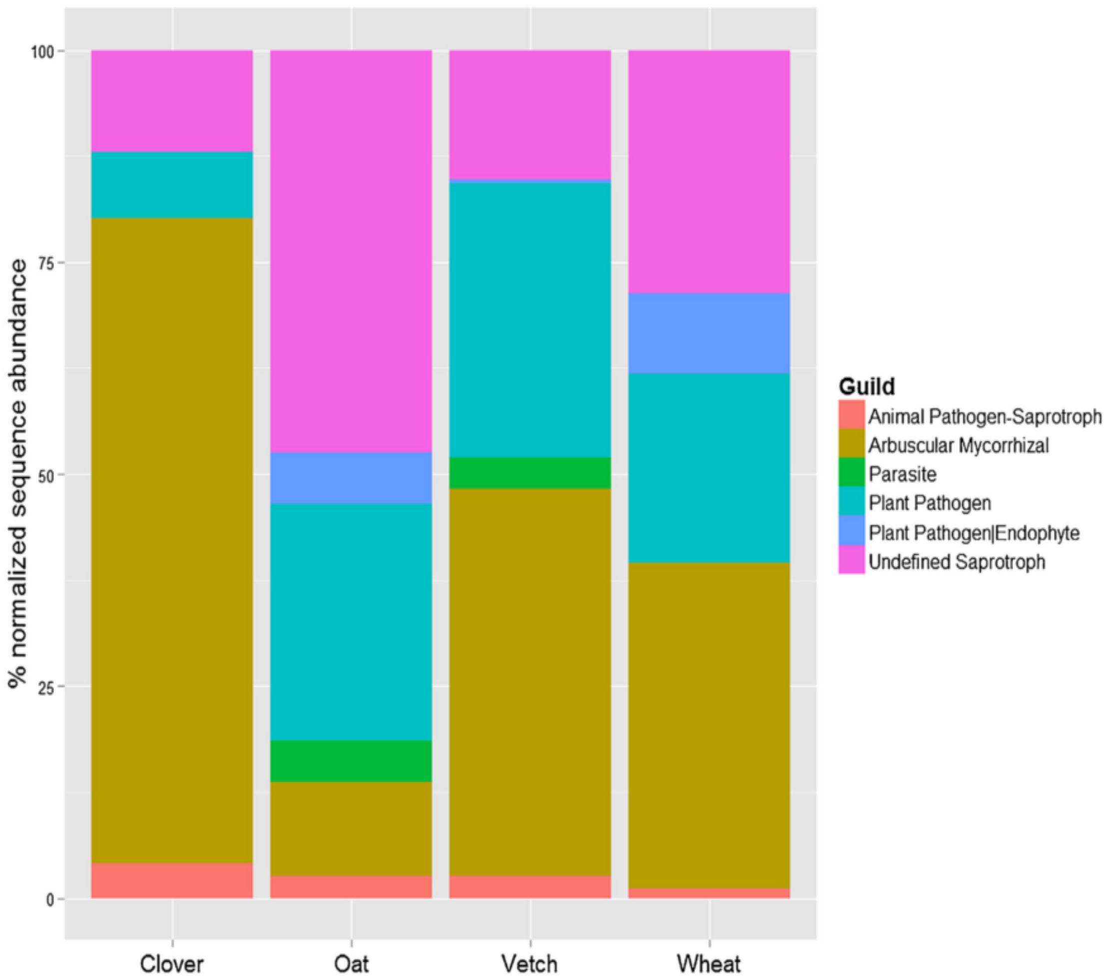
Effect of Winter Cover Crops on NO_3^--N Mining for Different Cropping Systems of South Central Colorado

Study No.	Cropping System	Winter Cover Crop	Time¶ of Planting	C:N Ratio	Soil NO_3^--N Fall (kg ha^{-1})	Soil NO_3^--N Spring (kg ha^{-1})
1	Organic carrots	Rye	Ep	12.4	49	28*
2	Spinach	Rye	Ep	9.0	829	556*
3	Potato	Rye	Lp	11.0	N/A	134
4	Potato	Rye	Lp	10.4	77	68*
5	Lettuce	Rye	Ep	15.7	171	18***
6	Lettuce	Rye	Ep	18.9	103	11***
7	Lettuce	Wheat	Lp	10.8	225	204**
8	Lettuce	Wheat	Ep	11.7	150	83**

Modified from Dabney, Delgado, & Reeves. 2001 Using winter cover crops to improve soil and water quality. Communications in Soil Science and Plant Analysis, 32:1221-1250.

Different cover crop species support different fungal functional groups

M.-S. Benitez et al. / Applied Soil Ecology 103 (2016) 72–82

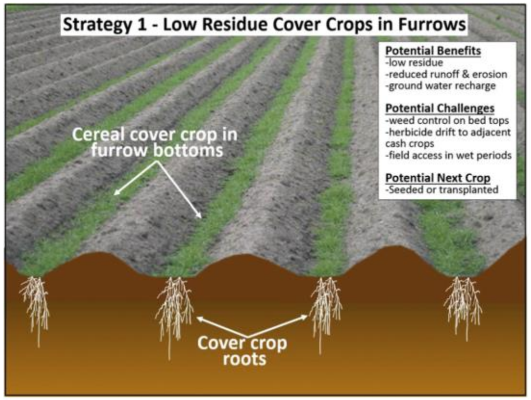


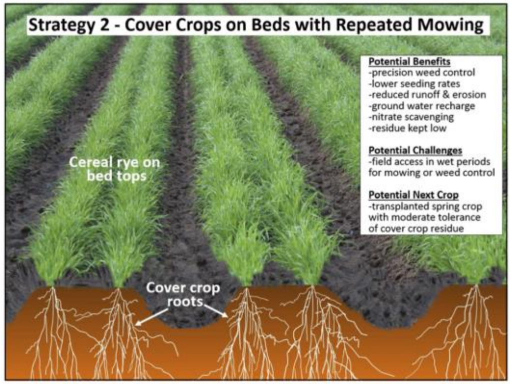
- Greatest diversity in spring wheat
- AMF highest in vetch & clover
- Oat for saprotrophs

United States Department of Agriculture

Cover Crops for Improved Yield

- **<u>Frequent cover cropping</u>** improved soil food web more than compost
- Vegetable yields were greater in frequently cover cropped systems compared to those infrequently cover cropped regardless of compost inputs





Brennan & Acosta-Martinez. 2017. Soil Biol Biochem 109:188-204
Brennan, E.B. 2017. HortTechnology 27:151-161

Biology Drives Yield Increases in Potato-Sorghum-Sudan Cover Crop System

- Sordan increased microbial biomass & changed microbiome
- Lowest disease index
- Highest siderophore production
- Yield increased 12-30%
- Quality: 40% tubers were 8oz or larger
- Income: $60-$400 per acre

Courtesy Dr. Dan Manter, USDA-ARS

Where does your cover crop seed come from?

Photos: Jmoore-Kucera, NRCS-SHD, 2017

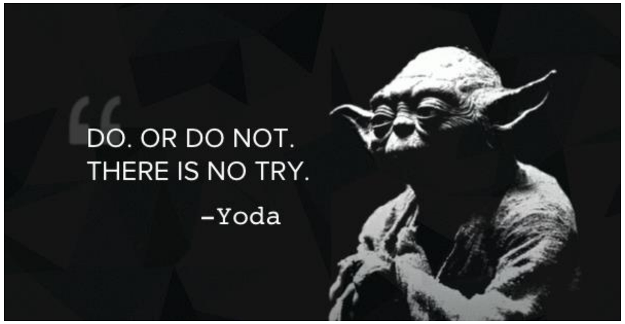
Managing for Biology

- Most ag soils are carbon depleted
- Disturbances destroys habitat and hyphal networks
- Bare, fallow fields provide little protection, no C
- Many fertilizer concentrations too high for symbiosis
- Agrichemicals have mixed effects

- ➢ Manage for hot spots
- ➢ Support biology to build aggregates and create pore space
- ➢ Protect the habitat
- ➢ Feed the soil so it can feed us
- ➢ Optimize biological nutrient cycling
- ➢ Optimize plant-microbe interactions for plant defense optimization

Thank You!

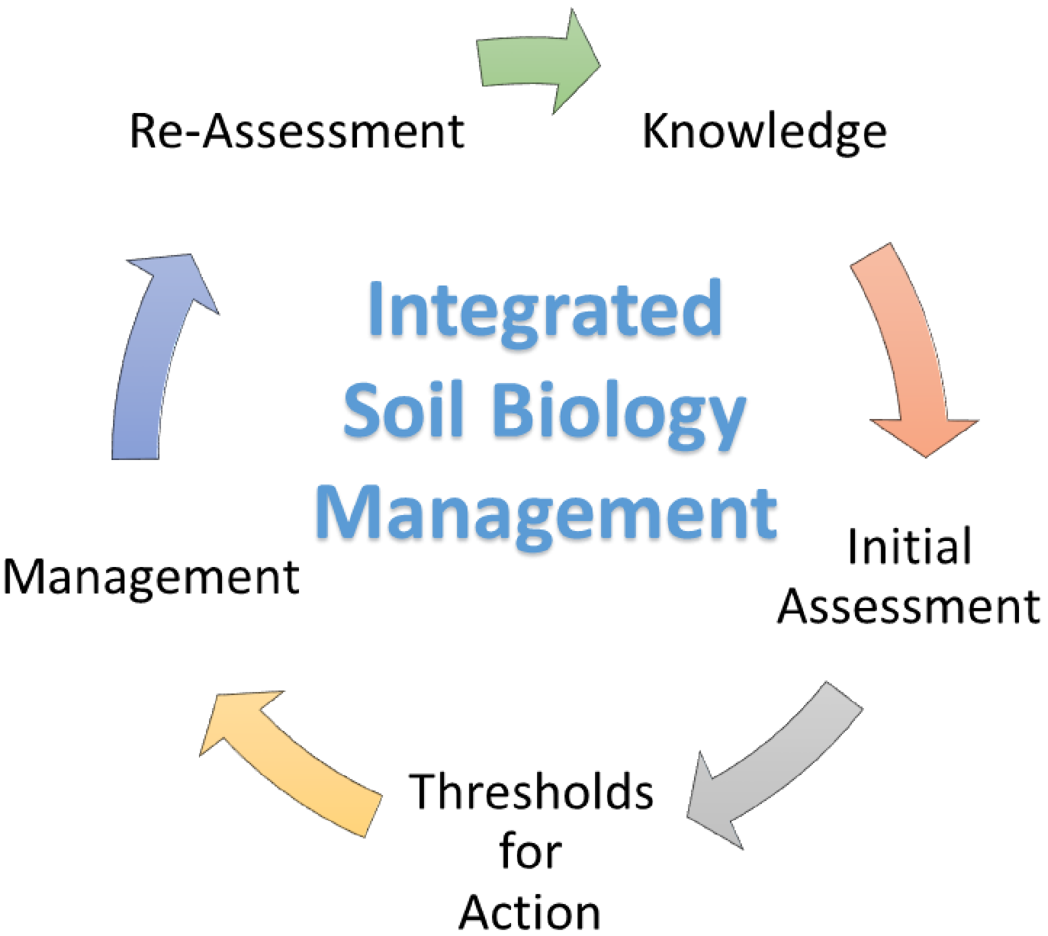
"Whether you think you can, or you think you can't you're right."
–Henry Ford



Jennifer.moorekucera@por.usda.gov
503-320-8286

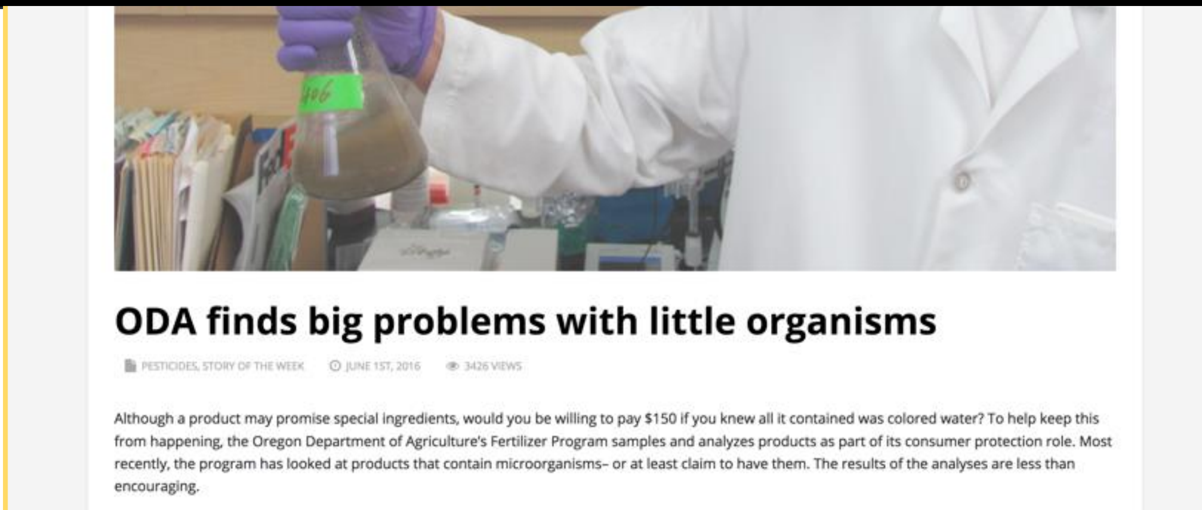
Integrated Soil Biology Management

1. **Knowledge**
   Typical problems
2. **Initial Assessment**
   Current status
   Who's there
3. **Thresholds for Action**
   What are acceptable levels?
   Is more always better
4. **Management**
   Chemical/Physical/Biological
5. **Re-assessment**
   Success
   Cost-effective



Slide Courtesy Dr. Dan Manter, USDA-ARS

Microbial Inoculants: Pitfalls

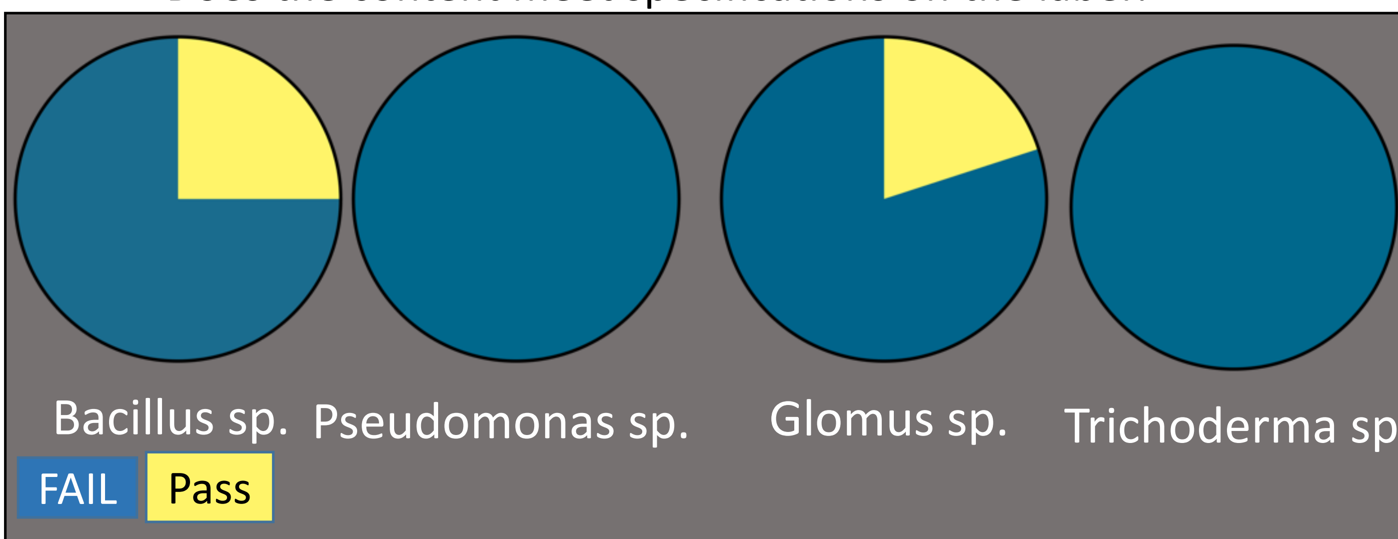


ODA finds big problems with little organisms

PESTICIDES, STORY OF THE WEEK · JUNE 1ST, 2016 · 3426 VIEWS

Although a product may promise special ingredients, would you be willing to pay $150 if you knew all it contained was colored water? To help keep this from happening, the Oregon Department of Agriculture's Fertilizer Program samples and analyzes products as part of its consumer protection role. Most recently, the program has looked at products that contain microorganisms– or at least claim to have them. The results of the analyses are less than encouraging.

Does the content meet specifications on the label?



Courtesy Dr. Trippe, USDA-ARS Corvallis

Microbial Inoculants: Pitfalls

Not all of the 700 products labeled in Oregon have been tested

http://www.oregon.gov/ODA/programs/Pesticides/Fertilizers/Pages/ReportsPublicationsForms.aspx

Courtesy Dr. Trippe, USDA-ARS Corvallis

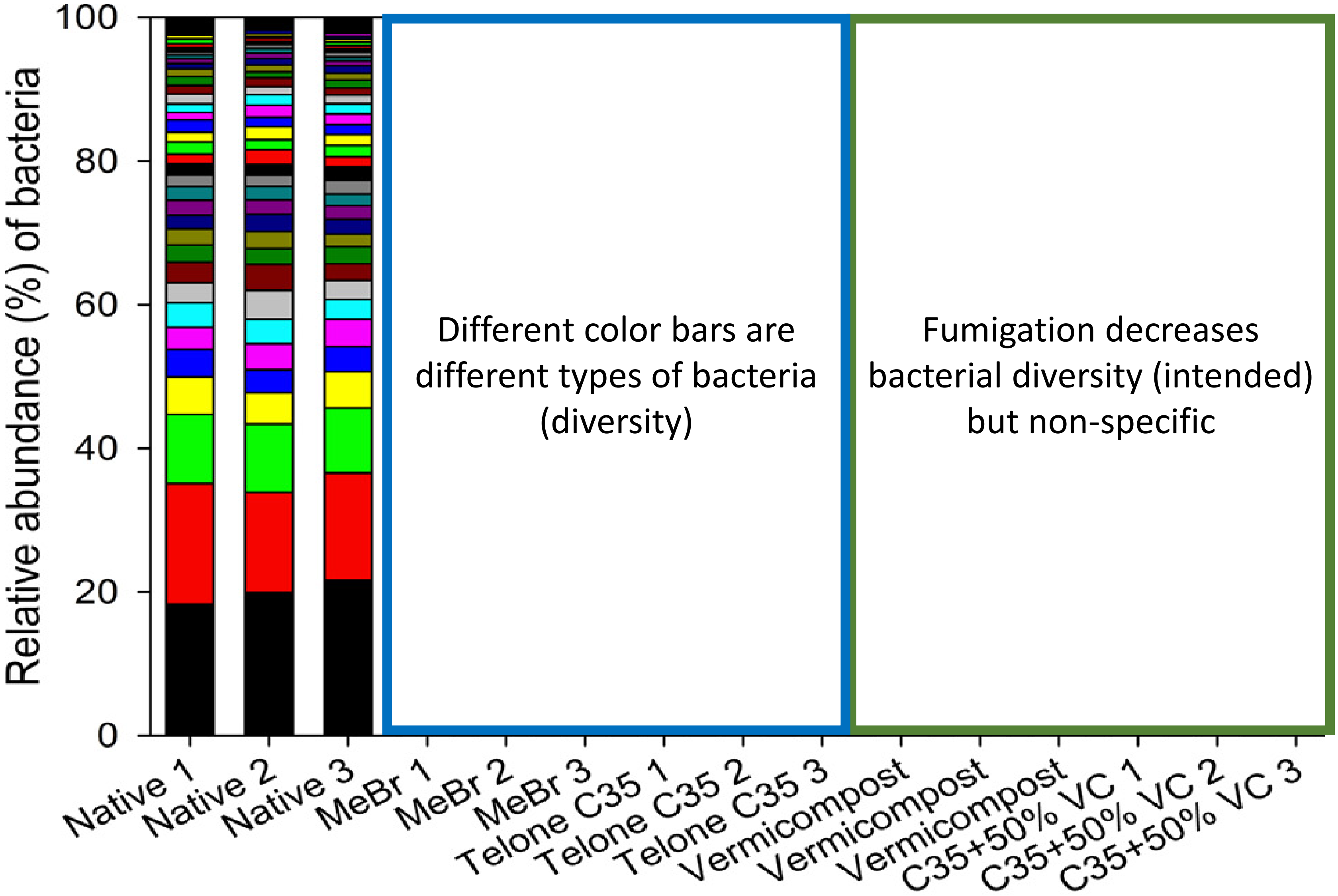
United States Department of Agriculture

Oregon Department of Agriculture Fertilizer Program

Company	Product	Sample Matrix	Reg. Status at Sampling	Genus	Lab Analysis	Label Guarantee
Advanced Nutrients Abbotsford, British Columbia	Piranha Beneficial Fungi	Liquid	Unregistered	*Glomus spp.* *Pseudomonas spp.* *Trichoderma spp.*	Not Detected Not Detected Not Detected	234 prop/ml 125,000 cfu/ml 55,500,000 cfu/ml
Baicor, L.C. Logan, Utah	5-7-5 Tree Feast + Micros with Micro-Organisms Added	Liquid	Registered	*Bacillus spp.*	Not Detected	240 cfu/ml
Beneficial Biologics Arcata, California	Root Bloom Myco-Bacterial Inoculant	Dry	Registered	*Bacillus spp.* *Pseudomonas spp.*	3,000 cfu/g Not Detected	14,000,000 cfu/g 2,200,000 cfu/g
Botanicare Chandler, Arizona	Hydroguard Bacillus Root Inoculant	Liquid	Registered	*Bacillus spp.*	33,000 cfu/ml	10,000 cfu/ml
Dr. Earth Company Winters, California	SuperActive Natural & Organic Biological Soil Inoculant with Nitrogen Fixing Bacteria	Dry	Registered	*Bacillus spp.*	15,000,000 cfu/g	4,500,000 prop/cc
Ecological Laboratories, Inc. Cape Coral, Florida	Vegetable & Fruit Yield Enhancer-O	Liquid	Unregistered	*Bacillus spp.* *Glomus spp.*	56,000,000 cfu/ml 13 prop/ml	20,250,000 cfu/ml 3.7184 prop/ml
	0-0.5-0.09 Photosynthesis Plus-O	Liquid	Unregistered	*Bacillus spp.* *Glomus spp.*	3,000 cfu/ml 9 prop/ml	20,250,000 cfu/ml 3.7184 prop/ml
GH Inc. Sebastopol, California	SubCulture-M Mycorrhizal Root Inoculant	Dry	Registered	*Glomus spp.*	13 prop/g	68 prop/g
	0.1-0.04-0.02 Subculture-B Bacillus Root Inoculant	Dry	Registered	*Bacillus spp.* *Pseudomonas spp.* *Trichoderma spp.*	87 cfu/g Not Detected Not Detected	161,000,000 cfu/g 24,000,000 cfu/g 24,000,000 prop/g

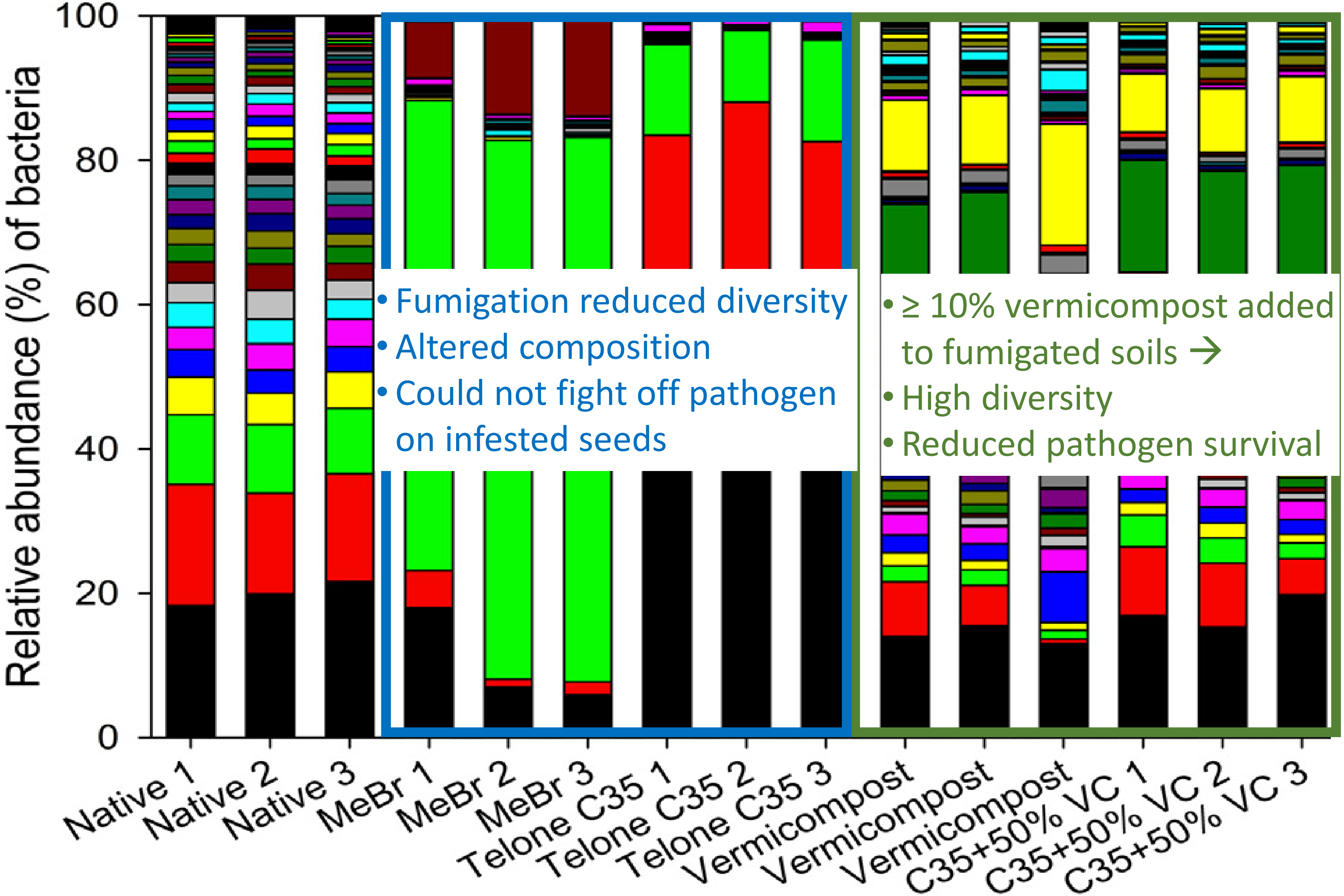
cfu = colony forming units prop = propagule g = grams ml = milliliter cc = cubic centimeter

Organic Amendments To Help Control Pathogens



 Strauss, Stover, Kluepfel. 2015. Impact of biological amendments on *Agrobacterium tumefaciens* survival in soil.

Organic Amendments To Help Control Pathogens



- Fumigation reduced diversity
- Altered composition
- Could not fight off pathogen on infested seeds

- ≥ 10% vermicompost added to fumigated soils →
- High diversity
- Reduced pathogen survival

 Strauss, Stover, Kluepfel. 2015. Impact of biological amendments on *Agrobacterium tumefaciens* survival in soil.

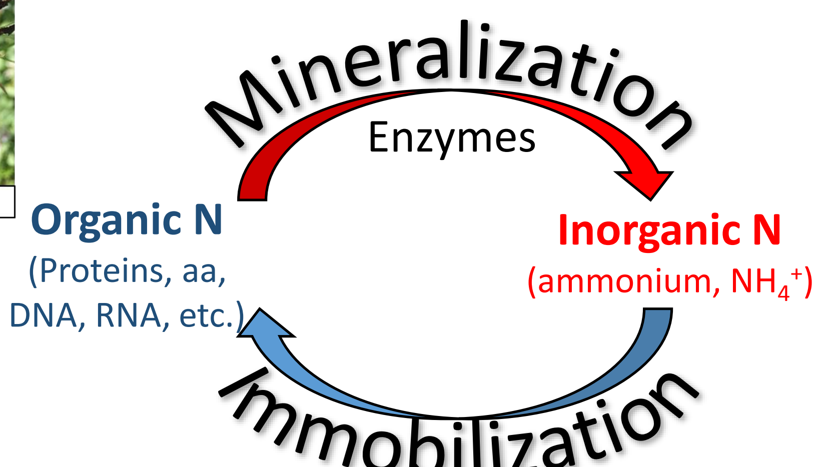
USDA United States Department of Agriculture

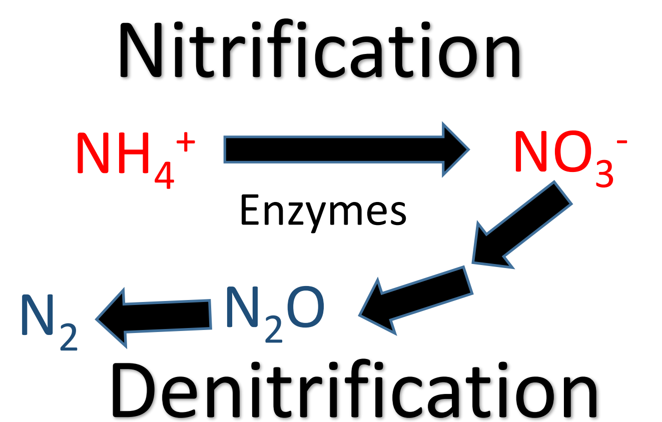
Biological Role in Nitrogen Cycling

Essentially all steps of N cycle are driven by soil biota:

- N-fixation → only bacteria
- Mineralization → microbes and microfauna
- Nitrification → mainly bacteria but also fungi & archaea
- Denitrification → mainly bacteria but also fungi & archaea

Fava Bean; Moore-Kucera, 2016





Organic Amendments Help Control Pathogens

Replant soil (M. Mazzola) **'Virgin' soil**

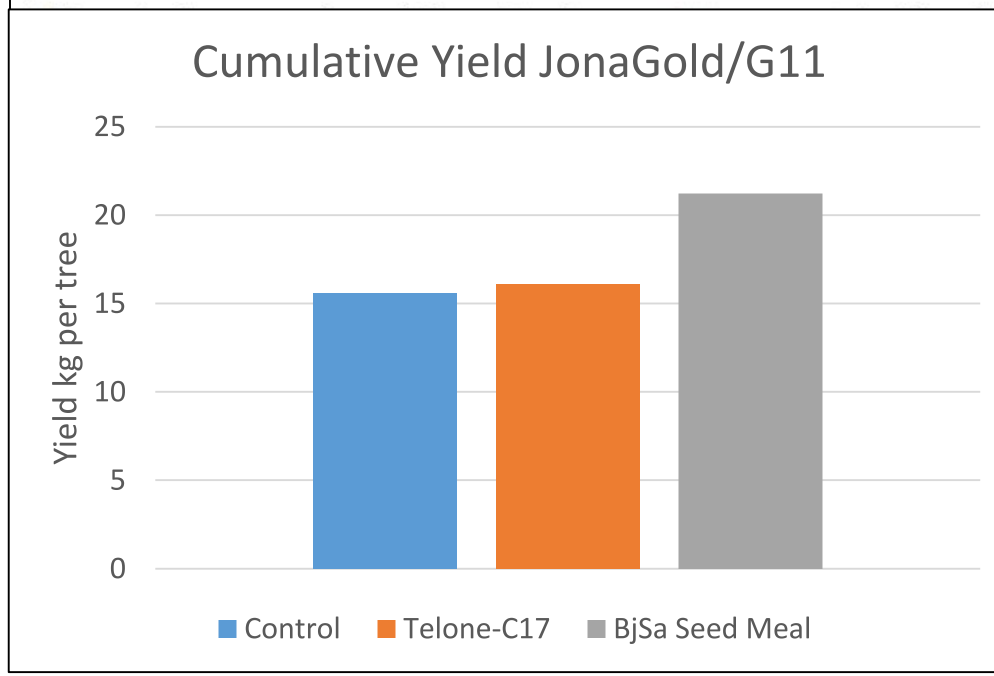
Effect of Apple Replant Disease
Gala/M26, Moxee, WA

Mazzola and Strauss, 2013; Mazzola et al. 2014.

Compared to Control & Fumigation:
Mustard seed meal altered types & numbers of fungal community but not diversity

TABLE 4. Density (number of g^{-1} root) of *Pratylenchus penetrans* recovered from roots of JonaGold/G11 apple as influenced by soil treatment at the SMR commercial organic orchard, Chelan, WA[y]

Soil treatment[z]	2010	2011	2012
Control	164 b	287 a	246 b
Telone-C17	80 ab	881 b	398 c
BjSa-Sp	9 a	163 a	52 a



Questions to discuss

- How do fertilizers affect soil organisms?
- How do herbicides affect soil organisms?
  - Glyphosate
  - Fungicides
- What is F:B ratio and how should I interpret it?
- Diversity and biomass – is more always better?
- Inoculation – does it work?
- Is the soil sterilized in a drought/heat wave?
- Plant-microbe-fauna communication pathways

Generalizations to Consider

- Management decisions should be made to serve a real (not perceived) purpose
- Important to know your starting point and your thresholds
- Optimizing habitat and food sources for soil organisms increases opportunities for beneficial or synergistic impacts