# Interplay between water adsorption and viscosity determines the spatial configuration of EPS and mucilage during soil drying

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*Soil Physics*

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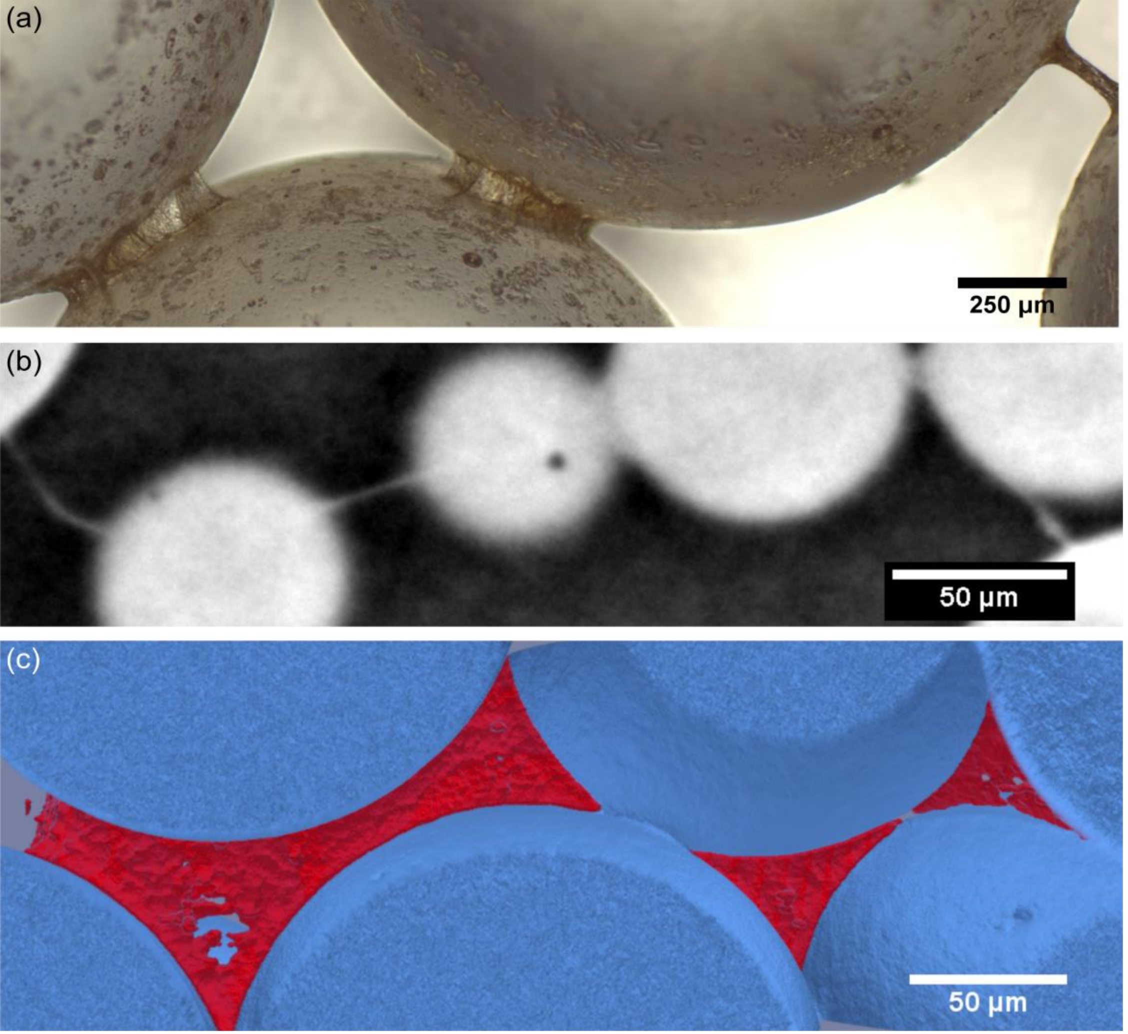
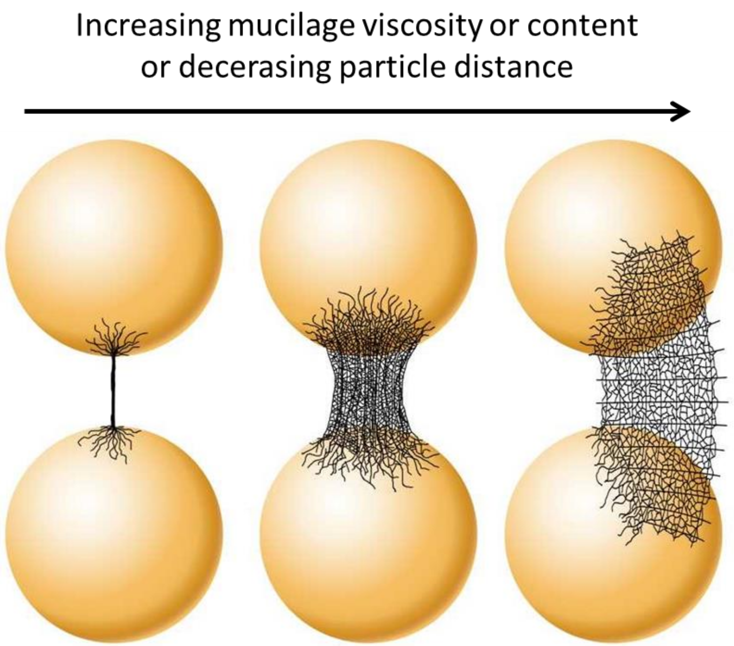
# Polymer solutions alters the liquid configuration in soils: observations of strands and surfaces




Maize (Zea mays) mucilage structures in glass beads. (a) Seedling maize mucilage with an initial concentration of 10 mg g-1 dried in glass beads of 1.7-2 mm in diameter. (b) Cross-section through a synchrotron-based X-ray tomographic microscopy volume of glass beads (1.7-2 mm in diameter) and dry crown root maize mucilage structures (initial concentration 30 mg g-1). (c) 3D segmentation of (b) with mucilage and glass beads shown in red and blue, respectively. At high mucilage content, the radius of mucilage structures approaches the glass bead radius and structures like the ones shown in (a) merge into 2D interconnected surfaces (Benard et al VZJ 2019).




What are the physical properties of polymer solutions that determine the shape of the liquid phase during drying in soils?

# Formation of 1D filaments

**Water cannot have this shape**

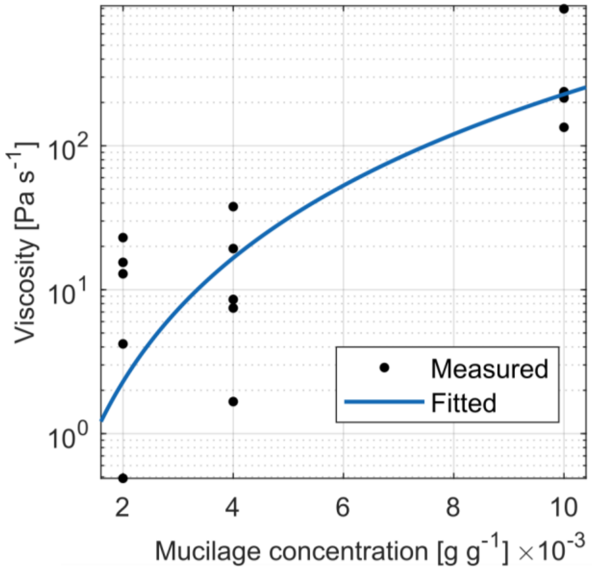
Rayleigh instability: Water filaments are unstable to any perturbations of the interface. Perturbations grow at increasingly faster velocity until the column breaks-up. For water with R=1 mm the break up time is ~ms

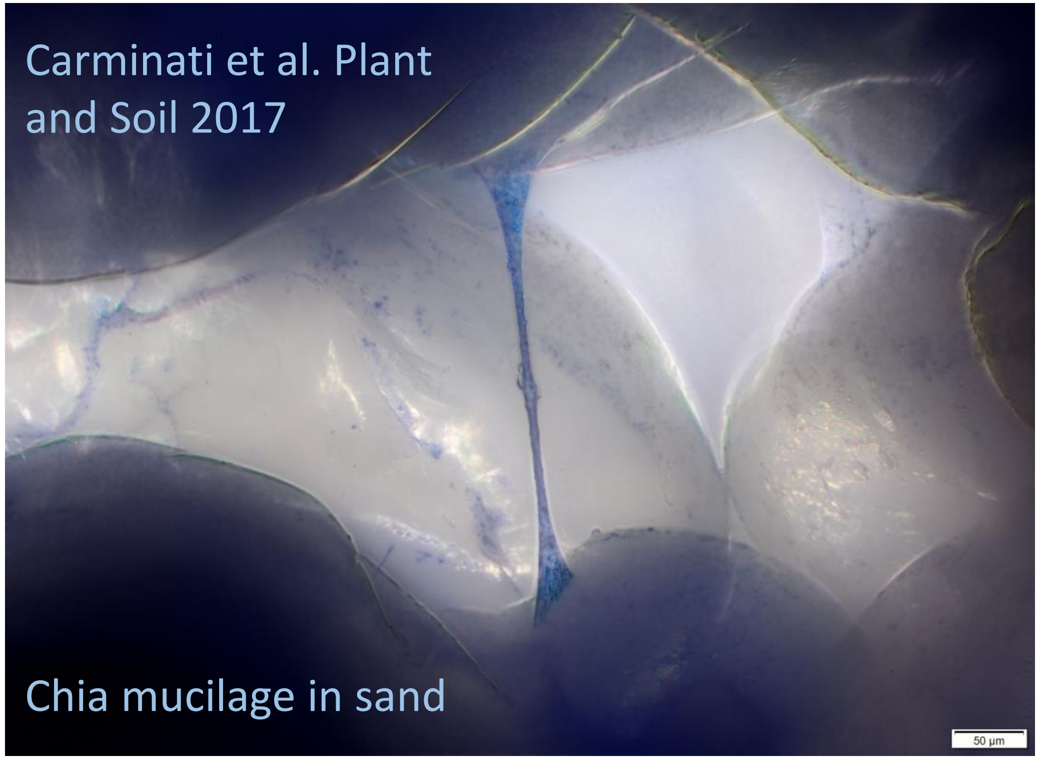
**EPS and mucilage can have this shape because of their high viscosity**

$$Oh = \frac{\mu}{\sqrt{\sigma\rho 2R}}$$

For $Oh >> 1$ : $\frac{\partial R}{\partial t} = -\frac{1}{6}\frac{\sigma}{\mu}$

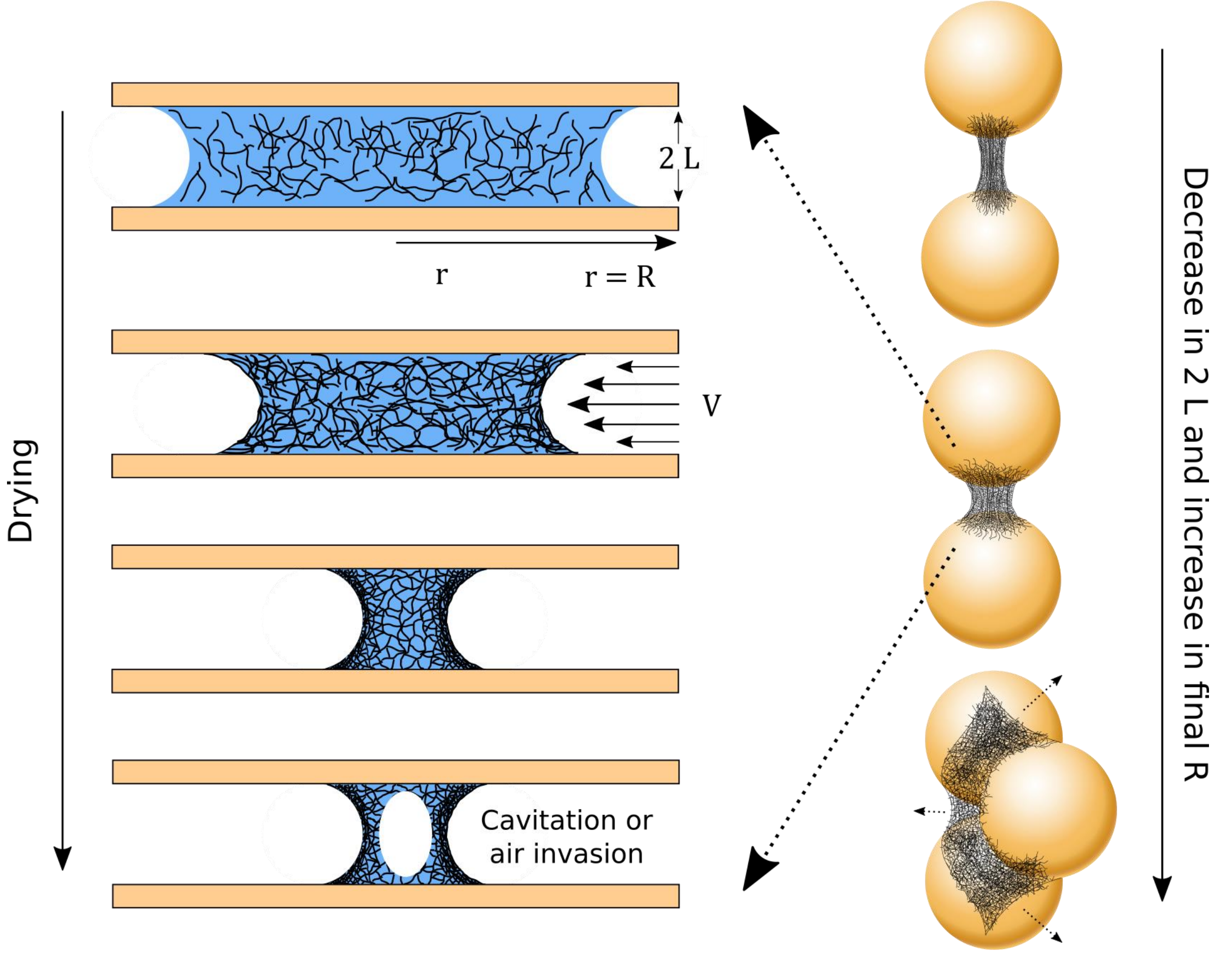
Were $\mu$ is the viscosity, $\sigma$ is the surface tension, $\rho$ is the density and $R$ is the radius of the filament. In polymer solutions viscosity increases during thinning preventing the break-up of the liquid phase.

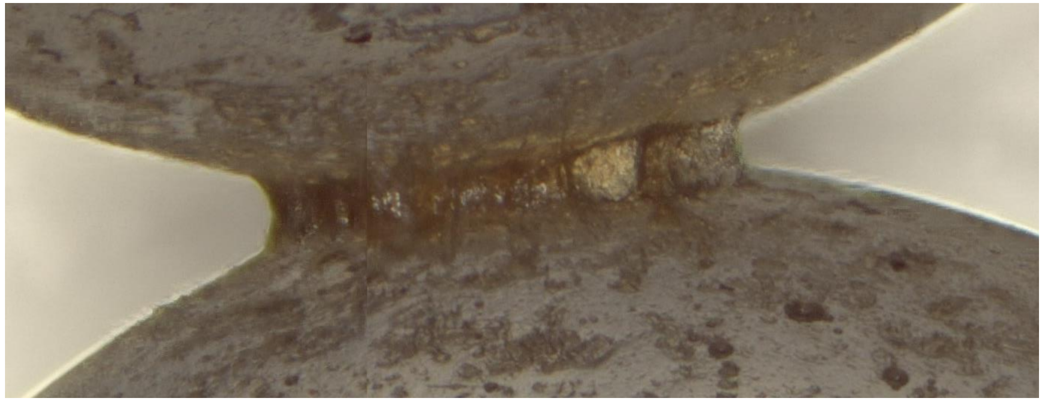



Unlike water, primarily shaped by surface tension, polymer solutions remain connected upon drying thanks to their high extensional viscosity. The integrity of one-dimensional structures is explained by the interplay of viscosity and surface tension forces (elegantly characterized by the *Ohnesorge* number)

# Formation of 2D surfaces

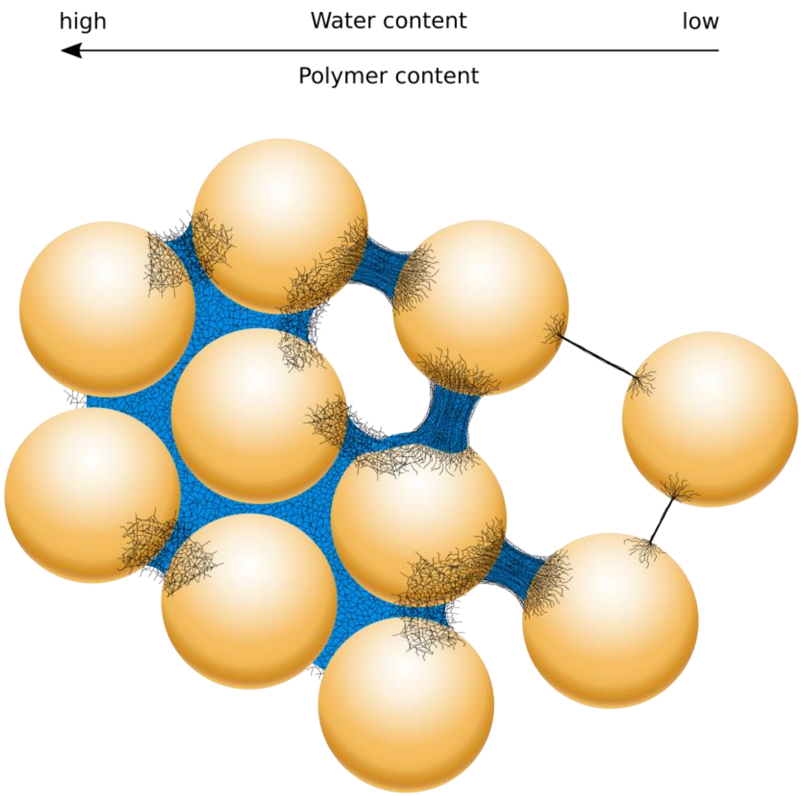


During drying, the viscosity of the polymer solution increases and, at a critical point, when the friction between polymers and solid surfaces overcomes the water adsorption of the polymers, the concentration of the polymer solution at the liquid-gas interface increases asymptotically and the polymers can no longer follow the retreating gas-water interface. At this critical point the polymers do not move any longer and are deposited as two-dimensional surfaces, such as hollow cylinders or interconnected surfaces. Viscosity of the soil solution, specific soil surface and drying rates are the key parameters determining the transition from one- to two-dimensional structures.

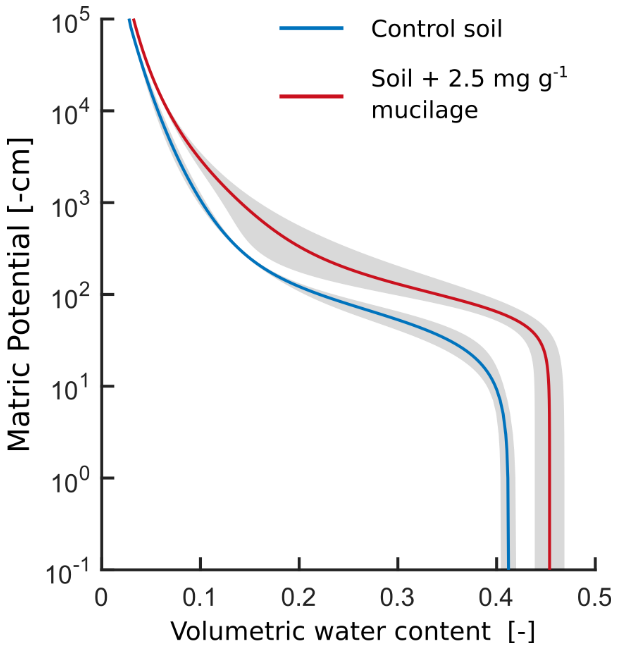
# Consequences for soil water dynamics

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

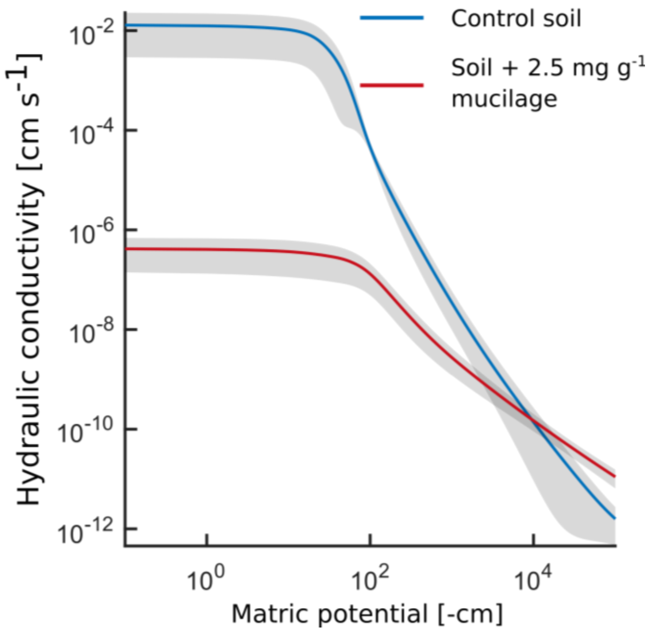



*Benard et al. 2019 VZJ*

Chia seed mucilage in loamy sand




Enhanced retention




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

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# Bibliography

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

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.

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

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