Microbial ecology of biochar-amended soils

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Crop and Soil Sciences
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10/9/2010
Thies and Jin, 2010
Outline

- Terra preta
  - Soil microbial dynamics
- Biochar-amended temperate soil
  - Cautionary notes
  - Soil and rhizosphere microbial dynamics
- C conserving pathways

Thies and Jin, 2010
‘Bitten’ by the biochar ‘bug’

Hatahara
Açutuba
Lago Grande
Dona Stella
2003

1st International Biochar Conference
Manaus, Brazil, 2001

Embrapa, 2001

Photo Thies © 2003

Johannes Lehmann

Thies and Jin, 2010
Higher bacterial abundance, diversity and actinomycete recovery


Significant changes in bacterial and archael diversity


Significantly lower respiration

• both basal and after addition of sugarcane residue

Stabilization of labile C by black C


Thies and Jin, 2010
Cumulative carbon mineralization of soils with high and low BC and with and without additions of sugar cane during a 10-month incubation (means and standard errors, n=4). Liang et al. (2009)
Field Design

Lehmann et al.

- Cornell Musgrave Farm, Aurora, NY, 2007
- Corn stover biochar incorporated into soil at 0, 1, 12, 30 t biochar ha\(^{-1}\)
- Corn planting density = 32,000 seeds acre\(^{-1}\)
- NH\(_4\)NO\(_3\) applied at 0.13 t ha\(^{-1}\) to each plot
- Bulk & rhizosphere soils sampled midsummer 2007 & 2008
- Best Energies corn stover biochar: slow pyrolysis at 600°C
- Honeoye silt loam

Thies and Jin, 2010
Biochar Amended Soil

Field samples

Biochar particles

Microbial biomass

Microbial respiration

DNA extraction

Exoenzyme activity

Exoenzyme Localization

Microbial activity

Microbial community composition

Bacterial 16S rRNA PCR

Fungi ITS PCR

Clone library

Sequencing

Fungi colonizing biochar surfaces

T-RFLP Fingerprinting

Exoenzyme dynamics

Adsorption!

Microbial abundance

Thies and Jin, 2010
Equilibrium isotherms for each rate, fitted to the Freundlich equation and used to adjust microbial biomass estimates.
Microbial biomass

Thies and Jin, 2010

Graph showing microbial biomass C (µg g⁻¹ soil) across different treatments and locations (Bulk and Rhizosphere), with comparison to 0, 1, 12, and 30 t ha⁻¹.
Soil respiration

Bulk

Rhizosphere

Thies and Jin, 2010
Possible mechanisms underlying observed reductions in soil respiration & metabolic quotient

- Changes in substrate quality (↑↑) and/or quantity (↓↓)
- Changes in the composition of the biotic community (e.g., increased fungal/bacterial ratio [15:1, 5:1, C:N])

Thies and Jin, 2010
Thies and Jin, 2010

Bacteria - 2008

A Bacteria digested by HhaI

[12 & 30 t ha⁻¹]

[0 and 1 t ha⁻¹]
2007 vs. 2008

Bacteria digested by HhaI

Fungi digested by HhaI

Thies and Jin, 2010
Fungal sequences

% Sequenced clones

Ascomycota
Basidiomycota
Zygomycota
Others

Control
Biochar

Thies and Jin, 2010
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- Changes in the diversity of the microbial community

Thies and Jin, 2010
Exoenzyme activity
MUF-P and MUF-G

Phosphatase activity

β-D-glucuronidase activity

Thies and Jin, 2010
Adsorption

Thies and Jin, 2010
Enzyme activities

Alkaline phosphatase activity was very high in biochar amended soils.

β-D-glucosidase activity was much lower in biochar amended soils.

Thies and Jin, 2010

<table>
<thead>
<tr>
<th>Incubation time</th>
<th>Treatments</th>
<th>Alkaline phosphatase</th>
<th>β-D-Glucosidase</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Km+Sn (uM)</td>
<td>Vmax (nmol·cm⁻³·h⁻¹)</td>
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<td>30 min</td>
<td>CT</td>
<td>50.36</td>
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<td>Low</td>
<td>60.05</td>
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### Enzyme activities

<table>
<thead>
<tr>
<th>Incubation time</th>
<th>Treatments</th>
<th>β-D-Cellobiosidase</th>
<th>L-Leucine aminopeptidase</th>
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<tr>
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<td>Km+Sn (uM)</td>
<td>Vmax (nmol·cm⁻³·h⁻¹)</td>
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<td>30 min</td>
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<td>276.49</td>
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<td>316.17</td>
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<td>125.12</td>
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<td>78.08</td>
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<td>458.33</td>
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<td>289.11</td>
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<td>148.22</td>
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L-Leucine aminopeptidase activity was higher in biochar amended soils. β-D cellobiase activity was much lower in biochar amended soils.

Thies and Jin, 2010
Alkaline phosphatase

β – D glucuronidase

Phosphatase

Thies and Jin, 2010
Enzyme-linked fluorescence (ELF)

Phosphatase activity

β-D-glucuronidase activity

Thies and Jin, 2010
Co-location increases C use efficiency

Inorganic nutrients

Microbes

Organic matter

Exoenzymes

Thies and Jin, 2010
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- Changes in the diversity of the microbial community
- Co-location of substrates, microbes, and their exoenzymes resulting in increased C use efficiency
- Carbon recycling within microbial biofilms
- Reduced efficiency of (or need for) some C mineralizing enzymes – methodological artifact?

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- Increased activity of autotrophs, particularly nitrifiers
- Participation in the carbonate cycle

Thies and Jin, 2010
Autotrophic nitrification

- $\text{NH}_4^+ + 1.5\text{O}_2 \rightarrow \text{NO}_2^- + \text{2H}^+ + \text{H}_2\text{O}$
  - Nitroso- 65 kcal/mole 6e-

- $\text{NO}_2^- + \text{H}_2\text{O} \rightarrow \text{NO}_3^- + \text{2H}^+$
  - Nitro- 17-18 kcal/mole 2e-

- H$^+$ used to generate reducing potential needed to fix CO$_2$ into carbohydrates.

Thies and Jin, 2010
Carbonate-silicate pathway

- $\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^- \rightleftharpoons \text{H}^+ + \text{CO}_3^{2-}$
  - carbonic acid
  - bicarbonate
  - carbonate

- Weathering of calcium silicates
  - $\text{CaSiO}_3 \rightarrow \text{Ca}^{2+} + \text{SiO}_2 + \text{O}$

- Formation of calcium carbonate
  - $\text{Ca}^{2+} + \text{HCO}_3^- \rightarrow \text{CaCO}_3 + \text{H}^+$

Thies and Jin, 2010