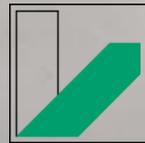


Pascal Benard, Mohsen Zarebanadkouki,  
Mutez Ahmed, Andrea Carminati, *Soil Physics*



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# High viscosity of polymer solutions supports life in soil hotspots

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## Polymer solutions (EPS and mucilage) alter the spatial configuration of the liquid phase in soil hotspots.

Plant roots and bacteria alter the soil physical properties by releasing a polymeric blend of substances. Despite extensive knowledge of their ecological importance, the physical mechanisms by which these polymers alter the spatial configuration of the liquid phase and the related hydraulic and biogeochemical properties remain unclear.

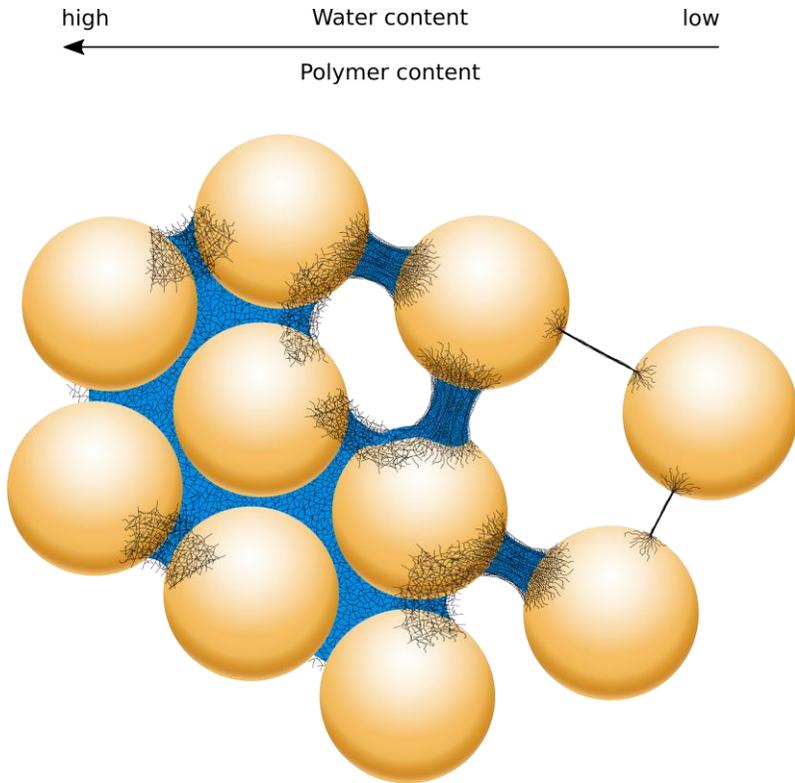
Unlike water, primarily shaped by surface tension, polymer solutions remain connected upon drying in soils thanks to their high extensional viscosity. The integrity of one-dimensional structures and formation of two-dimensional surfaces is explained by the interplay of viscosity, surface tension and water adsorption.

*Benard et al. 2019 VZJ*

*Examples of polymeric structures formed by mucilage and extracellular polymeric substances (EPS) in porous media: (a) light microscope image of threads of mucilage (mucilage content =  $4.5 \text{ mg g}^{-1}$  [mg dry mucilage per g of particles]) formed across a large pore during drying; (b) light microscope image of cylinder formed between neighboring glass beads (1.7–2 mm in diameter) at intermediate mucilage content ( $0.7 \text{ mg g}^{-1}$ ); (c) two-dimensional EPS-based structures joining quartz grains in intact biocrusts imaged with synchrotron-based X-ray tomographic microscopy (Couradeau et al., 2018), where high EPS content resulted in the formation of characteristic structures (red arrows) comparable with those formed by maize mucilage (the blue arrow marks a cyanobacterial bundle with the EPS sheath surrounding the trichomes of *Microcoleus vaginatus*); (d) cross-section through a synchrotron-based X-ray tomographic microscopy volume of dry maize mucilage structures in glass beads (bright circles) (mucilage content =  $8 \text{ mg g}^{-1}$ ; glass bead diameter = 0.1–0.2 mm); and (e) three-dimensional segmentation of dry mucilage structures (red) from (d) that formed interconnected surfaces of  $\sim 1\text{-}\mu\text{m}$  thickness within the pore space of glass beads (blue).*

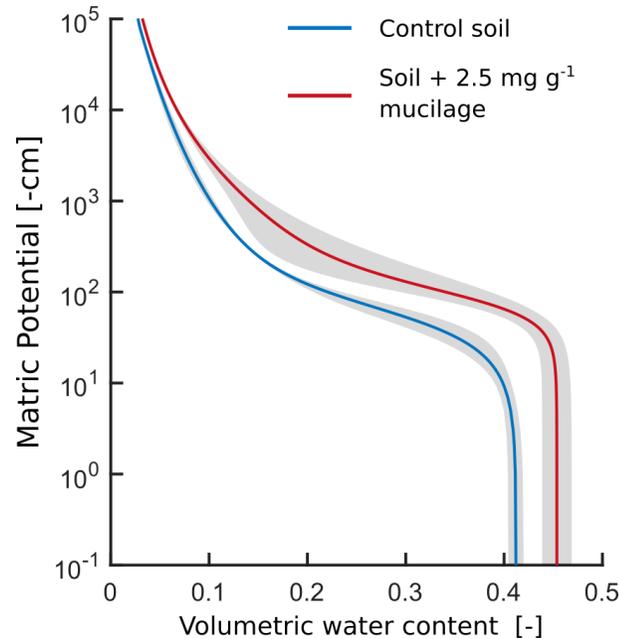
# Consequences for soil water dynamics

Polymer solutions adsorb water, increase viscosity and decrease the surface tension of the liquid phase. This induces the formation of 1D and 2D interconnected structures in soils, which increase soil water retention, soil hydraulic conductivity and diffusion.

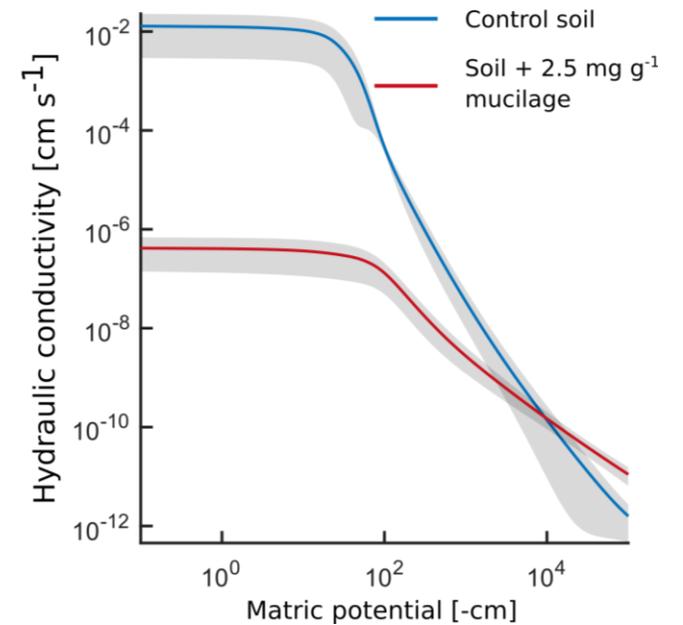


Benard et al. 2019 VZJ

## Chia seed mucilage in loamy sand



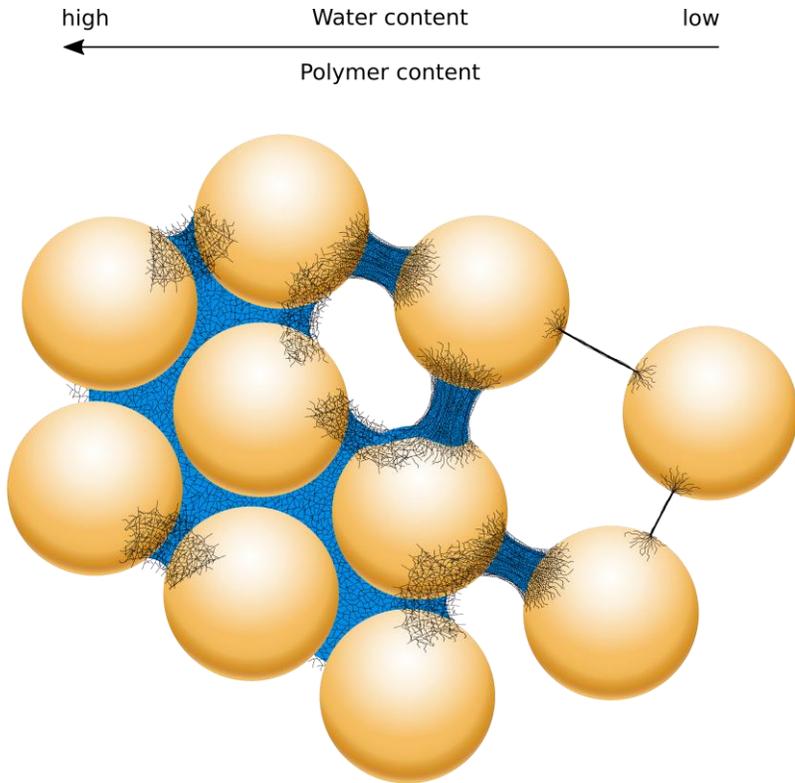
Enhanced retention



Lower  $K^{sat}$  but smaller decrease in  $K(h)$

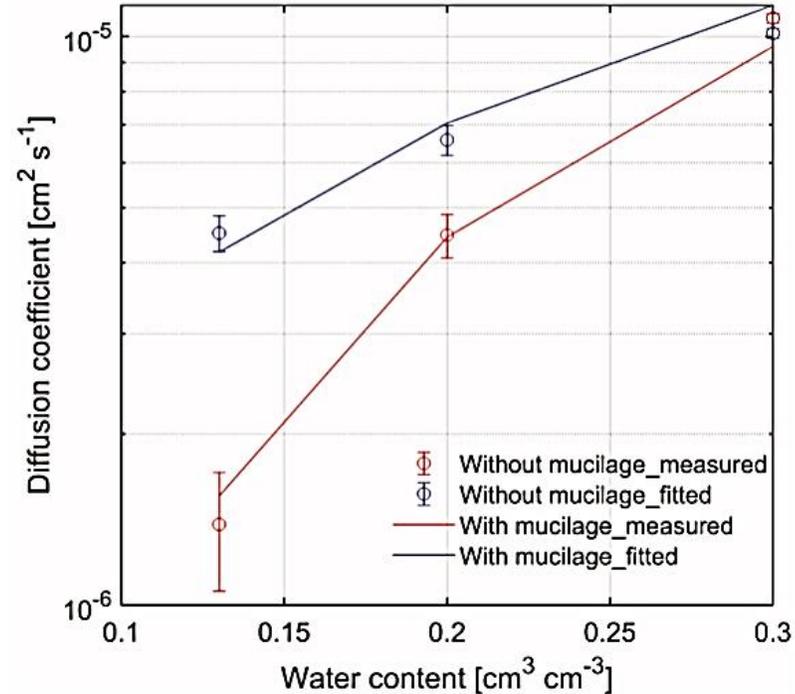
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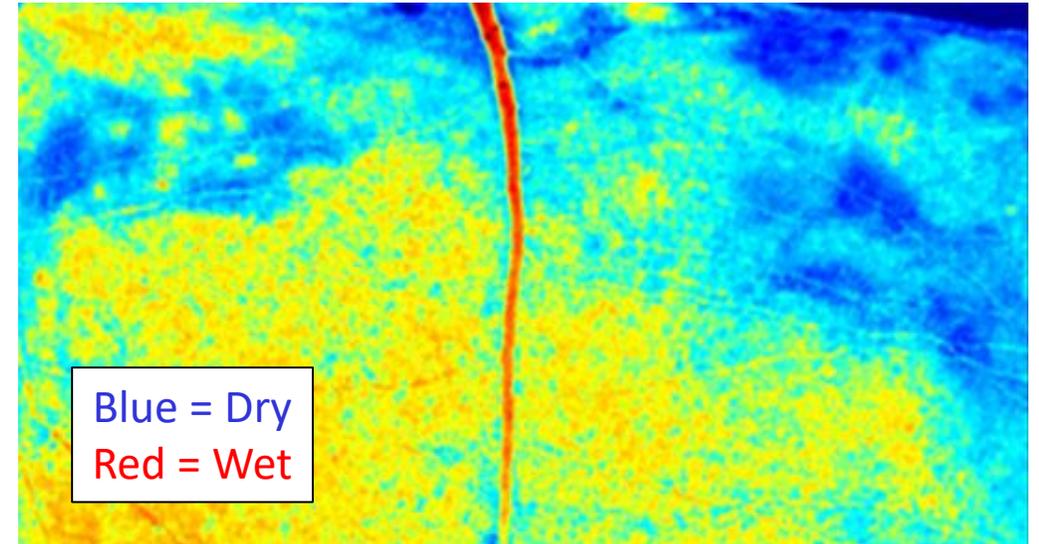
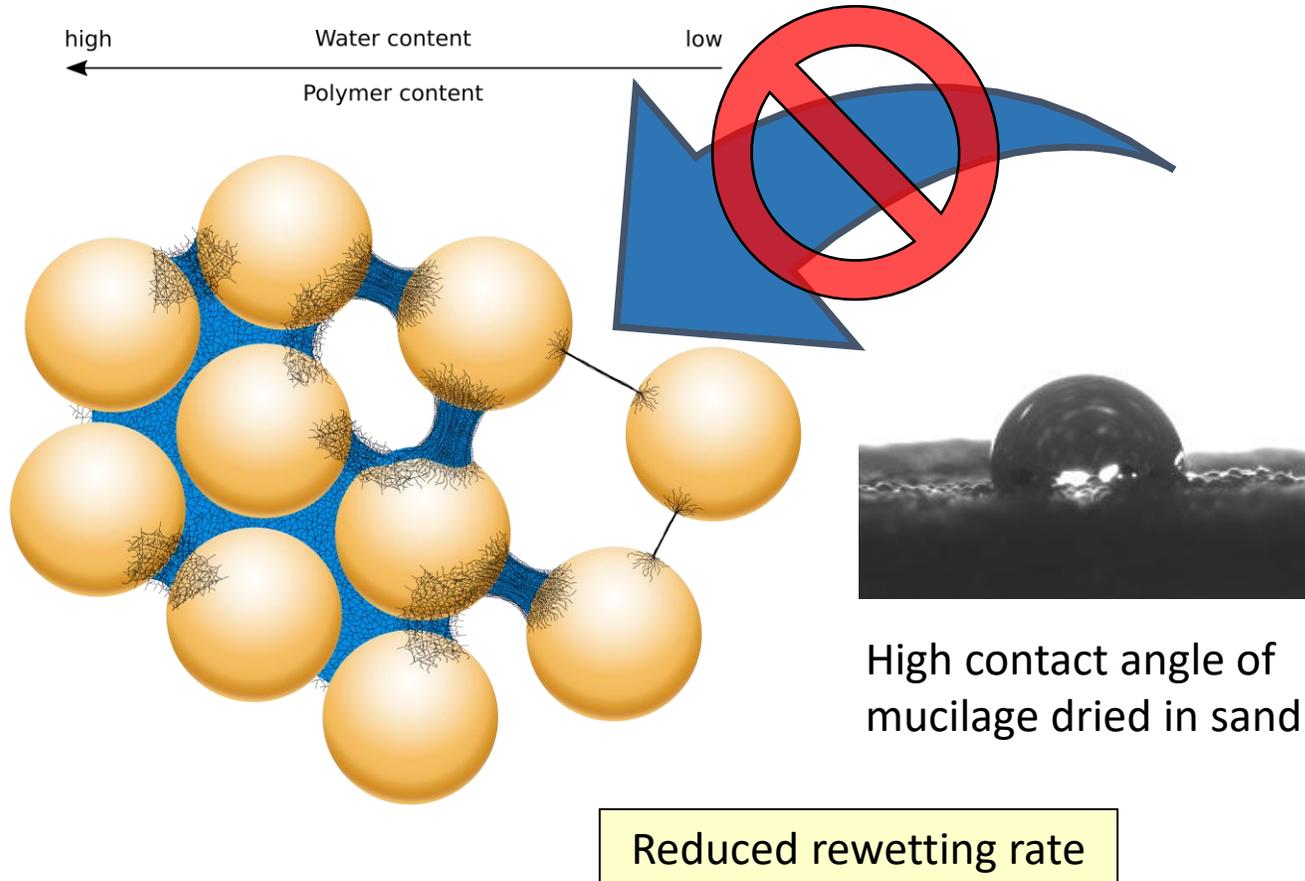
*Zarebanadkouki et al. 2019 VZJ*



Enhanced diffusion

# Consequences for soil water dynamics

Upon rewetting, the formation of extensive two-dimensional structures corresponds to a sudden increase in soil water repellency, which reduces the rewetting kinetics and maintains gas diffusion preventing sudden water saturation.



Neutron radiography of a 4 weeks old lupines 30 minutes after irrigation by capillary rise. The rhizosphere remains dry for 1-2 days.  
*Carminati 2013 Frontiers in Plant Science*

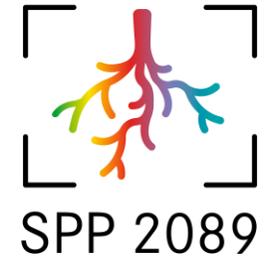
# Conclusions

In summary, polymer solutions (EPS and mucilage) buffer fluctuations in soil water contents, maintaining the diffusion through the liquid phase (during drying) and through the gas phase (during rewetting), and protecting roots and soil microorganisms against severe drying and sudden rewetting in soil hotspots.

# Acknowledgement

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**Vadose Zone Journal | Advancing Critical Zone Science**

Vadose Zone J. 18:180211. doi:10.2136/vzj2018.12.0211

## Original Research

### Core Ideas

- Plant mucilage and bacterial extracellular polymeric substances (EPS) prevent the breakup of the soil liquid phase.
- Formation of continuous structures buffers soil hydraulic properties.
- The release of viscous polymeric substances represents a universal strategy.

## Microhydrological Niches in Soils: How Mucilage and EPS Alter the Biophysical Properties of the Rhizosphere and Other Biological Hotspots

Pascal Benard,\* Mohsen Zarebanadkouki, Mathilde Brax, Robin Kaltenbach, Iwan Jerjen, Federica Marone, Estelle Couradeau, Vincent J.M.N.L. Felde, Anders Kaestner, and Andrea Carminati

Vadose Zone J. 18:190021. doi:10.2136/vzj2019.02.0021

## Original Research

### Core Ideas

- Our aim was to test whether mucilage promotes diffusion of nutrients in dry soil.
- Mucilage favors transport of nutrients in drying soil and their uptake by plant.
- Mucilage increases the soil moisture in the rhizosphere as soil dries.
- Mucilage maintains the connectivity of liquid phase in the rhizosphere as soil dries.

## Mucilage Facilitates Nutrient Diffusion in the Drying Rhizosphere

Mohsen Zarebanadkouki,\* Theresa Fink, Pascal Benard, and Callum C. Banfield

Despite detailed investigations of its distinct biochemical properties and their effects on the availability of nutrients for plants, the biophysical aspects of the rhizosphere, particularly the effect of mucilage on the transport of water and nutrients, are poorly understood. The aim of this study was to investigate the effect of mucilage on the diffusion of nutrients and consequently their transport through the rhizosphere into the plant roots. Phosphor imaging technique determined the temporal distribution of  $^{137}\text{Cs}$  in a model rhizosphere (sandy