Technische Universität Braunschweig

Institute of Geoecology
Soil Science and Soil Physics

Effect of biofilm on soil hydraulic properties: Laboratory studies using xanthan as surrogate

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Introduction

Extracellular polymeric substances (EPS) are produced by many soil bacteria in the porous soil matrix and are attached to the bacterium cell and soil particles. The desiccation and rewetting behavior of EPS-influenced soils is changed in a way that the bacteria can better adapt to altered environmental conditions. For experimental purposes, xanthan can be used as a surrogate for the EPS because it has very similar physical characteristics.

The objective of this work is the quantification of the effect of xanthan on soil hydraulic properties. We determined the soil water retention and hydraulic conductivity curves of xanthan-affected soils with different experiments using small laboratory columns.

Mixture model

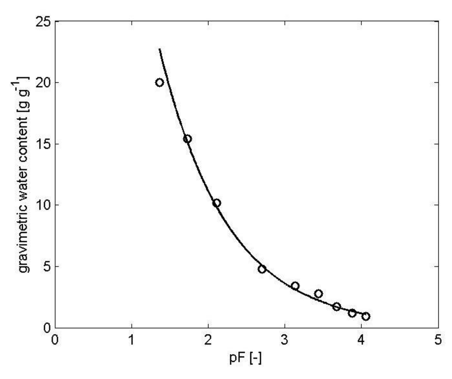

Fig. 1: Water retention curve of pure xanthan. The relation between the gravimetric water content and the matric potential is given as a power law (according to Rosenzweig et al., 2012).

The mixture model is based on the linear superposition model of Rosenzweig et al. (2012) and is used to predict the soil water retention curve of the soil-xanthan mixtures. This approach uses the mass fraction of xanthan f and the retention properties of pure soil and the pure xanthan:

$$\theta_{g,mix}(h) = \theta_{g,soil}(h)(1-f) + \theta^{c}_{g,x}(h)\, f$$

$$\theta^{c}_{g,x}(h) = \begin{cases} 20 & h > -10^{1.47} \\ 105.76\,|h|^{-0.489} & h \le -10^{1.47} \end{cases}$$

The gravimetric water content of the pure xanthan as a function of the matric potential $\theta^{c}_{g,x}(h)$ was computed from the water retention curve (Fig. 1). The gravimetric water content of the pure soil as a function of the matric potent $\theta_{g,soil}(h)$ was obtained from a fit of the Fayer and Simmons (1995) model to the measured retention data. The measured mean bulk densities of the three replicates of each xanthan addition level were used to convert volumetric water contents to gravimetric ones.

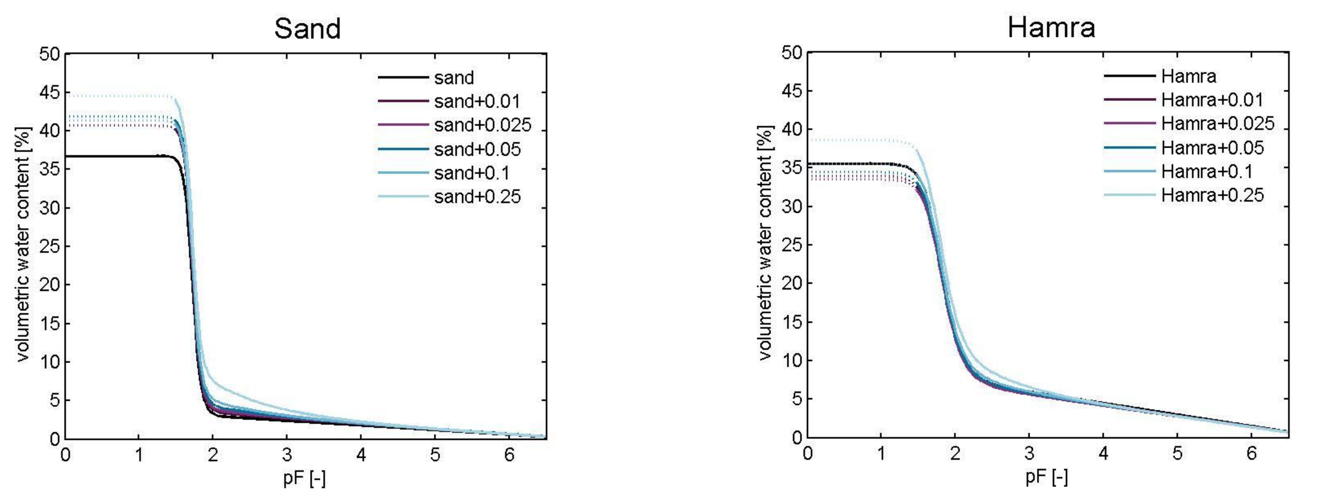

Fig. 2: Prediction of soil water retention curves of the sand and sand-xanthan samples (left), and the Hamra and Hamra-xanthan samples (right). The curves of the pure soils were estimated with the model of Fayer and Simmons (1995). The curves of the soils containing xanthan were calculated using the mixture model of Rosenzweig et al. (2012). Below a pF value of 1.47 the gravimetric water content of the xanthan was set to 20 g g⁻¹ (dashed part of the lines).

Acknowledgement

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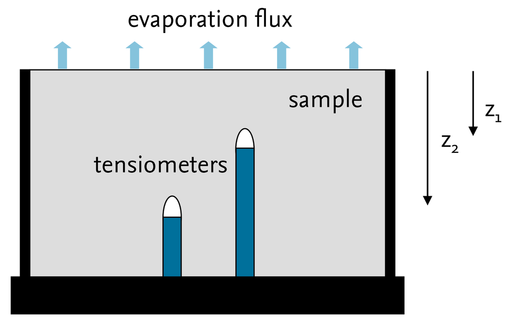
Material and methods



The soil water retention and hydraulic conductivity functions of two biofilm-affected sandy soil materials (pure quartz sand and Hamra) were determined by using xanthan as an EPS-surrogate. The amount of added xanthan was varied in 6 stages from zero to 0.25 %. Evaporation experiments were conducted on the pure materials and the mixtures. The experimental data was evaluated by the simplified evaporation method of Schindler (1980). Measurements of soil water retention using the chilled mirror dewpoint method (WP4c, Decagon Devices, Inc.) closed the remaining gap from the evaporation method to air-dryness.

Results: Evaporation

The results of these measurements show that the xanthan reduced the evaporation rate. The measurement period was almost quadrupled for sand with high xanthan amounts and almost doubled for Hamra with high xanthan amounts compared to the pure materials (Fig. 3 and 4). In addition, the stage 1 evaporation was suppressed for higher xanthan amounts for both soils and only stage 2 evaporation occurs (Fig. 5).

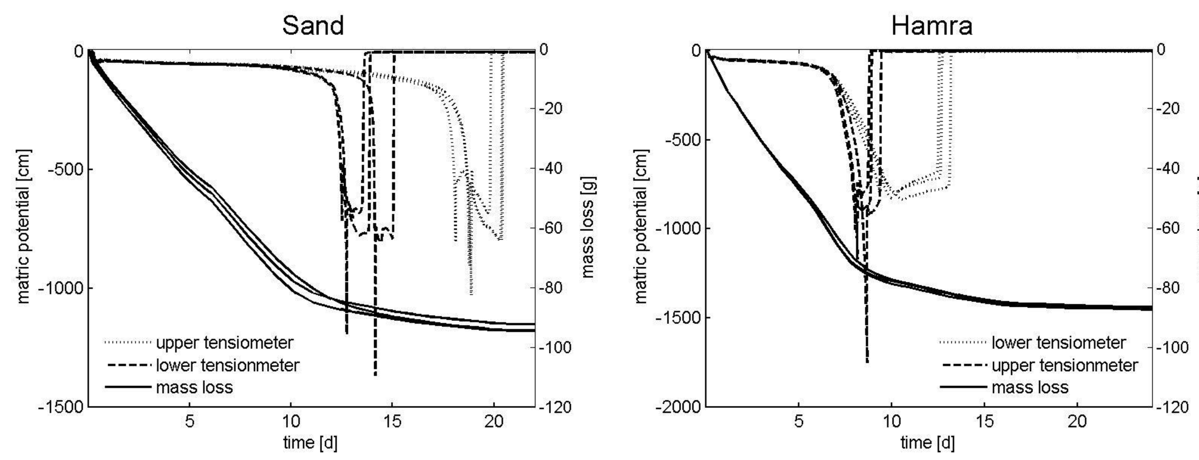


Fig. 3: Matric potentials and cumulative mass loss of the pure sand (left) and Hamra (right) samples as well as the sand and Hamra samples with 0.25 % (w/w) xanthan measured by the evaporation method. In all cases, results are shown for three replicate experiments.

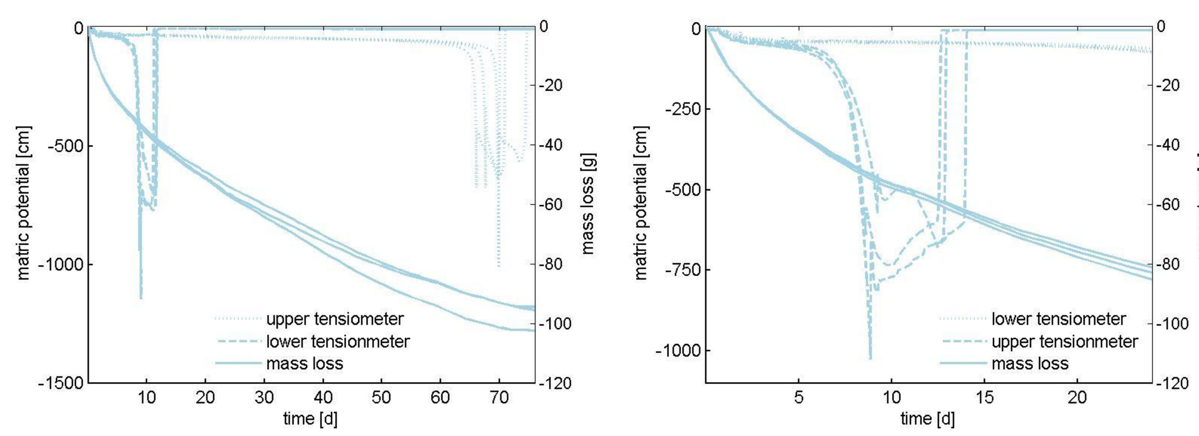


Fig. 4: Matric potentials and cumulative mass loss of the pure sand (left) and Hamra (right) samples as well as the sand and Hamra samples with 0.25 % (w/w) xanthan measured by the evaporation method. In all cases, results are shown for three replicate experiments.

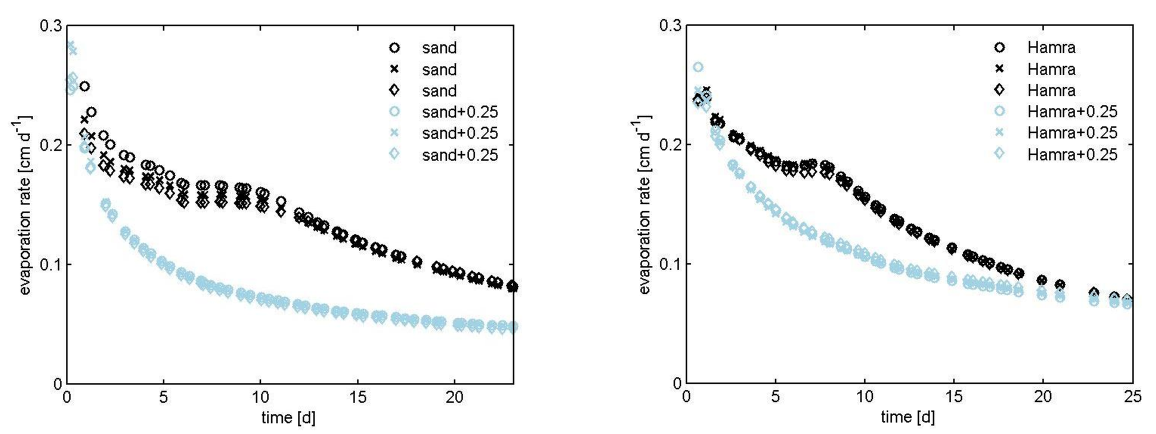


Fig. 5: Comparison of evaporation rates of three replicate samples of pure sand and sand with 0.25 % (w/w) xanthan (left) and of pure Hamra and Hamra with 0.25 % (w/w) xanthan (right).

Results: Retention and conductivity

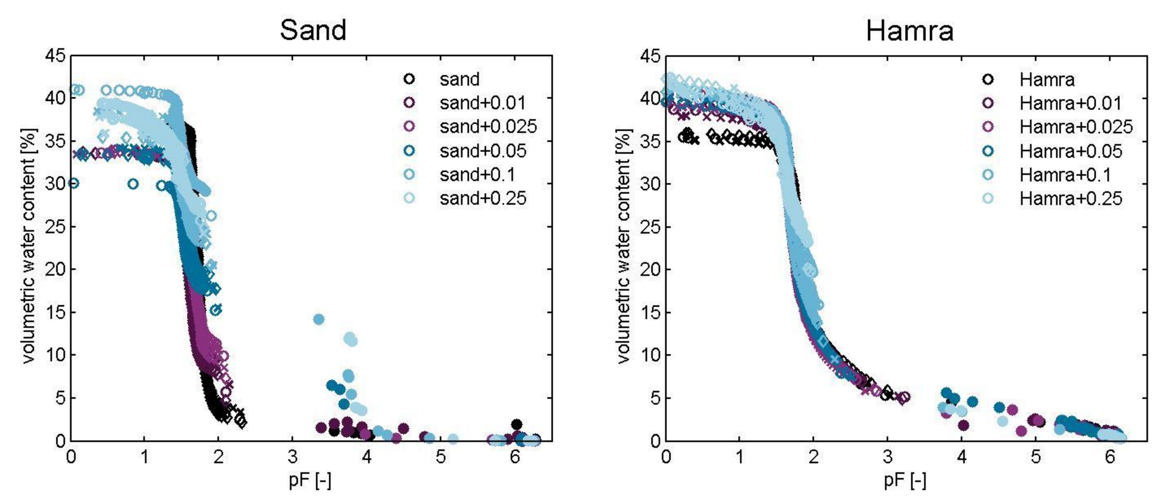


Fig. 6: Soil water retention data of the sand and sand-xanthan samples (left) and all Hamra and Hamra-xanthan samples (right). The data were obtained from the evaporation (circles, crosses, diamonds) and dewpoint method (filled circles).

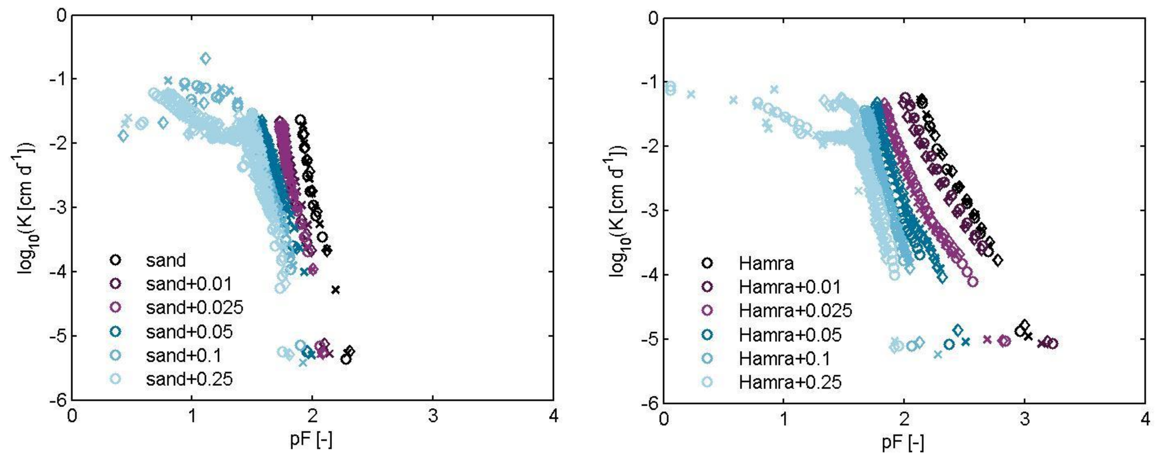


Fig. 7: Hydraulic conductivity as a function of the matric potential of all sand samples (left) and all Hamra samples (right) calculated with the simplified evaporation method (Schindler, 1980).

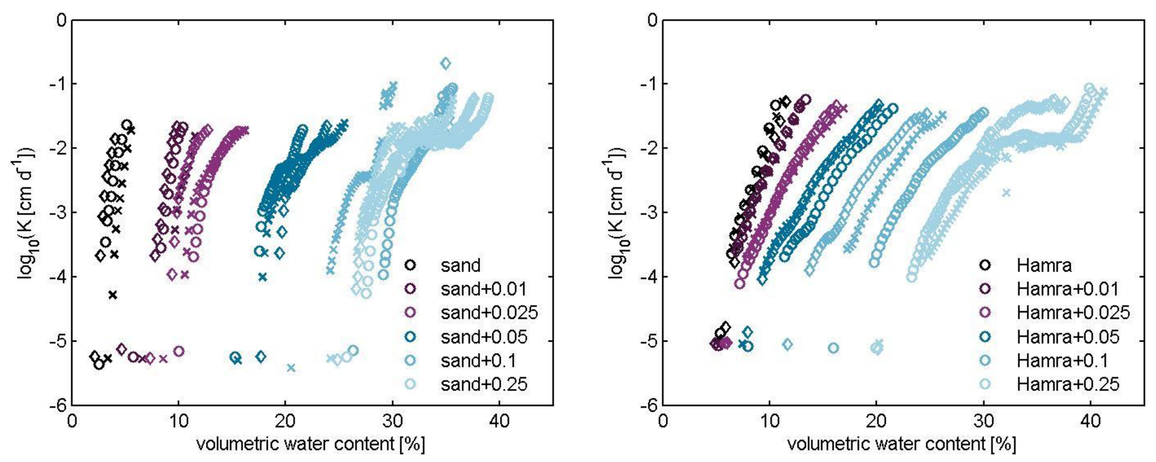


Fig. 8: Hydraulic conductivity as a function of the water content of all sand samples (left) and all Hamra samples (right) calculated with the simplified evaporation method (Schindler, 1980).

Conclusions

- The shape of the soil water retention curve is altered for all levels of xanthan addition because of the high water-holding capacity of the xanthan .
- The unsaturated hydraulic conductivity is reduced markedly by the added xanthan. The reason for this is the low permeability of the xanthan which blocks the pores.
- The reduction in unsaturated hydraulic conductivity is high enough to fully suppress stage-one evaporation for the soil-xanthan mixtures.
- The prediction of the soil water retention curve with the mixture model is possible.

References

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