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Soil Biology and Organic Pest Management
ENT 401
November 30, 2009
Contents

A. The Soil Biology Primer

B. Birkhofer et al. 2008. Long-term organic farming fosters below and aboveground biota...

Soil food web: Prokaryotes (archaea and bacteria)

• Passive dispersal
  – Water channels and soil organisms for movement
• High absorptive surface area:volume
  – Efficient nutrient scavengers
• Single cells in direct contact with surrounding environment
  – Susceptible to osmotic perturbations at microscale (1 um = 0.001 mm)
• Limited to diffusion of C and nutrients
  – Cannot actively explore soil habitat

*Spirillium* is a better competitor than *Pseudomonas* (rods) when substrate is limiting
Soil food web: Bacteria

- Biological N fixation
- Primary consumers of simple C substrates (sugars and cellulose)
- Specialized groups (e.g. actinomycetes) break down more recalcitrant soil organic matter (S.O.M) (e.g. lignin)
- K-strategists: many offspring and high turnover
- Biofilms: important in colonization, env. modification (N fixation), protection, soil aggregation
- Unknown diversity
  - >99% spp. are not cultivable (Torsvik et al. 1990)
  - Molecular methods: bypass cultivation requirement
  - Uncultivable species less amenable to experimental manipulation
  - Overall, more diverse than soil eukaryotes
Soil food web: Archaea

- Extremophiles (temperature, redox state)
- Ubiquitous mesophiles, including soils
- Most species are not culturable
- Functions inferred via gene copy number, lipid profiles, and few culturable representatives
- Important ammonia oxidizers ($\text{NH}_4^+ \rightarrow \text{NO}_2^-$) in some soils
  - Functional redundancy with ammonia-oxidizing (nitrifying) bacteria
Soil food web: fungi

• Mycelium (body) composed of hyphae (tubular cells), each divided by septa
  – Compartmentalization
    • Cytoplasm concentrated at actively growing hyphal tips
    • Allows exploration at minimal cost
  – Tissue differentiation
    • Cells specialized for symbiosis (haustoria), pathogenicity (appressoria), reproduction (various sexual and asexual spores)

• Produce wide array of extracellular enzymes
Soil food web: microfauna, mesofauna, and macrofauna

- Microfauna
  - Protozoa
    - Amoebae, ciliates, flagellates
    - Bacterial grazers
    - Nitrogen mineralization: excrete about 1/3 N consumed
  - Nematodes
    - 4 feeding groups
      - Fungivores, bacteriavores, herbivores, predators
Soil food web: microfauna, mesofauna, and macrofauna

• Mesofauna
  – Arthropods
    • Collembola, mites
    • Fungal grazers, o.m. shredders
  – Enchytraeids
    • Similar role to earthworms in acid soils

• Macrofauna
  – Earthworms, ants, termites
  – Ecosystem engineers
  – Shred large organic matter particles, expose area to decomposers (fungi and bacteria)
Spacial heterogeneity of soil

- intraaggregate (< 1 um) archaea and bacteria
- rhizosphere (microbes and microfauna)
- soil pore space (~ 50 um; microbes, micro- and mesofauna)
- create own habitat (macrofauna)
- vs. bulk soil (black box approach)
<table>
<thead>
<tr>
<th>Organism</th>
<th>Soil $\psi$ matric, -MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plants</td>
<td></td>
</tr>
<tr>
<td>Sunflower</td>
<td>1.5</td>
</tr>
<tr>
<td>Creosote bush</td>
<td>5.0</td>
</tr>
<tr>
<td>Soil Heterotrophs</td>
<td></td>
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<tr>
<td>Fungi</td>
<td>3.0</td>
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<tr>
<td>Bacteria</td>
<td>2.0</td>
</tr>
<tr>
<td>Nematodes</td>
<td>0.15</td>
</tr>
<tr>
<td>Protozoa</td>
<td>0.10</td>
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</tbody>
</table>

NB: Field capacity = 0.01 MPa; Wilting point = 1.5 MPa
S.O.M. carbon structure, size class, and microbial processing

- Most soil S.O.M. has undergone microbial processing
- S.O.M. is stabilized by physical (through adsorption and aggregation) rather than biochemical means
- Active S.O.M. is mainly plant-derived
Amendment C:N ratio, quality and soil nitrogen turnover

- Average microbe C:N = 10:1
- C respired = 50% inefficiency
- N mobilized (made available) if substrate C:N < 20
- N immobilized if substrate C:N > 20
- does not hold for recalcitrant O.M. (lignin, humus)

<table>
<thead>
<tr>
<th>Material</th>
<th>C:N</th>
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<tbody>
<tr>
<td>Soil</td>
<td>10–12</td>
</tr>
<tr>
<td>Poultry manure</td>
<td>10</td>
</tr>
<tr>
<td>Clover and alfalfa (early)</td>
<td>13</td>
</tr>
<tr>
<td>Compost</td>
<td>15</td>
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<tr>
<td>Dairy manure (low bedding)</td>
<td>17</td>
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<tr>
<td>Alfalfa hay</td>
<td>20</td>
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<tr>
<td>Green rye</td>
<td>36</td>
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<tr>
<td>Corn stover</td>
<td>60</td>
</tr>
<tr>
<td>Wheat, oat, or rye straw</td>
<td>80</td>
</tr>
<tr>
<td>Oak leaves</td>
<td>90</td>
</tr>
<tr>
<td>Fresh sawdust</td>
<td>400</td>
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<tr>
<td>Newspaper</td>
<td>600</td>
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</tbody>
</table>
Birkhofer et al. 2008
“Long-term organic farming fosters below and aboveground biota: Implications for soil quality, biological control and productivity”

Study rationale and objectives

– Agroecosystems require nutrient inputs for sustained yields
– DOK trial: 30-year comparison of organic and conventional farming and fertilization practices
– Previous DOK trial results: organic fertilizer promotes bacteria and AM fungi
– Current objectives:
  • Are soil food web organisms and their functions affected by management (organic vs conventional) and fertilization practices?
  • Does enhanced soil food web function translate aboveground?
Birkhofer et al. 2008

“Long-term organic farming fosters below and aboveground biota: Implications for soil quality, biological control and productivity”

Treatments

BIODYN

Organic pest management + composted manure + biodynamic preparations (e.g. pebble with horsetail)

BIOORG

Organic pest management + rotted manure

CONORG

Synthetic pest management + stacked manure + synthetic fertilizer

CONMIN

Synthetic pest management + synthetic fertilizer
Birkhofer et al. 2008

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Variables

– Soil chemistry
  • pH, C, N

– Microorganisms
  • Fungal and bacterial biomass
  • Basal respiration, growth parameter (A), maintenance parameter (C)
  • Potential N mineralization

– Soil fauna
  • Flagellates, naked amoebae, nematodes, enchytraeids, others

– Aboveground fauna and vegetation
  • Vegetation-based fauna
  • Surface-active fauna
  • Diversity and evenness indices
  • Grain and straw yield
Birkhofer et al. 2008

“Long-term organic farming fosters below and aboveground biota: Implications for soil quality, biological control and productivity”

Preplanned comparisons

1. Conventional vs organic
2. Stockless vs mixed
3. Conventional + manure vs organic
4. Conventional, no manure vs all manure treatments
5. Compost-based organic vs manure-based organic
Birkhofer et al. 2008

“Long-term organic farming fosters below and aboveground biota: Implications for soil quality, biological control and productivity”

• Results
  – Most soil parameters (microbial abundance and activity, soil fauna) improved in BIODYN, BIOORG, CONFYM
  – Higher basal respiration in CONMIN vs. BIODYN and BIOORG
    • Higher C availability and lower microbe efficiency in CONMIN?
  – No differences in mycorrhizal NFLA and protozoa abundance
    • Mycorrhizal functional differences?
  – Higher aboveground predator abundance in BIODYN and BIOORG
    • And lower pest (aphid) abundance...
  – Higher grain and straw yields in CONMIN
Conclusions

- Cascading effects of enhanced soil food web on aboveground faunal abundance
  - Manure additions indirectly affect aboveground ecosystem services
- Soil C unchanged in CONFYM despite 2278 kg C ha\(^{-1}\) yr\(^{-1}\)
  - Synthetic N -> preferential loss of active soil C?
  - Synthetic N -> reduced aggregate stability and S.O.M. protection?
- Reduced soil quality and increased pest susceptibility in conventional farming does not justify increased yields?
What are mycorrhizae?

• Present in >90% of plant species
  – Ectomycorrhizae (EC)
    • basidiomycetes, some ascomycete fungi
    • Extra-radical mantle, intercellular Hartig net
    • Forest trees
  – Arbuscular mycorrhizae (AM)
    • Zygomycota (Glomeromycota)
    • Grasses, most agricultural crops
  – Other types
    • (Ericoid, ectendo-, orchid, arbutoid, DSE)

• Structure implies function!
  • Plant assimilation of N (0-90%), P (0-85%), and micros taken up by fungus
  • Reciprocal transfer of plant C (4-20%) to symbiotic fungus
arbuscule

AM fungi binding soil aggregate
Does synthetic fertilization alter mycorrhizal mutualisms?

Allen et al. 2003
Does synthetic fertilization alter mycorrhizal mutualisms?

AM fungi from fertilized plots required the same “costs” (root C allocation and vesicles), but with reduced “benefits” (shoot growth and arbuscules).  

Johnson 1993
Soil: not just a “black box” of dirt

- Few things matter more to humans than their relations with the soil. Despite this, soil remains the least understood, and perhaps most abused habitat on earth.