Impacts of microbes and biochar on soil health

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Video showing decomposition in compost and soil

https://www.facebook.com/earthwormsoc/posts/1945299029030730
What is “soil health”?

Services:
• Efficient nutrient use
• Building and regeneration
• Strong skeleton/musculature
• Disease prevention

Self-maintaining

Services:
• Efficient/tight nutrient cycles
• C transformations
• Soil structure maintenance
• Disease/pathogen resistance

Self-maintaining

www.theatlantic.com/health/archive/2013/06/healthy-soil-microbes-healthy-people/276710/
How microorganisms contribute to agricultural ecosystems (the good, the bad and the ugly)
Our understanding of SOM formation and stability has changed. Microbes are drivers and also “feedstock” for SOM.
Studies estimate that ~ 80% of SOC can be derived from microbial biomass.
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Biological processes are very important to aggregate formation, particularly at larger (microaggregate) scales and in low clay soils.
Well-structured soil allows for more storage and movement of water and gases, and habitat for organisms.

(a) Well-structured soil

- Large pores
- Air, water, and nutrients stored in pores
- Water remains near surface
- Water and nutrients move very slowly down profile; air may be excluded

(b) Poorly structured soil

- Very small pores

Managing the N cycle means managing microbes.
The Soil Food Web

First trophic level: Photosynthesizers
Second trophic level: Decomposers, Mutualists, Pathogens, Parasites, Root-feeders
Third trophic level: Shredders, Predators, Grazers
Fourth trophic level: Higher level predators
Fifth and higher trophic levels: Higher level predators
<table>
<thead>
<tr>
<th>Aggregate Ecosystem Functions</th>
<th>Functional Assemblages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C Transformations</strong></td>
<td>• Decomposers</td>
</tr>
<tr>
<td></td>
<td>• Fungi, bacteria, microbivores, detritivores</td>
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<tr>
<td><strong>Nutrient cycling</strong></td>
<td>• Nutrient transformers</td>
</tr>
<tr>
<td></td>
<td>• Decomposers, element transformers, N-fixers, mycorrhizae</td>
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<tr>
<td><strong>Soil structure maintenance</strong></td>
<td>• Ecosystem engineers</td>
</tr>
<tr>
<td></td>
<td>• Megafauna, macrofauna, fungi, bacteria</td>
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<tr>
<td><strong>Biological population regulation</strong></td>
<td>• Biocontrollers</td>
</tr>
<tr>
<td></td>
<td>• Predators, microbivores, hyperparasites</td>
</tr>
</tbody>
</table>
Does soil biodiversity matter?
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The more diversity in each function, the wider our “latitude of health” or resilience.
So how do we manage soil for microbes?

Feed them

- More **carbon** inputs to soil
  - Compost
  - Cover crops
  - Crop residues
  - Living roots
  - Biochar (?)

House them

- Create conditions that favor **aggregation** formation
  - Smart timing/amount of tillage
  - Increased microbial biomass and activity

There are still many questions regarding changes in microbial diversity and composition and what they **really mean**.
Biochar characteristics

**Biochar**: Thermal degradation of an organic feedstock through pyrolysis under low/no $O_2$ conditions.

![Biochar image](image-url)

- **Production Temperature**
  - Stability
  - pH
  - Surface area

![Biological images](image-url)

Tan et al., 2015 (biomass image); Lehmann & Joseph, 2009; Mukome et al., 2013 (SEM image)
Soil variables affecting organisms

• Soluble carbon
• Nutrient availability
• pH
• Pore space
• Sorption potential – enzymes, signaling, nutrients, toxins
• Soil moisture
• Presence of inhibitory compounds and contaminants

• Changes in:
  • Microbial abundance
  • Microbial activity
  • Community composition
Effects of biochar on microbes

Change also depends on the soil you’re adding it to

- Substrate bioavailability
- Sorption of allelopathic compounds
- Disruption of quorum sensing

- C and N mineralization rates
- Microbial habitat and growth

- Nutrient solubility
- Microbial biomass & composition
- Microbial processes sensitive to pH

Modified from Lehmann et al., Soil Biol Biochem, 2011
What can happen when biochar changes pH?

- Affects **nutrient** availability
  - Could increase or decrease
- **Microbial biomass** tends to increase with increasing pH
- Many microbial processes sensitive to pH
  - Nodulation and N fixation
  - Nitrification
Anticipated effects of raising pH from 3-4 to 5-6 with biochar

McCormack et al., GCB Energy, 2013
Sometimes biochar adds a C and nutrient source

- Short term burst of activity from soluble C?
- *Co-location* of enzymes, C compounds, and microbes?

**Graphs:**

- **C and N released from biochars**
- **Cumulative CO₂ evolution (μmol CO₂ kg⁻¹)**
  - Soil
  - Soil + biochar
  - Soil + water washed biochar
  - Soil + plastic chips
  - Greater respiration when biochar is added

**References:**

- Jones et al., *Soil Biol Biochem*, 2011
- Mukherjee and Zimmerman, *Geoderma*, 2013
In other cases, there can be decreased microbial activity

- **Lower** net N mineralization and nitrification rates
  - Lower microbial biomass?
  - Sorption of ammonium (NH$_4^+$)?
  - Negative priming of SOM?

![Graph showing inorganic N (mg N kg$^{-1}$) vs. incubation period (Weeks) with different biochar additions](image)
Changes in microbial community composition

Grossman et al., *Microbial Ecology*, 2010

Steinbeiss et al., *Soil Biol Biochem*, 2009
Increased microbial biomass but not activity

- Biochar didn’t affect C transformations
- Higher microbial biomass in high biochar may be due to increased soil moisture content

Domene et al., *Soil Biol Biochem*, 2014
Fungal hyphae growing within biochar pores

Bacterial cells clinging to biochar surfaces
Mycorrhizal colonization

- Increased colonization with biochar
- But decreased biomass at high N + biochar treatment
- Biochar causing parasitic activity by mycorrhizae?

LeCroy et al., *Soil Biol Biochem*, 2013
Surface Area and Sorption Capacity

- Surfaces for biofilm formation and attachment
- Sorption of inhibitory compounds
- Sorption of signaling compounds
- Lower substrate bioavailability?

E. Coli attached to activated carbon

Decreased response with increased surface area
Legume-Rhizobia Signaling Process

1. Flavonoid
2. NodD activation
3. LCO Nod Factor
4. Plant root
Can biochar interfere with this process?

Biochar interferes with LCO Nod Factor activation.

No NodD activation.
**Number of nodules per plant**

![Bar chart for Silt loam and Sand treatments](chart.png)

Figures 1 and 2. Mean ± SE.

**Conclusions**

- Walnut shell biochar has the potential to reduce nodulation in cowpeas
- Important to compare to biochars of other feedstocks/pyrolysis temperature
- Repeat experiment with method of pH adjustment for limed controls
Can we use biochar to manage microbes?

- Inoculant carrier
- Reduce pathogens

Concerns:
- Toxic volatile matter
- Salts
- Heavy metals

Can we manipulate biochar to have the right characteristics?
- Microbes are affecting biochars’ fate just as it affects them
- At what timescale is biochar having effects?

Elmer et al., *Plant Disease*, 2011
Take-home messages

- **Healthy** soils provide food/fiber while also...
  - Storing carbon
  - Cycling nutrients
  - Creating strong soil structure
  - Resisting pathogens

- **Soil organisms** play a key role in all of these services

- **Some biochars** may increase microbial activity and desired functions, but not for all biochar/soil combinations
Thank you!


