Plants possibility to control gas exchanges via mucilage

Adrian Haupenthal, Mathilde Brax, Klaus Schützenmeister, Hermann Jungkunst, Jonas Bentz, Eva Kröner
Motivation

- Soil respiration is an important factor for plant growth and soil $O_2$ and $CO_2$ exchanges with atmosphere.
- Mucilage plays a key role in shaping the physical properties of the rhizosphere.

How does mucilage affect soil gas diffusion?
Mucilage – a rhizodeposition

- **Chia seed mucilage** as a model for plant mucilage
- Similar physical properties as plant mucilage:
  - Can hold large amounts of water
  - More **viscous** as maize or barley mucilage
- Freeze-dried and pulverized after collection
State of the art

Diffusion:
• Main process for gas movement in soil.
• **Most important factor** for controlling soil-gas diffusion is the gas diffusion coefficient $D$ ($cm^2/s^{-1}$).
• $D$ highly depends on air-filled pore-connectivity and tortuosity.

Model for root respiration (Ben-Noah and Friedman, 2018 VZJ):
• Diffusive resistance of the *mucilage* layer is one of the dominant factors in determining respiration rate.
• Thickness of *mucilage* is limiting respiration rate.
• But increasing viscosity of drying mucilage is expected to have a much higher influence -> diminishing positive effect of reducing mucilage thickness at lower water potentials.

Existing models treat mucilage as an uniform layer coating the root.
Environmental Scanning Electron Microscopy

- Glass beads, diameter: 0.2mm
- Mixed with chia seed mucilage
- Oven-dried for 24h at 30° C
- Concentrations: 0.16%; 0.25%; 0.49%
- Chamber pressure: 60 – 80 Pa
- Acceleration voltage: 12.5 – 15 kV

https://www.fei.com/products/sem/quanta-sem/
(a), (d) 0.16%: thin filaments span throughout the pore space

(b), (e) 0.25%; (c), (f) 0.49%: mucilage forms hollow cylinders up to interconnected surfaces

During drying mucilage forms liquid bridges between particles
Hypothesis:
- At low concentration of mucilage, thin filaments have a small effect on gas diffusion.
- At high concentration, mucilage is able to block pores, disconnecting the gas phase and reduce gas diffusion significantly.
Soil samples

- Soil particle size: 500-630 µm
- Mixed with chia seed mucilage
- Dry chia seed mucilage was diluted in water
- Amount of water was according to soil maximum water capacity
  ➔ No change in porosity during drying
- Concentrations: 0%; 0.1%; 0.3%; 0.6%
- Drying for 48 h at 20°C ± 1°C
  ➔ Gravimetric water content < 1%

<table>
<thead>
<tr>
<th>Weight</th>
<th>Volume</th>
<th>Area</th>
<th>Height</th>
<th>Bulk density</th>
<th>Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 g</td>
<td>5.77 cm³</td>
<td>9.62 cm²</td>
<td>0.6 cm</td>
<td>1.74±0.01 g cm⁻³</td>
<td>0.34±0.01 cm³ cm⁻³</td>
</tr>
</tbody>
</table>
Gas diffusion measurements

- **Gas diffusion coefficient** $D_p$ as a function of mucilage
- Diffusion chamber method (Rolston and Moldrup 2002)
- Tracer gas: **Oxygen**; diffusion coefficient in free air $D_0 = 0.231 \, cm^2 s^{-1}$
- Temperature: **20°C ± 1°C**
Gas diffusion measurements
Gravimetric water content < 1%

Diffusion coefficient decreases with increasing mucilage concentration
Summary

• During drying mucilage forms liquid bridges between soil particles
• With increasing mucilage concentration gas diffusion coefficient decreases

Next Steps

• We look forward to gain a better understanding of the influence of mucilage on soil gas diffusion using experimental and modelling techniques
• Variation of soil and mucilage properties, e.g. particle size distribution, water content, mucilage type,…
• How interactions with microbial communities additionally alter how plants control soil gas exchanges