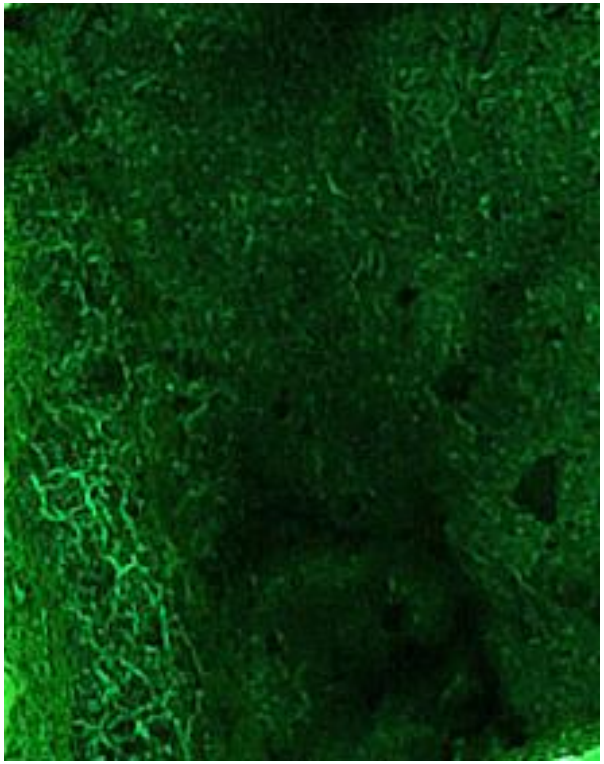
Macropore-matrix mass transfer: reactive solute transport as quantified with Fluorescence imaging

Christoph Haas*, Ruth Ellerbrock, and Horst H. Gerke

Working Group “Hydropedology”, RA1 “Landscape Functioning”, Leibniz Centre for Agricultural Landscape Research (ZALF) Müncheberg, Germany

*E-Mail: Christoph.Haas@zalf.de



Federal Ministry of Food, Agriculture and Consumer Protection

LAND BRANDENBURG

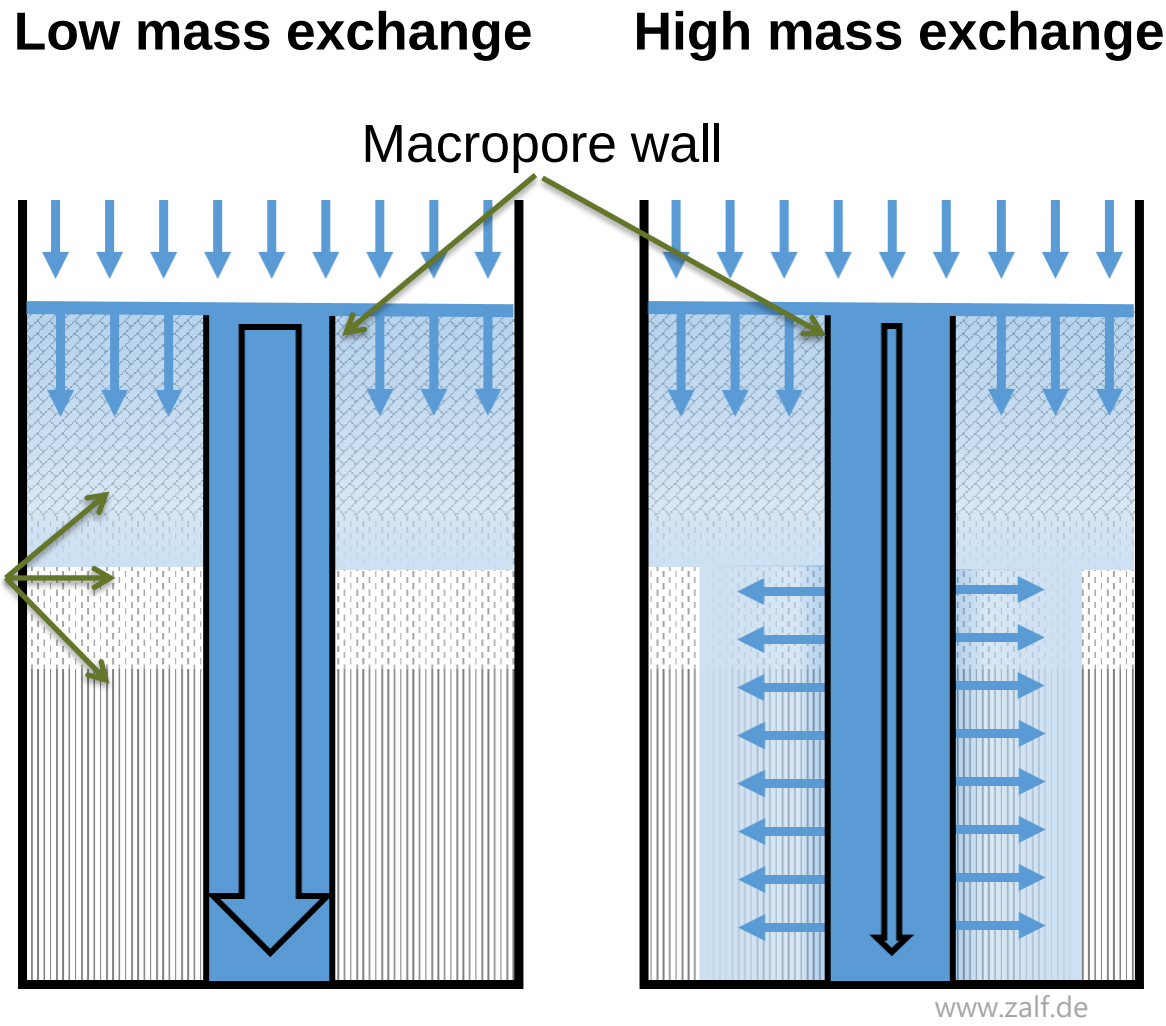
Member of the Leibniz Association

Structural and physico-chemical properties of macropore coatings control mass transfer

Focus: Biopores

→ Preferential flow paths
→ Adsorption sites
→ >70% by volume, 50-60% by pore wall surface area (Pagenkemper et al., 2013)

Foto: Timo Kautz



www.zalf.de

Hypotheses, Problems and Objectives

Hypotheses:

- Heterogeneously distributed physico-chemical and physical soil properties in coatings control macropore-matrix mass transfer of water and solutes.

- *Fluorescence imaging* with Na-Fluorescein as fluorescent dye can be used to determine dissolved and adsorbed masses of dye, after calibration.

Objectives:

- Visualization and quantification of hydraulic transport, and sorption characteristics of earthworm-, root- and shrinkage-induced interfaces.

Problems:

- Limited size, small-scaled heterogeneity, accessibility of adsorption sites

Sampling site and macropore matrix interfaces:

Samples from **Bt horizon** located in Holzendorf, Germany, 23.7 % Clay, 23.3 % Silt, 53.0 % Sand, 2.4 g kg^{-1} SOC.

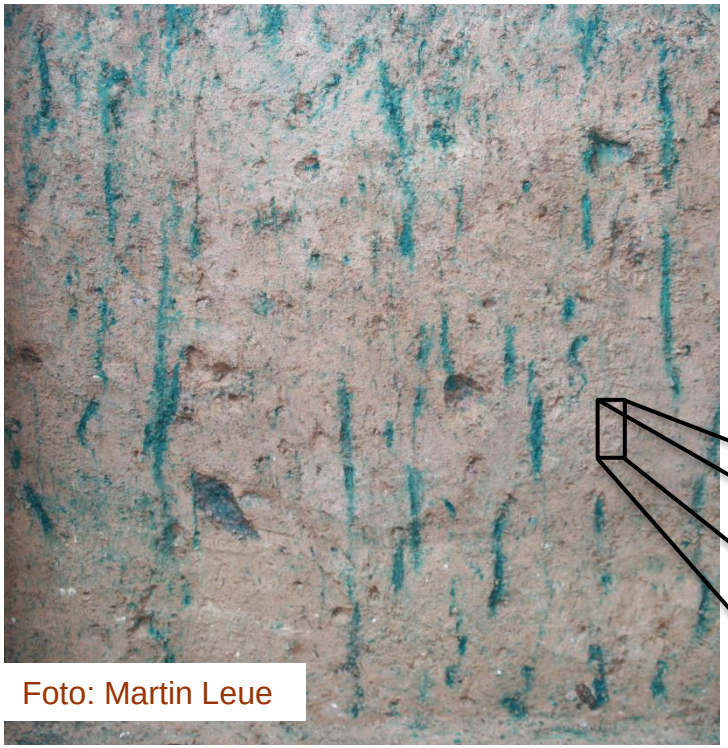
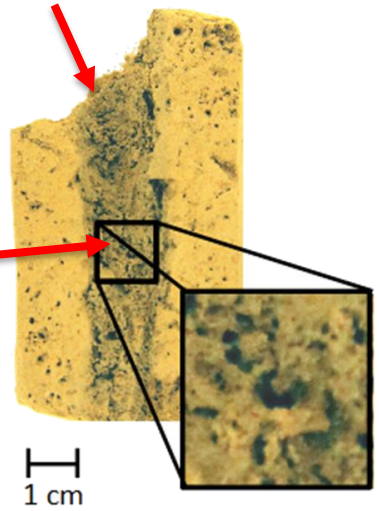


Foto: Martin Leue

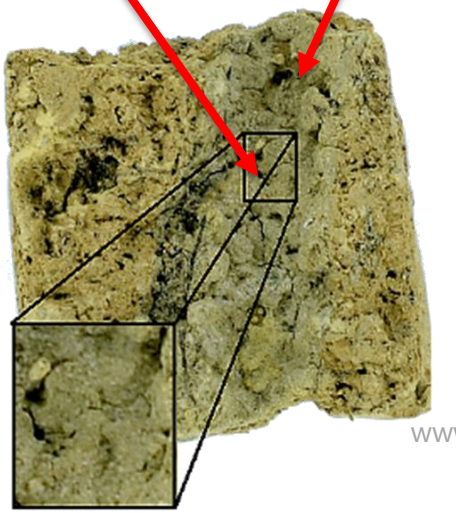
Interfaces with differences in micro-aggregation (Haas and Horn, 2018).

Shrinkage crack

Plant root channel



Earthworm burrow



Calibration I

Calibration as described in *Haas* et al. (2020):

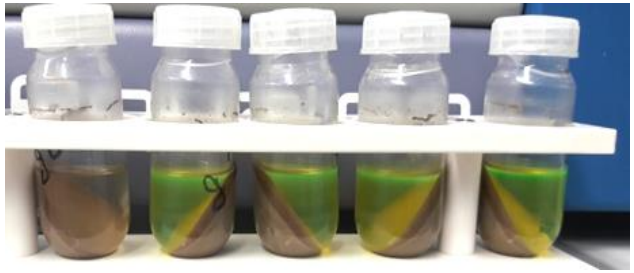
1. Aqueous solutions with defined Na-Fluorescein concentrations (c) were used to derive fluorescence peak intensity (FPI):

$$c = \left(\frac{FPI - 66.79}{103.19}\right) \qquad \text{(Eq. 1)}$$

2. Aqueous solutions with **homogenized** soil and defined c. Equilibrated Na-Fluorescein concentration (c_{eq}) in soil solution was calculated with Eq. 1. Na-Fluorescein concentration adsorbed to soil was calculated with Eq. 2 and used to parameterize adsorption characteristics:

$$c_s = c - c_{eq} \qquad \text{(Eq. 2)}$$

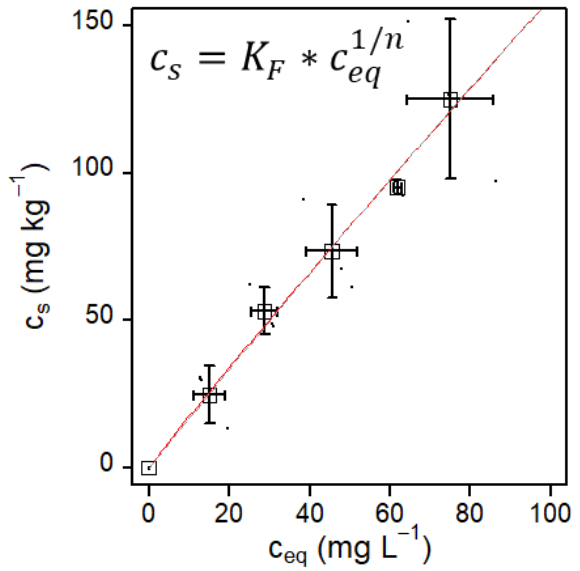
Uv/vis spectrometer to excited the samples with λ_{ex}: 420 nm and to determine FPI. See Haas et al. (2020).



Soil mixed with aqueous solutions used for calibration

Calibration II

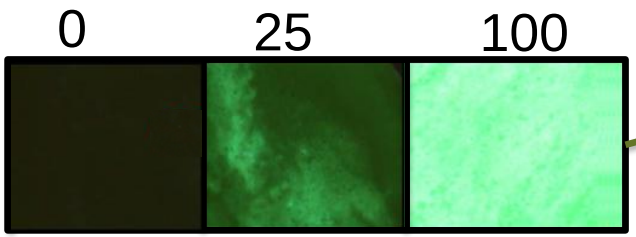
3. Sorption characteristics



4. *Fluorescence imaging* with saturated soil pastes to derive c_{eq} from grayscale values (GS) with Eq. 3 (c.f., Haas et al., 2020)

$$c_{eq} = a * GS^b \quad \text{(Eq. 3)}$$

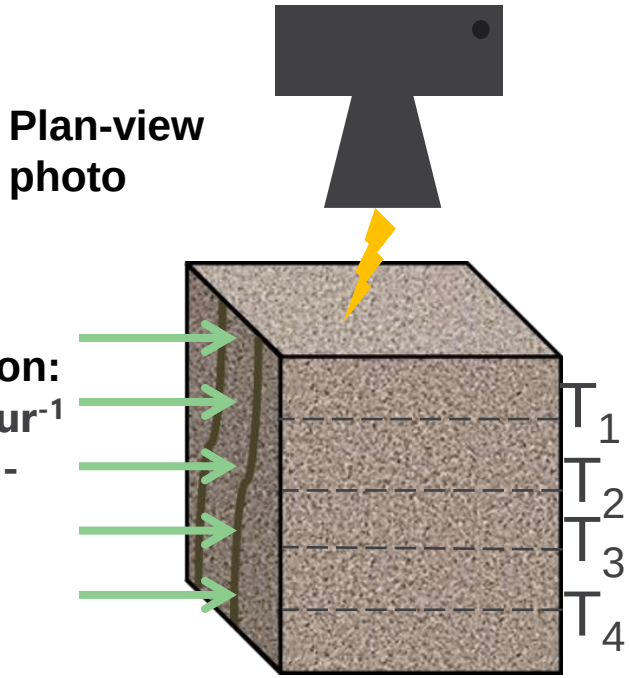
with *a* equal to 50.7*10^{-6} and *b* equal to 2.758 as fitting parameters.



Soil pastes with defined c (mg/L)

Darkhood for *Fluorescence imaging*

Experimental set-up for tracer application



Plan-view Photo

Slicing and Fluorescence imaging after one (T1), two (T2), and three hours (T3) of tracer application as described in Haas et al. (2020).

Fluorescence imaging: Some impressions

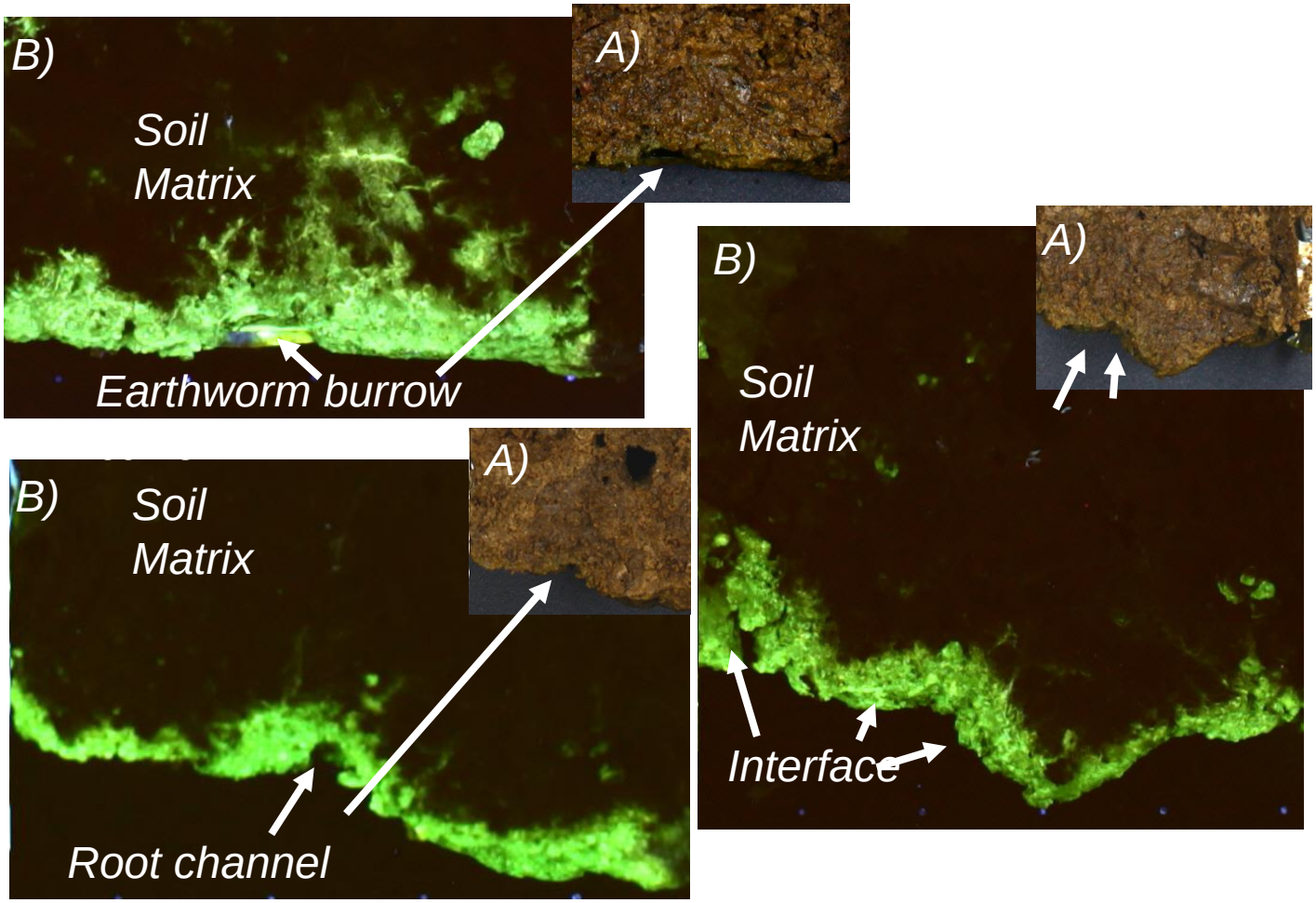
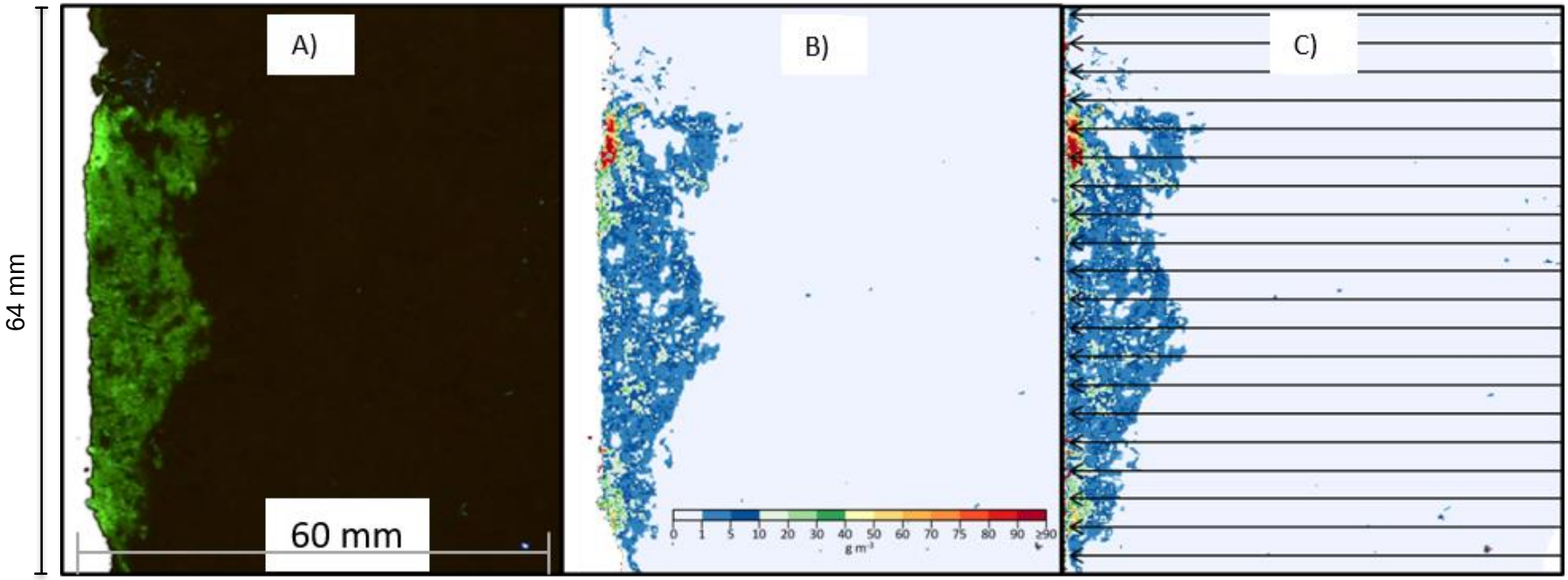


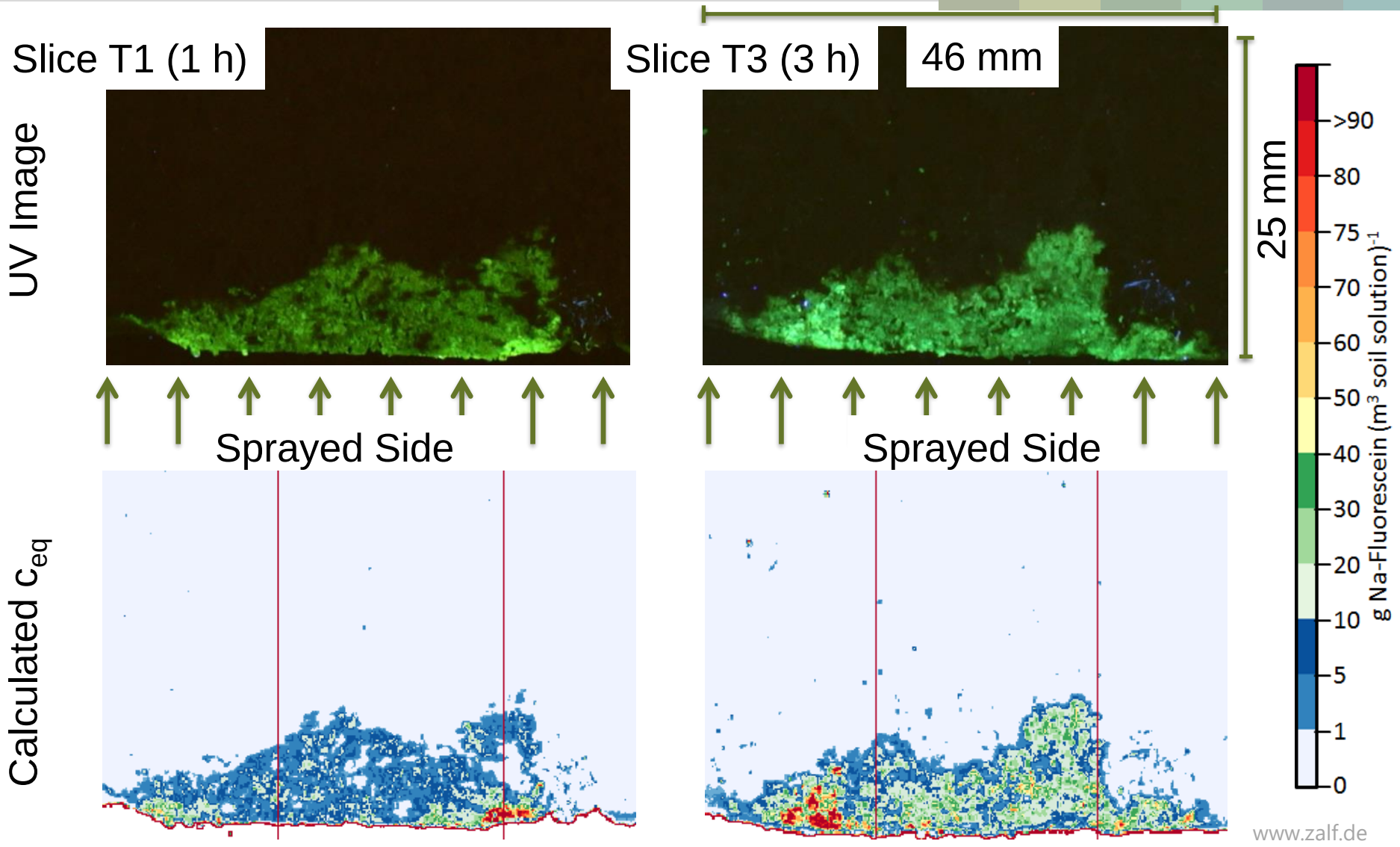
Fig.: *Exemplary photos (A) with Fluorescence images (B).*

Data processing and mass distribution maps



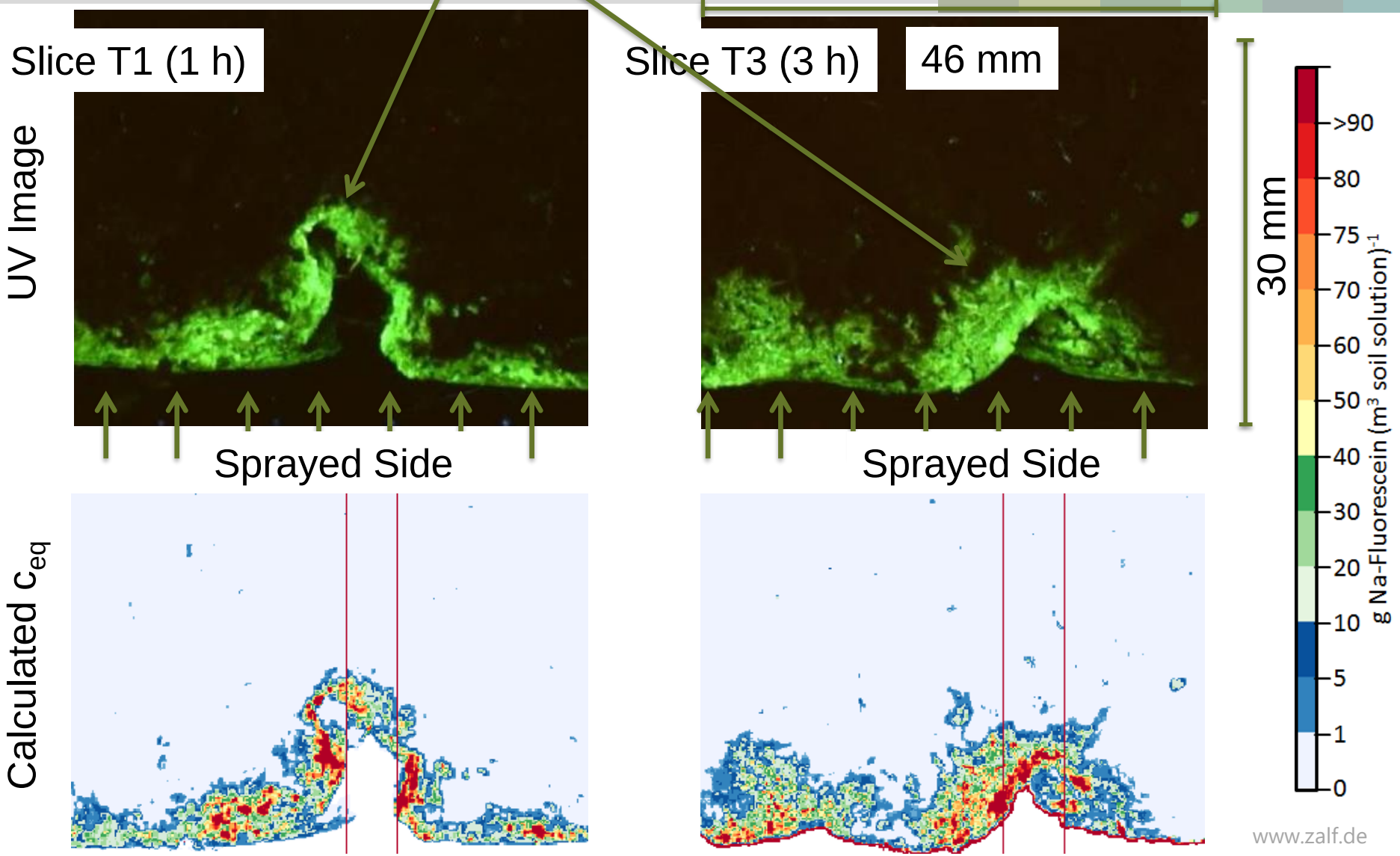
Exemplary Fluorescence image after three hours of dye application to the vertical crack surface (left-hand side), with B) Na-Fluorescein concentration in soil solution (c_{eq}) as calculated from grayscale values and C) the same image but aligned to the crack surface.

Shrinkage Crack *- Na-Fluorescein in soil solution*

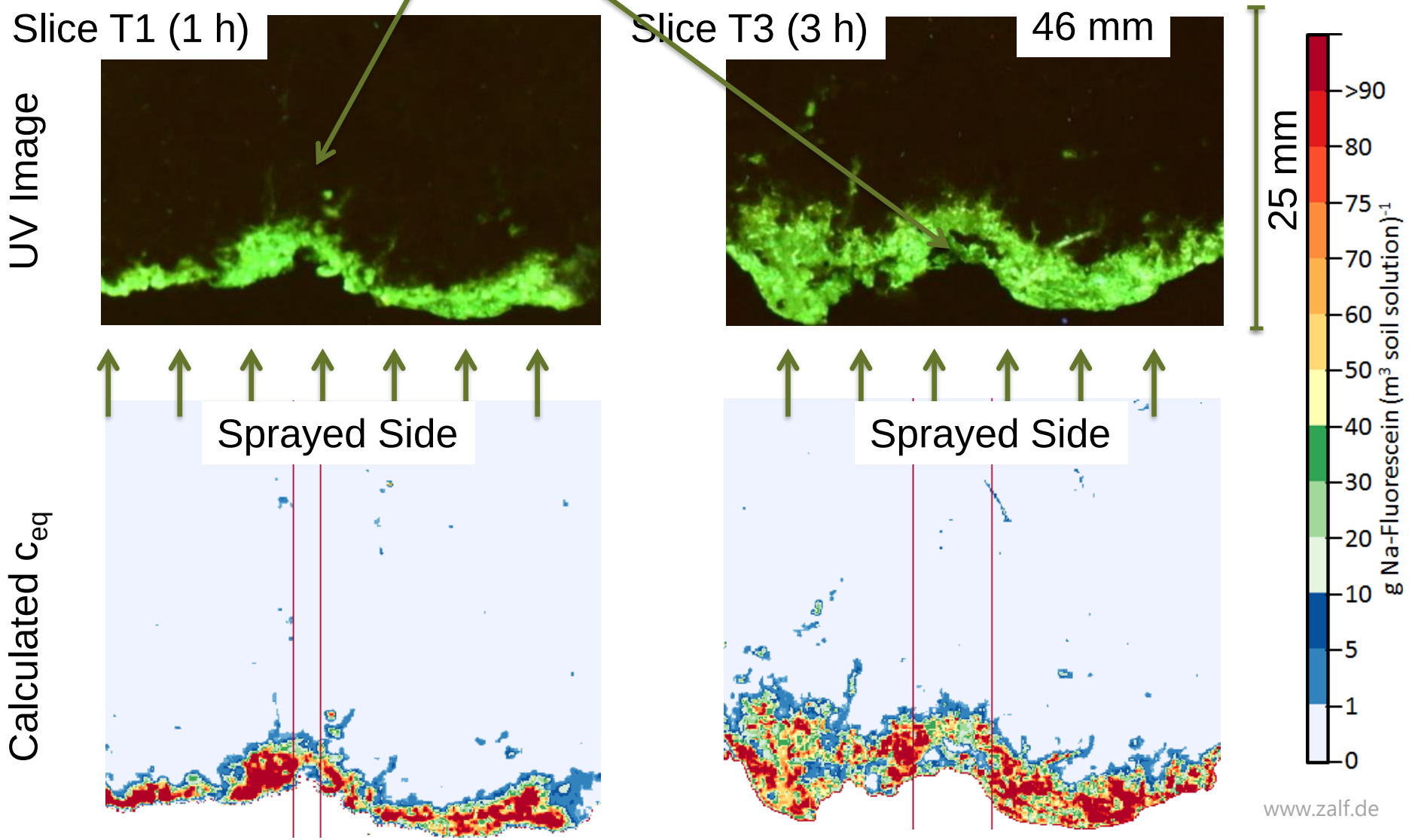


www.zalf.de

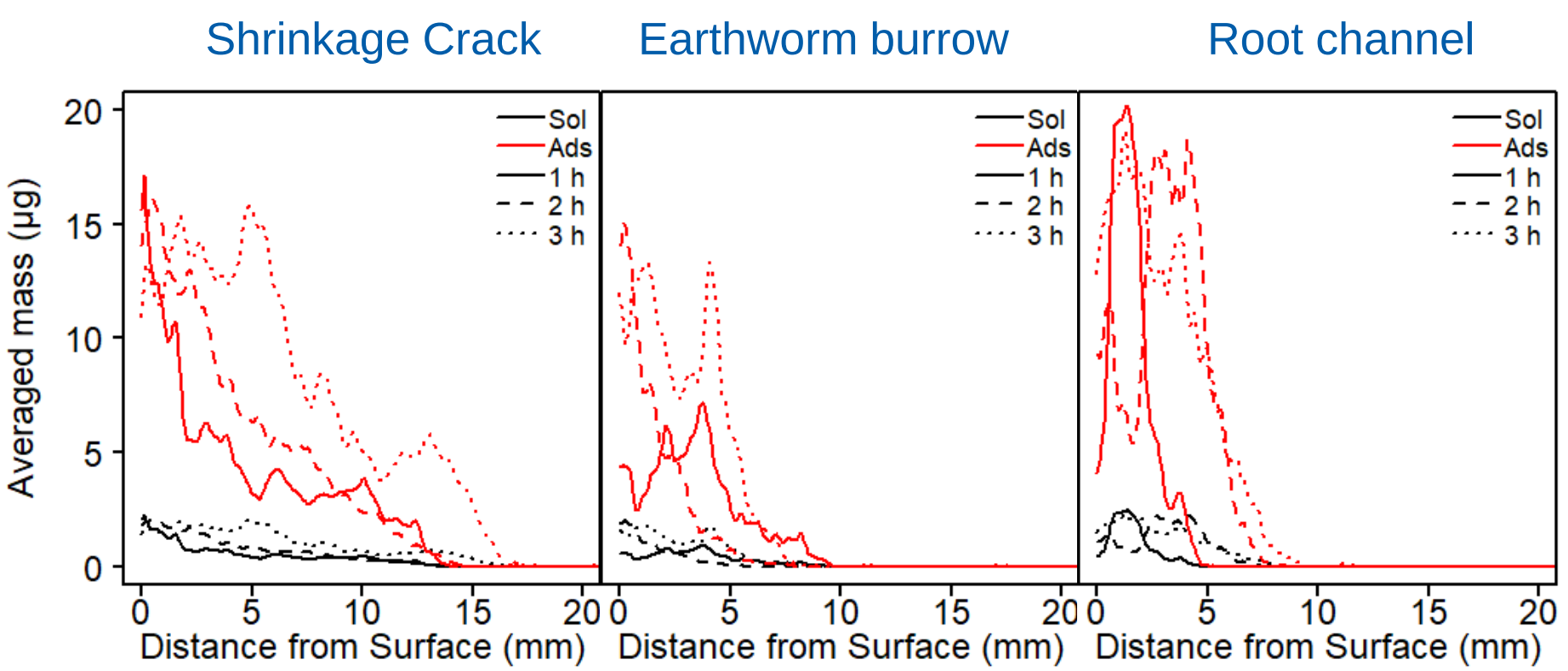
Earthworm burrow *- Na-Fluorescein in soil solution*



Plant root channel *- Na-Fluorescein in soil solution*



Na-Fluorescein Mass distributions



Discussion and Conclusions

- The method allows visualization of flow paths, and mapping of small-scaled distributions of dye masses

- Mass transfer depends on the type of macropore-matrix interface

Limitations

- Soil pH, SOC and other fluorescent compounds, Water content distributions

Acknowledgements

Thanks to:

… **ZALF** (e.V., Müncheberg Germany) and the Deutsche Forschungsgemeinschaft for Financial support under the grant **GE990/10** (Solute mass transfer through soil structural interfaces (SoMaTra))

…and you for your interest!

References

Haas, C. and R. Horn (2018). Impact of small-scaled differences in microaggregation on physicochemical parameters of biopore walls in two Bt horizons of a Haplic Luvisol. Frontiers in Environmental Science, section Soil Processes. Front. Environ. Sci. 10.

Haas, C., Horn, R., Ellerbrock, R. H., Gerke, H. H. (2020) Fluorescence imaging for mm-scale observation of macropore-matrix mass transfer: calibration experiments. Geoderma 360, Article 114002.

Pagenkemper, S. K., Peth, S., Uteau, D. and R. Horn (2013): Effects of root-induced biopore architectures on physical processes investigated with industrial X-ray computed tomography. In: S. H. Anderson and J. W. Hopmans (ed.): Soil–Water–Root Processes: Advances in Tomography and Imaging. SSSA Special Publication 61. Madison, WI, USA. 289 p.