Soil Biology
Links to Soil Health & Ecosystem Functionality

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West Regional Soil Health Team Leader
NRCS Soil Health Division
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National Cover Crop Conference, Indianapolis, IN
Soil Health

The continued capacity of a soil to function as a vital, living ecosystem that sustains plants, animals, and humans.”
# Life Belowground Supports Life Aboveground

<table>
<thead>
<tr>
<th>Organisms</th>
<th>Number (per 10 ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Microorganisms</strong></td>
<td></td>
</tr>
<tr>
<td>Bacteria &amp; Archaea</td>
<td>100 trillion – 1 quadrillion</td>
</tr>
<tr>
<td>Actinobacteria</td>
<td>1-10 trillion</td>
</tr>
<tr>
<td>Fungi</td>
<td>1-10 million per 3 ft</td>
</tr>
<tr>
<td>Algae</td>
<td>1-10 billion</td>
</tr>
<tr>
<td><strong>Fauna</strong></td>
<td></td>
</tr>
<tr>
<td>Protists</td>
<td>10 million – 100 billion</td>
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<tr>
<td>Nematodes</td>
<td>100,000 – 10 million</td>
</tr>
<tr>
<td>Mites</td>
<td>100 - 1 million</td>
</tr>
<tr>
<td>Collembola</td>
<td>100 - 1 million</td>
</tr>
<tr>
<td>Earthworms</td>
<td>10 - 100</td>
</tr>
<tr>
<td>Other fauna</td>
<td>100-10,000</td>
</tr>
</tbody>
</table>

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

It Takes a Village To Make Soil Function

Nutrients cycle
Aggregates form
Organic matter increases
Plant roots are protected
Plants growth is enhanced
Pollutants are detoxified

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*

Atmospheric CO₂

Plant C

“Active” organic matter C

Microbial Biomass C

Soil Organic Matter
Soil Aggregation is a Biological Process

- 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


**‘Ideal’ Soil**

- 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

Optimize Biological Hot Spots ➔ Optimize Nutrient Cycling & Availability

Microbes release P from minerals

Image source: The Nature and Properties of Soils, 15e, Weil and Brady
Plant Selection for Plant Protection?

Aphids attack leaf

Plants under attack send chemical signal in air

Aphid-hunting wasps receive signal

Blight & other pathogens cause plant tissue death

Belowground signals bacteria to the rescue

Drought induces plant stress

Fungal mycelial networks transmit warning to neighbors

http://www.thescientist.com/?articles.view/articleNo/38727/title/Plant-Talk/
Manage For Biological Hotspots
Soil Health Principles to Optimize Biological Hotspots and Function

- Maximize Continuous Living Roots
- Minimize Disturbance
- Maximize Soil Cover
- Maximize Biodiversity

[Images of plants and soil]

- Feed & Fuel
- Soil Biology
- Protect Soil Aggregate & Organic Matter
Soil Health Principles

Minimize Disturbance & Maximize Cover

- Maintain stable aggregates
- Reduce erosion and runoff risk
- Buffer temperature
- Reduce evaporation
- Maintain soil organic matter
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
Practices that Feed & Protect

- Reduced Tillage
- Controlled Traffic
- Avoid Tillage When Wet
- No-till

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

- Reduced Tillage
- Forage & Biomass Planting
- Residue Retention

USDA | NRCS | Soil Health Division
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
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
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

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

![Graph showing the effect of fertilization on soil organic carbon and microbial biomass](http://www.ipni.net/publication/bettercrops.nsf/0/2860E3614494E0D185257DAA00507C4F/$FILE/BC%202014-4%20p13.pdf)
Historical N Additions May Negatively Affect Nitrogen-Fixing Bacteria

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

Dylan J. Weese,1,2,3 Katy D. Heath,1 Bryn T. M. Dentinger,3 and Jennifer A. Lau2
1Department of Biology, St. Ambrose University, 518 West Locust St, Davenport, Iowa 52803
2Kellogg Biological Station and Department of Plant Biology, Michigan State University, 3700 E. Gull Lake Drive, Hickory Corners, Michigan 49060
3Department of Plant Biology, University of Illinois, 192 Edward R. Madigan Lab, 1201 W. Gregory, Urbana, Illinois 61801

Ecological genomics of mutualism decline in nitrogen-fixing bacteria

Christie R. Klinger1, Jennifer A. Lau2 and Katy D. Heath1
1Department of Plant Biology, University of Illinois Urbana-Champaign, 505 South Goodwin Avenue, Urbana, IL 61801, USA
2W.K. Kellogg Biological Station and Department of Plant Biology, Michigan State University, East Lansing, MI, USA

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

<table>
<thead>
<tr>
<th>Study No.</th>
<th>Cropping System</th>
<th>Winter Cover Crop</th>
<th>Time$^\text{a}$ of Planting</th>
<th>C : N Ratio</th>
<th>Soil NO$_3^-$/N (kg ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fall</td>
</tr>
<tr>
<td>1</td>
<td>Organic carrots</td>
<td>Rye</td>
<td>Ep</td>
<td>12.4</td>
<td>49</td>
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<tr>
<td>2</td>
<td>Spinach</td>
<td>Rye</td>
<td>Ep</td>
<td>9.0</td>
<td>829</td>
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<tr>
<td>3</td>
<td>Potato</td>
<td>Rye</td>
<td>Lp</td>
<td>11.0</td>
<td>N/A</td>
</tr>
<tr>
<td>4</td>
<td>Potato</td>
<td>Rye</td>
<td>Lp</td>
<td>10.4</td>
<td>77</td>
</tr>
<tr>
<td>5</td>
<td>Lettuce</td>
<td>Rye</td>
<td>Ep</td>
<td>15.7</td>
<td>171</td>
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<tr>
<td>6</td>
<td>Lettuce</td>
<td>Rye</td>
<td>Ep</td>
<td>18.9</td>
<td>103</td>
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<td>7</td>
<td>Lettuce</td>
<td>Wheat</td>
<td>Lp</td>
<td>10.8</td>
<td>225</td>
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<tr>
<td>8</td>
<td>Lettuce</td>
<td>Wheat</td>
<td>Ep</td>
<td>11.7</td>
<td>150</td>
</tr>
</tbody>
</table>

Different cover crop species support different fungal functional groups

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

*Source: M.-S. Benítez et al./Applied Soil Ecology 103 (2016) 72-82*
Cover Crops for Improved Yield

• **Frequent cover cropping** 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


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

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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

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Slide Courtesy Dr. Dan Manter, USDA-ARS
Microbial Inoculants: Pitfalls

ODA finds big problems with little organisms

Although a product may promise special ingredients, would you be willing to pay $1.50 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?

- Bacillus sp.
- Pseudomonas sp.
- Glomus sp.
- Trichoderma sp.

FAIL  Pass

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

*cfu = colony forming units, prop = propagule, g = grams, ml = milliliter, cc = cubic centimeter*
Organic Amendments To Help Control Pathogens

Different color bars are different types of bacteria (diversity)

Fumigation decreases bacterial diversity (intended) but non-specific
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

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
Organic Amendments Help Control Pathogens

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

<table>
<thead>
<tr>
<th>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, WA²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soil treatment</strong></td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Control</td>
</tr>
<tr>
<td>Telone-C17</td>
</tr>
<tr>
<td>BjSa-Sp</td>
</tr>
</tbody>
</table>

Cumulative Yield JonaGold/G11

- **Yield kg per tree**

Effect of Apple Replant Disease
Gala/M26, Moxee, WA
Mazzola and Strauss, 2013; Mazzola et al. 2014.
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