A novel experiment for measuring infiltration into seasonally frozen soil

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Introduction

Depending on the water content the infiltration of frozen soil can decrease compared to unfrozen conditions due to pore blockage of ice and leads to increased surface runoff during rain-on-snow or winter storm events. Under these circumstances the hydraulic conductivity of the matrix becomes small and ice-free macropores become a crucial factor for infiltration capacity of the frozen soil. Field experiments showing evidence of the importance of preferential flow pathways in seasonally frozen soil are still rare.

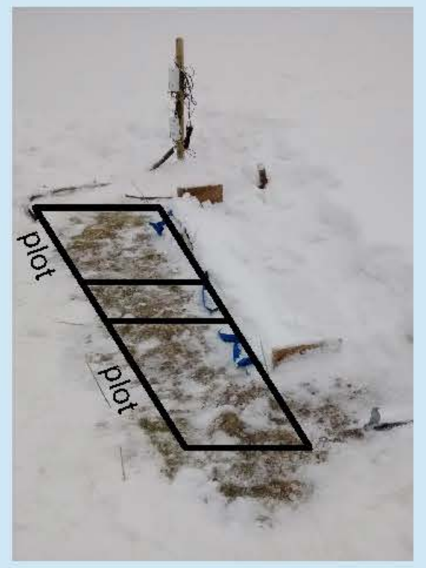
Objective:

1) Development of a experimental approach to identify flow processes inseasonally frozen soil
2) Show the relevance of macropores under these conditions

Study Site

The Schauinsland study site is located at a typical montane (~1200 m a.s.l.) grassland site in the Black Forest, Germany. Soils are Cambisols developed over Gneiss with a loamy texture. Soil thickness was 40-50 cm with a very high rock fraction deeper than 50 cm. In 10 cm depth 30 macropores/m² (≥ 2 mm Ø) were found.

depth [cm]	Horizon	ρ_b [g/cm³]	ϕ [-]
0-17	Ah	0.93	0.64
17-40	B	1.09	-

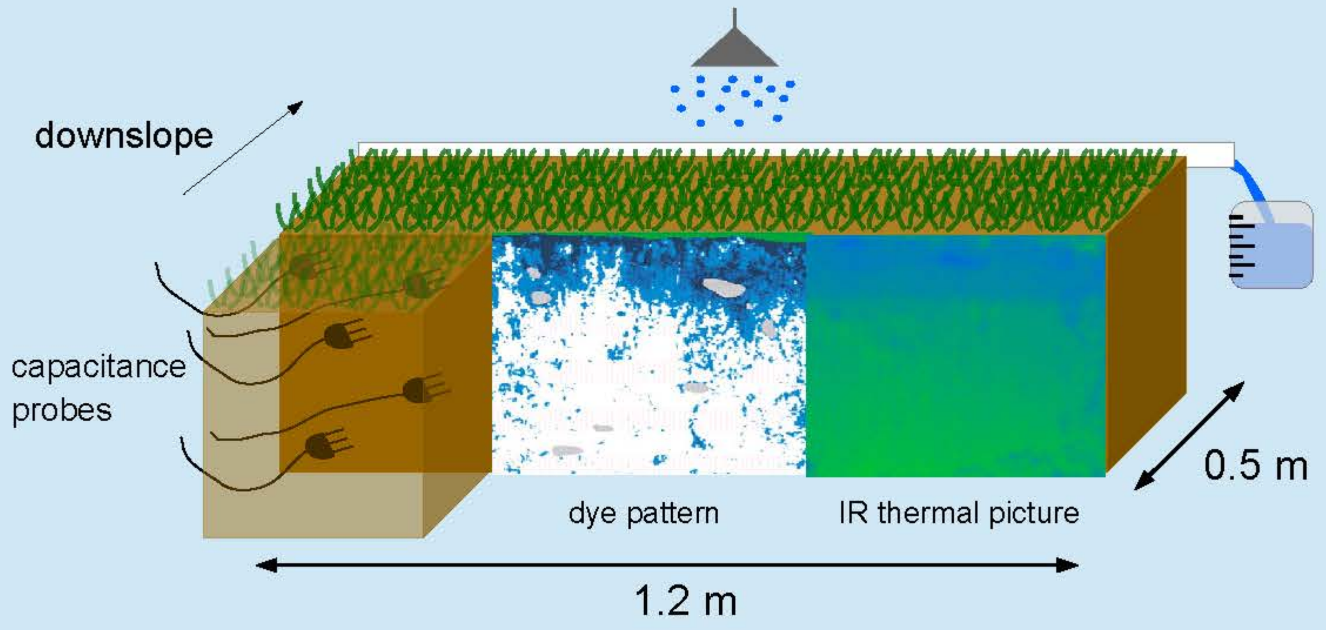


Experimental Setup

- Sprinkling experiments under frozen conditions with different rates for 1 h (30,40,50 mm/h)
- Four plots, each with an area of 0.6 m²
- Initial water content $\theta_{0\text{-}15cm}$ = 0.44
- Five capacitance probes (Decagon 5TE) per plot at different depths (5,10, 15, 25 and 35 cm) were installed in autumn
- Added tracer: Brilliant Blue FCF (4 g/l), NaCl (5 g/l, EC_{water} = 10 mS/cm)
- Thermal infrared imagery of frozen profiles and thermal time lapse pictures during the sprinkling events
- Test of higher sprinkling water temperature as flow path tracer
- Soil cores to measure change in total water content
- Surface runoff was collected and measured every 5 minutes
- Reference measurements under unfrozen condition in autumn with two initial water contents

Sprinkling rate [mm/h] for all 6 plots and respective sprinkling water temperature or initial moisture status

unfrozen		frozen	
dry	wet	3°C	8°C
50	50	30	40
		50	40



Results

Unfrozen Brilliant Blue dye patterns

wet $\theta_{0\text{-}15cm}$ = 0.41

dry $\theta_{0\text{-}15cm}$ = 0.31

Preferential flow with matrix interactions under unfrozen wet conditions.

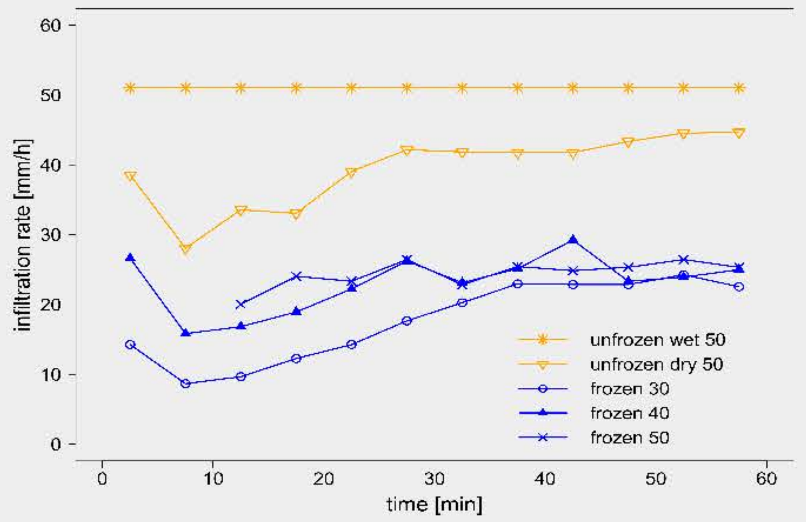
No matrix flow or interactions in the frozen layer. Blue stained areas were found below the frozen layer.

Flow in the frozen layer was always associated to roots.

Temperature change too small to detect water change due to temperature change using thermal imagery.

Frozen layer was detectable on the thermal infrared pictures.

Frost layer thickness was not uniform and ranged from 5-15 cm.



Frozen soil infiltration rates were much lower than those of the unfrozen plots.

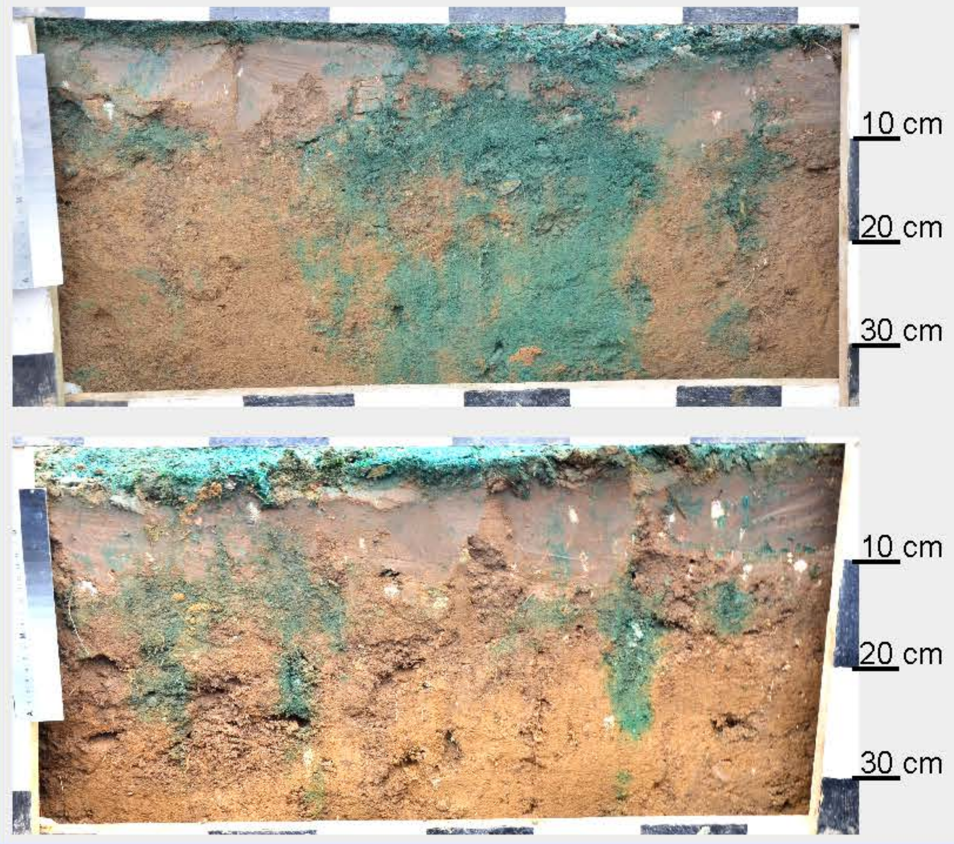
40 minutes after the start of the sprinkling the frozen infiltration rate became constant at ~ 25 mm/h.

Surface runoff started immediately after the beginning of the sprinkling for all frozen soil plots.

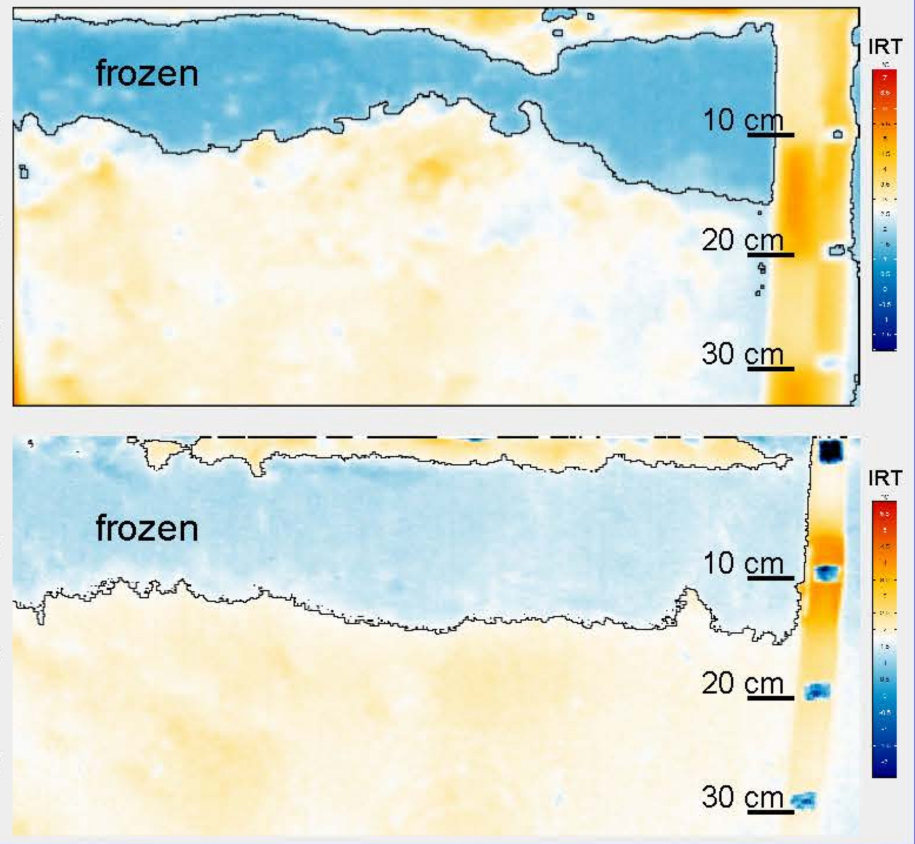
A peak in surface runoff was found under dry conditions in autumn.

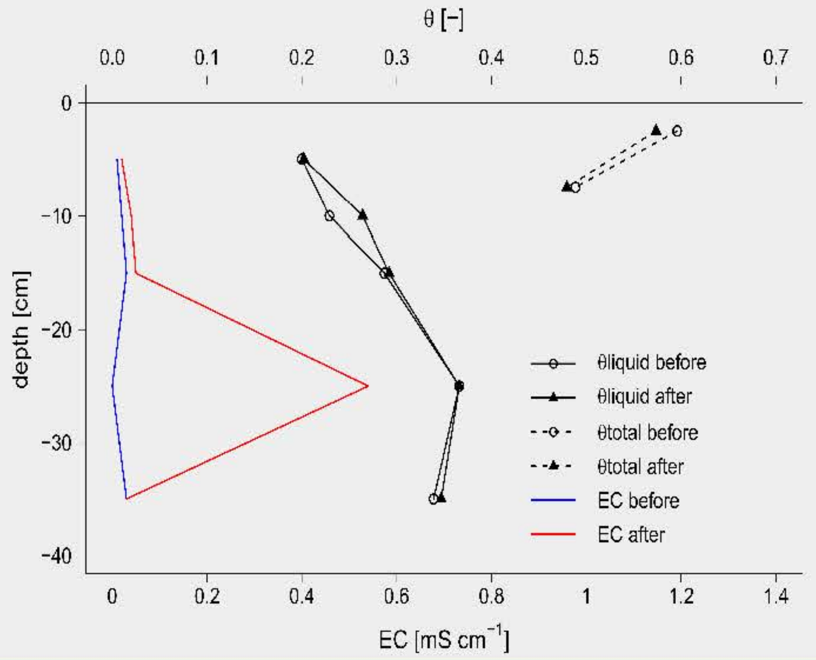
Frozen Brilliant Blue dye patterns

$\theta_{0\text{-}15cm}$ =0.44



Thermal infrared pictures (ε = 1)





Total water content in the frozen layer stayed constant for all plots.

Most capacitance probe data showed an increase of water content or bulk electrical conductivity (EC) under the frozen layer.

Conclusion

Relatively high infiltration rate for a frozen soil

Water is channelized through the frozen layer by macropores

Heterogeneous preferential flow below the frost layer

Nearly no matrix flow and interaction in the frozen layer

Spatial information on frost layer thickness can be obtained by thermal infrared imagery, providing additional details on the water flow path

Frozen soil surface runoff was much higher than under unfrozen conditions and independent of frost depth and sprinkling rate

Acknowledgments

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