The effects of biochar interpores and intrapores on soil-gas transport

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Gas transport and biochar

• In many soils, biochar enhances water retention.
  • This could reduce gas transport, as more water is held in pores.

• If gas diffusion can be maintained, this is beneficial for agriculture industry & waste minimization industry

✓ Gas diffusion can minimize CH$_4$
✓ Gas diffusion increases plant growth w/ enhanced water retention
✓ Gas diffusion increases microbial respiration
Gas transport and biochar

• Past work:
  • Biochar *increases* gas diffusion [Sun, 2013]
  • Biochar *decreases* gas diffusion [Arthur, 2017]
  • Biochar has *no affect* on gas diffusion [Amoakwah, 2017]

• Fundamental understanding of the mechanism is needed
The effects of biochar on soil-gas transport

Biochars change pore characteristics of soils. Biochars have intrapores that vary with feedstock and pyrolysis conditions. Biochars can affect interpores that change pore throat sizes. Air filled porosity describe gas properties.

Hypothesis:
Gas diffusion is controlled by air filled interporosity. Even if air-filled interporosity is the same, biochar particles are more angular increasing tortuosity.
Materials

Biochars

- Poultry Litter Biochar (PLBC)
  - 300°C
  - 0.5 mm < $d_p$ < 0.595 mm

- Soil Reef (pinewood) Biochar (SRBC)
  - 550°C
  - 0.5 mm < $d_p$ < 0.595 mm

Media

- Sand
  - 0.5 mm < $d_p$ < 0.595 mm

- Sandy Loam
  - 0.02 mm < $d_p$ < 9.5 mm
Intrapore Size Determination Techniques
Methods

Volumetric Water Content

Water suction pressure (pF)

Tension Table

Saturation to Field Capacity

Pressure Plate Extractor

Field Capacity to Wilting Point

WP4C Dewpoint Potentiometer

Sorbed Water
Fick’s law of diffusion

\[ J = -D_p \nabla C_g \]

- \( J \) = diffusion flux
- \( D_p \) = diffusion coefficient
- \( \nabla \) = gradient operator
- \( C_g \) = concentration of gas
Methods - Diffusion cell

Packed sample (Control, Control + 7%BC)

Helium

Gas Chromatograph

\[ D_p = - \ln \frac{C_r \varepsilon}{\alpha_1^2} \]
Results

<table>
<thead>
<tr>
<th>Sample type</th>
<th>SSA(^a) m(^2) g(^{-1})</th>
<th>Intrapore volume mL g(^{-1})</th>
<th>Biochar air entry pressure pF = log(-h, cm-H(_2)O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poultry litter biochar</td>
<td>1.53 ± 0.15</td>
<td>0.23 ± 0.01</td>
<td>1.9 ± 0.1</td>
</tr>
<tr>
<td>Pinewood biochar</td>
<td>350 ± 30</td>
<td>0.83 ± 0.01</td>
<td>1.9 ± 0.1</td>
</tr>
</tbody>
</table>

\(^a\) specific surface area  
\(^b\) standard error
Gas diffusion at the same matric potential

- The total air filled porosity doesn’t increase with biochar
- This is from water held in pores despite higher total porosity
- At the same pF values around 1.5, biochars have lower diffusivity than sand
- PLBC = poultry litter biochar
- SRBC = pinewood biochar
Results – Relative gas diffusion (sand)

![Graph showing relative gas diffusion](image_url)
Geometric characteristics of sand & biochar

Sand  Poultry litter biochar  Pinewood biochar
X-ray tomography image (Mills et al, 2018)

Sand + pinewood biochar
X-ray tomography study (Mills et al, 2018)
Sand+Pinewood Biochar: extracted segmented volume
(4.9 x 4.9 x 4.9 mm³)

(Mills et al., 2018)
### Percentage Phase Composition (Mills et al., 2018)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Sand(new): %volume</th>
<th>Biochar: %volume</th>
<th>Void: %volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand + Biochar (X-ray)</td>
<td>38.2</td>
<td>12.24</td>
<td>49.5</td>
</tr>
<tr>
<td>Pure Sand (X-ray)</td>
<td>59.4</td>
<td>0</td>
<td>40.6</td>
</tr>
<tr>
<td>Sand + Biochar (EXP)</td>
<td>39.86</td>
<td>12.94</td>
<td>47.20</td>
</tr>
<tr>
<td>Pure Sand (EXP)</td>
<td>61.73</td>
<td>0</td>
<td>38.27</td>
</tr>
</tbody>
</table>

- Sand has lower total (entire volume) and effective (multiple sub volumes) porosity compared to the Sand + Biochar data sets.
- The experimental and simulated porosity values are approximately equal.
The effect of biochar on pore radii

(Mills et al., 2018)
Results – Relative gas diffusion (sandy loam)
Gas diffusion at the same matric potential

- The total air filled porosity was not improved
- This is from water held in pores despite higher total porosity
- Biochars have similar diffusivity than sandy loam
- Biochars did not decrease in diffusivity unlike sand
Summary

• **In Sand:**
  • Particle sizes were sieved to the same size
  • Biochar shapes were not uniform
    • Interpores were reduced with biochar, which reduced diffusion in sand.
    • Intrapores stored water, reduced diffusion
      • Biochar increases tortuosity

• **In SL:**
  • Biochars shift the particle size distribution increasing air-filled interpores
    • Biochars (~0.5mm)
    • SL (74% particles > 0.075 mm, 13% particles 0.005-0.05 mm, 13% (<0.005 mm)
  • Biochar alters both interpore and intrapores
  • Intrapores reduce gas diffusion from the particle geometry. Increase particle size of BC to increase gas diffusion to control pore sizes
  • Adding biochar may not increase gas transport at the same air-filled porosity
  • Lower diffusivity may imply lower GHG emissions from soil
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X-ray tomography study (Mills et al, 2018)