Soil Microbiology and Its Effects on Nutrient Availability and Uptake in Plants (and other things)

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Outline

• Soil biodiversity and farming (short film)
• Role of soil microbes in growing things
  – Organic matter
  – Nitrogen cycling
  – Phosphorus cycling
  – Soil structure
• Managing soil biology for plant growth and sustainability
• Indicators—how do we measure how we are doing?
• Discussion
Film
Most ecoecosystems concentrate biodiversity belowground.

Above ground diversity is often intentionally low in managed systems.
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.
How microorganisms contribute to farms and gardens (the good, the bad and the ugly)
Microbes tightly coupled with plants and soil: can’t decouple biodiversity from soil

Adapted from Brussaard et al. 2007
Soil organic matter (SOM) formation

Microbes are enzymatic drivers and also “feedstock” for SOM

Fertile Soil Doesn't Fall from the Sky: Contribution of Bacterial Remnants to Soil Fertility Has Been Underestimated Until Now

Dec. 14, 2012 — Remains of dead bacteria have far greater meaning for soils than previously assumed. Around 40 per cent of the microbial biomass is converted to organic soil components.

Until now, it was assumed that the organic components of the soil were composed mostly of decomposed plant material which is directly converted to humic substances. In a laboratory experiment and in field testing the researchers have now refuted this thesis. Evidently the easily biologically degradable plant material is initially converted to microbial biomass which then provides the source material to soil organic matter.

The electron micrograph shows bacteria (Hyphomicrobium sp.; Yellow) growing up partly on solid surfaces, floors and sediment grains. During growth whatsoever cells die and deformed or fragmenting cell envelopes remain. Small-scale fragments of these shells (red) then set the microparticulate matrix in soils and sediments.

Miltner et al.. SOM genesis: microbial biomass as a significant source. Biogeochemistry, 2011
If soil organic matter contains higher proportion of microbial biomass carbon, is it better nutrient source?
Microbial biomass is early indicator of changes in total soil organic carbon.

Microbial biomass is indicator of how much N available to plant over season from organic matter in soil.

Microbial biomass nitrogen and release of nitrogen decreasing with depth (Murphy et al., 1998).

Crop rotation
Organic Resource Quality
Tillage
Climate
Management
Crop rotation
Organic Resource Quality
Tillage
Plant and Soil Biodiversity
Soil Properties and processes
Carbon and Nutrient Cycles
Maintaining soil structure
Nutrient Use Efficiency
Water Use Efficiency
Carbon Sequestration

NUTRIENT CYCLING: N and P
e.g., Organic matter, texture
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, NOT MATTER THE 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))
Mineral P taken up in soil solution; general microbial activity increase P availability. Mycorrhizae help find and take up.

Organic P relies on decomposition of organic material to be released.
CREATING/MAINTAINING SOIL STRUCTURE

- Climate
- Management
  - Crop rotation
  - Organic Resource Quality
  - Tillage

Plant and Soil Biodiversity

Soil Properties and processes
  - e.g., Organic matter, texture

Carbon and Nutrient Cycles

Maintaining soil structure

Nutrient Use Efficiency

Water Use Efficiency

Carbon Sequestration
SOIL STRUCTURE
Role of organic matter and microbes in creating structure: fueled by carbon inputs
Implications of structure for water movement and gas exchange

a. Well-structured soil
- Air, water and nutrients stored in pores
- Water remains near surface

b. Poorly structured soil
- Water and nutrients move very slowly down profile; air may be excluded
Management practices for managing 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 (?)

• Other soil amendments: biochar, calcium, signaling compounds?


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

• Promote symbiotic relationships with plants that short-circuit some of the soil processes providing N—less physical disturbance for mycorrhizal fungi?

• Inoculate with consortia, specific strains?….often equated with “soil biology” but evidence for efficacy is inconsistent. Lot to learn.
Indicators: what do we measure to show how we are doing?

**Figure 1. Soil function – indicator matrix:** When a direct relationship exists between the function and indicator, increasing reliability and ease of use of the associated assessment method is shown with increasing stars.

<table>
<thead>
<tr>
<th>Soil Quality Indicator</th>
<th>Sustain biological diversity, activity, and productivity &quot;D&quot;</th>
<th>Regulate and partition water and solute flow &quot;W&quot;</th>
<th>Filter, buffer, degrade, detoxify... organic and inorganic materials &quot;F&quot;</th>
<th>Store and cycle nutrients and carbon &quot;N&quot;</th>
<th>Physical stability and support for plants and... structures associated with human habitation... &quot;S&quot;</th>
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</thead>
<tbody>
<tr>
<td>Aggregate Stability^a,c,f</td>
<td>★★★</td>
<td>★★★</td>
<td>—</td>
<td>★★★</td>
<td>★★★</td>
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<tr>
<td>Available Water Capacity^a,g</td>
<td>★★★★★</td>
<td>★★★</td>
<td>—</td>
<td>★★★</td>
<td>—</td>
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<tr>
<td>Bulk density^a,h</td>
<td>★★★</td>
<td>★★★</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Infiltration^b,e,i</td>
<td>—</td>
<td>★★★</td>
<td>★</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Respiration^b</td>
<td>★★★★★</td>
<td>—</td>
<td>★</td>
<td>★★★★★</td>
<td>—</td>
</tr>
<tr>
<td>Slaking^b,g,i</td>
<td>★</td>
<td>★★★</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Soil Crusts^b,d</td>
<td>—</td>
<td>★★★</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Soil Structure and Macropores^b,d</td>
<td>★★★</td>
<td>★★★</td>
<td>—</td>
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<tr>
<td>Indicator</td>
<td>How measure</td>
<td>Why useful</td>
<td></td>
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<td>-------------------------------------------------------------------------</td>
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<tr>
<td>Who are they and who is in their communities? How diverse are they?</td>
<td>Sequencing of 16/18S rRNA: probing or PCR, including clone libraries, pyrosequencing, DNA fingerprinting, metagenomics</td>
<td>Determines WHO is there based on universal phylogenetic standard, helps understand evolutionary relationships, gives idea of “potential”</td>
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<td>How many/much are they?</td>
<td>Fumigation-extraction, PLFA, DNA, microscopic counts, quantitative PCR</td>
<td>Estimates amount of nutrients in microbial biomass. Gives an idea of how fast they carry out functions.</td>
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<td>What functions do they perform?</td>
<td>Substrate utilization, product formation (respirometry, GC, GC-MS, measure stable isotopes--natural abundance, labeled compounds).</td>
<td>Measures the actual impacts of microorganisms on environment through what they remove, release, etc.</td>
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<td>Presence/quantity of functional genes (Geochip, PCR or probing); RNA expression of functional genes</td>
<td>Measures the potential and or activity of genes responsible for specific microbial processes</td>
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<td>How are they doing?</td>
<td>ATP charge, PLFA stress markers, vital stains, RNA expression</td>
<td>Are organisms metabolically active? At full capacity? Are they stressed??</td>
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Challenges and benefits in managing soil biology rather than relying only on chemically based systems

- Much of what we think of as “soil” processes is actually biological activity.

- “Indirect” management practices often more fruitful than direct manipulation of biology

- 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 this growing season) to get it to where the positive benefits are substantial and consistent.

- Resistance/resilience of agroecosystems is largely due to biological systems

- 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 well help
Helpful tools and resources

• Oregon State University Organic Fertilizer and Cover Crop Calculator [http://smallfarms.oregonstate.edu/calculator](http://smallfarms.oregonstate.edu/calculator)


• Cornell University Soil Health Initiative [http://soilhealth.cals.cornell.edu/](http://soilhealth.cals.cornell.edu/)

• “Soils are Alive” online textbook (Australian Soil Club) [http://www.soilhealth.com/soils-are-alive/](http://www.soilhealth.com/soils-are-alive/)

• Sustainable Soil Management (Appropriate Technology Transfer for Rural Areas) [http://www.soilandhealth.org/01aglibrary/010117attrasoilmanual/010117attra.html](http://www.soilandhealth.org/01aglibrary/010117attrasoilmanual/010117attra.html)

• Film: Symphony of the Soil [http://www.symphonyofthesoil.com/](http://www.symphonyofthesoil.com/)