

Windows to the underground

Micro-engineered Soil Chips reveal microbial interactions with space

P. Micaela Mafla-Endara

Edith C. Hammer

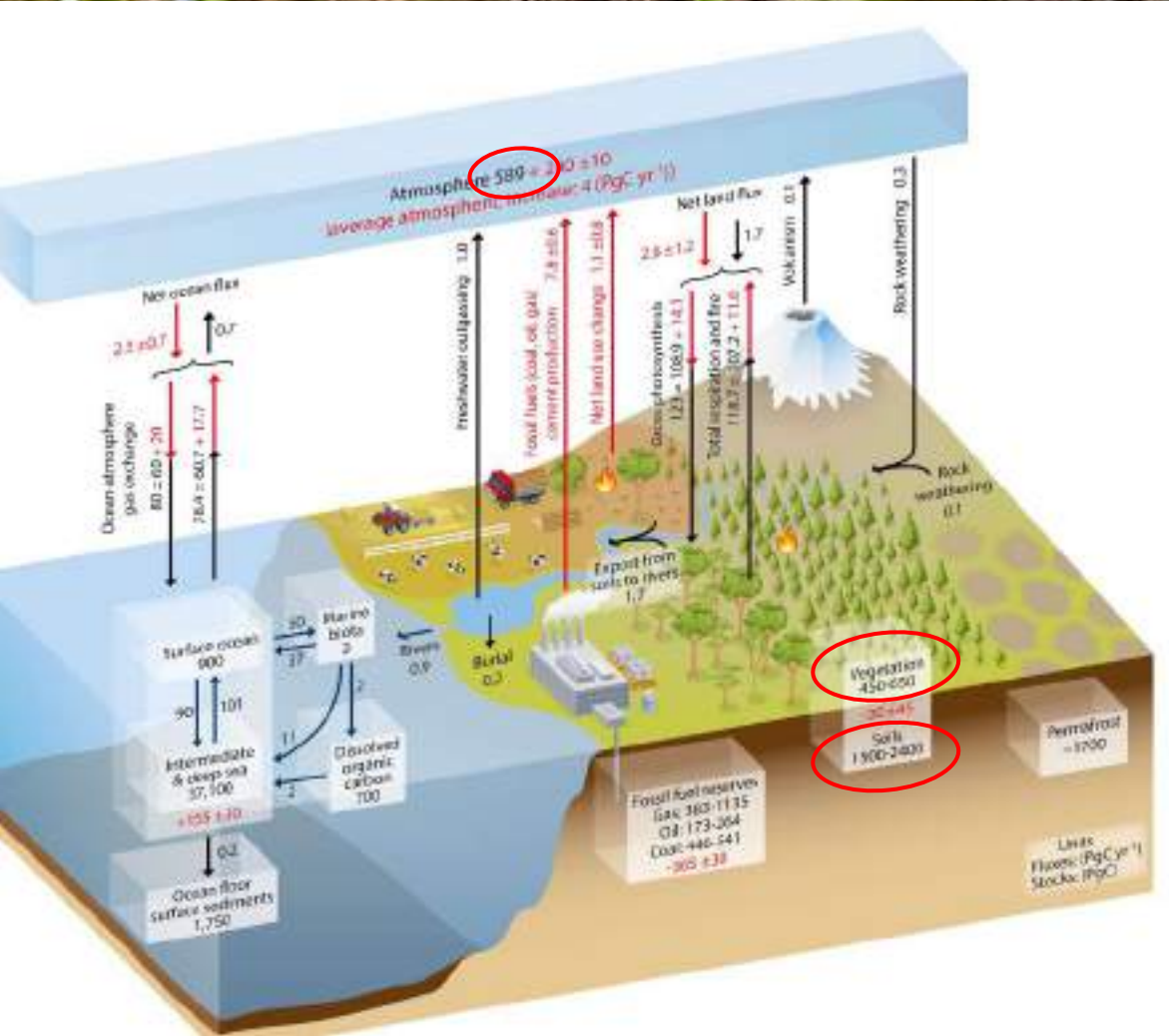
Department of Biology, Lund University, SWEDEN

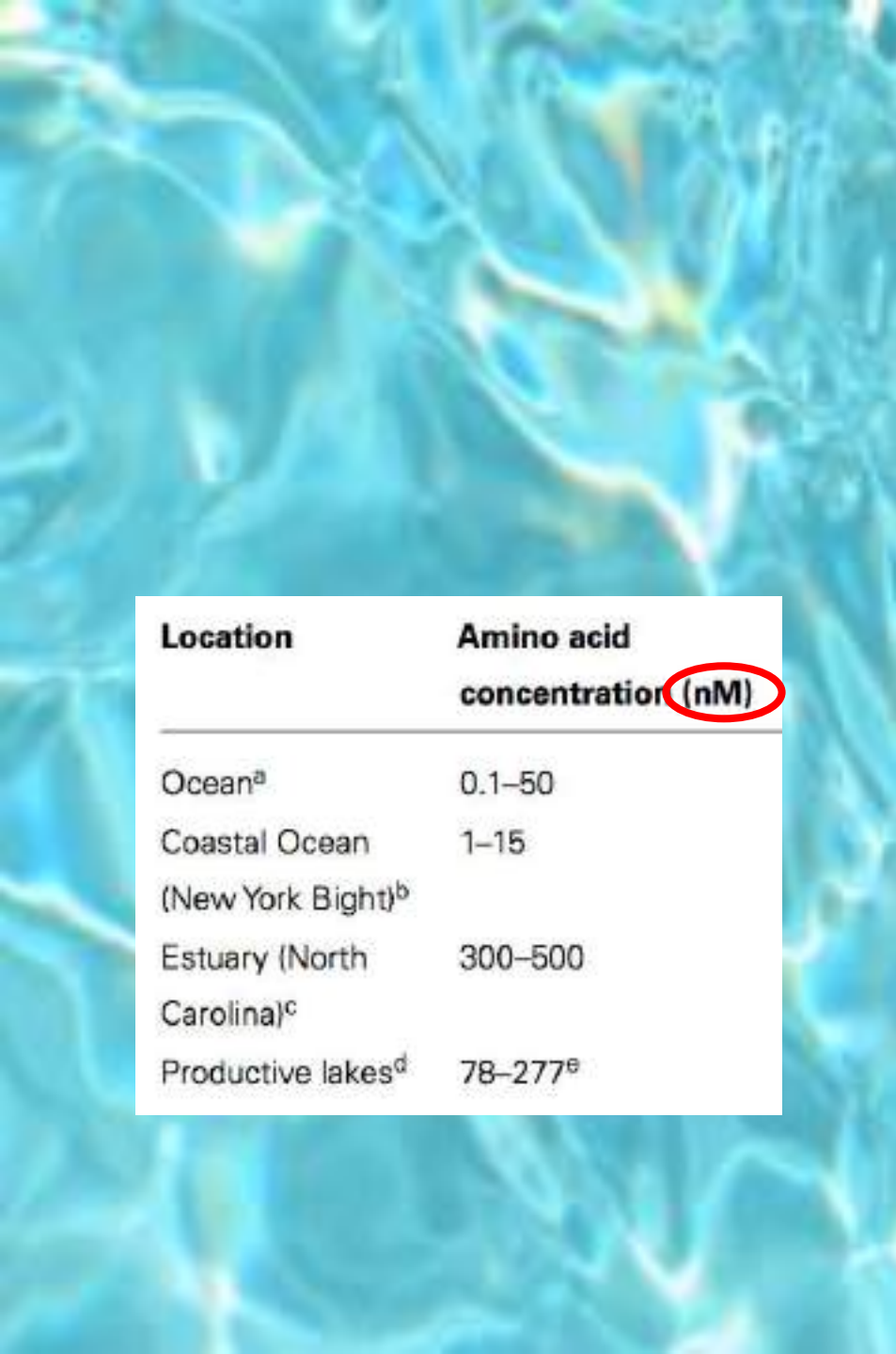
edith.hammer@biol.lu.se,

twitter @EdithCHammer, www.soilchip.wixsite.com/soilchip







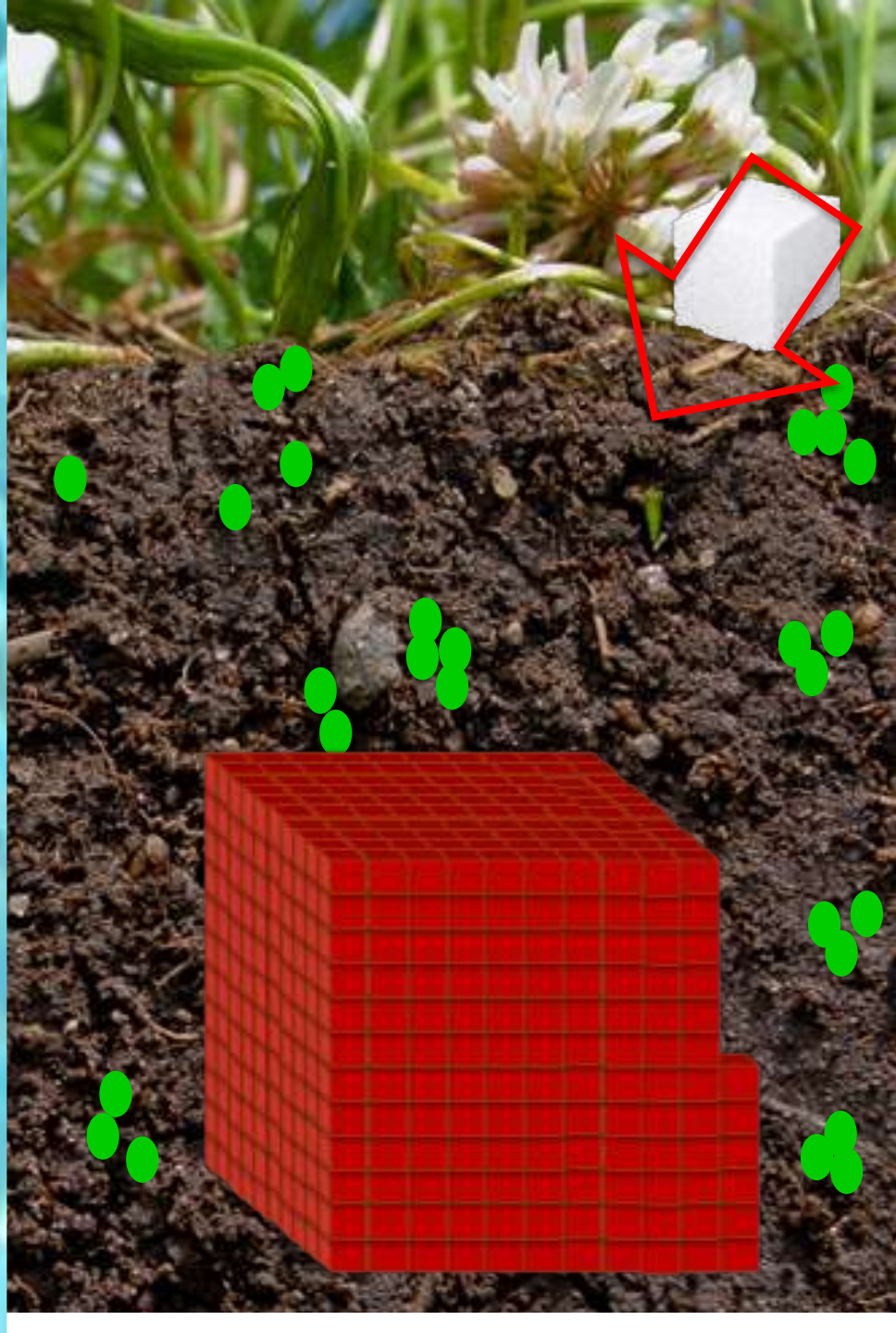


Location	Amino acid concentration (nM)
Ocean ^a	0.1–50
Coastal Ocean (New York Bight) ^b	1–15
Estuary (North Carolina) ^c	300–500
Productive lakes ^d	78–277 ^e



System studied	Amino acid concentration (μM)
40 soils worldwide ^a	23 ± 5
Boreal forest, Sweden ^b	42–106
	5–20
Pine forest, California ^f	35
Temperate forest, U.S. ^g	301

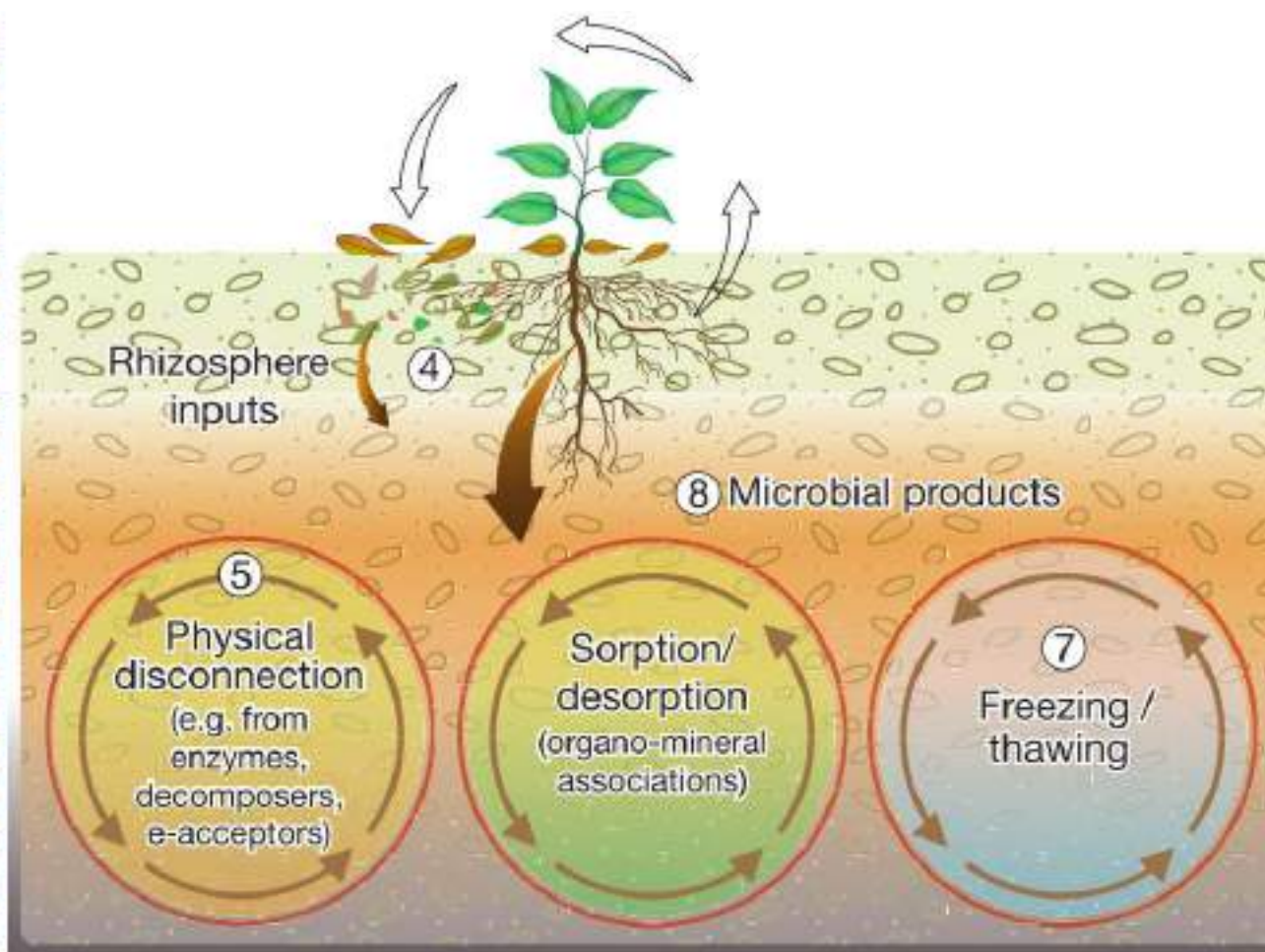
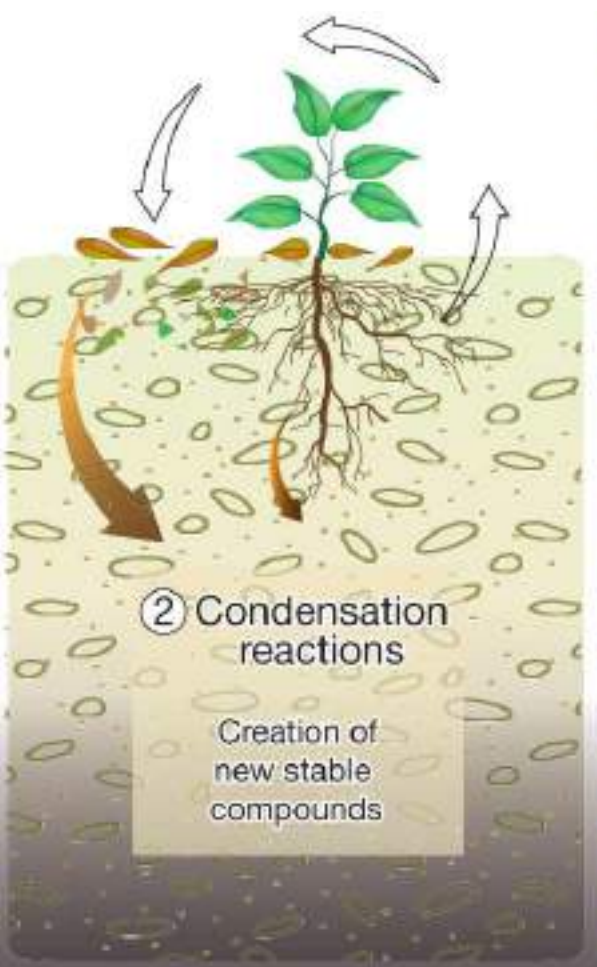
Reviewed by Hobbie & Hobbie 2012



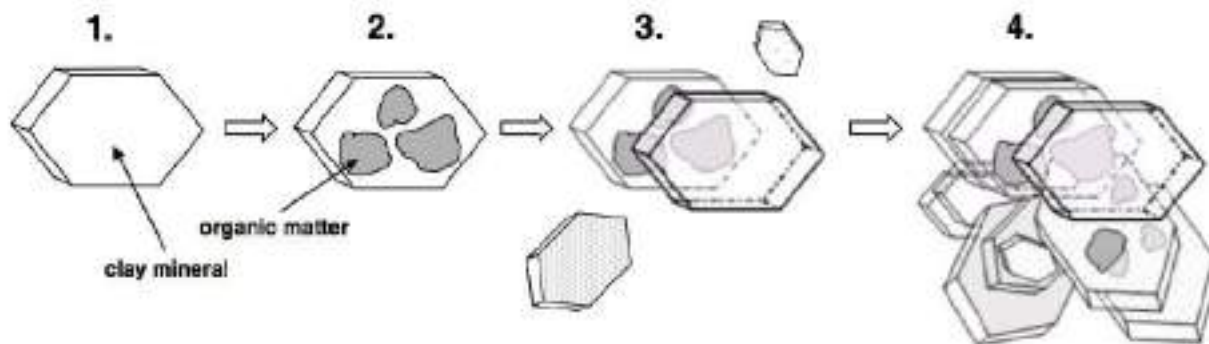




<https://www.youtube.com/watch?v=7fhufJHzGsM>: John W. Crawford, University of Sydney, with permission. The sample was scanned using X-ray microtomography scanner and reconstructed in 3D. The structure is real, the texture is artificial. With permission by John W. Crawford.

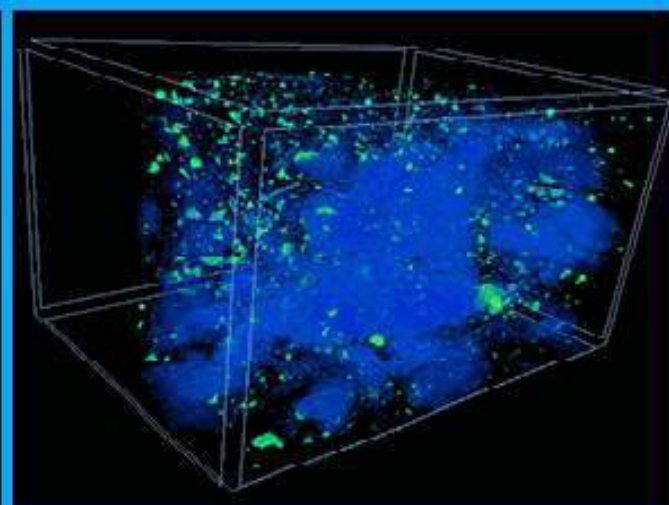
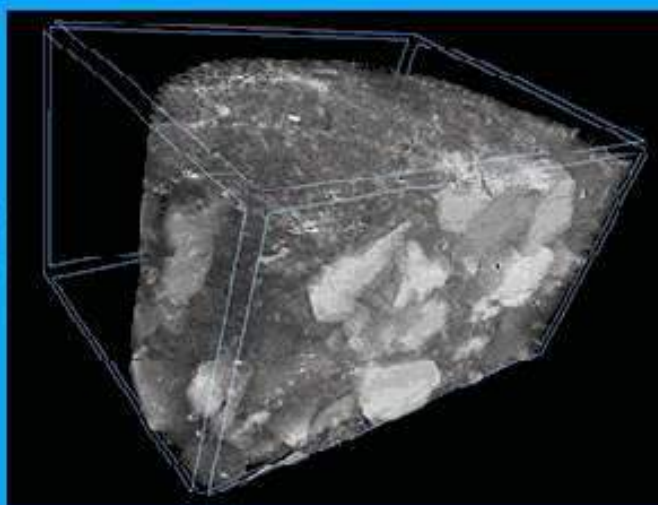
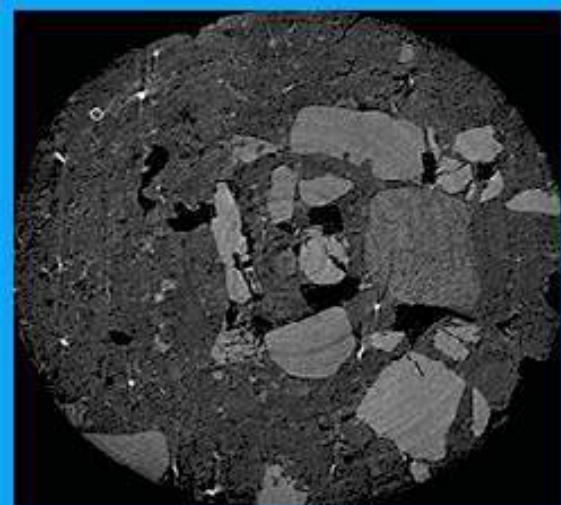


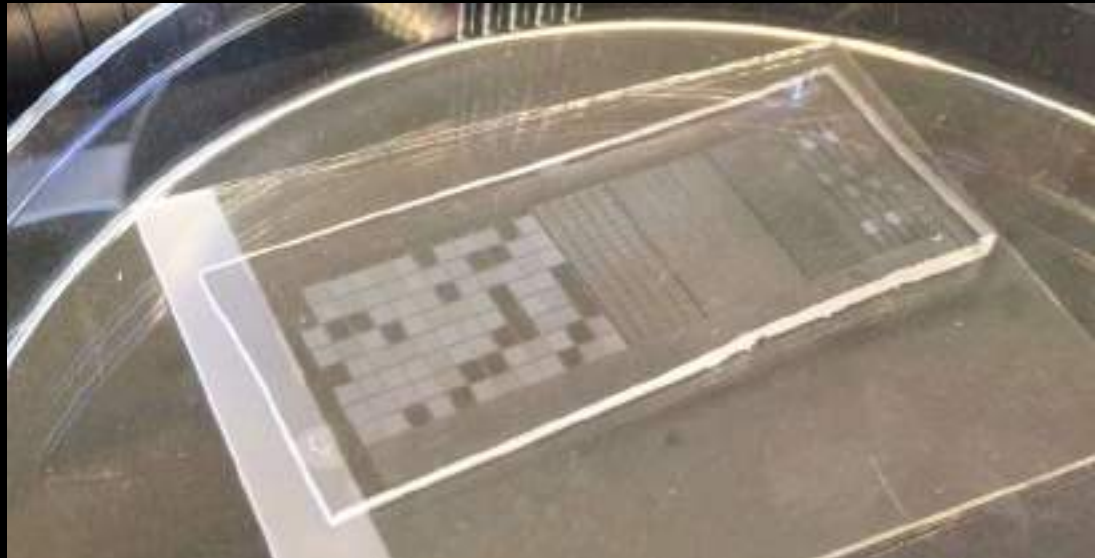
Schmidt et al. 2011



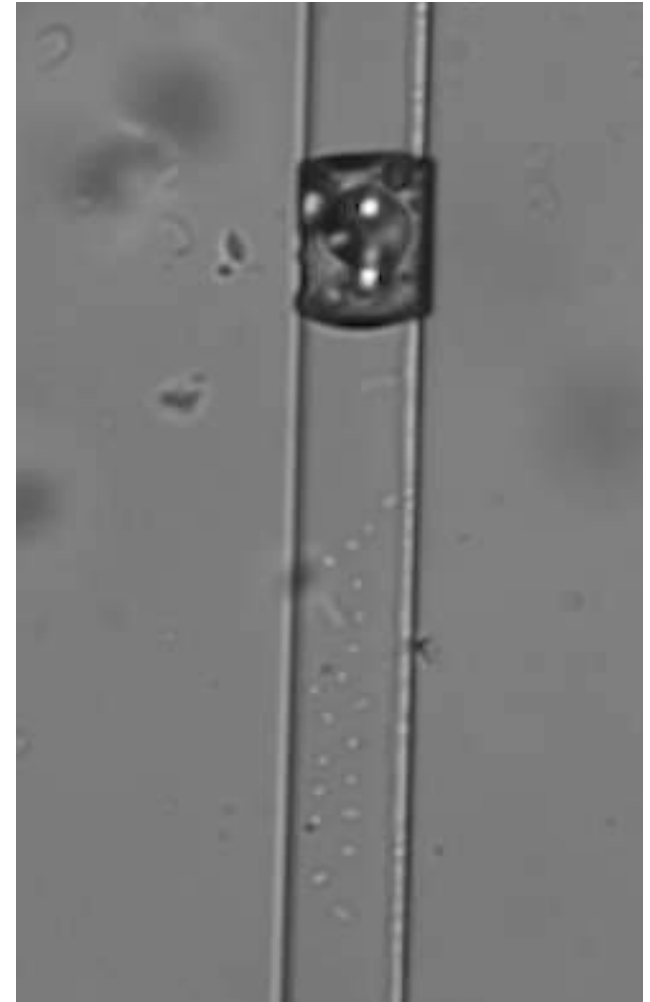
Lehmann et al. 2006







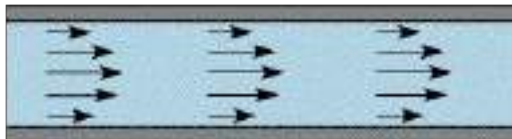
The world at microscale



Turbulent



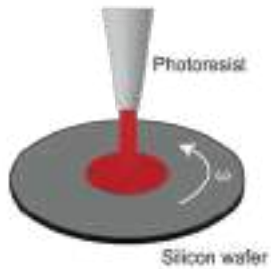
Laminar



Soft lithography

Master fabrication

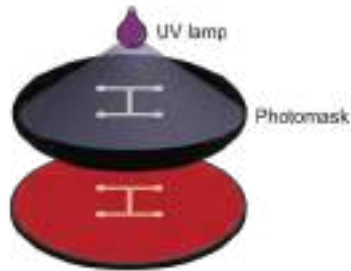
a. Deposit photoresist



Profile



b. Expose to UV light



Profile



c. Develop exposed wafer



Profile



Device fabrication

d. Pour PDMS



Profile



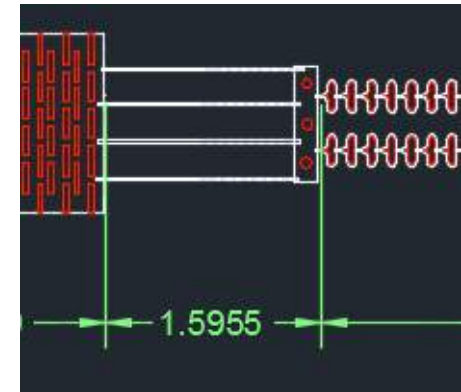
e. Activate surfaces



f. Seal the chip



Profile

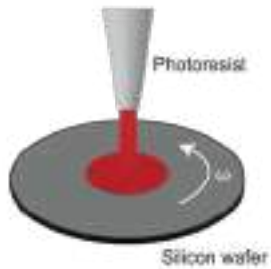


Design drawn in CAD

Soft lithography

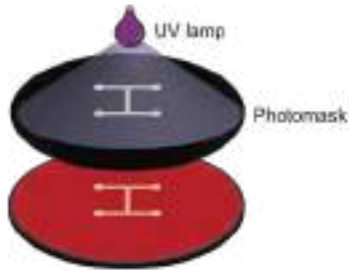
Master fabrication

a. Deposit photoresist



Profile

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Device fabrication

d. Pour PDMS



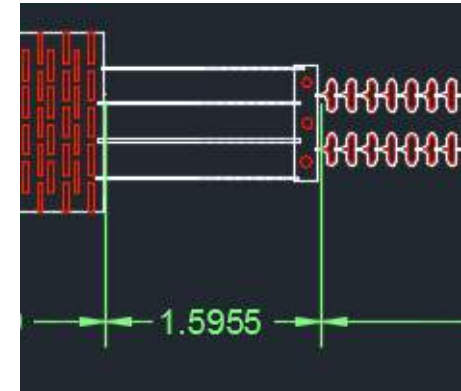
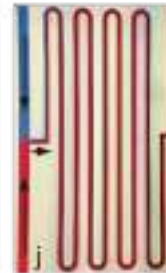
e. Activate surfaces



f. Seal the chip



Device utilization

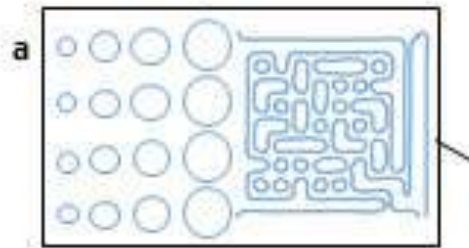


Design drawn in CAD

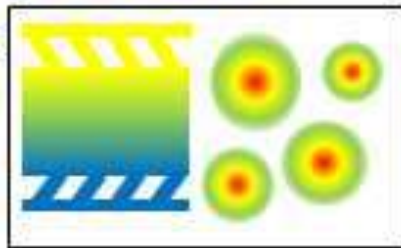


Aleklett et al. & Hammer 2018 ISMEJ

How can we use microfluidics to study microbial ecology in soil systems?



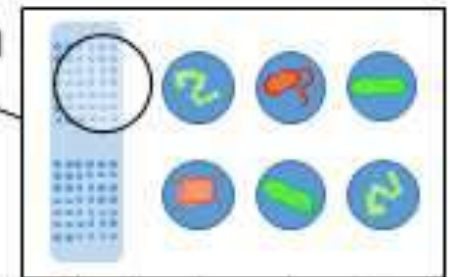
a Simulating physical heterogeneity



b Creating chemical gradients and patches



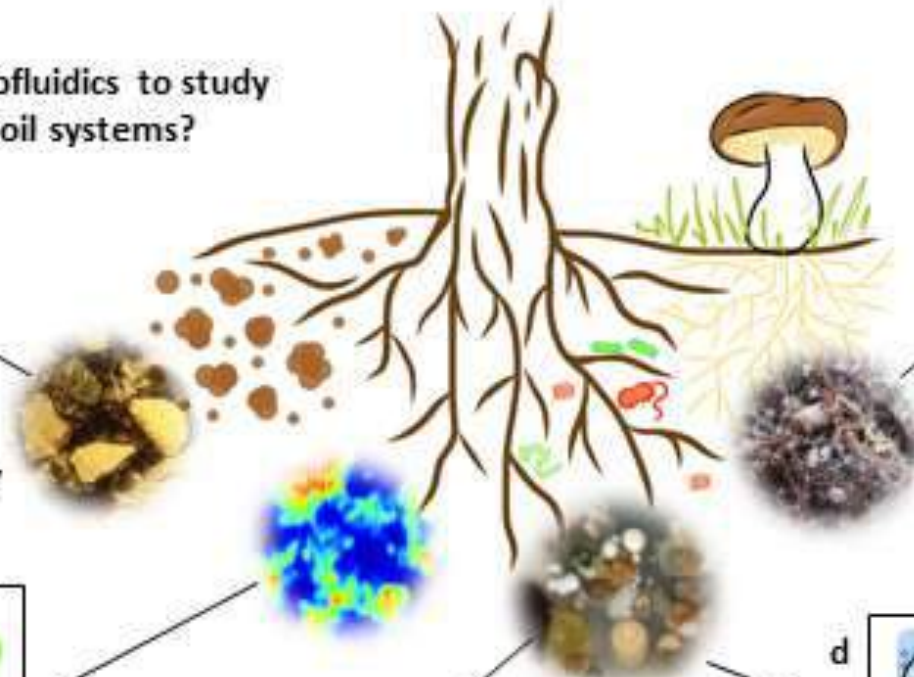
c Manipulating microbial interactions



d Culturing the unculturable

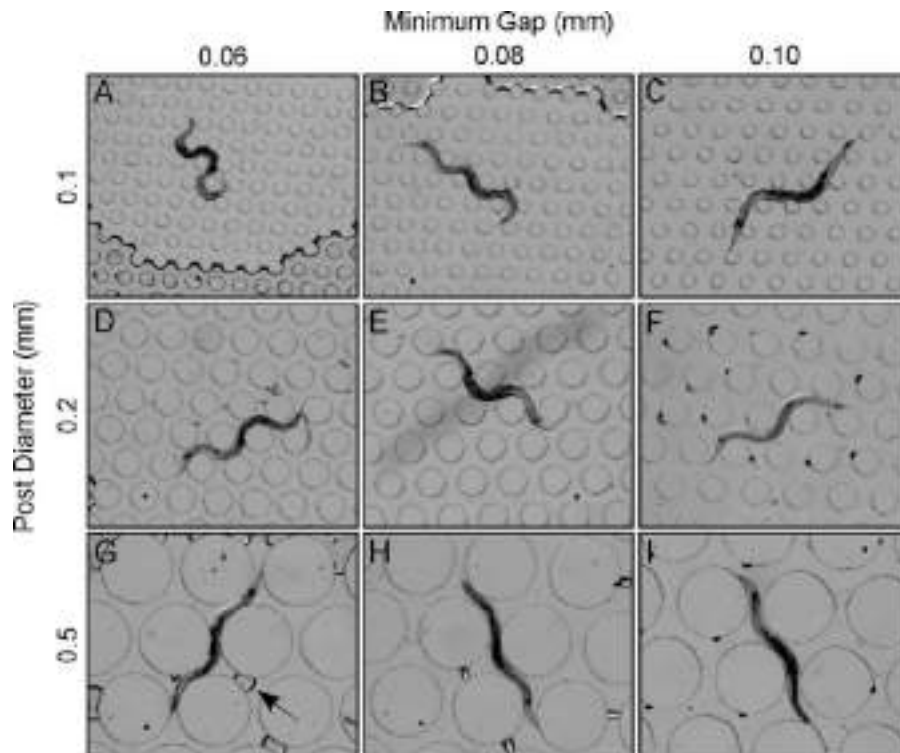


e Studying rhizosphere interactions



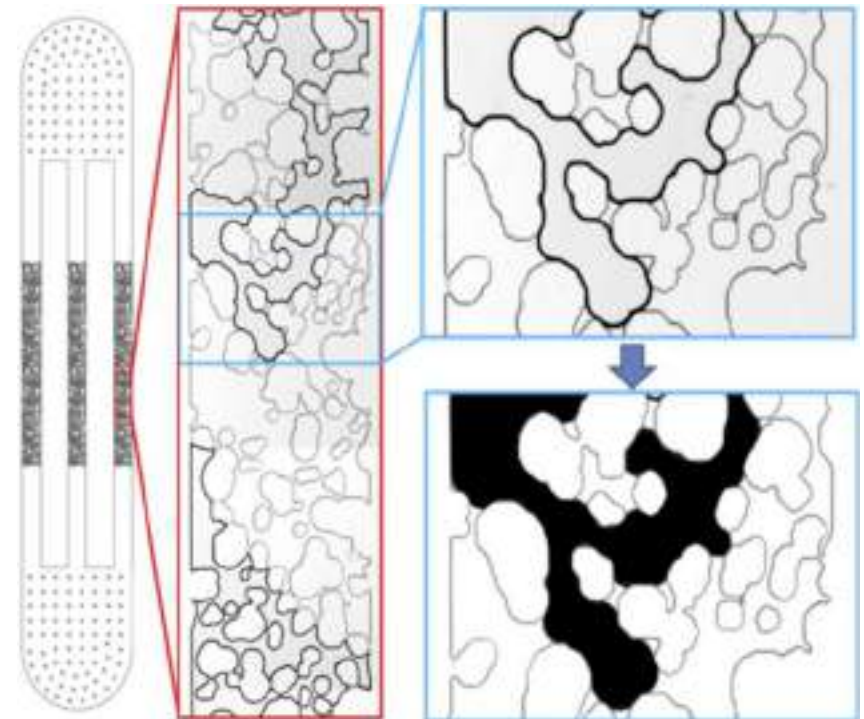
Creating micro-structures to simulate soil

Nematode movement in different "particle sizes".



Lockery et al. 2008 J Neurophysiology

Effects of microbial EPS on soil moisture retention.



Deng et al. 2015 Soil Biol Biochem

Fungi in chips: Held et al., 2019 PNAS

Millet et al. 2019, Fung Biol Biotech

Bhattacharjee et al. 2021 bioRxiv

Stanley et al. 2021, CommsBio.

Soufan 2018, Frontiers Envir Sci

Physical soil C
stabilization – can OM
hide in the soil pore
space?

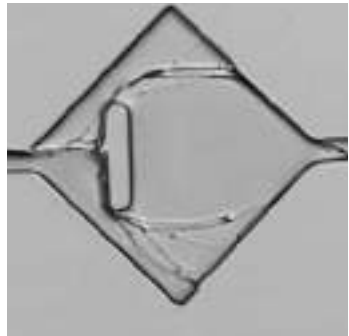


Main current and recent projects

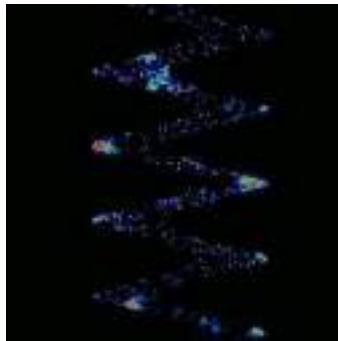
Pelle Ohlsson



Fungal foraging behavior



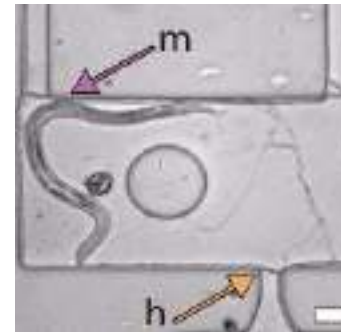
Spatial microbial activity



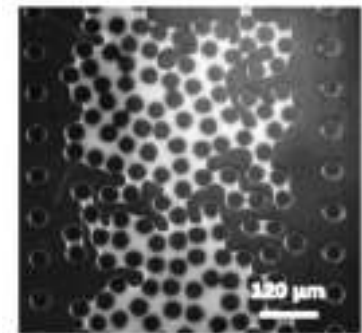
Micro-spectroscopy



In-situ soil microbial interactions



Chemical patchiness



Kristin Aleklett



Carlos G. Arellano



Milda Pucetaite



P. Micaela Mafla Endara

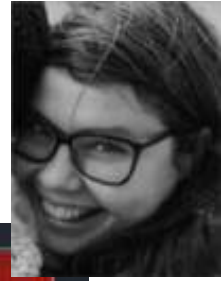


Joe Hanbang Zou

What is spatial availability for fungi?

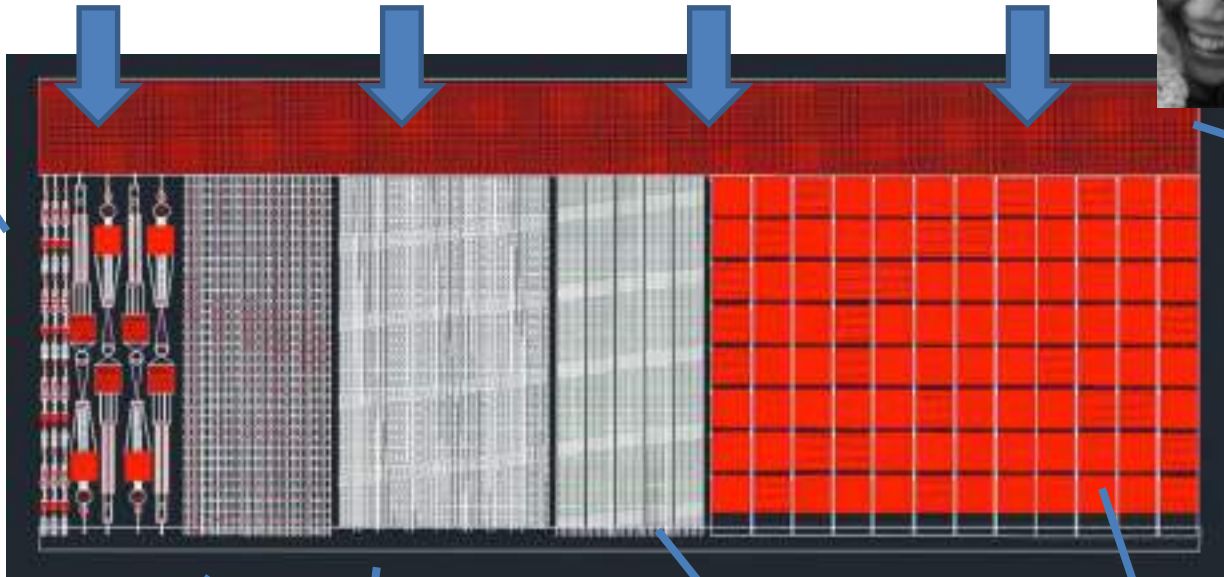


The "Obstacle chip"



Kristin Aleklett

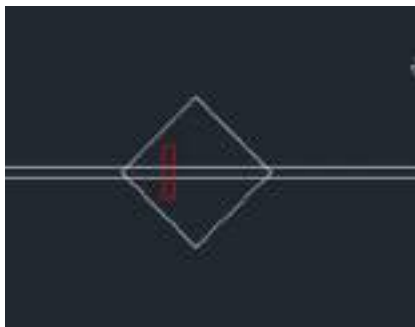
Obstacle courses



Entry-way pillar system



Alternating narrow and wide channels.



Angled channels



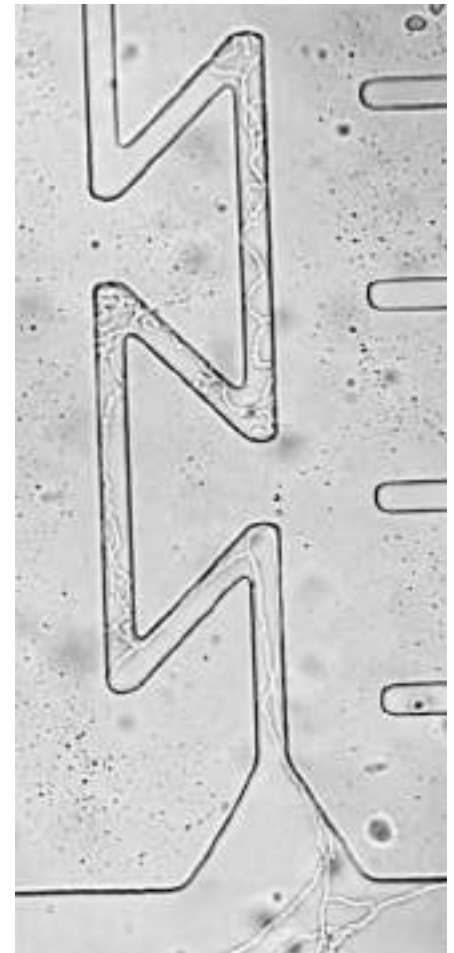
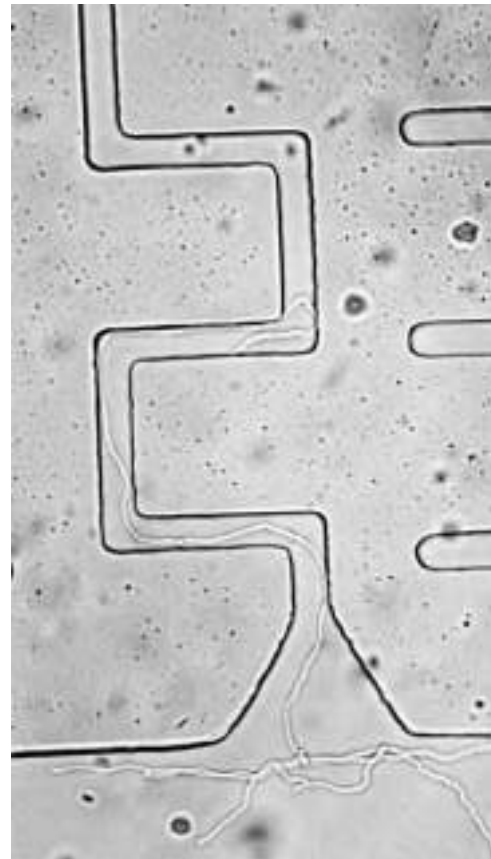
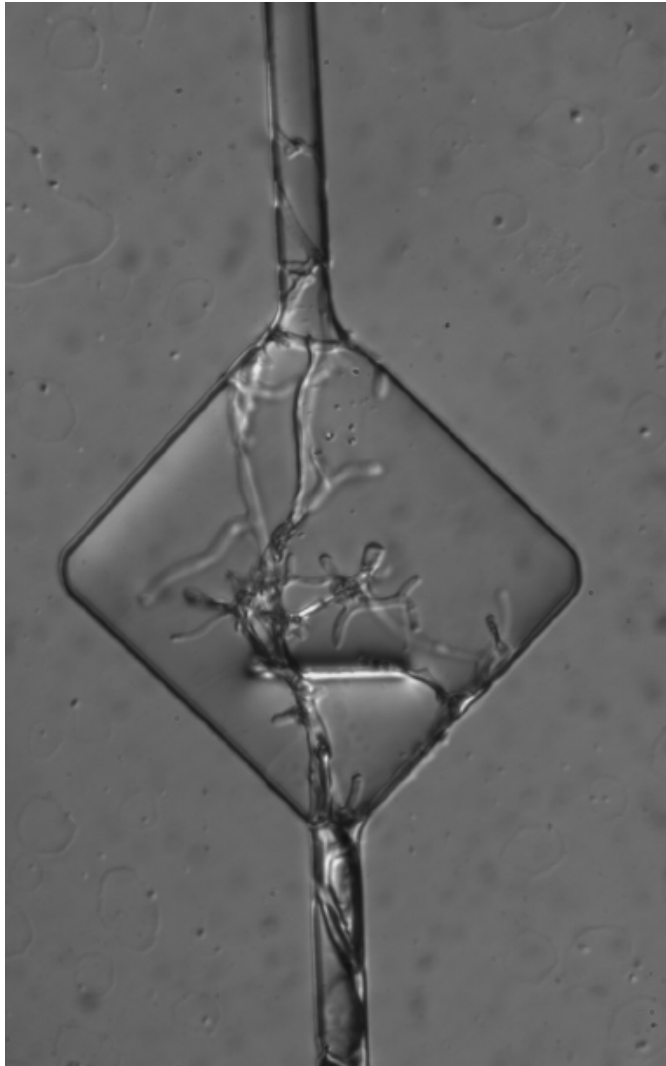
Channels of different width



Squares with honeycomb patterns of different width and spacing.

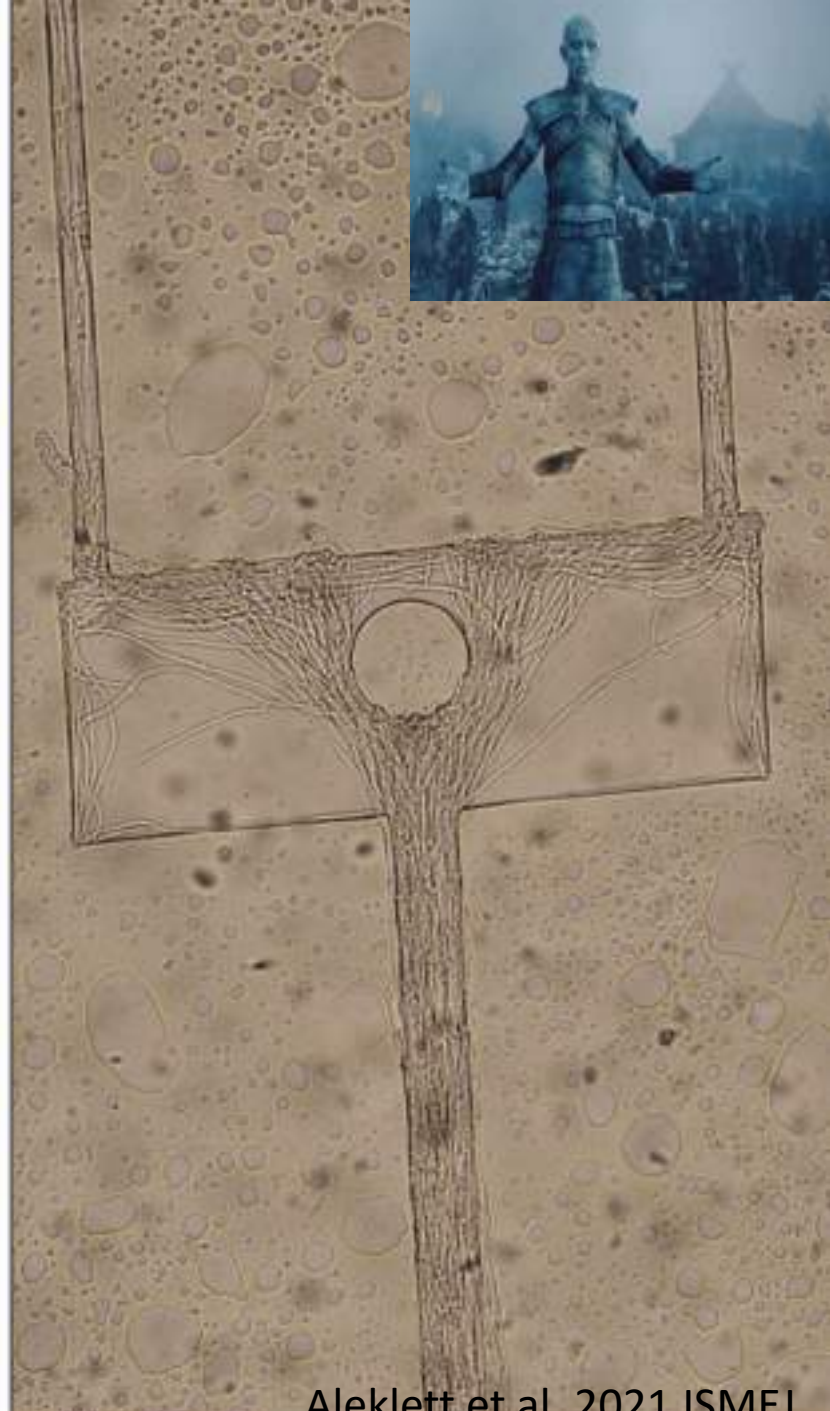
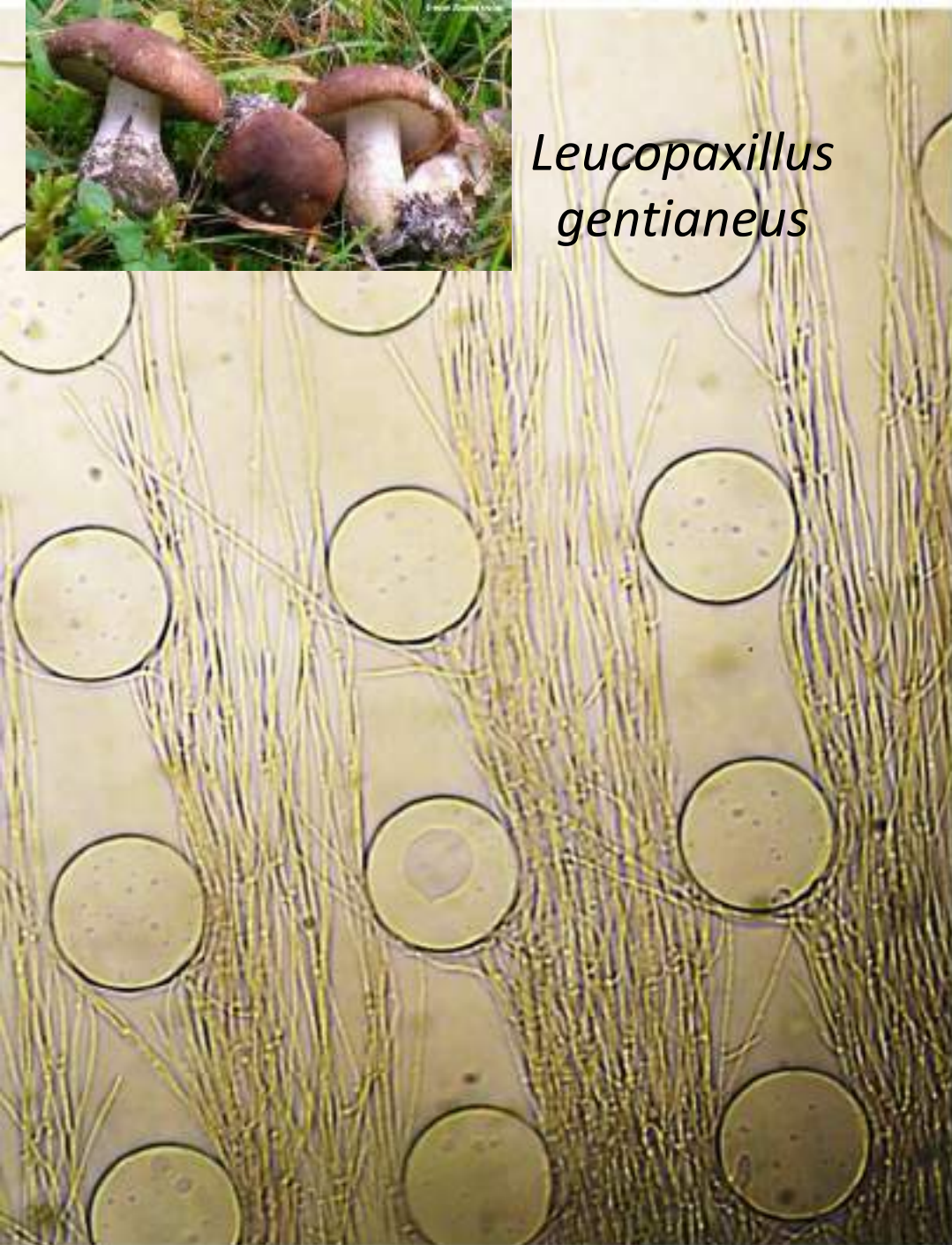


Psilocybe subviscida

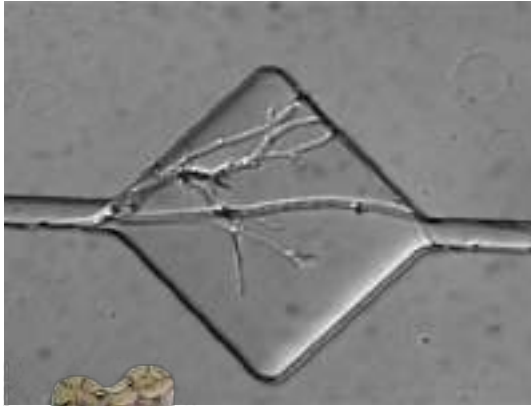




Leucopaxillus gentianeus



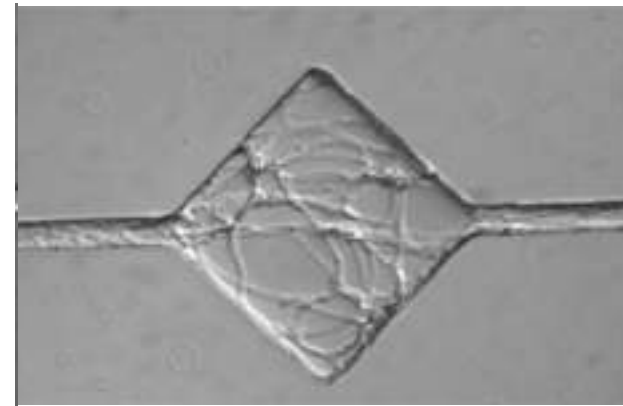
Exploring or not exploring sudden openings?



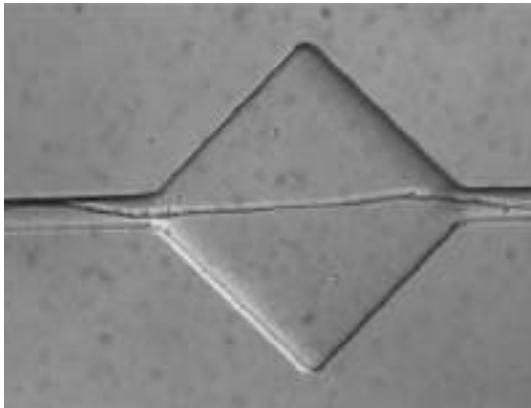
Gymnopus



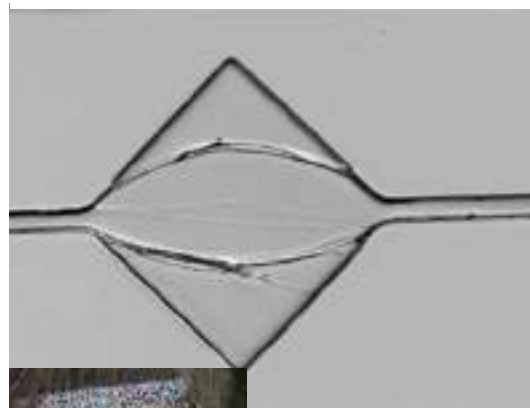
Psilocybe



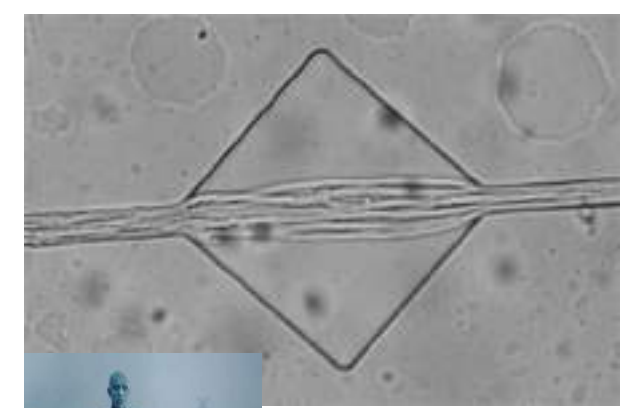
Mycetinis



Lepiota

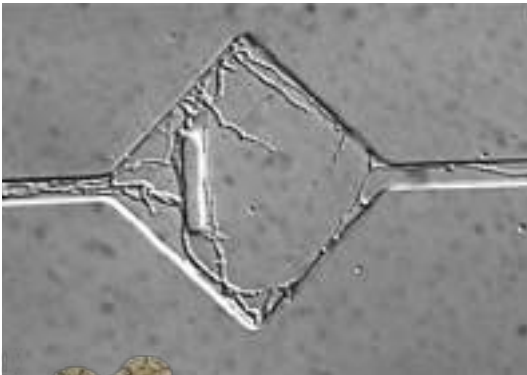


Coprinellus

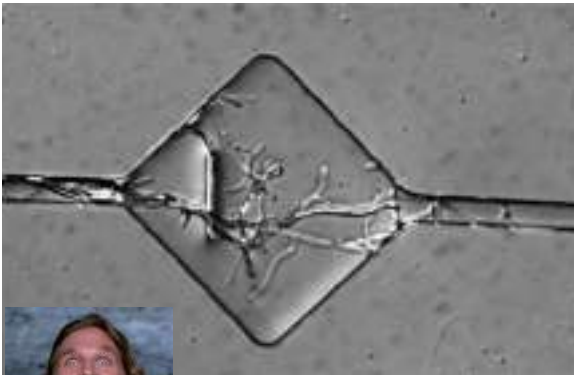


Leucopaxillus

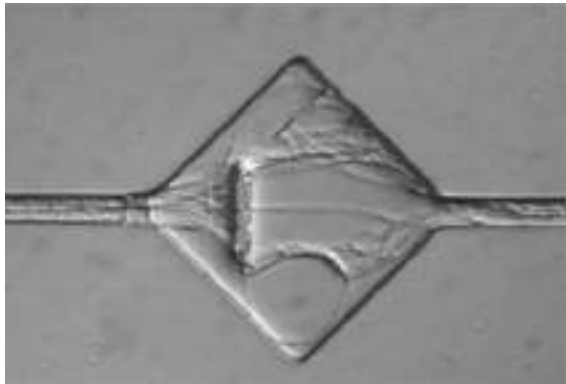
Does an obstacle to the tip change foraging behaviour?



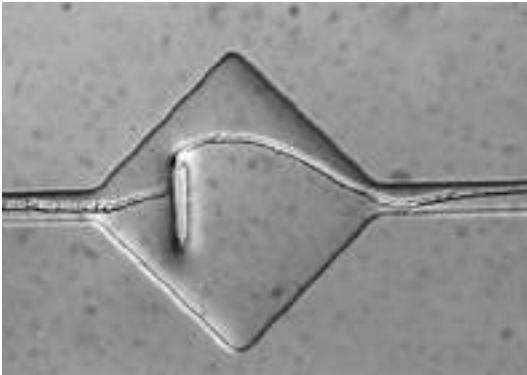
Gymnopus



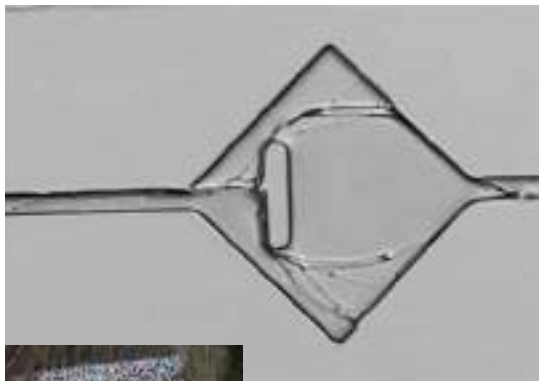
Psilocybe



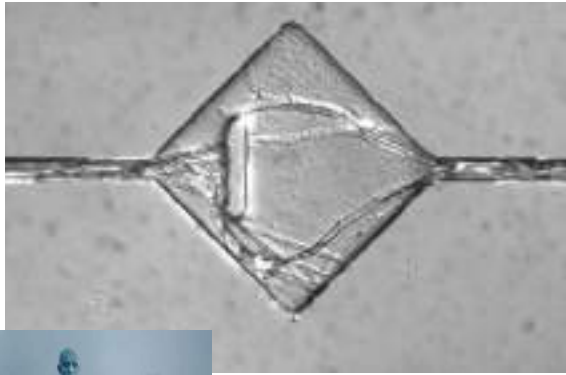
Mycetinis



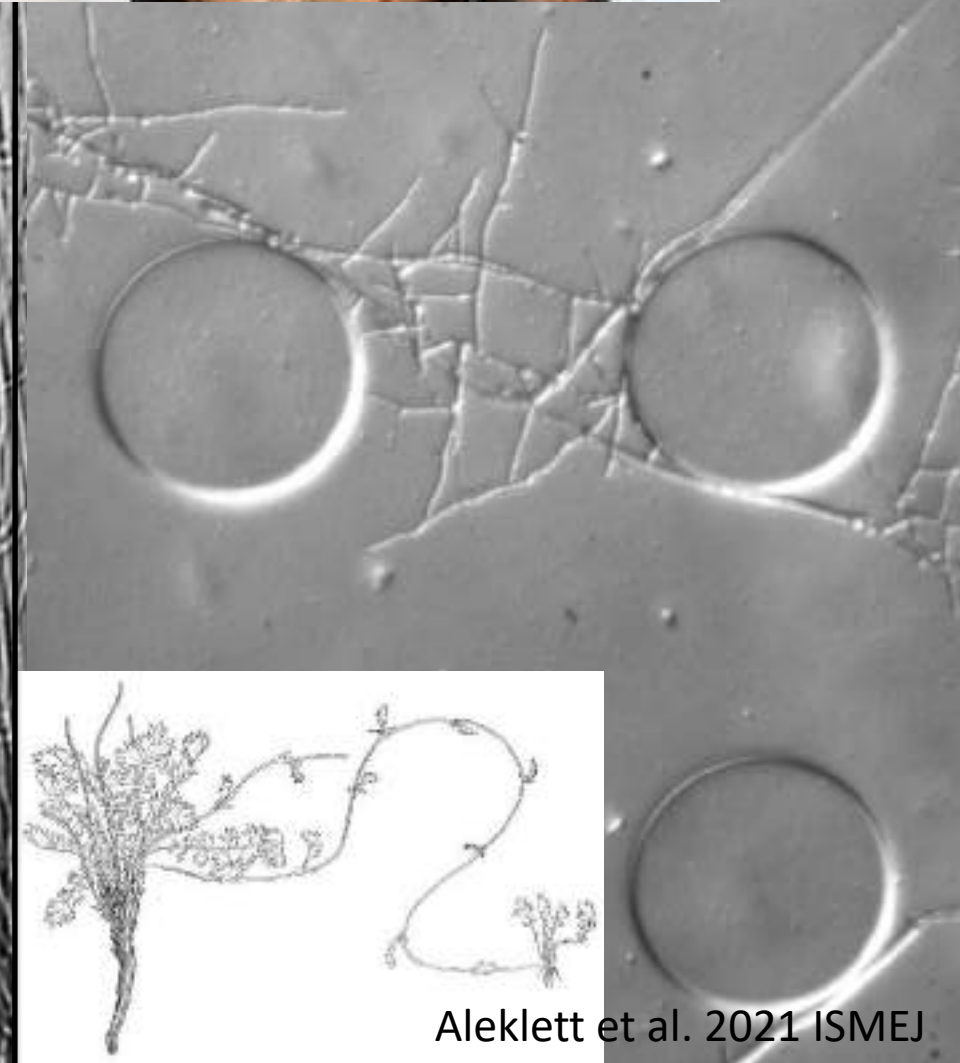
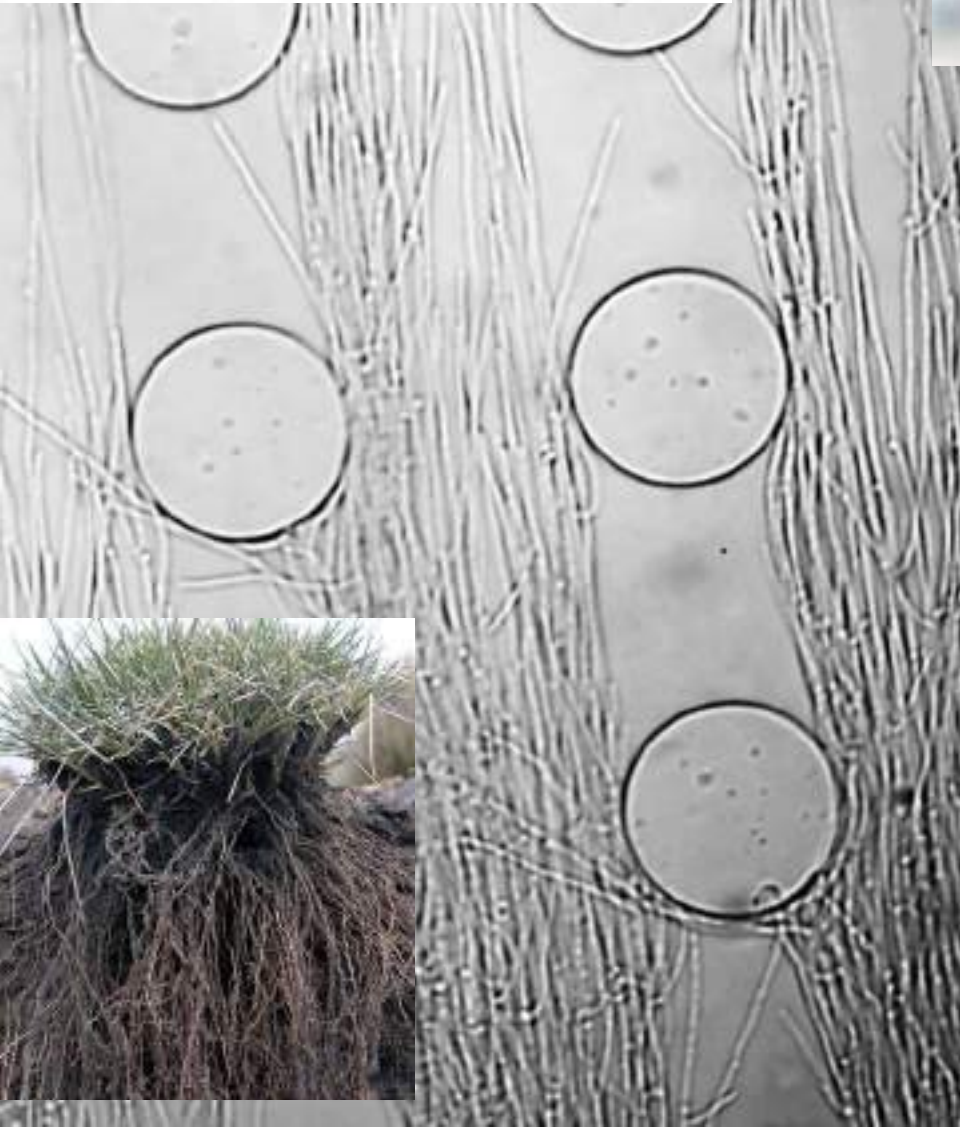
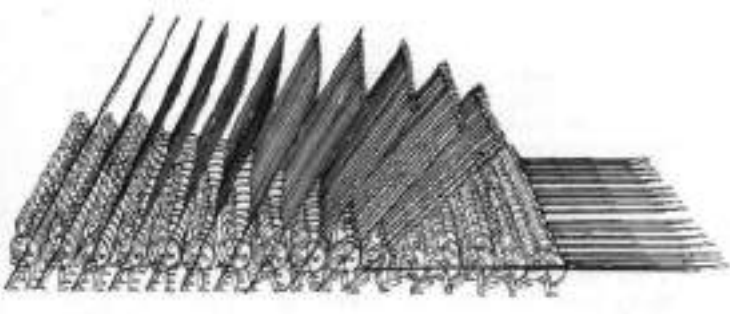
Lepiota

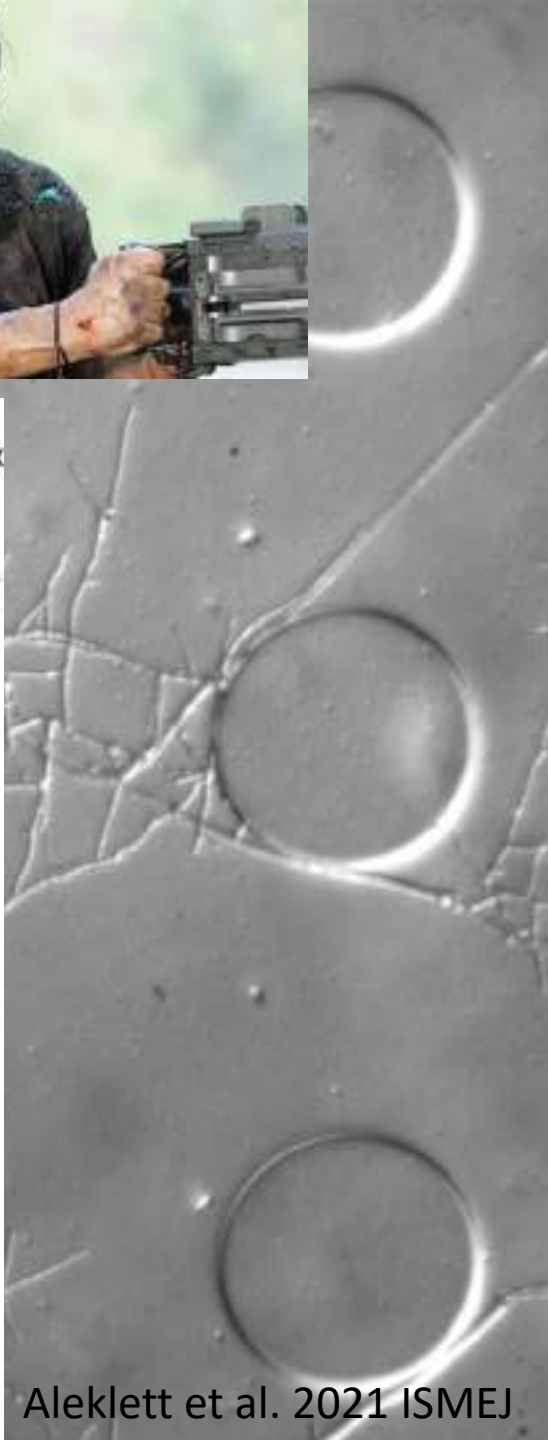
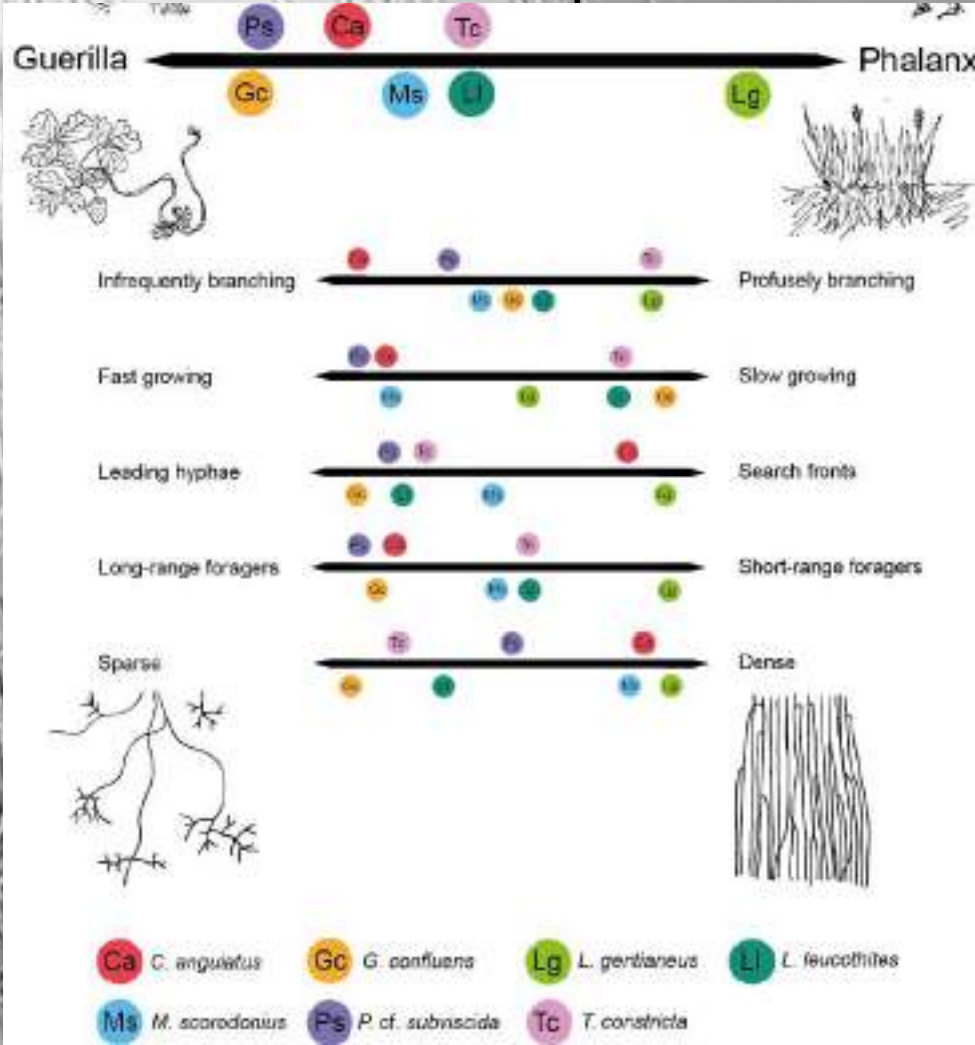
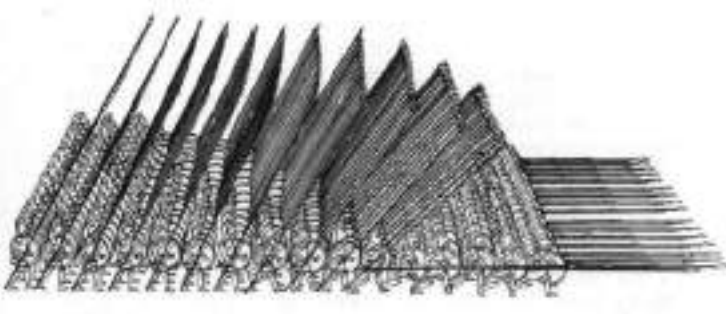


Coprinellus

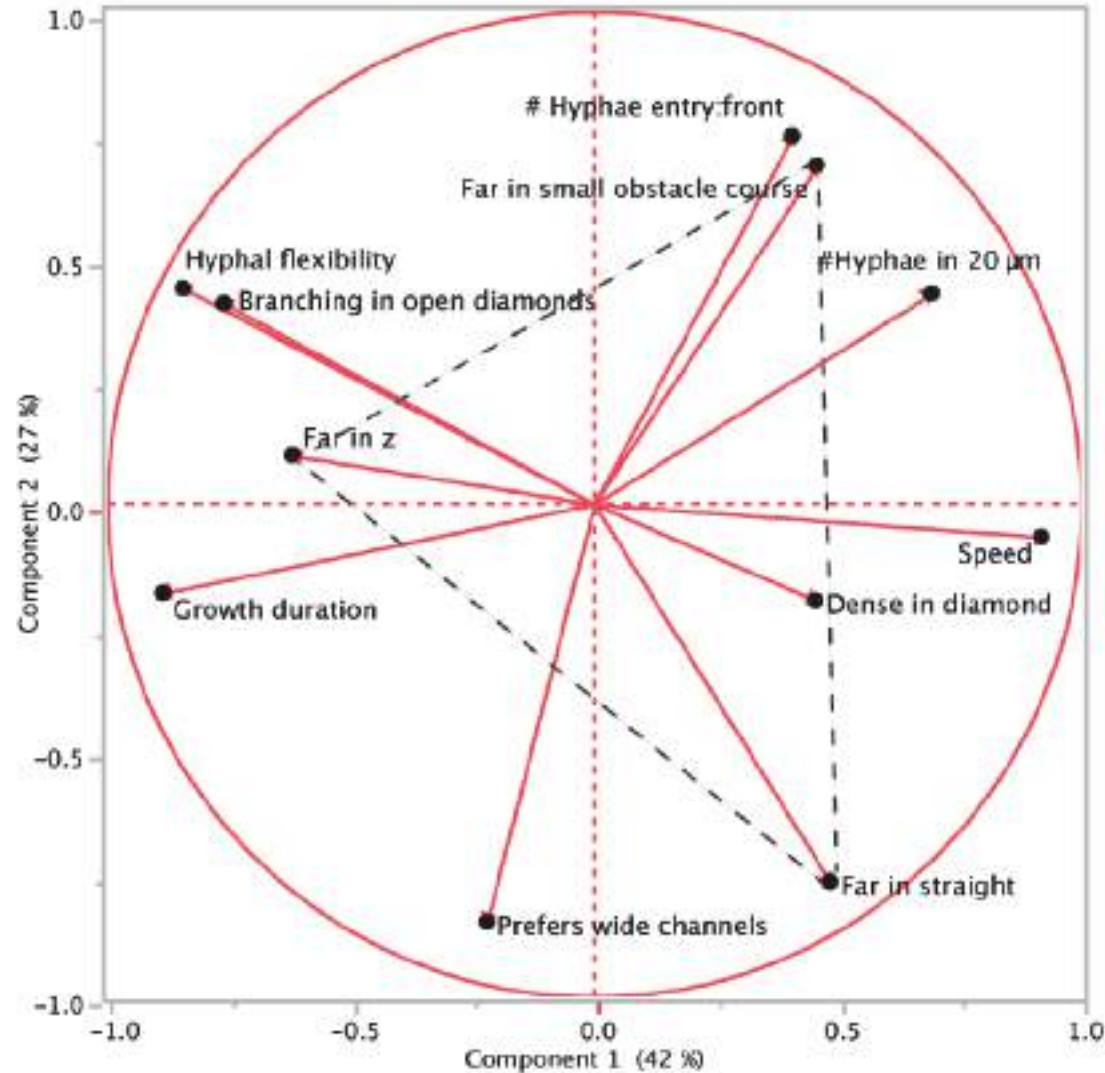
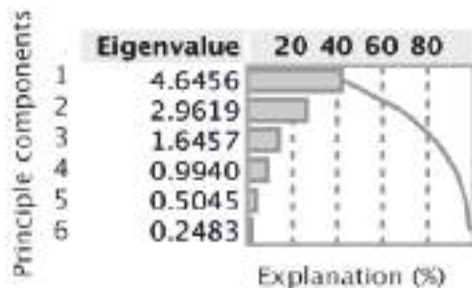
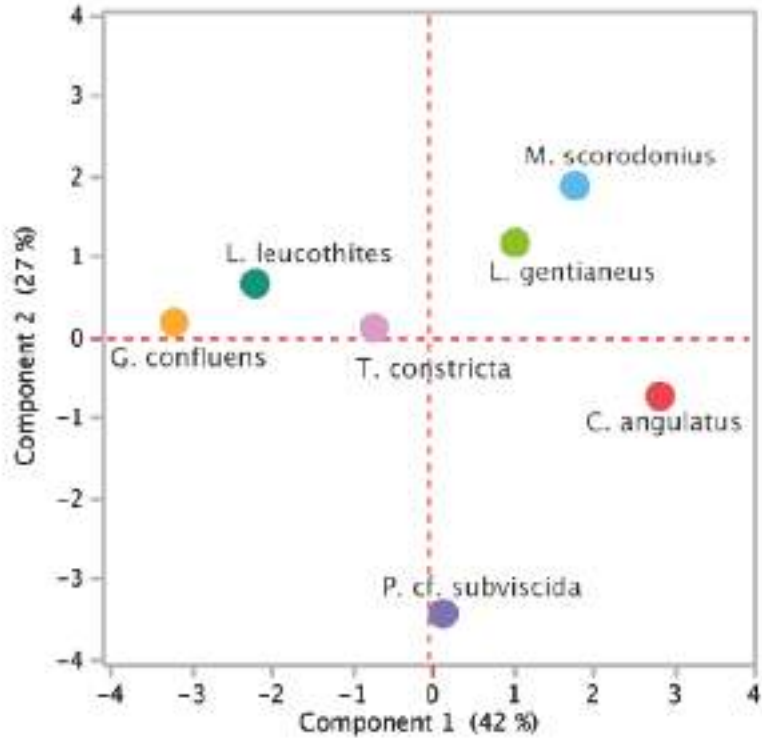


Leucopaxillus

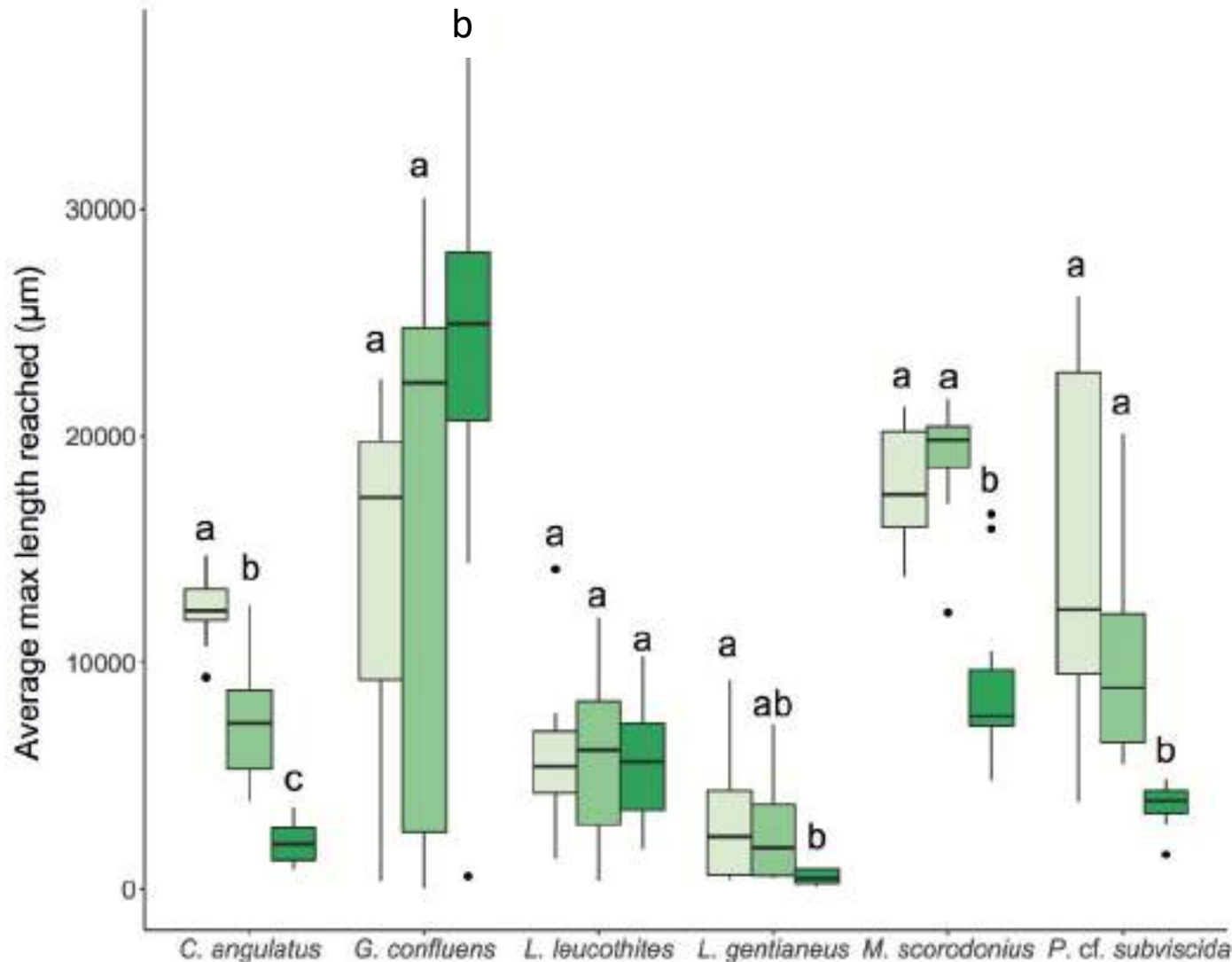




Many more measurable traits in the Soil chip



Difficult spatial structures?



Type of channel

zigzag



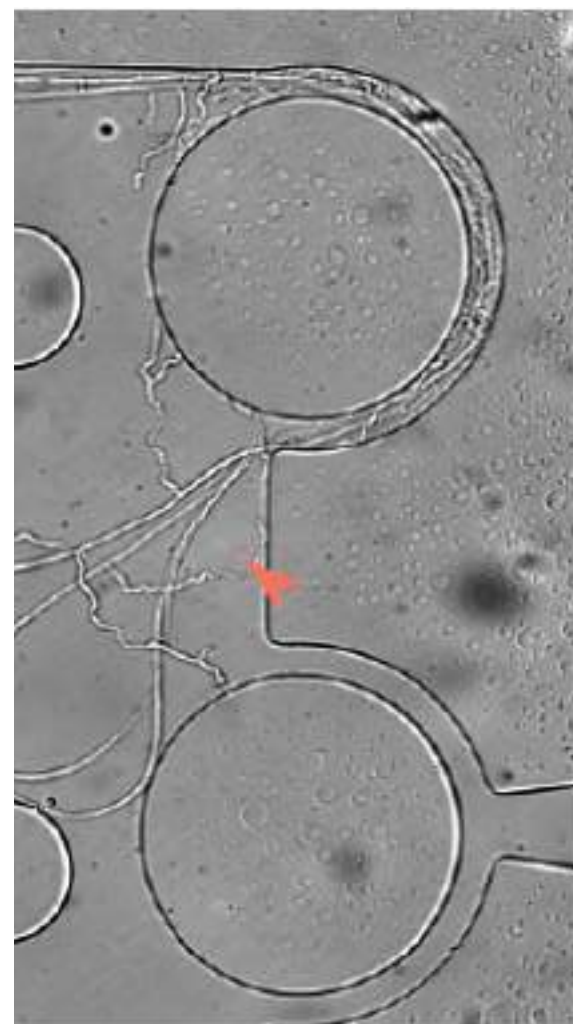
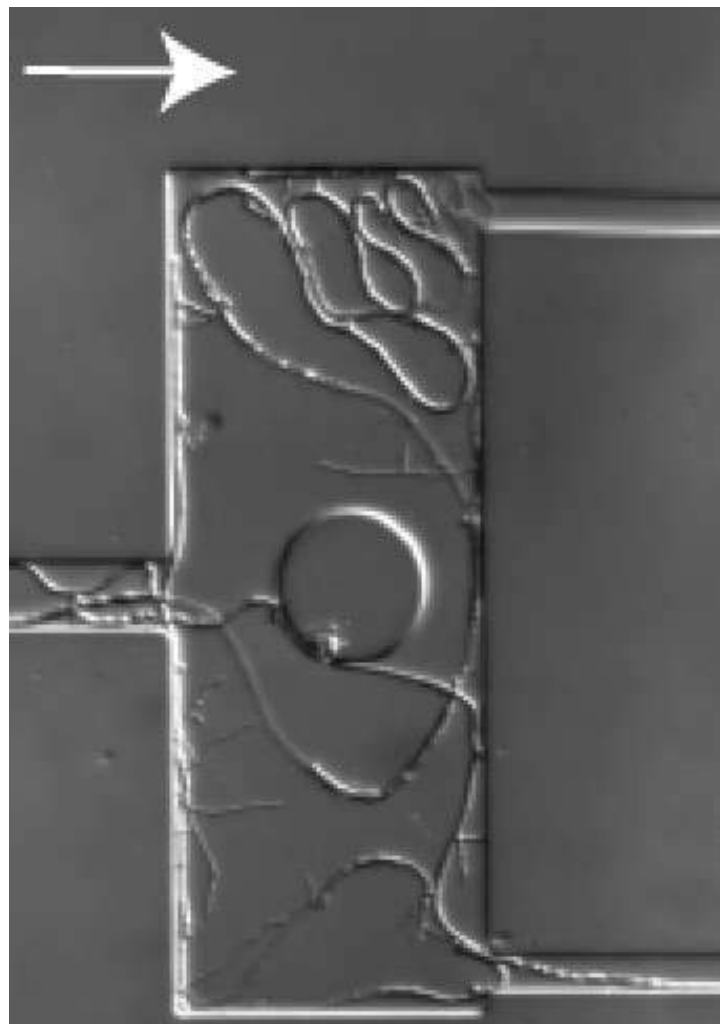
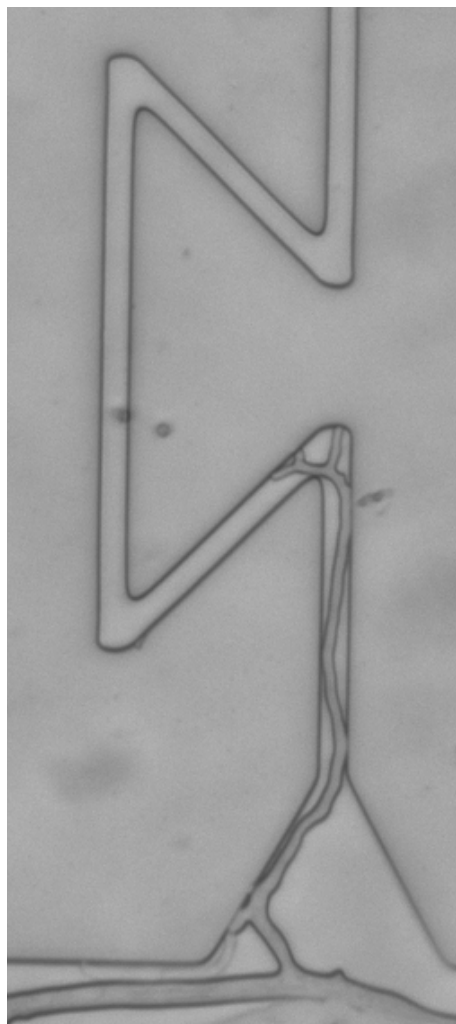
square



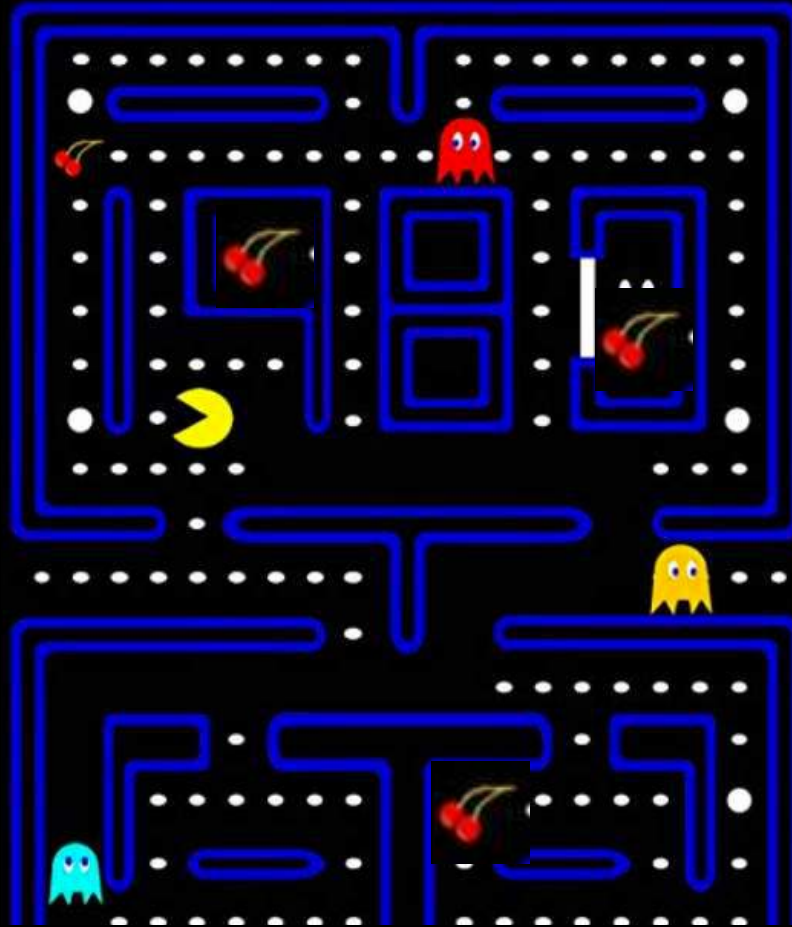
z-shape



Difficult spatial structures?



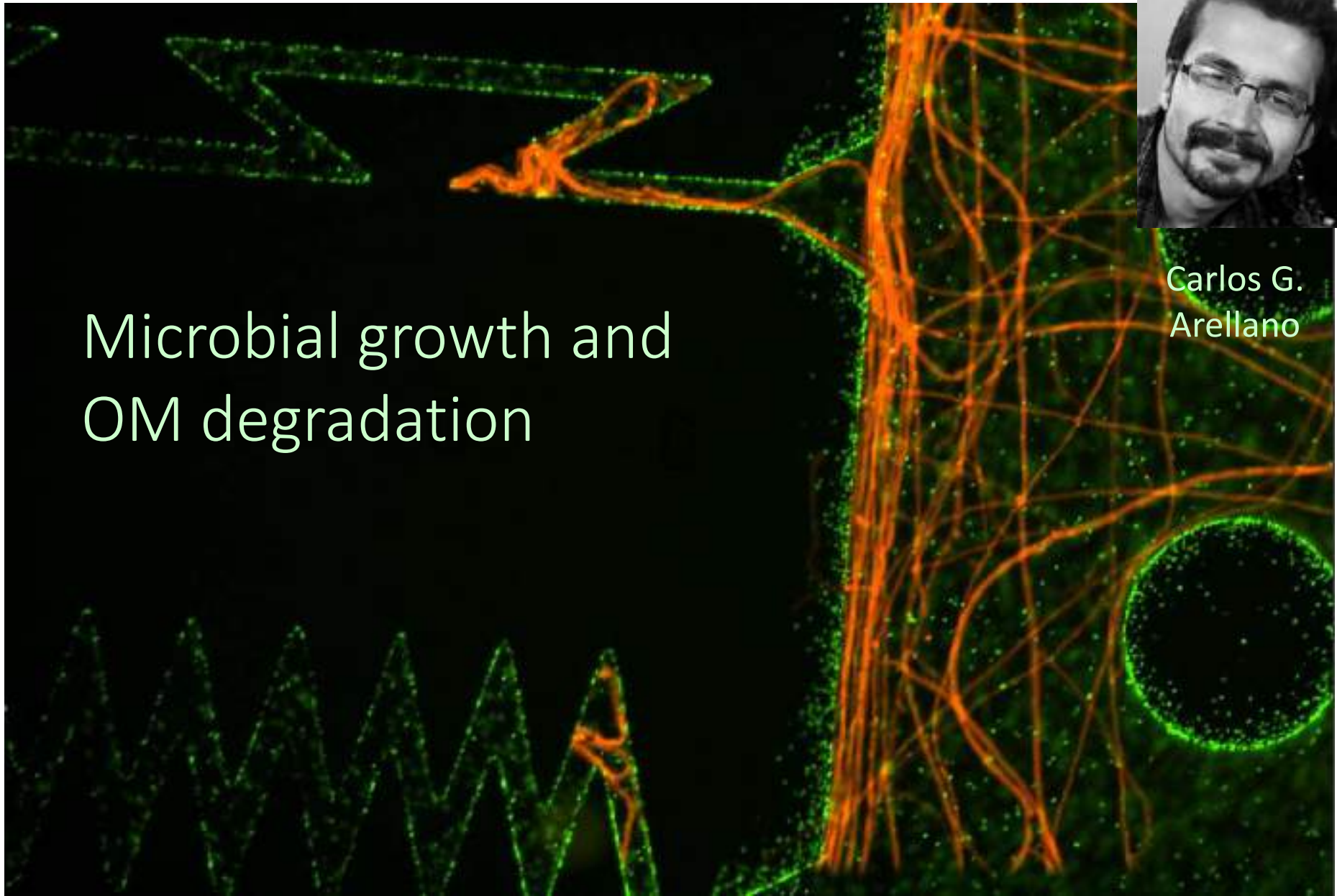
Can organic matter hide in the soil pore space?





Carlos G.
Arellano

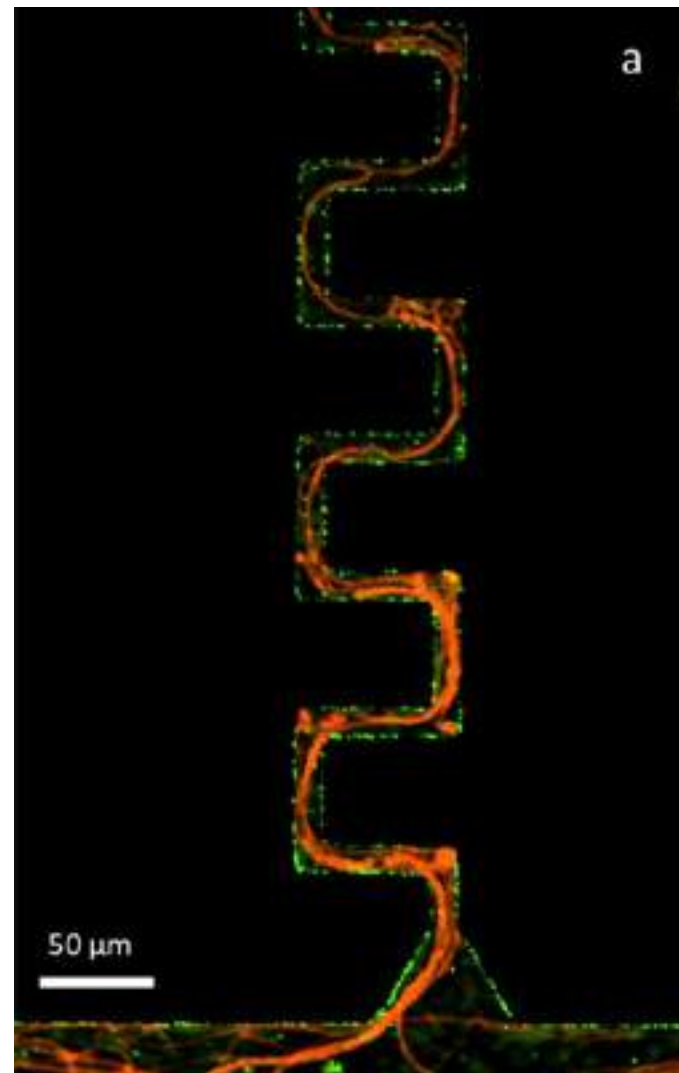
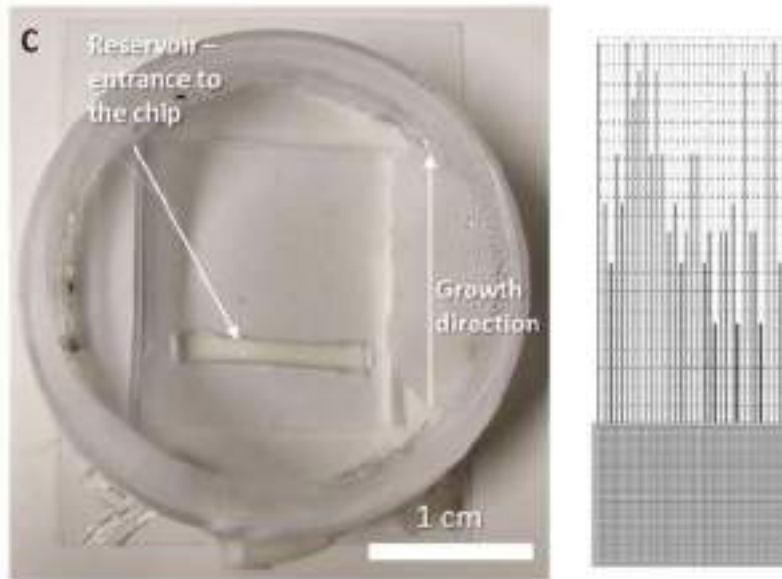
Microbial growth and OM degradation



Microbial growth and OM degradation

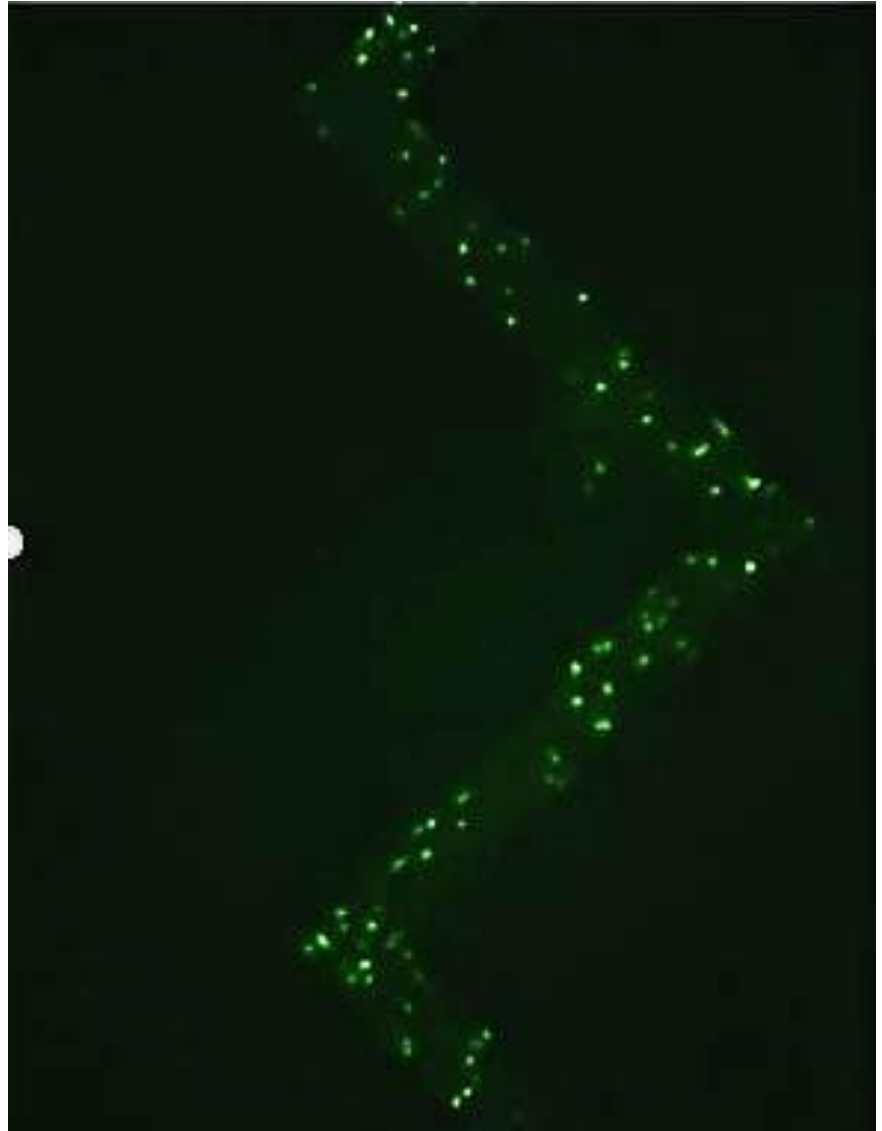
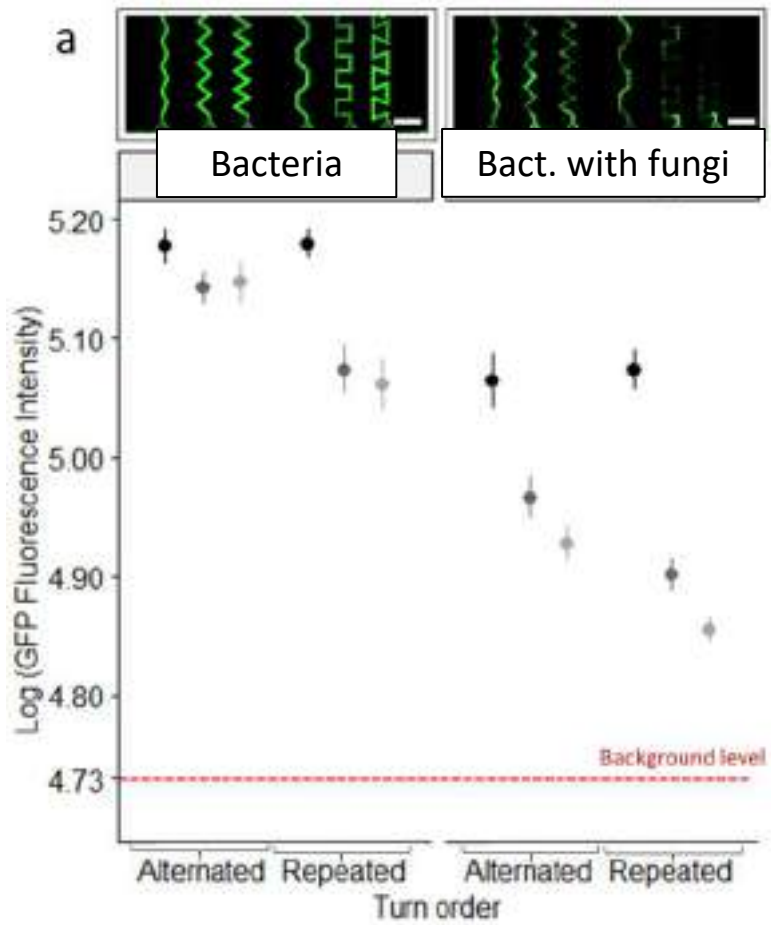


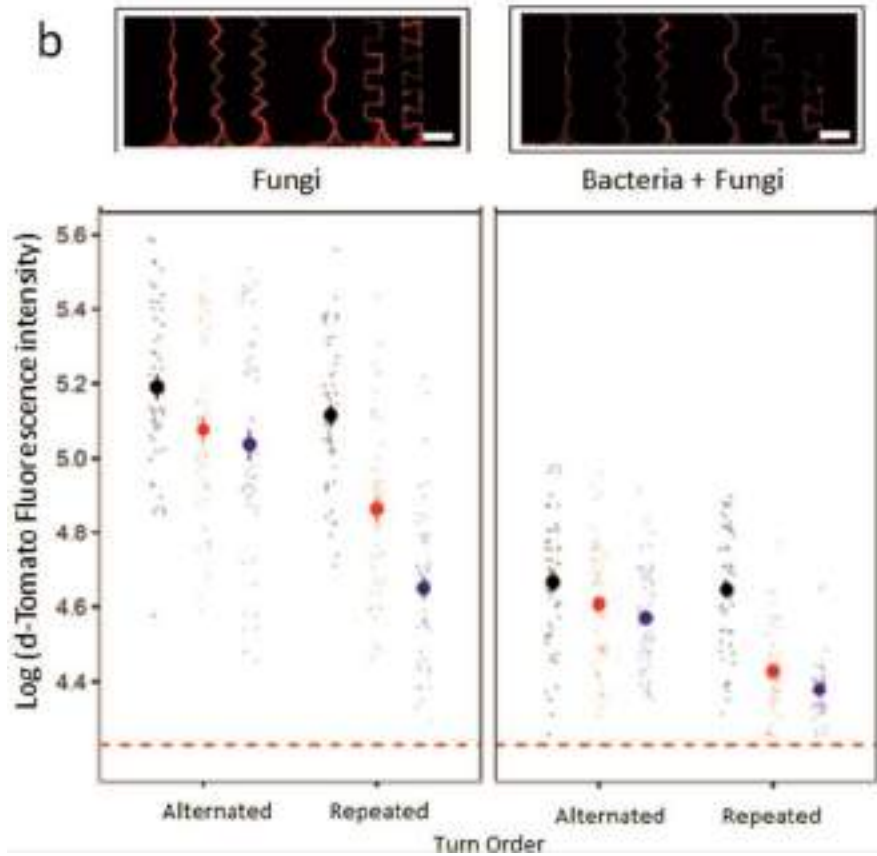
Carlos G. Arellano

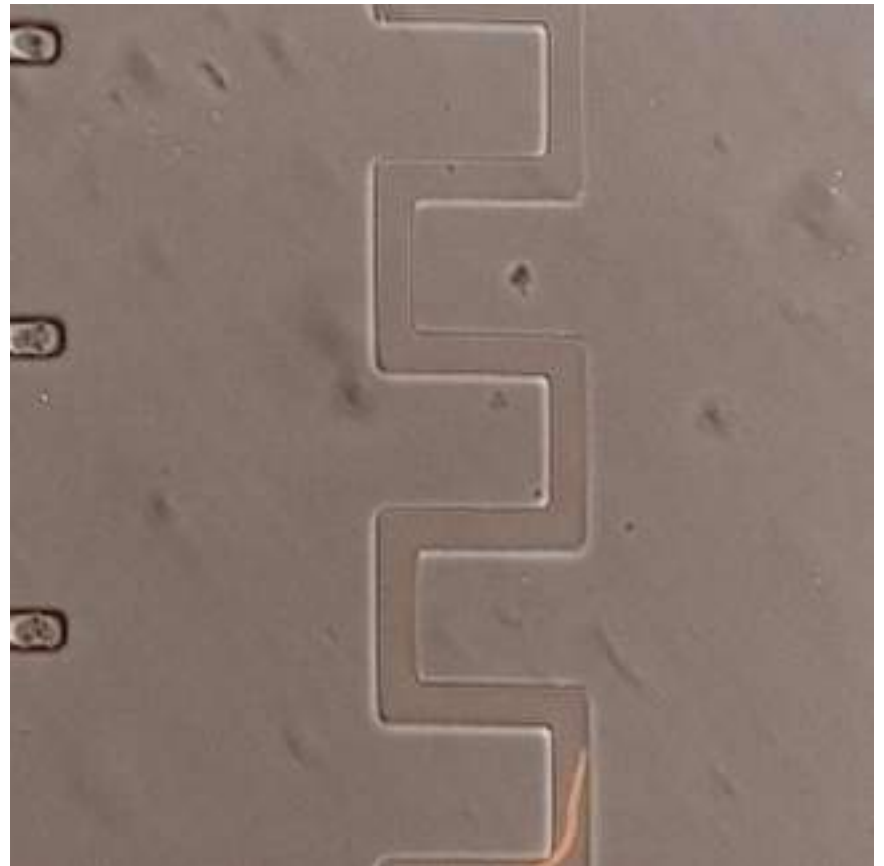
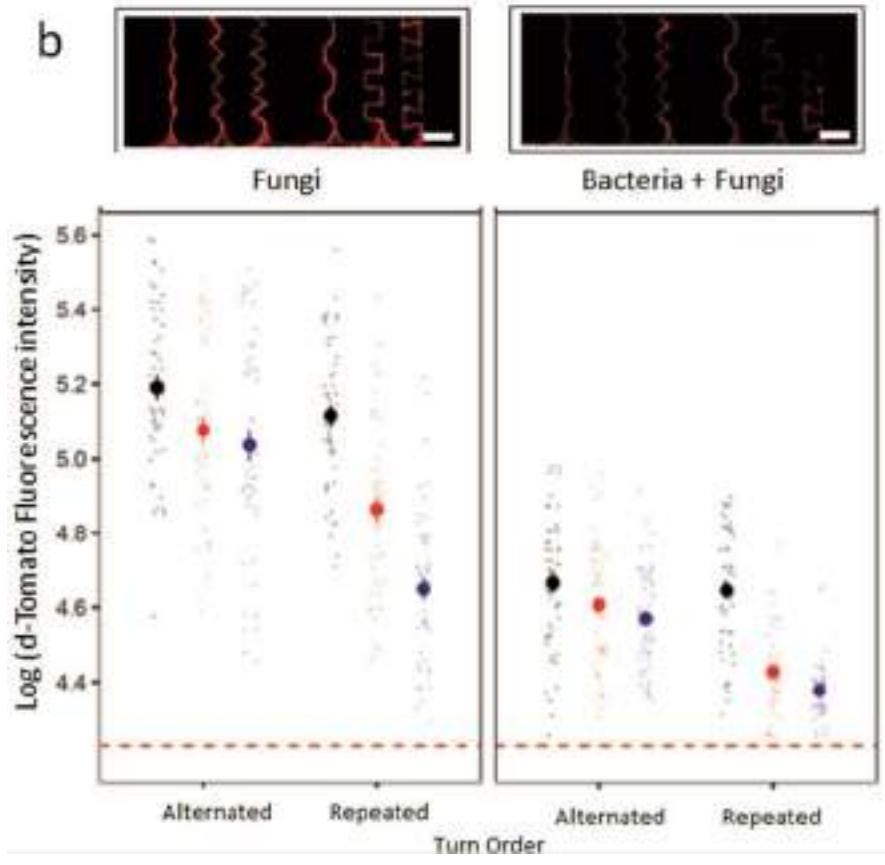


Arellano-Caicedo et al. 2021 Nat ComBiol

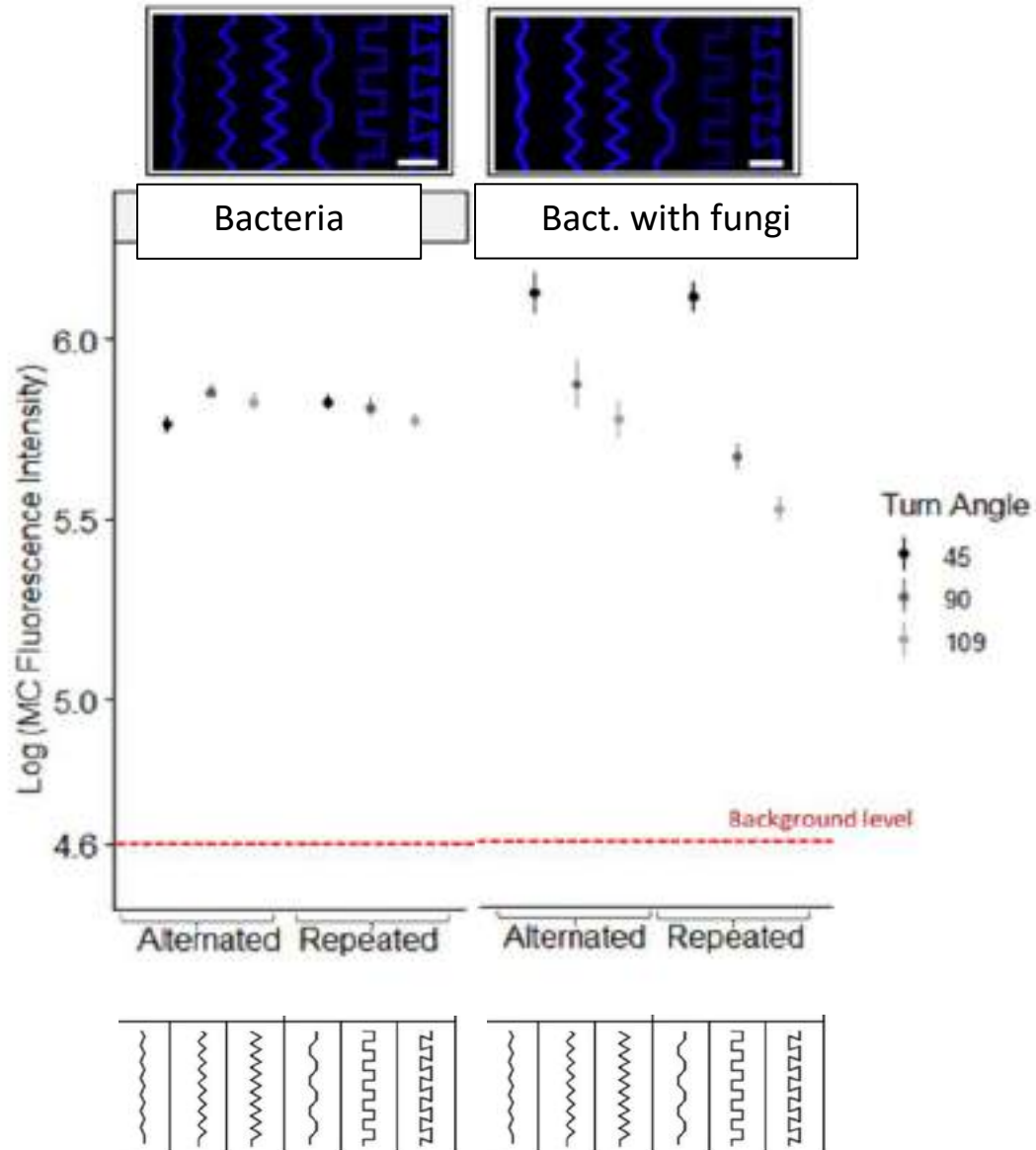
Turn angle	45°	90°	109°	45°	90°	109°
Turn order	Alternated			Repeated		
Channel shape						
Channel tortuosity	1.07	1.41	1.72	1.17	1.99	2.38







OM degradation

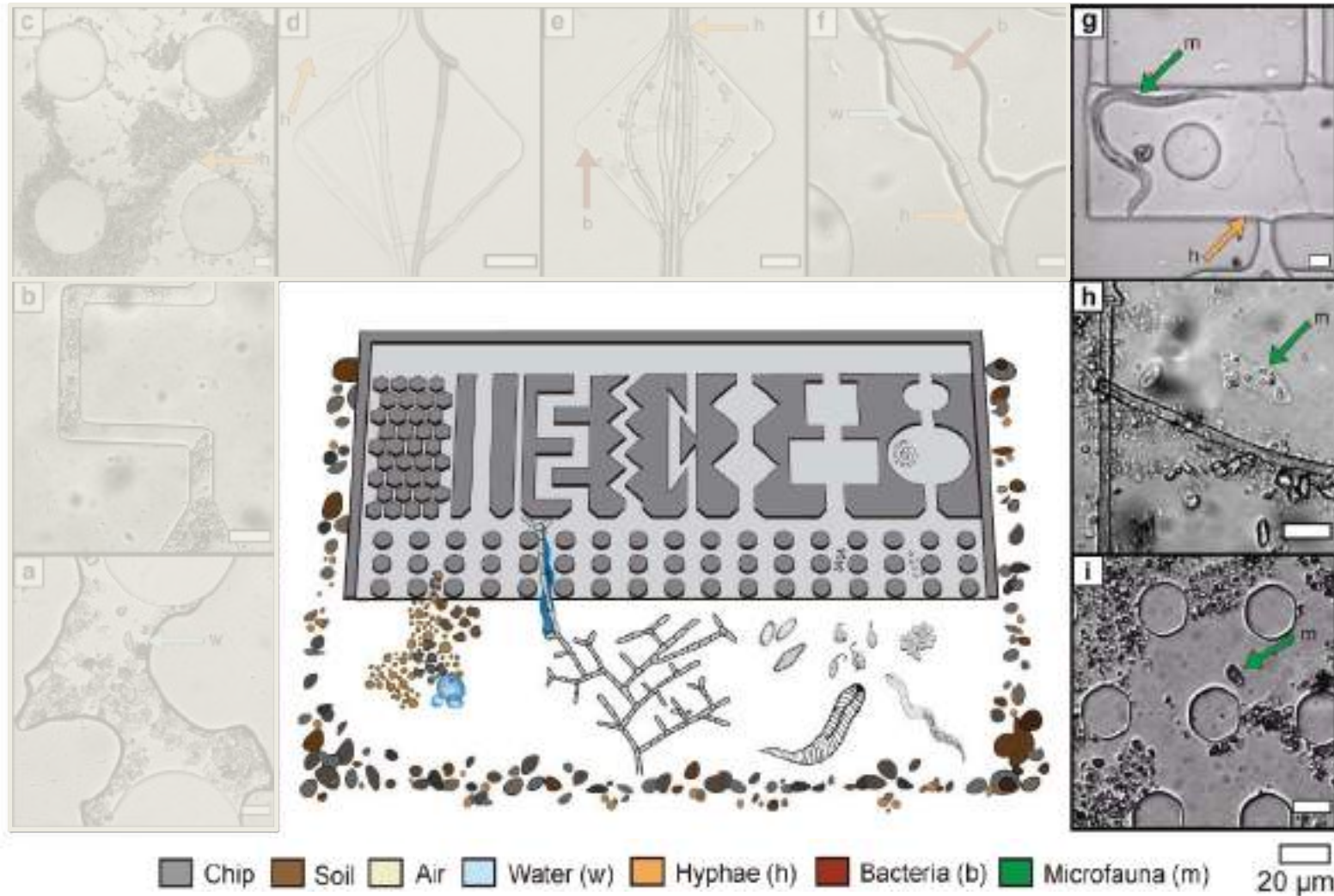


A window to the underground



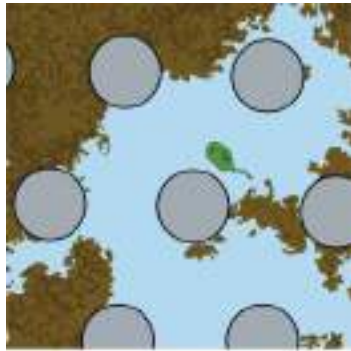
P. Micaela
Mafla Endara



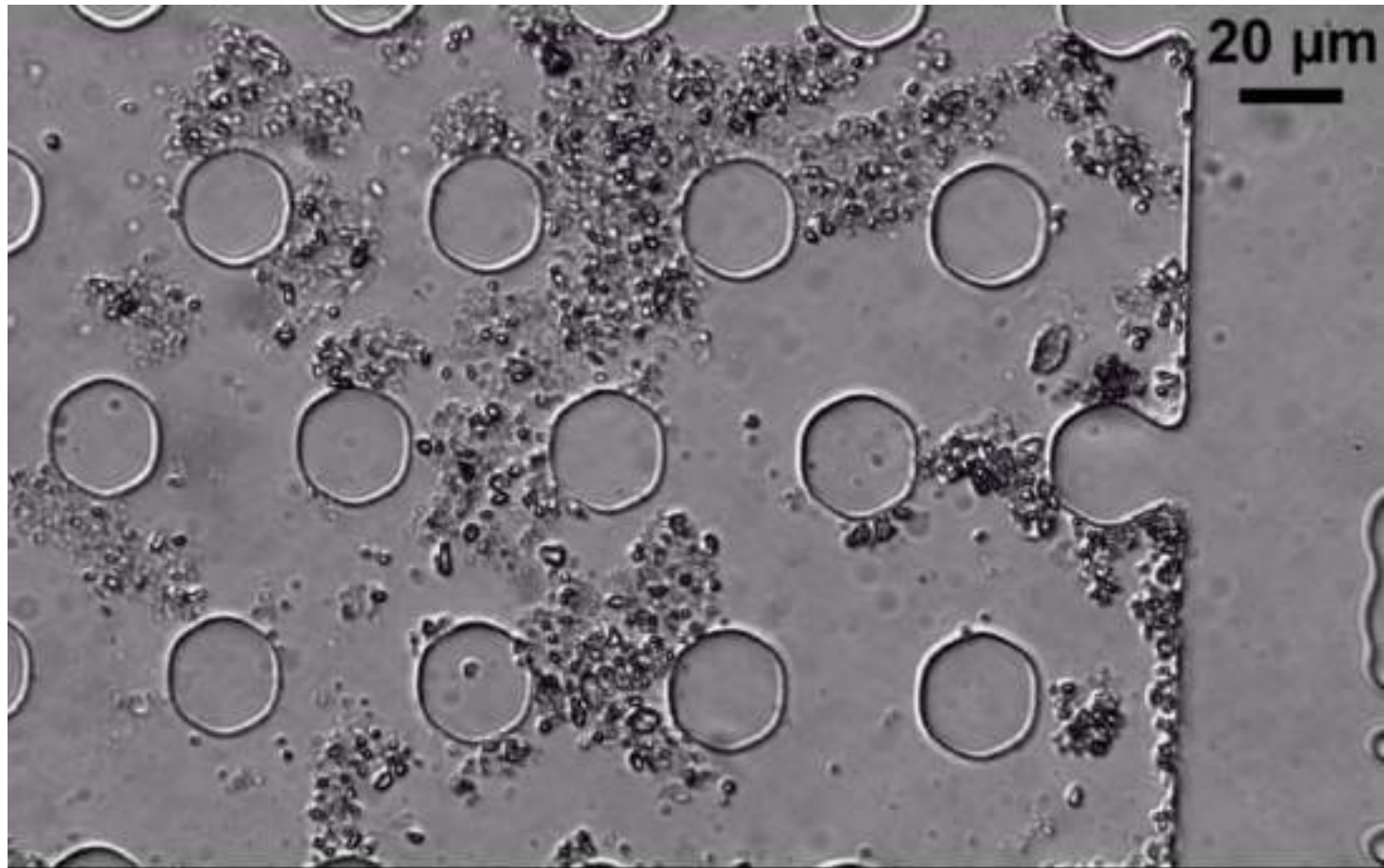


Soil food web dynamics

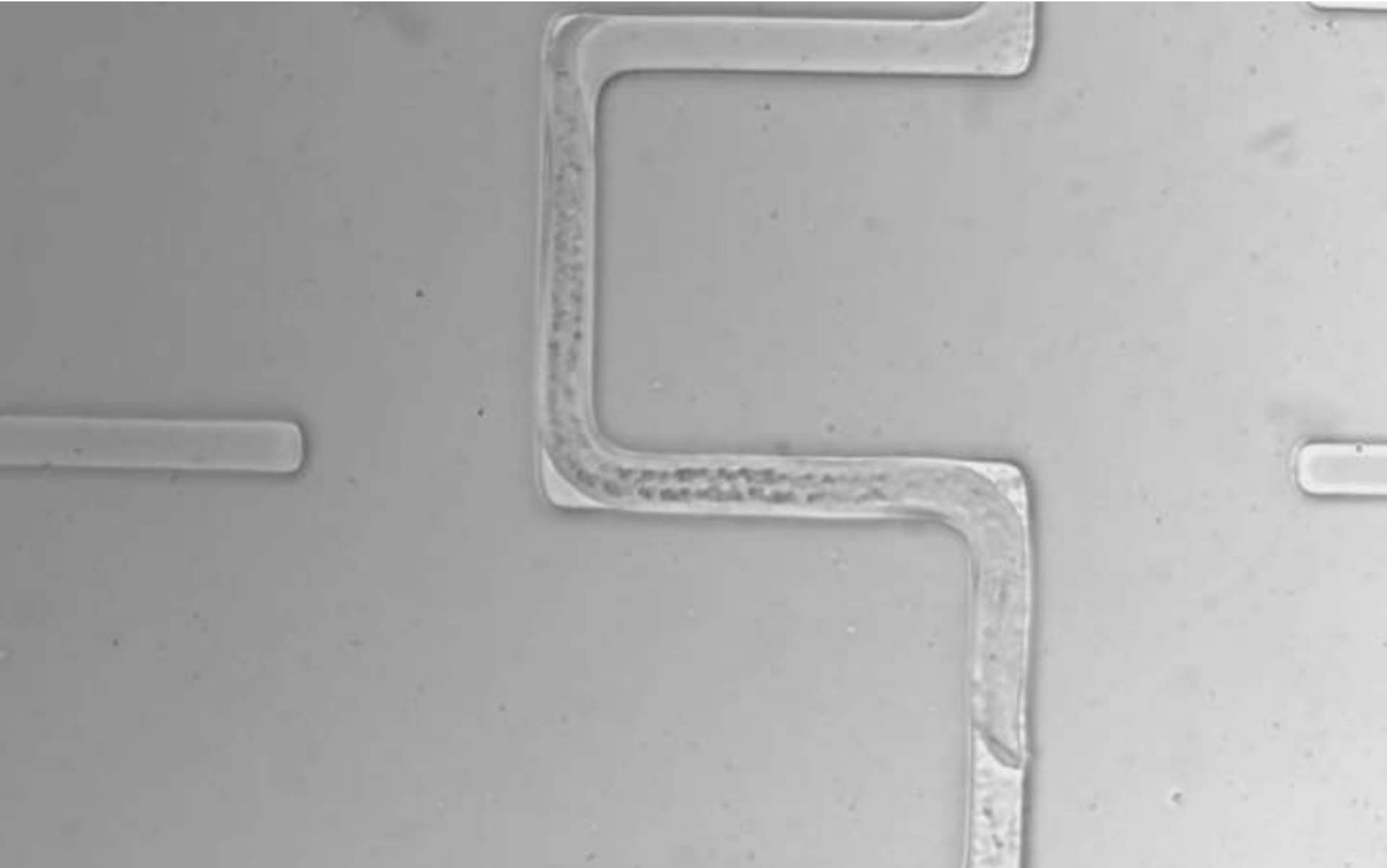
Soil food web dynamics



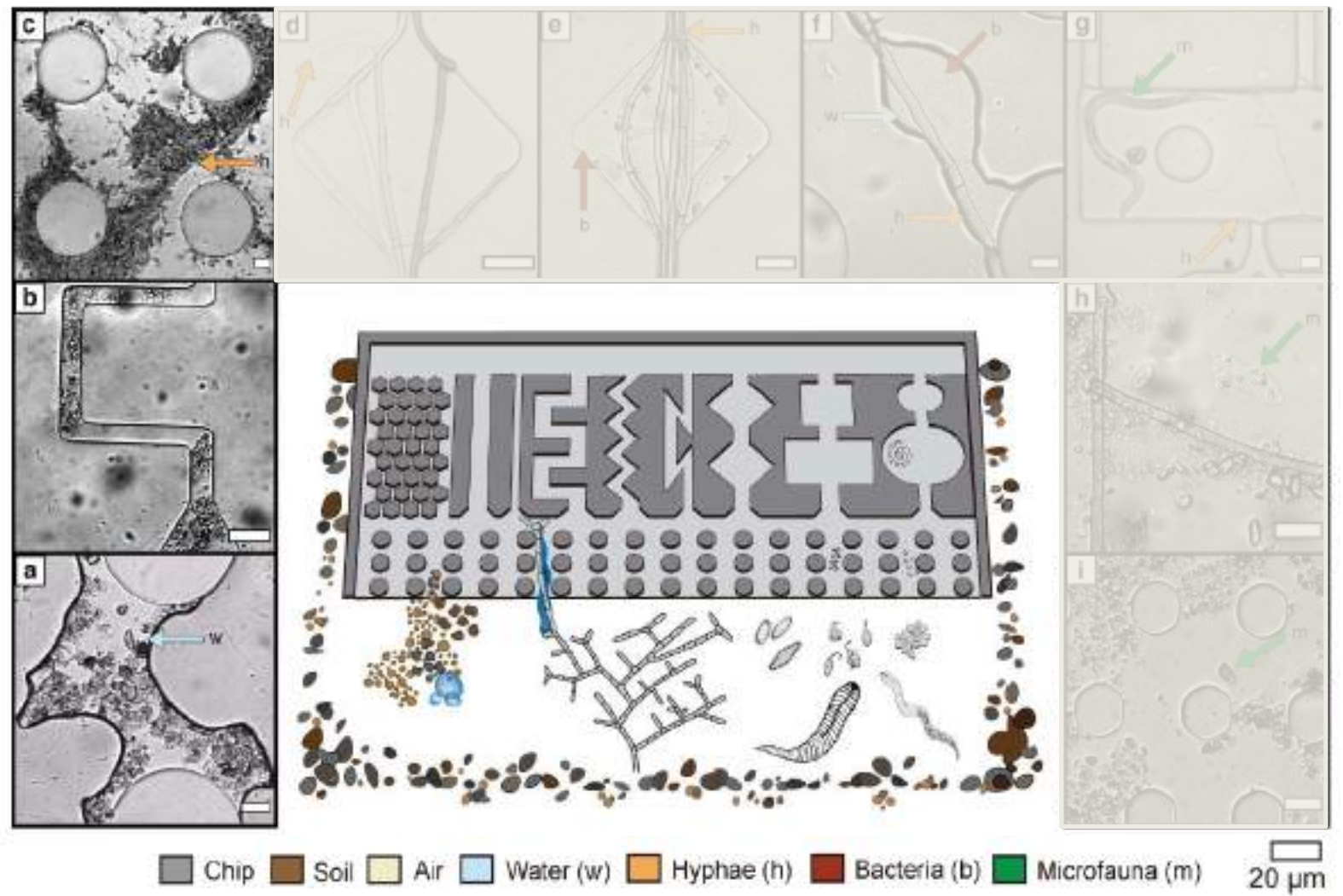
- Chip
- Soil
- Air
- Water (w)
- Hyphae (h)
- Bacteria (b)
- Microfauna (m)



Soil food web dynamics



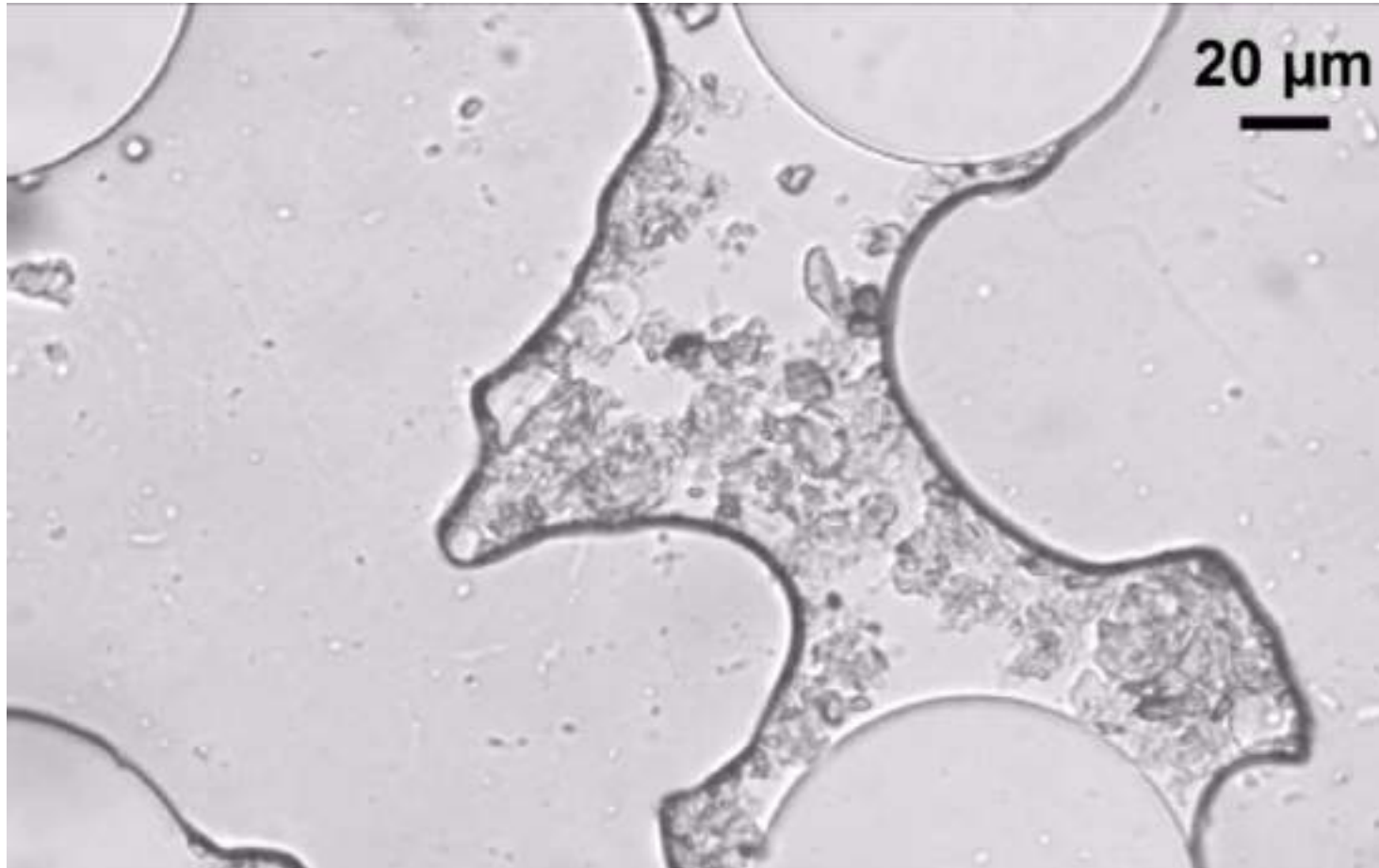
Microhabitat formation



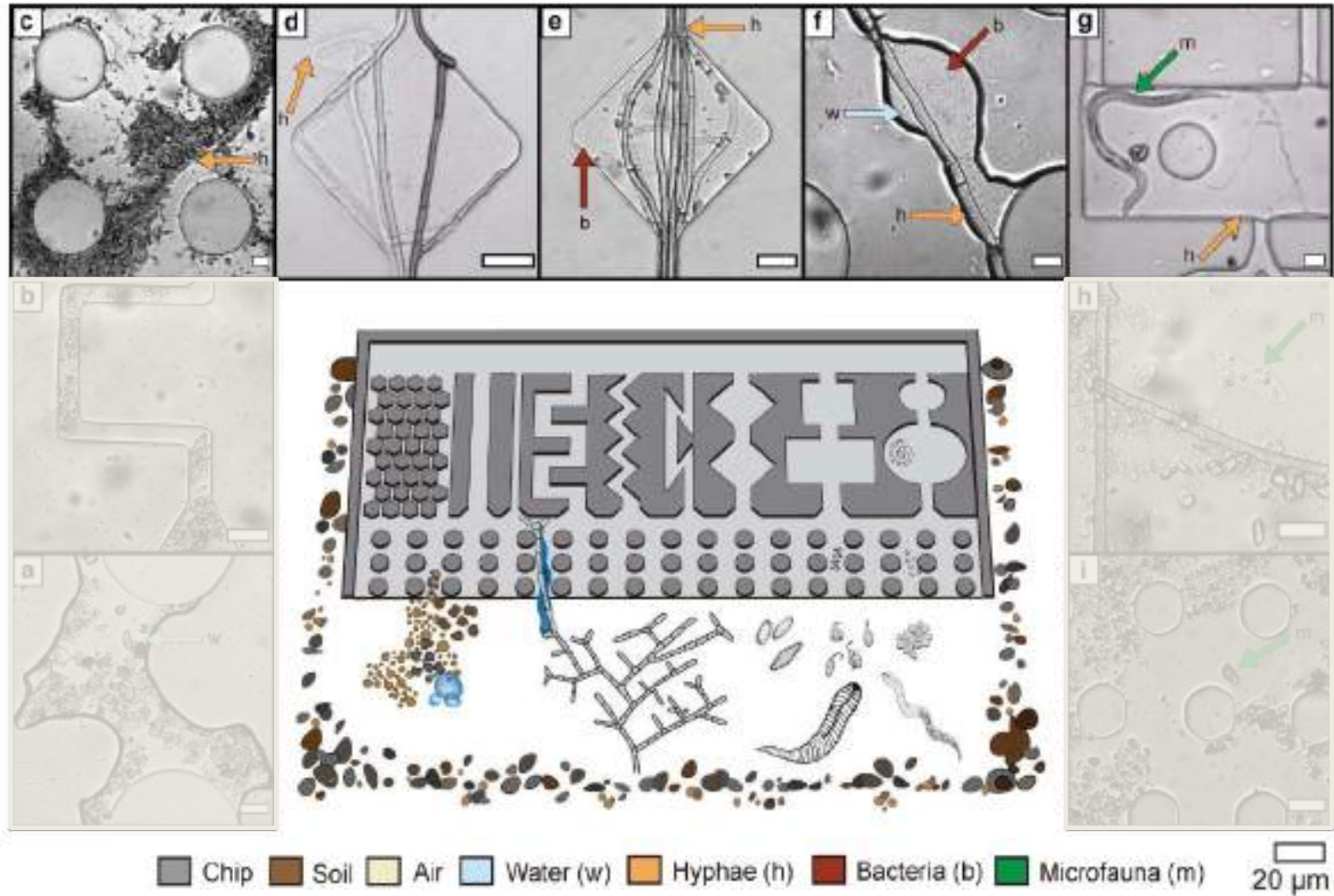
Microhabitat formation



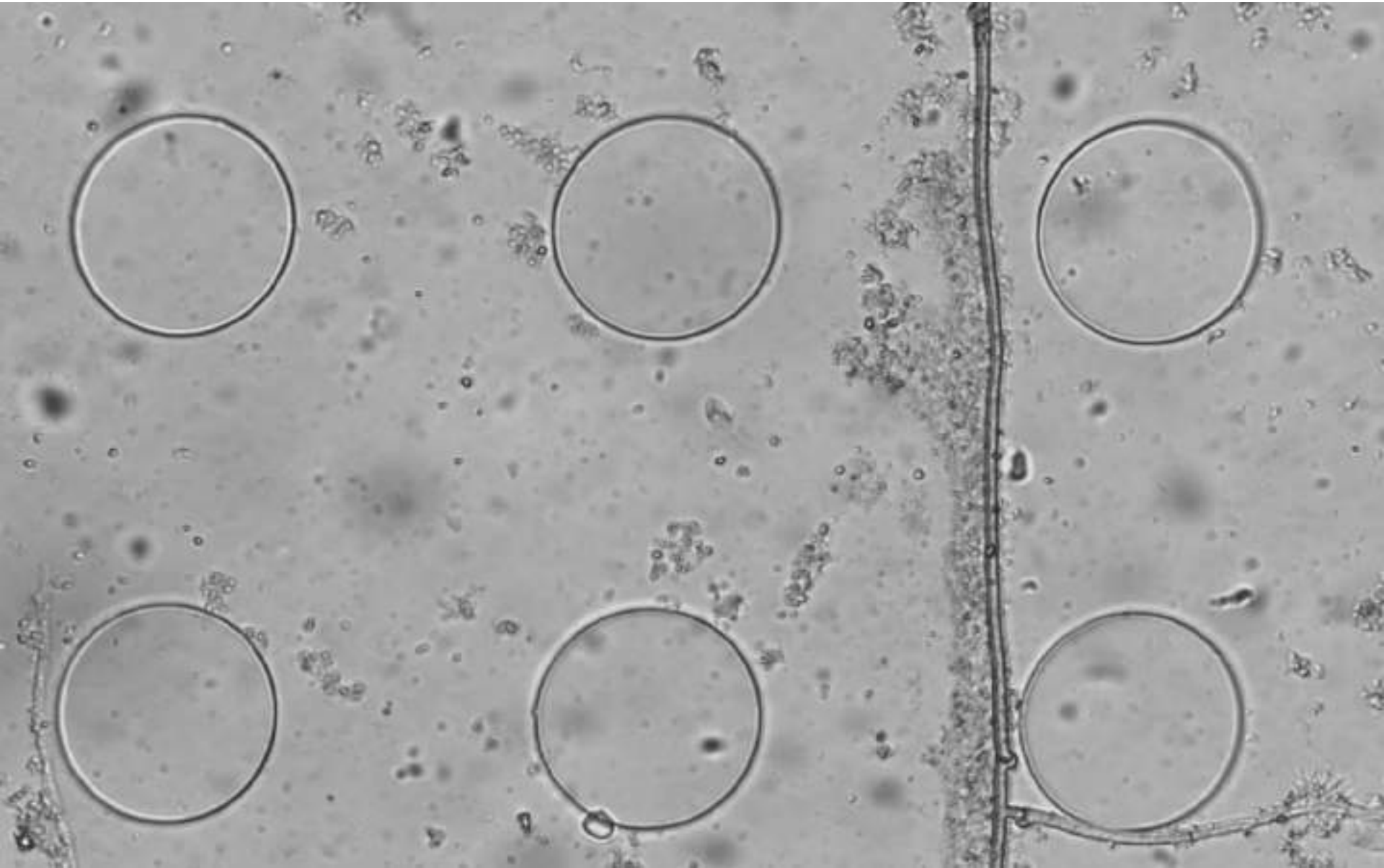
- Chip
- Soil
- Air
- Water (w)
- Hyphae (h)
- Bacteria (b)
- Microfauna (m)

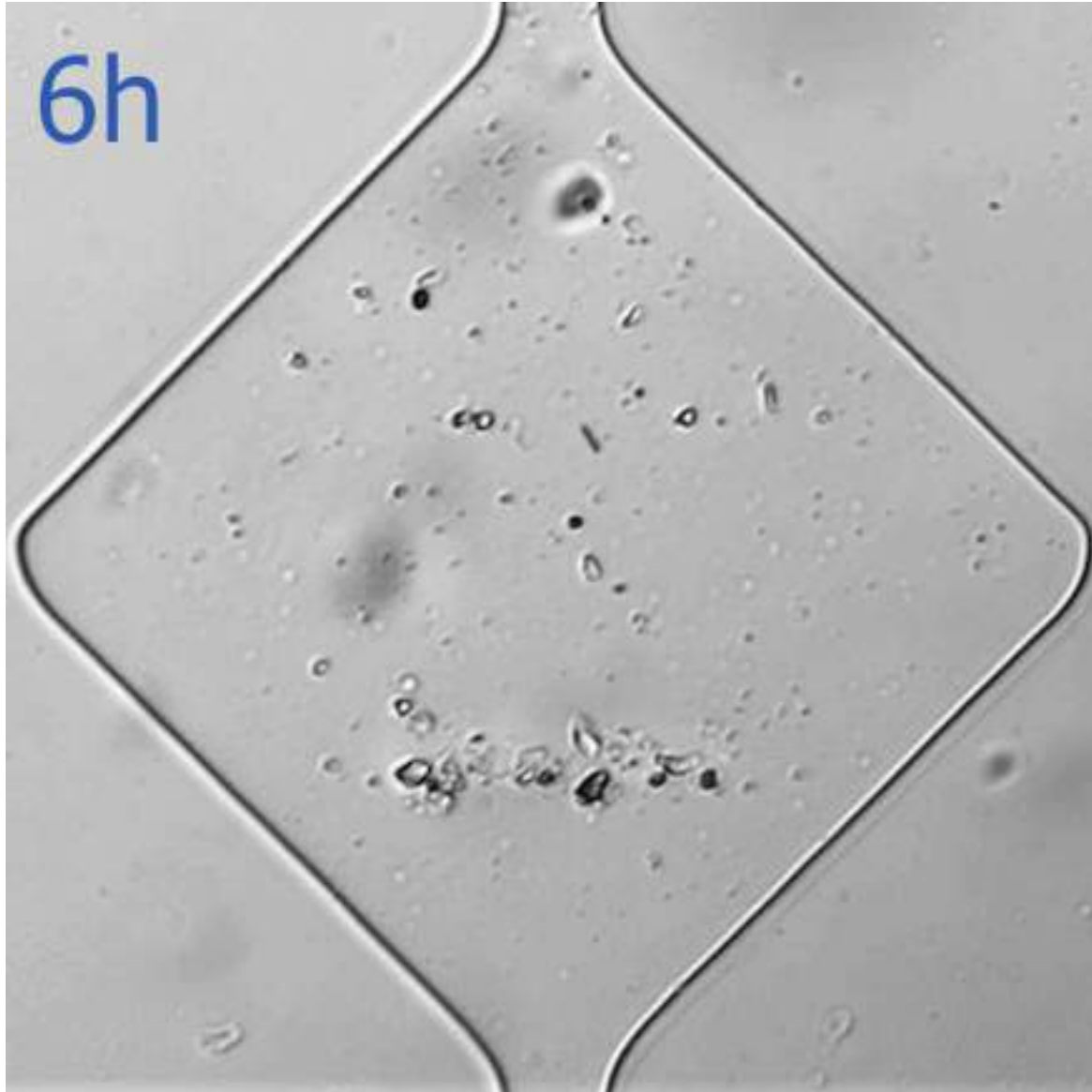


Soil dynamics influenced by fungi

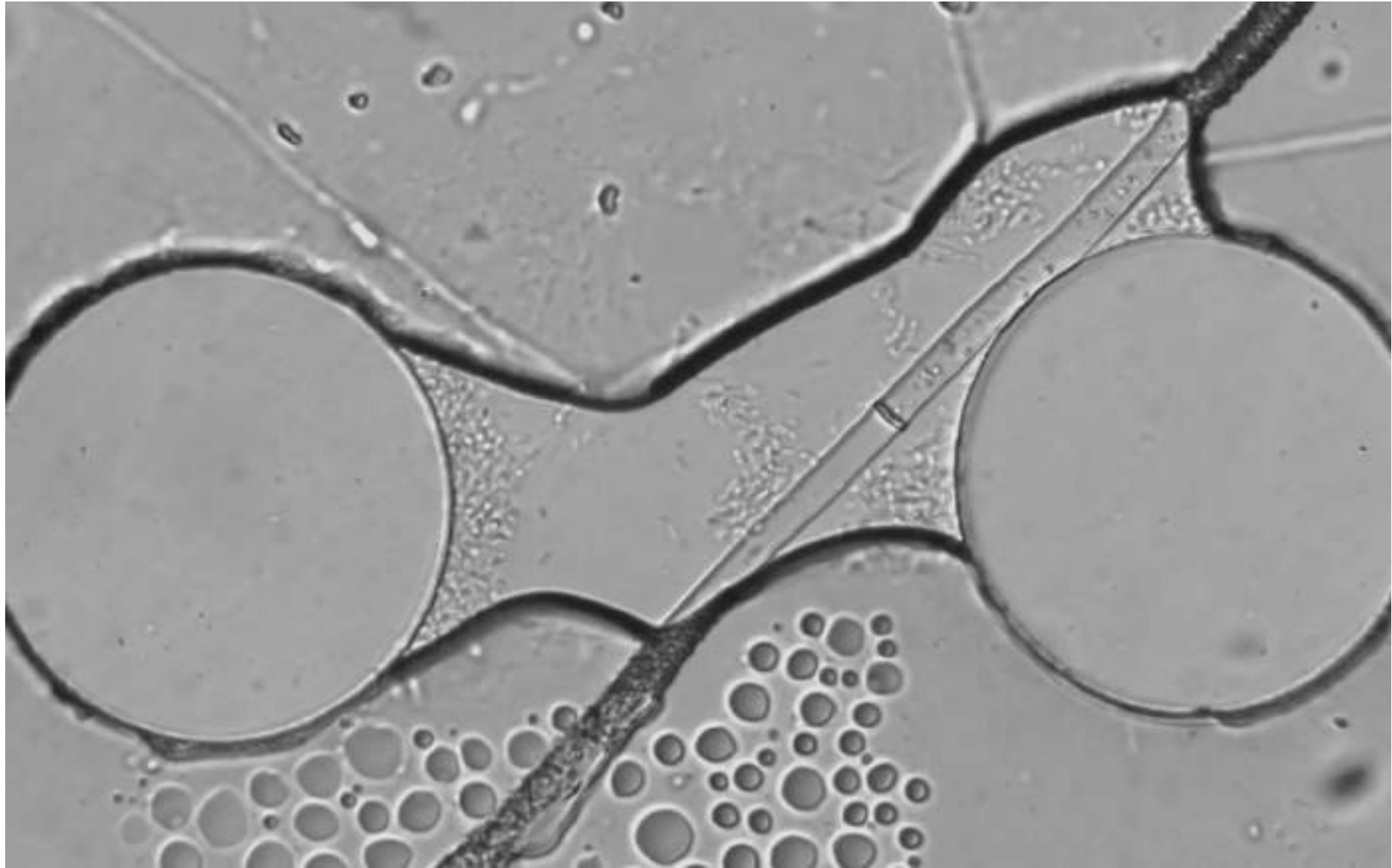


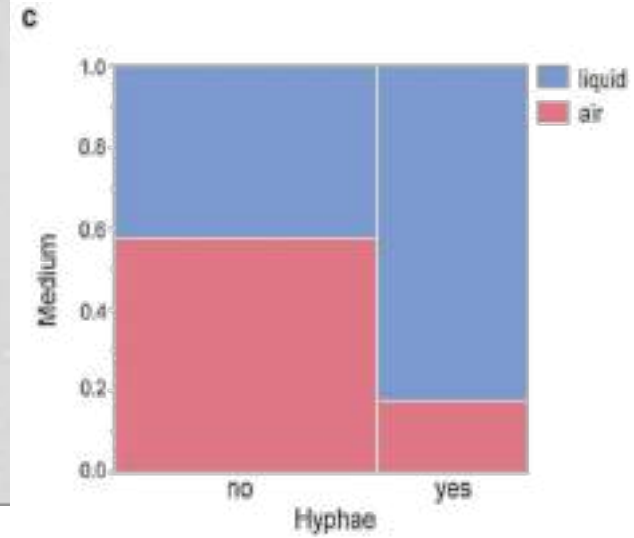
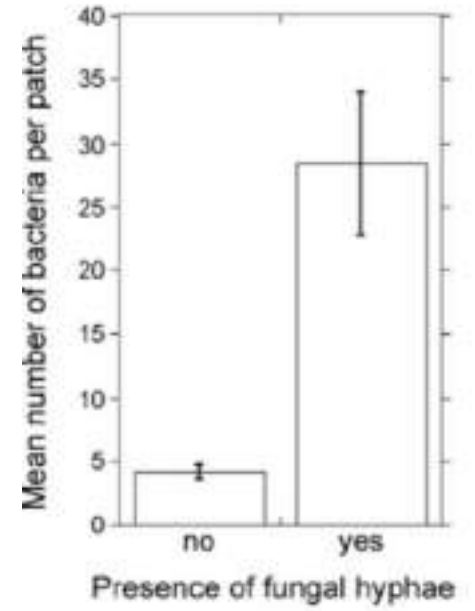
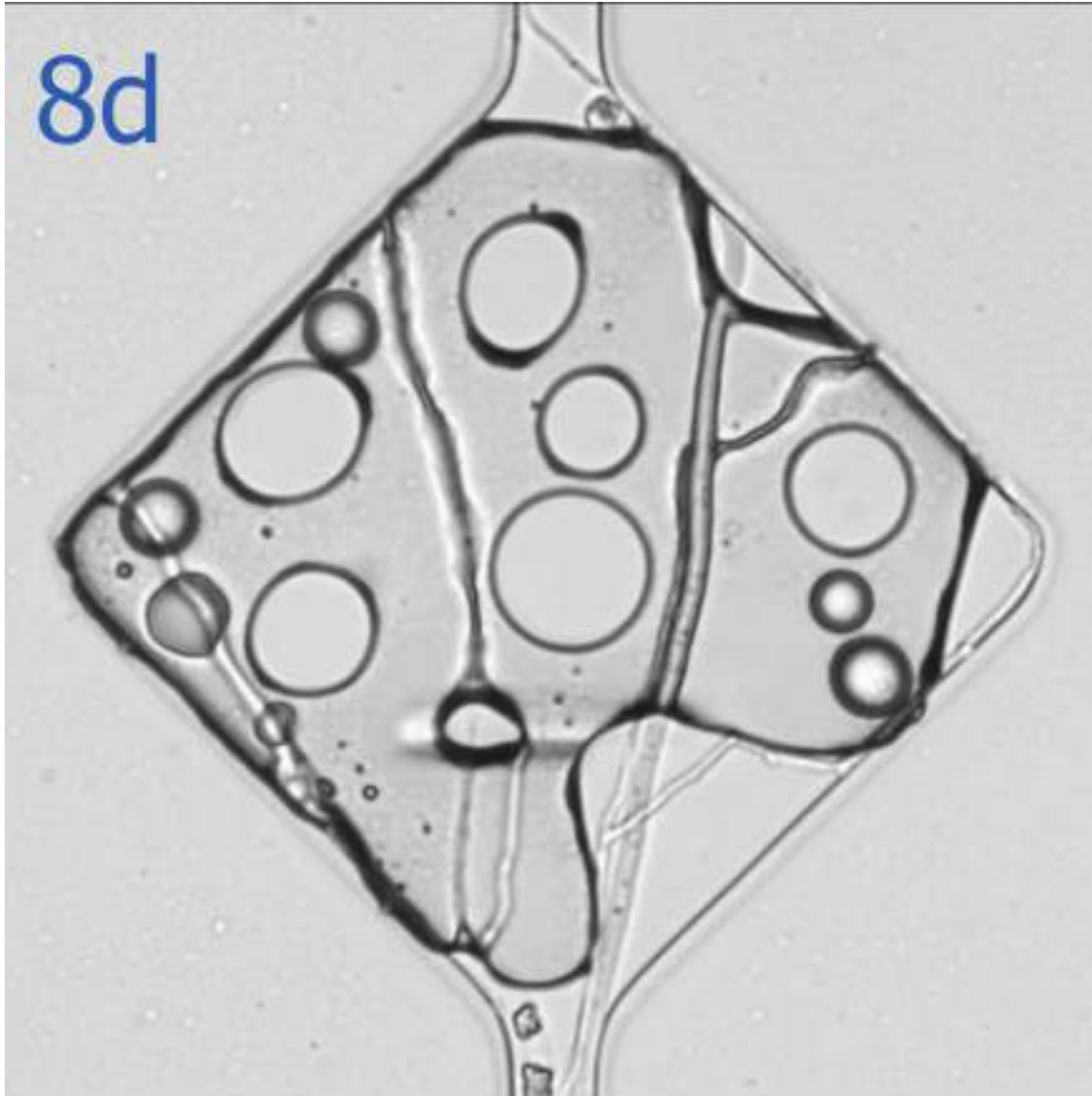
Soil dynamics influenced by fungi

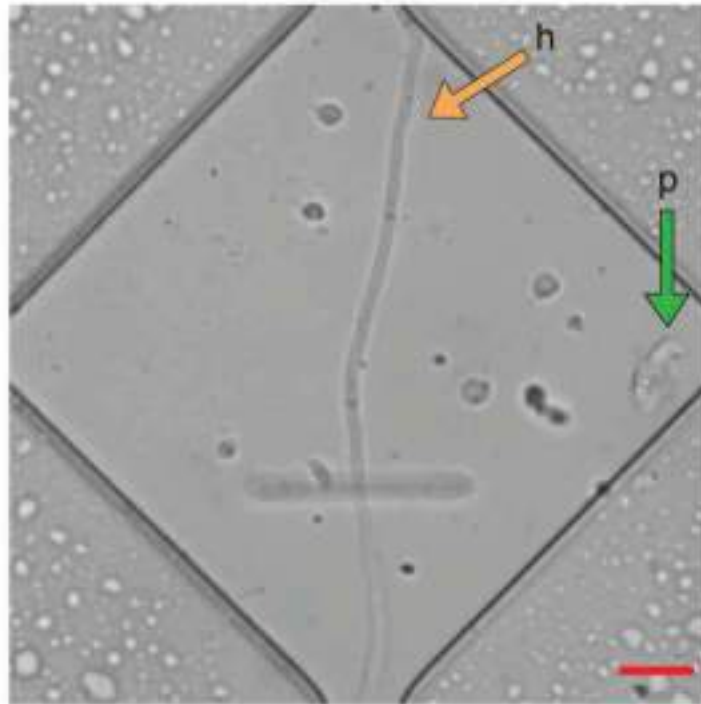




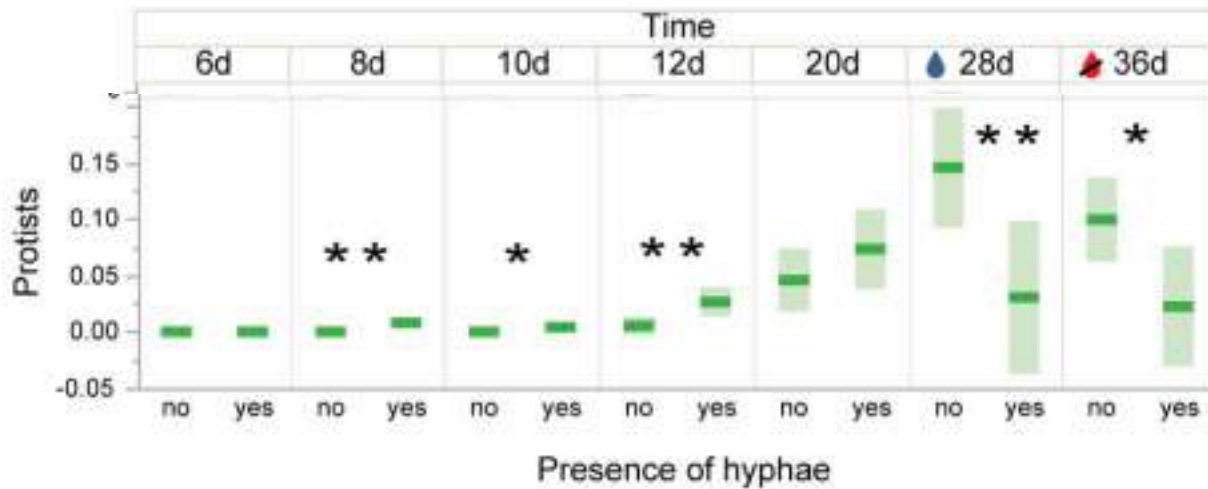
Dispersal – fungal highways





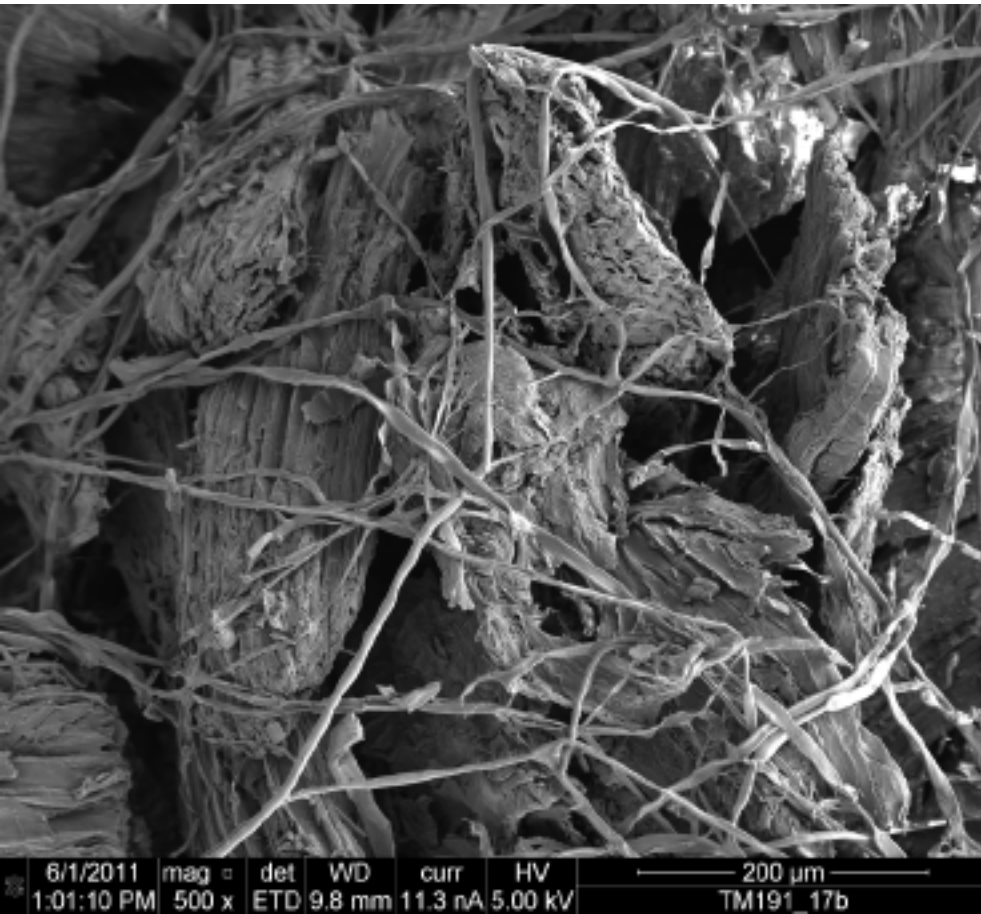


Hyphae (h)
 Protist (p)

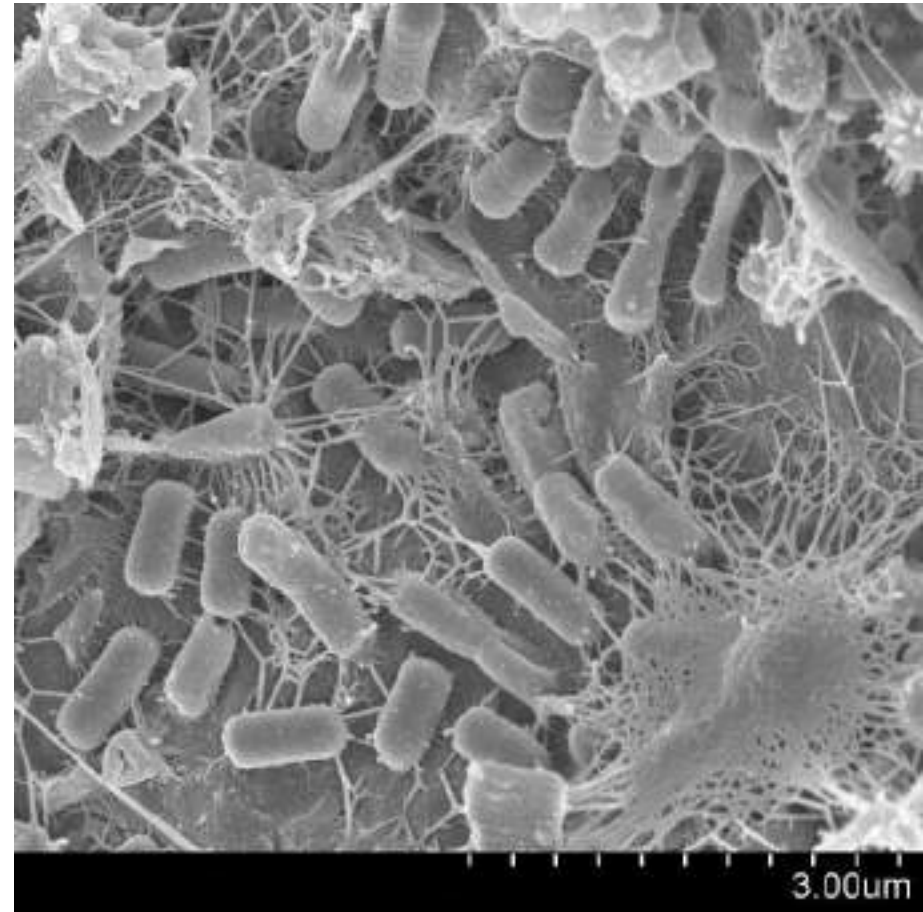




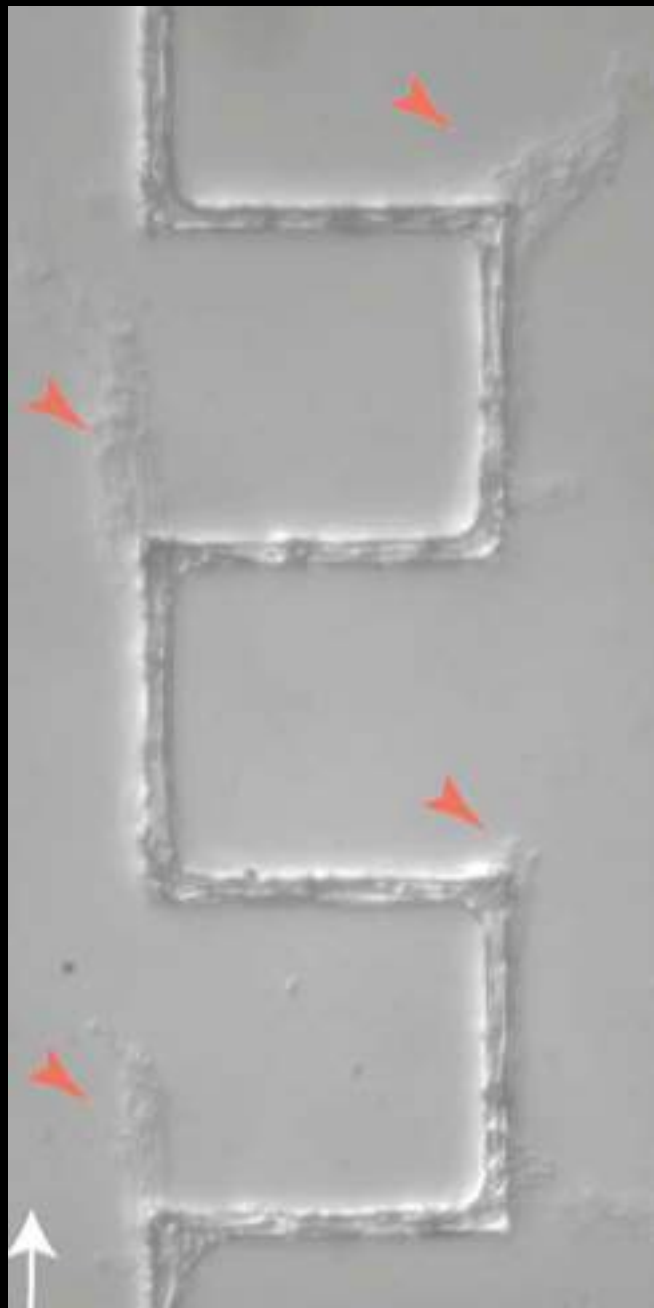
Decomposers are also construction workers

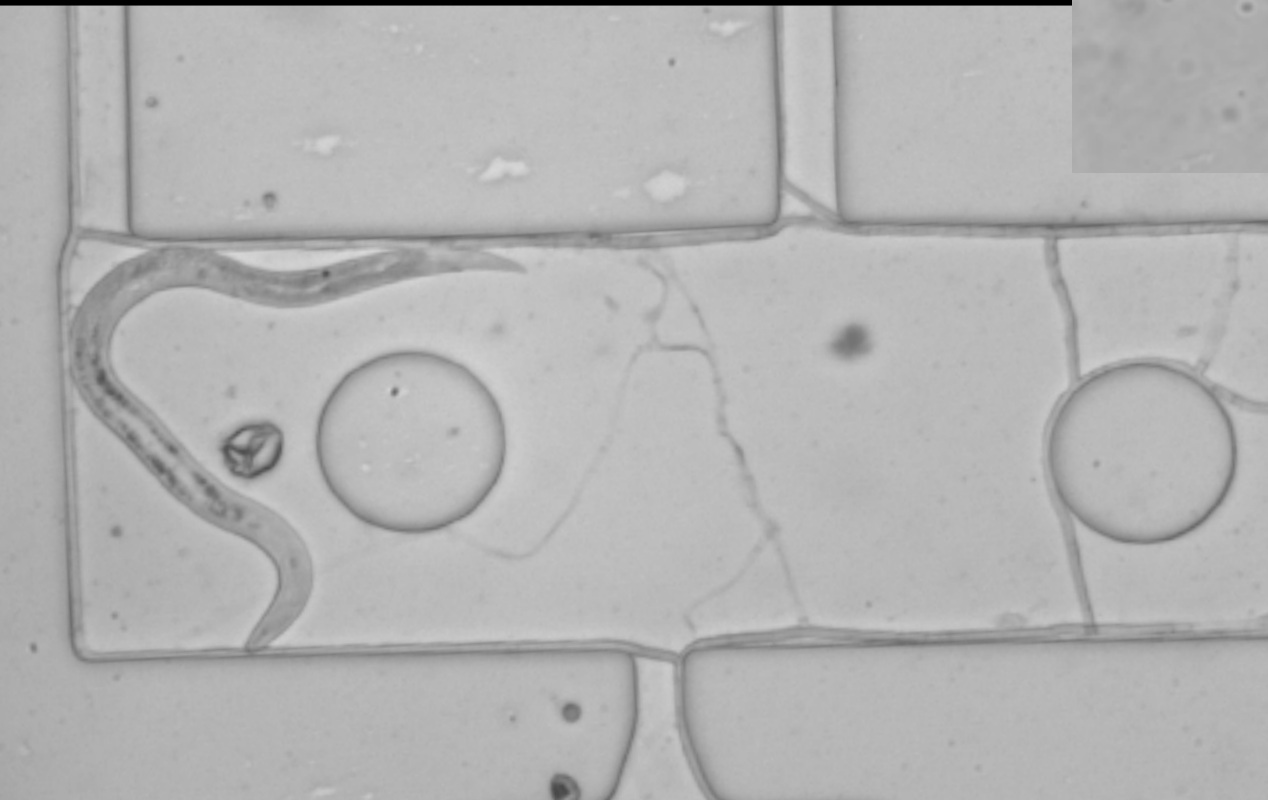
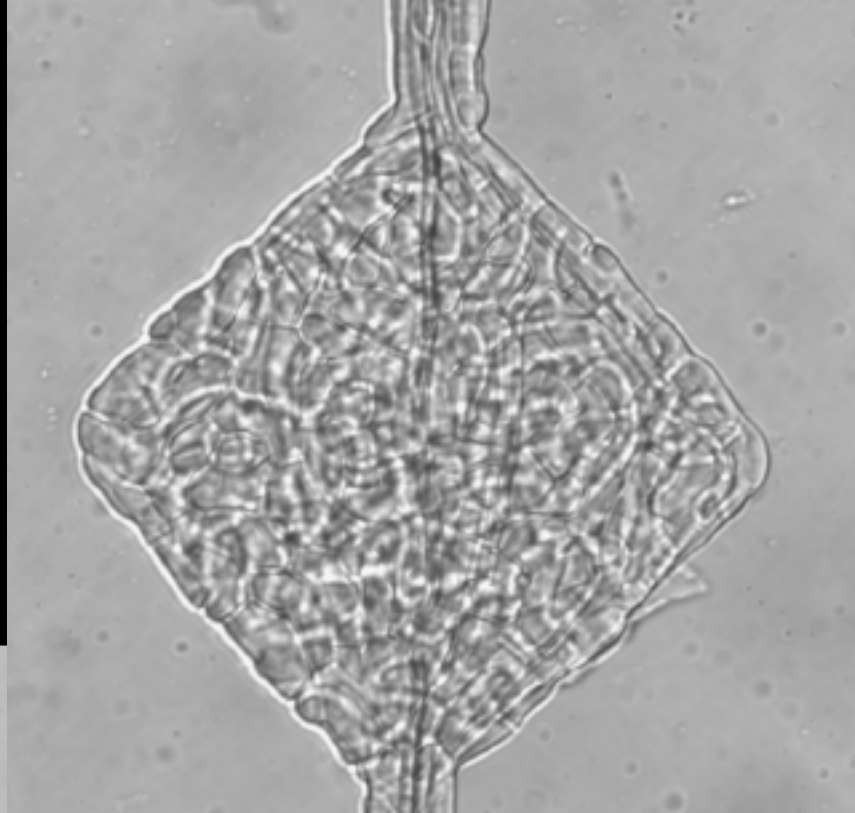


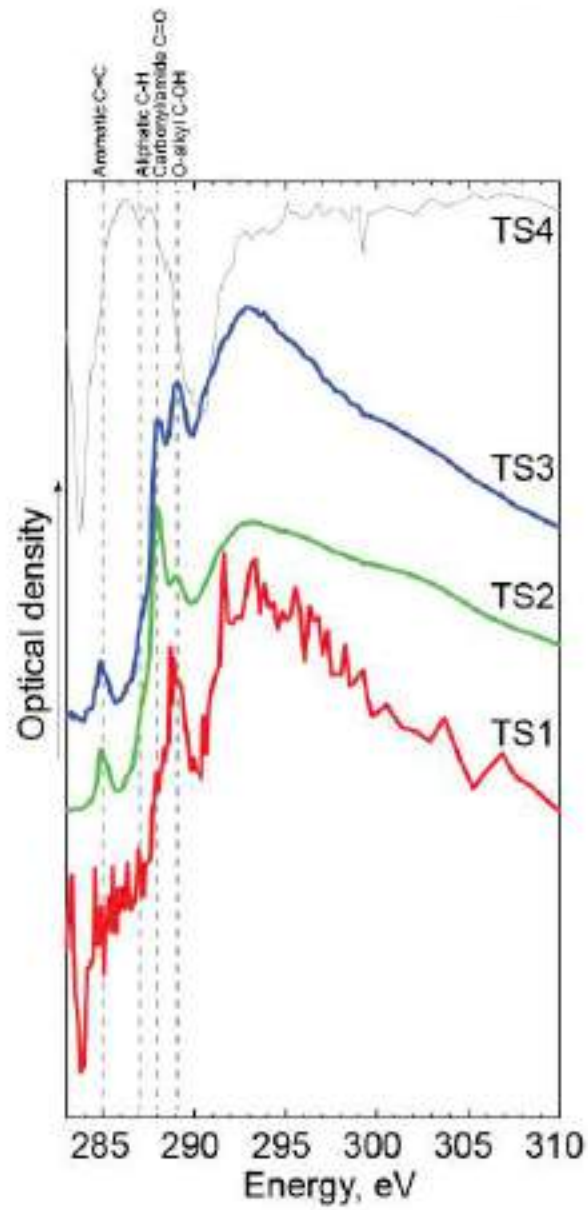
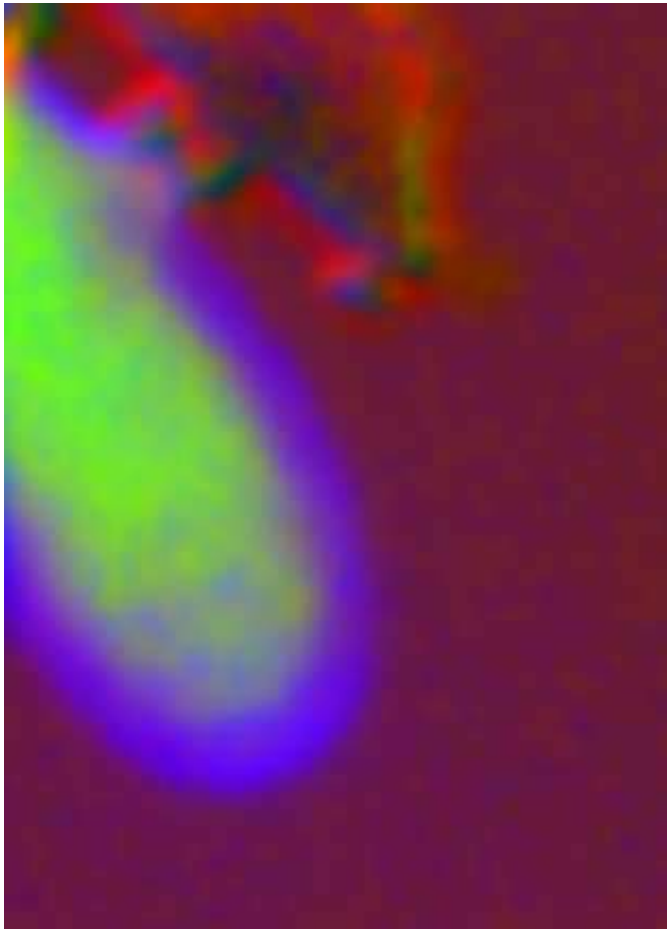
Hammer et al. 2014



Mann et al. 2016



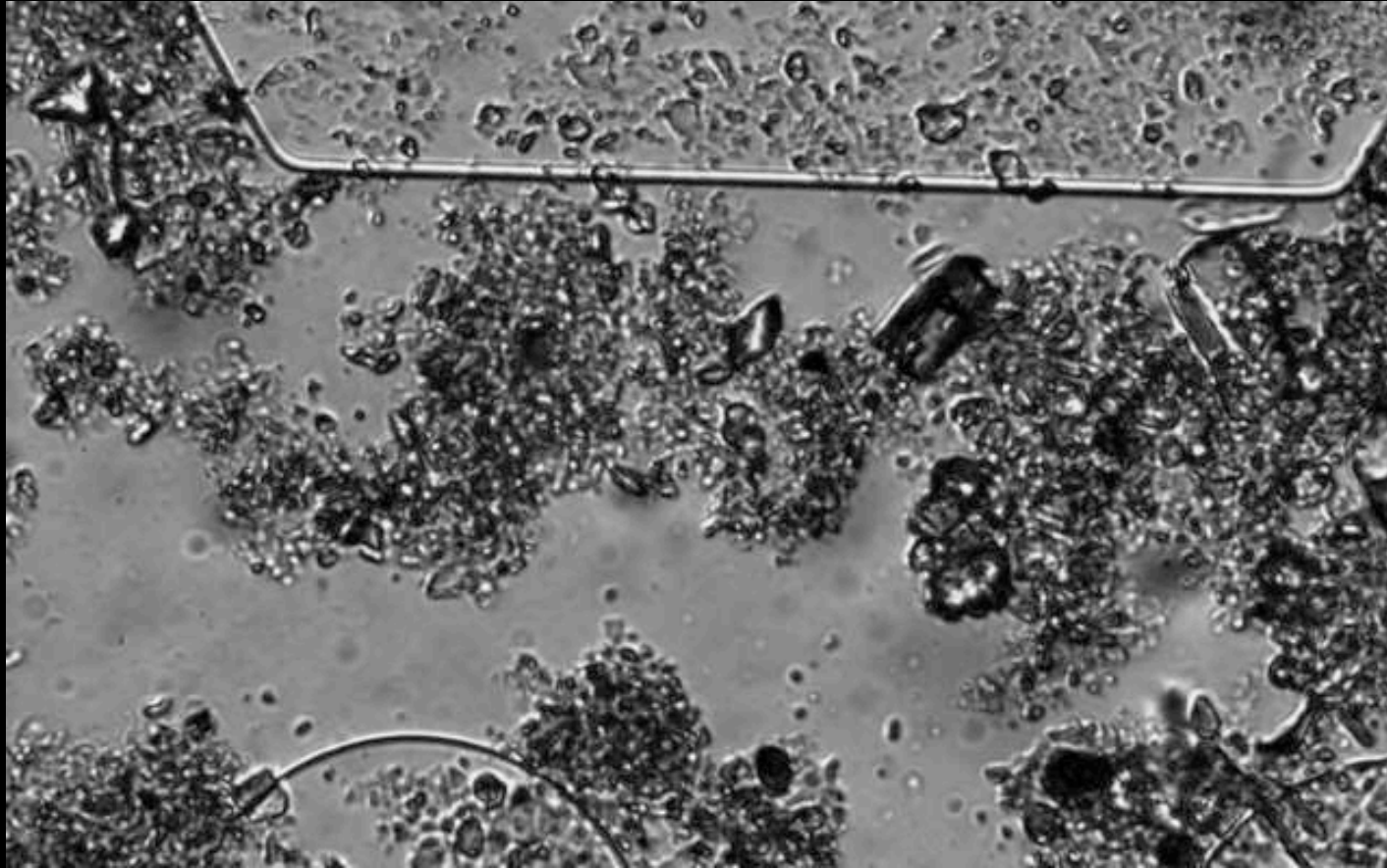


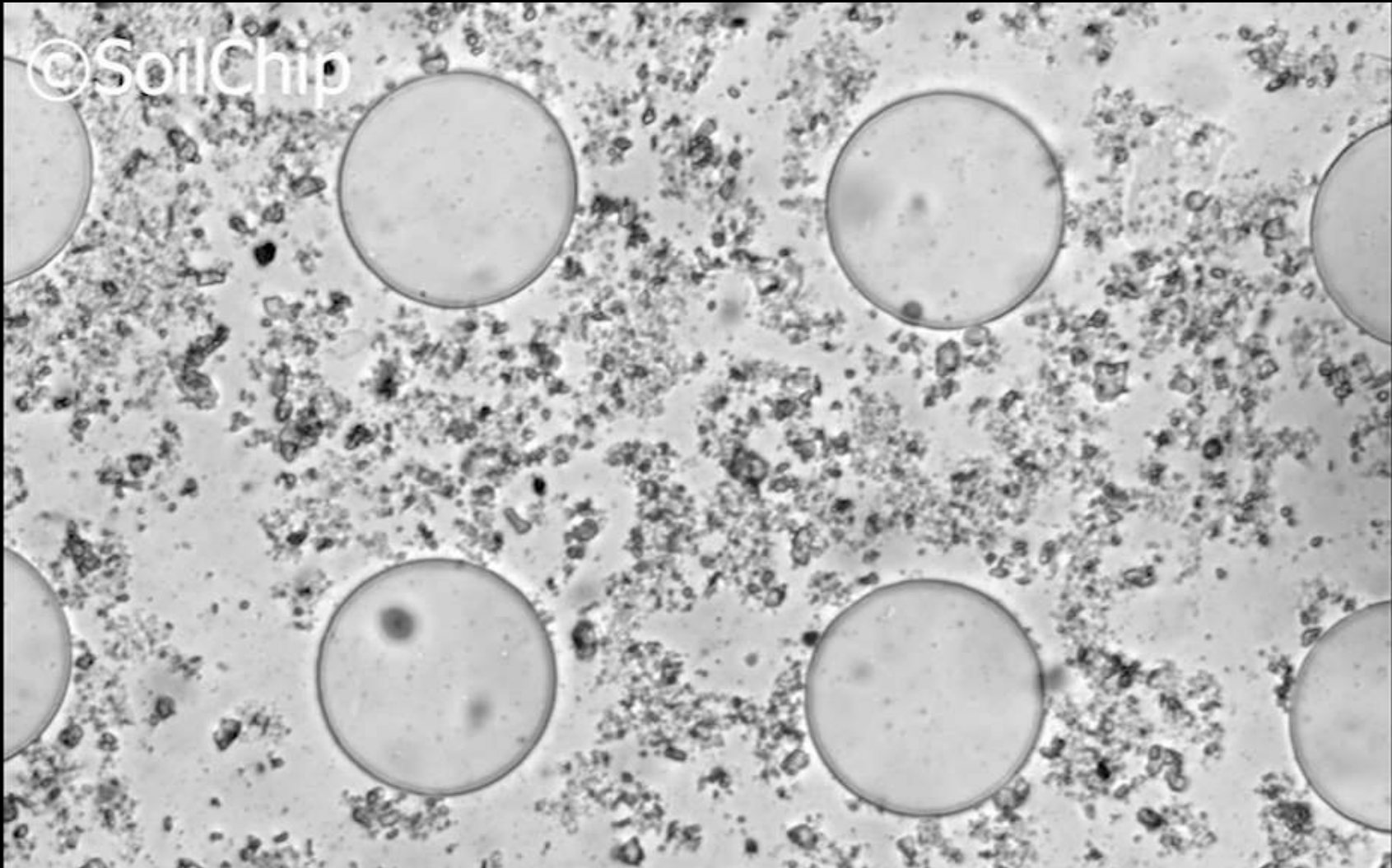


Milda Pucetaite

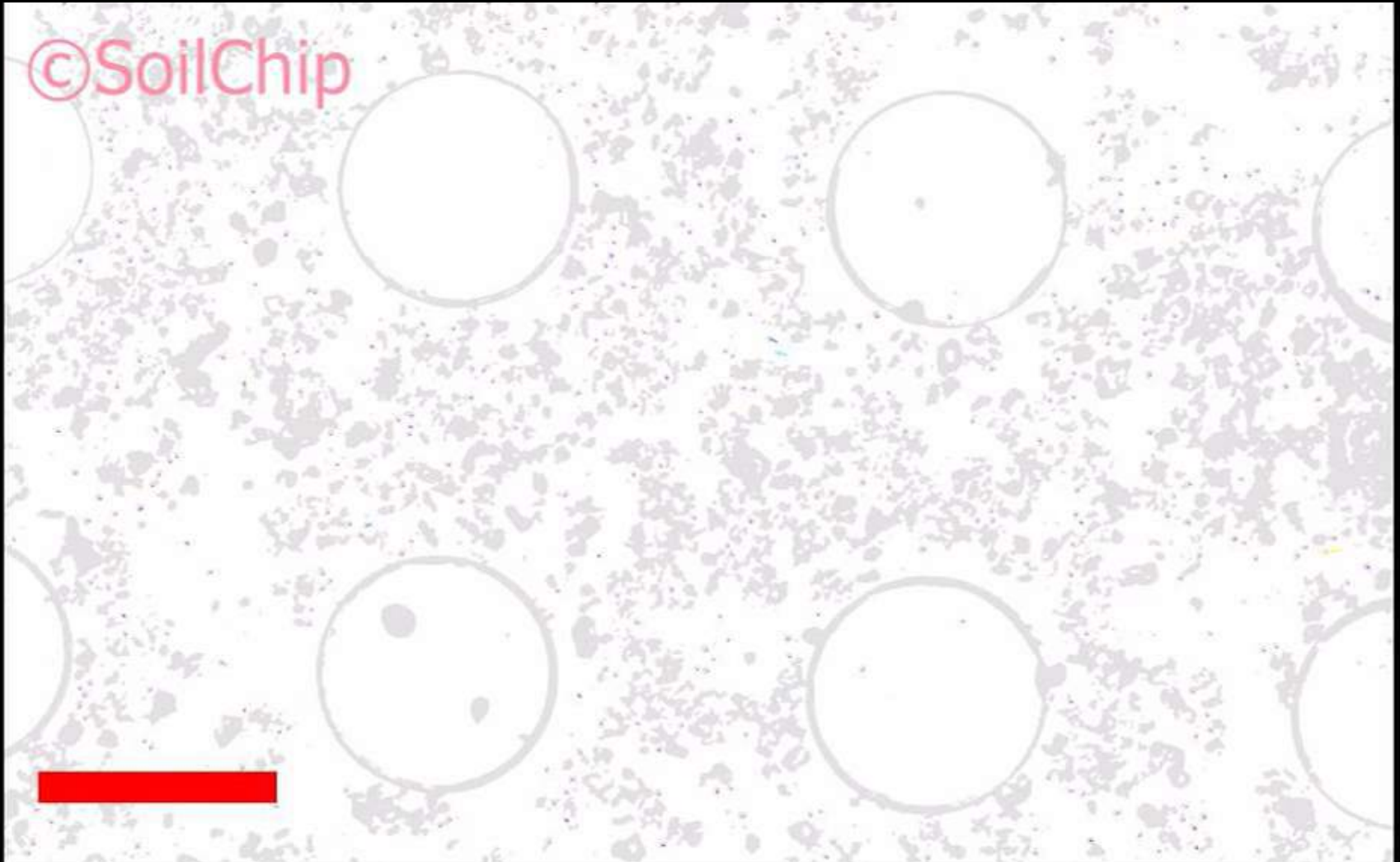


Other microbiota affecting the soil environment

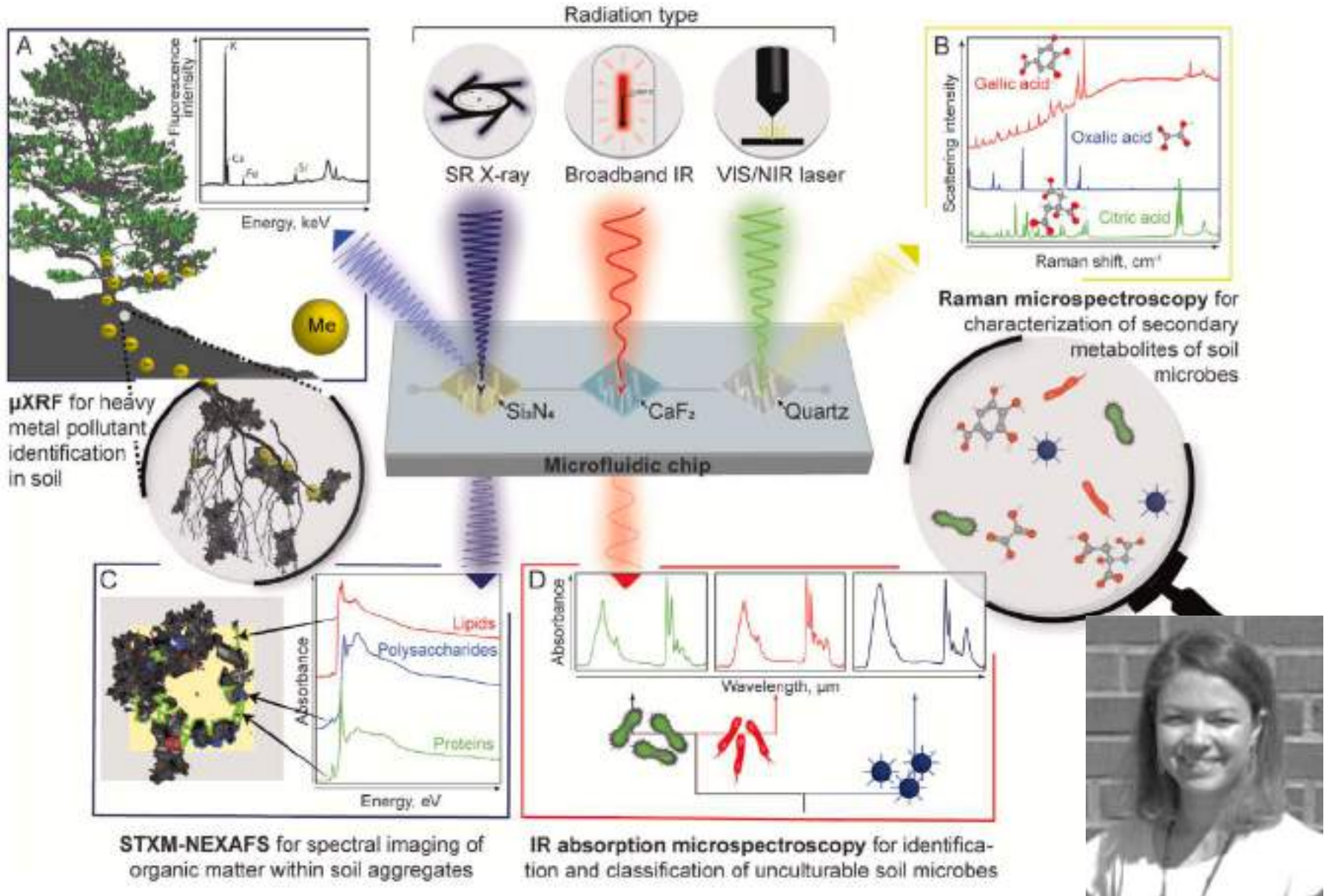




Physical forces affecting the soil environment



Outlook



Freezing soils

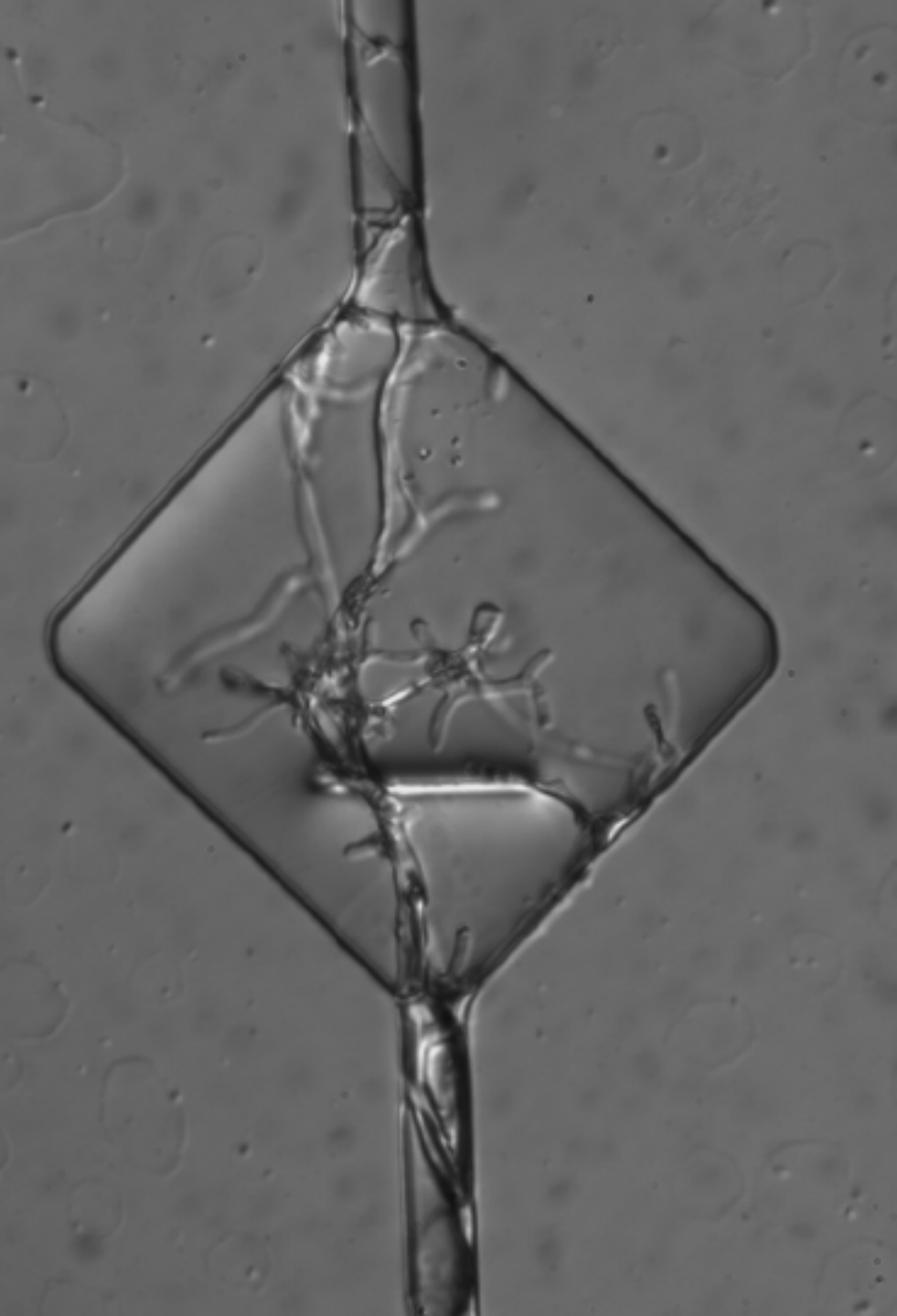
Fredrik
Klinghammer



Julia
Duljas



In prep



The SoilChip project



LUND
UNIVERSITY



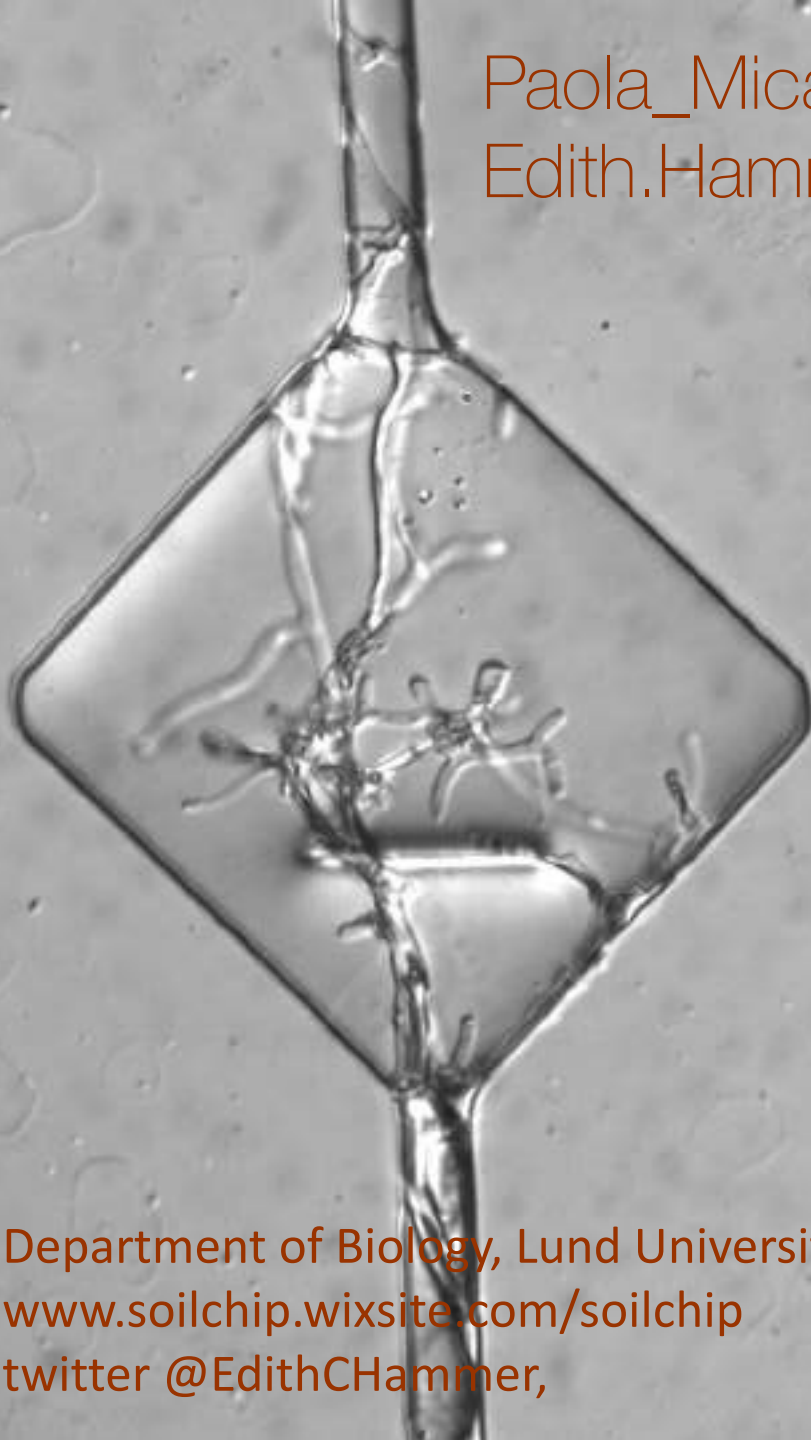
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