Soil crack dynamics as driver for preferential flow in clay-rich soils

UNI FREIBURG | HYDROLOGY

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Introduction

- Clay-rich soils develop soil cracks during summer due to shrinkage of the clay minerals.
- Shrinkage and swelling of clayey soils is a dynamic process.
- Soil cracks can serve as preferential flow path that channel water and solutes into deeper soil layers.
- Little is known about the effect of the crack dynamics on soil water flow under field conditions.

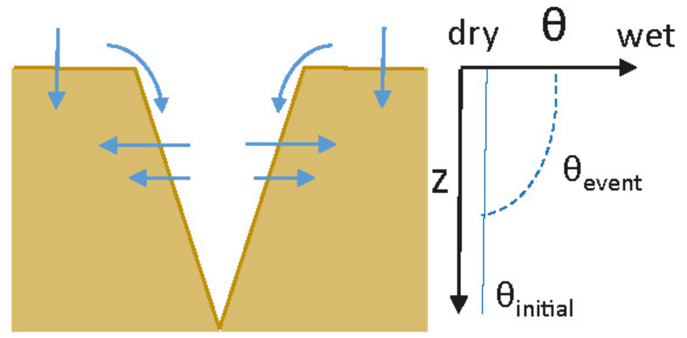
Aim:
Analyze the influence of soil crack dynamics on the soil water content dynamics and on initiation of preferential flow.

Agricultural site in Luxembourg

Conceptual Model

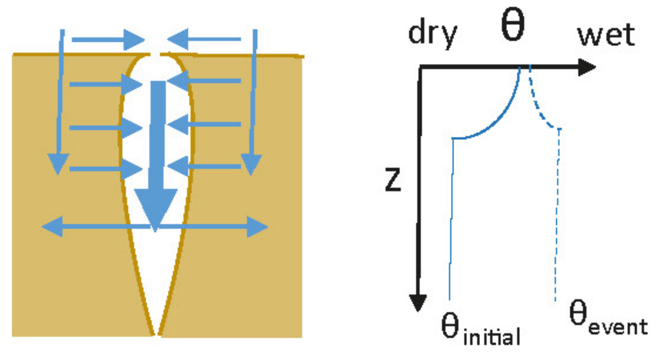
Surface initiation

crack surface area: high



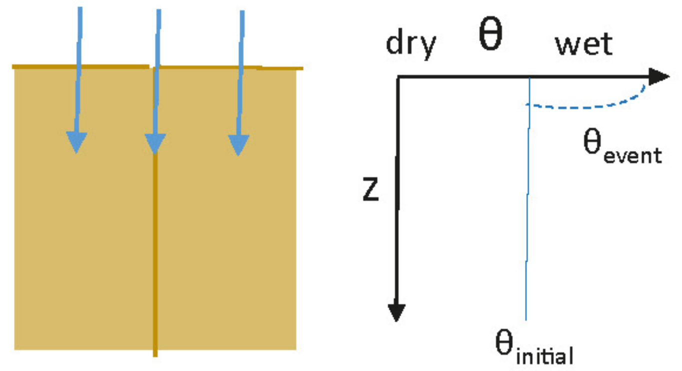
Subsurface initiation

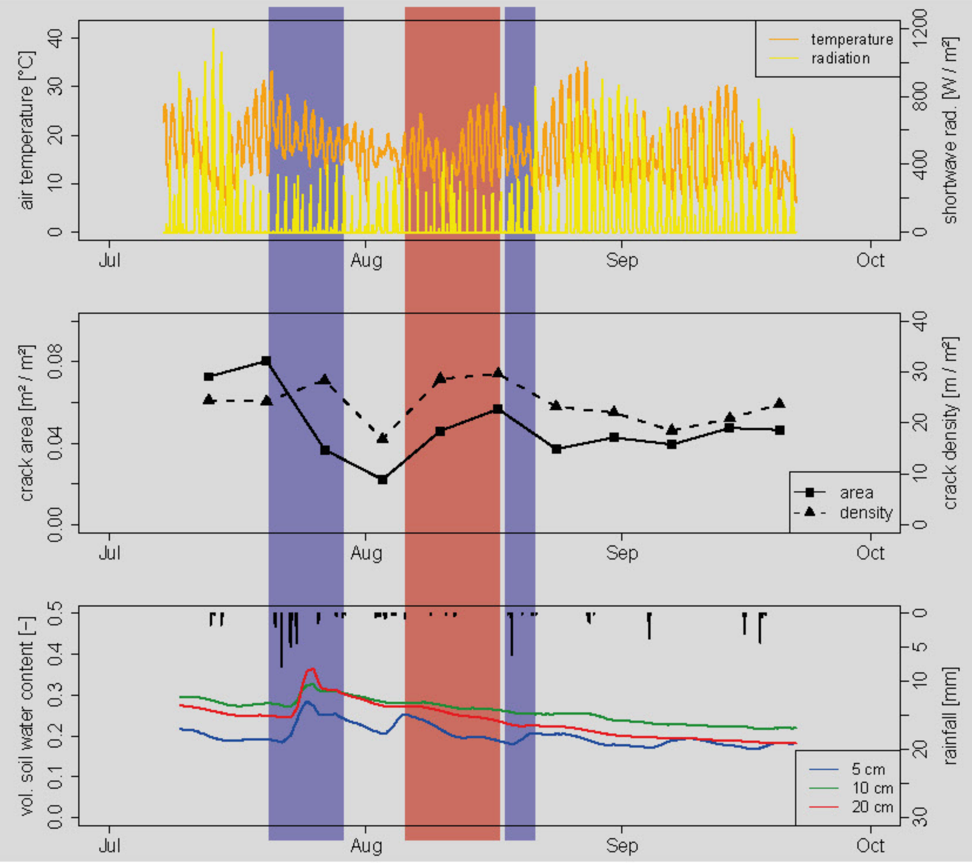
crack surface area: small



Homogeneous flow

crack surface area: very small





Mean temporal dynamics

Three major phases:

- Wetting 1: 21-26 July - 4 rainfall events (41 mm)
- Drying: 3-17 Aug - only minor rainfall
- Wetting 2: 18 Aug - 1 rainfall event (9.7 mm)

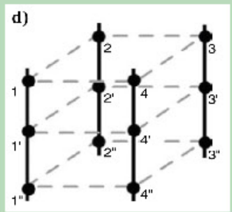
Material & Methods

Three plots (0.7 x 0.7 m) were installed on a corn field with a silty clay texture

Period: July 7th - September 21st

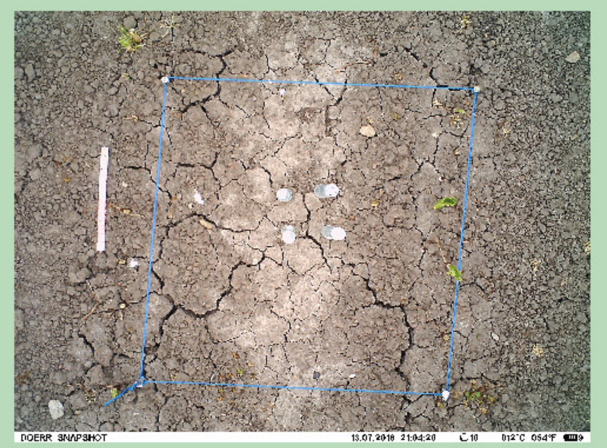
Measurements:

- Crack extent at the soil surface: time lapse photography (1 photo/hour)
- Crack depth: anisotropy of apparent electrical resistivity (AAER) - 3 cm depth resolution
- Soil water content: 3 depths (5, 10, 20 cm)
- Meteorological forcing: rainfall (radar), shortwave radiation, air temperature



Greve et al. 2010

Image Processing

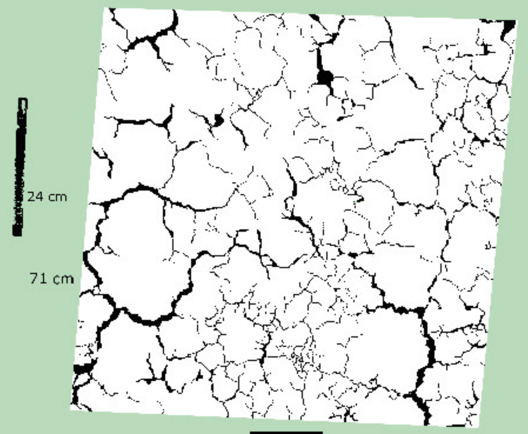


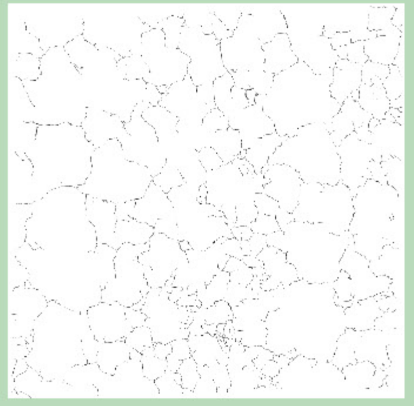
Crack Surface Area [m² / m²]

One image per week at all three plots was manually digitized.

Additionally, digital image processing was used to classify cracks during specific events. This was based on the Python code of Reck et al. (2018) which includes:

- contrast enhancement (8 bit greyscale)
- threshold filtering
- morphological opening
- size filtering

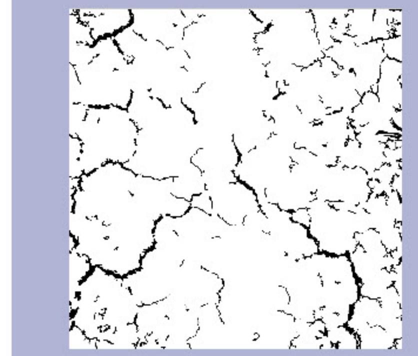




Crack Surface Density [m / m²]

ImageJ (Fiji): Analyze Skeleton tool

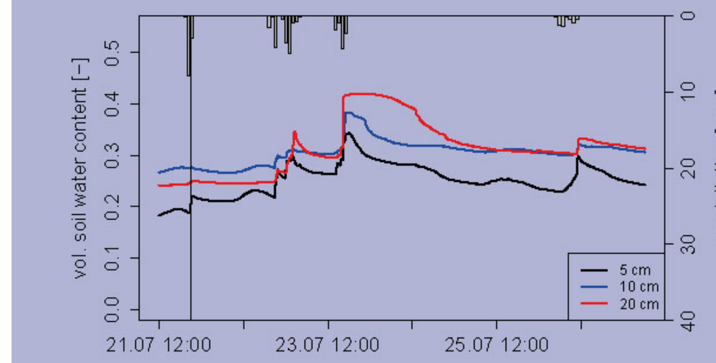
Wetting 1



1h

Event rainfall: 10.9 mm

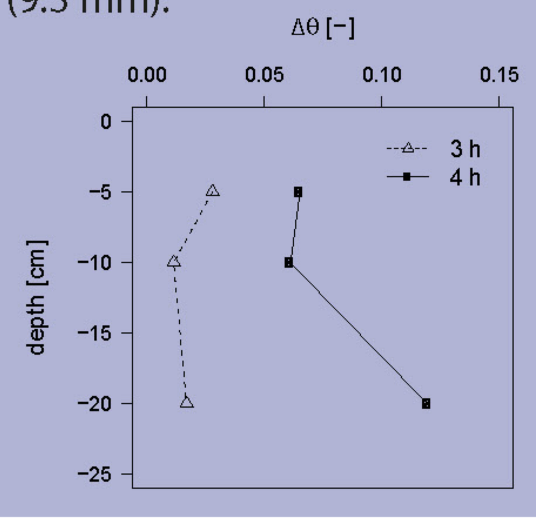
5.2	→	1.6 %	mean area
16.9	→	4.0 m / m²	mean density



Crack area decreases rapidly after the first rain (21 July) with only a small soil moisture reaction in 5 cm depth.

Following rainfall events: 23 July

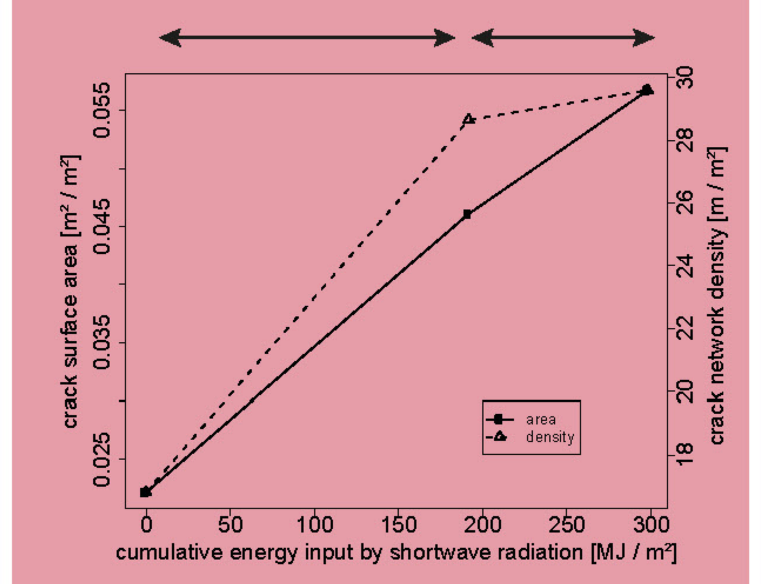
Mean soil water content (Δθ) change with depth since the begin of the event on 23 July (9.3 mm).



Strong and fast increase of soil water content in 20 cm depth with a rainfall amount similar to the first event. Surface crack area is still small prior to the rainfall and cracks are potentially not closed in deeper zones.

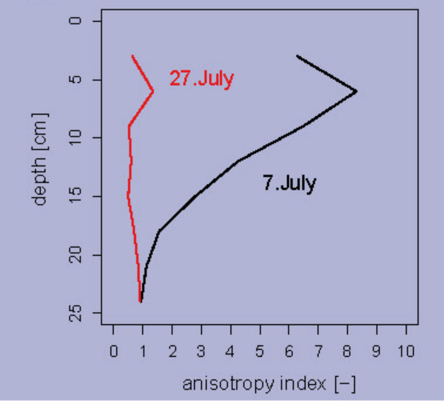
Subsurface initiation of preferential flow!

Drying

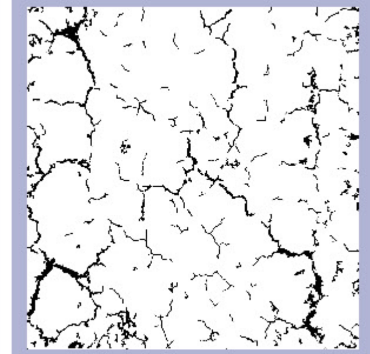


Change in crack area is similar in week 1 and 2. The change in the surface density of the crack network is decreasing in week 2, indicating a widening of the cracks.

After 41 mm of rain during wetting 1 the soil cracks closed also in greater depth as measured by AAER. A anisotropy index of 1 indicates a homogeneous medium.



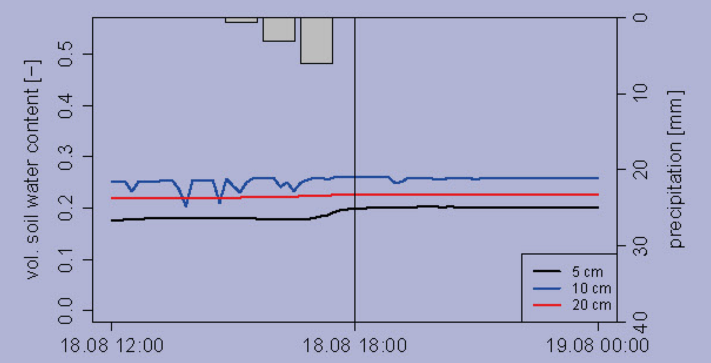
Wetting 2



1h

Event rainfall: 9.7mm

4.6	→	0.5%	mean area
15.7	→	1.7 m / m²	mean density



After the drying the reaction is similar to the first event of wetting 1 with the large change in crack area, but only a small water content change in the topsoil.

Conclusion

- Large surface crack area does not lead to higher amounts of preferential flow.
- Surface crack area and density decreases rapidly during a rain event (hour).
- For following events a higher topsoil water content favors subsurface initiation of preferential flow unless cracks are closed at the surface.
- High amounts of rain are necessary for closing a soil crack in the subsurface.

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Greve AK, Acworth RI, Kelly BFJ. 2010. Detection of subsurface soil cracks by vertical anisotropy profiles of apparent electrical resistivity. Geophysics 75 (4).
Reck A, Jackisch C, Hohenbrink TL, Zangerlé A, Schaik L Van. 2018. Impact of Temporal Macropore Dynamics on Infiltration : Field Experiments and Model Simulations. Vadose Zone Journal 17 (1).

DFG Deutsche Forschungsgemeinschaft
CAOS catchments as organised systems