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Roots at the percolation threshold - how mucilage affects water flow in soils

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Much of the carbon assimilated by plants during photosynthesis is lost to the soil via rhizodeposition. One component of rhizodeposition is mucilage, a hydrogel that dramatically alters the soil physical properties. Mucilage can hold large volumes of water, but it becomes hydrophobic after drying. Drying/swelling dynamics of mucilage lead to a dynamic relation between water content and water potential, resulting in a non-equilibrium water retention curve of the rhizosphere.

Here we present experimental evidence of this non-equilibrium during rewetting. Additionally we propose a model of water flow across the rhizosphere. The model is based on the Richards' equation and accounts for 1) the reduced mobility of water in mucilage filled pores, 2) the increased water holding capacity of the rhizosphere under equilibrium conditions and 3) the non-equilibrium dynamics induced by swelling and shrinking dynamics of mucilage. We expect this non-equilibrium behavior to be more important during rewetting: the dryer the mucilage the longer it takes for the rhizosphere to go to equilibrium. By choosing a relaxation time that depends on water content this idea is included in our model.

Our model predicts that under certain rewetting conditions water flows across a dry rhizosphere without rewetting it significantly during the first hours. To justify this concept, we developed a pore network model in which mucilage is randomly distributed through the pore domain. The pores covered with mucilage are assumed to be hydrophobic and are not rewetted upon irrigation. The pore network model predicts that there is a critical mucilage concentration at which the fraction of mucilage covered pores is high enough to prevent the water flow through the rhizosphere. This critical mucilage concentration corresponds to the percolation threshold. Near the percolation threshold water can cross the region, without rewetting it significantly. Using the pore network model we derive an analytic relation between mucilage concentration at percolation threshold and soil particle size.

The proposed theoretical relation is confirmed by experimental results of capillary rise in soils with varying concentration of mucilage and particle size.