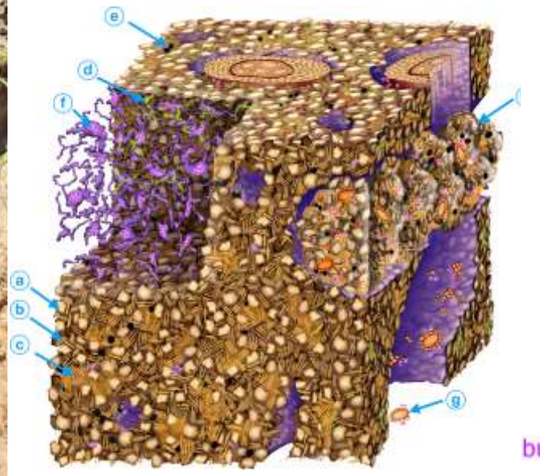
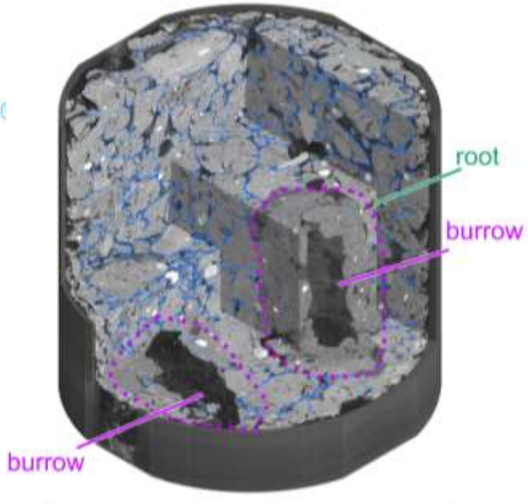
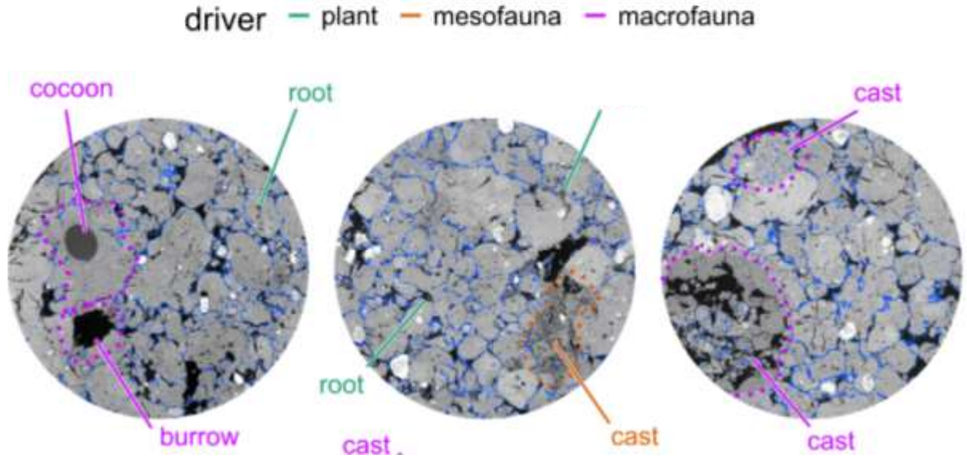
Funded by DFG Deutsche Forschungsgemeinschaft German Research Foundation

Quantifying temporal dynamics of soil structure using X-ray CT scanning

Frederic Leuther (frederic.leuther@uni-bayreuth.de)



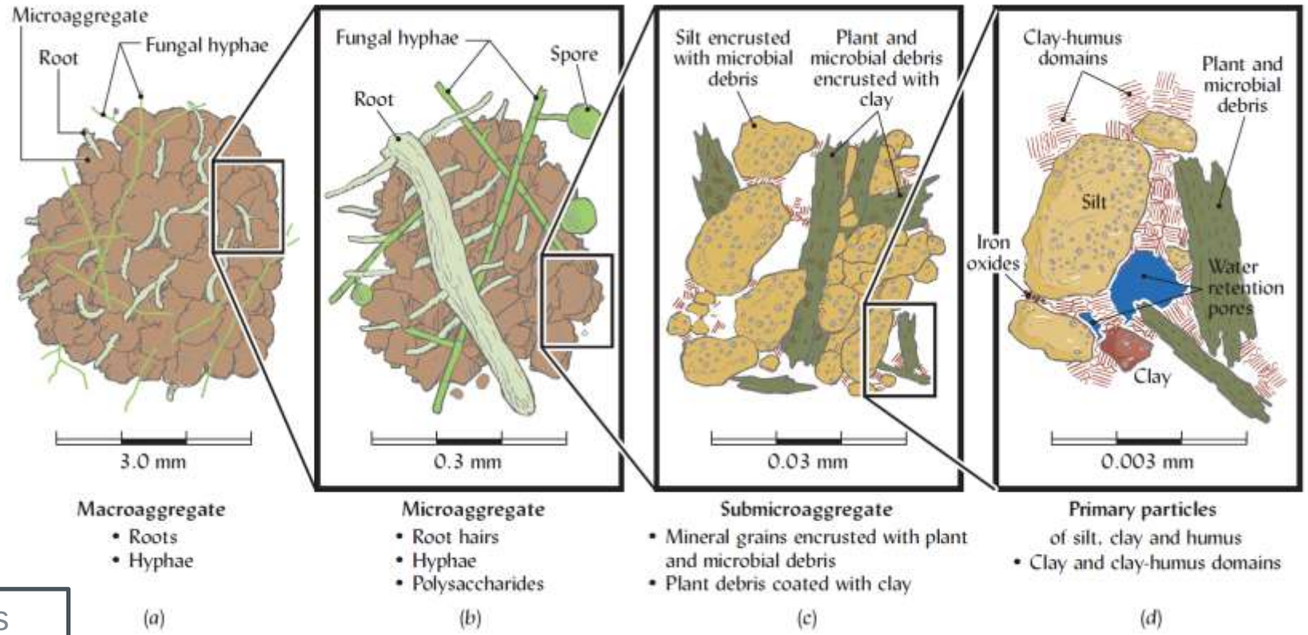




Quantifying temporal dynamics of soil structure using X-ray CT scanning

- What is soil structure?
- Soil structure and soil functions – a case study: biological activity
- Soil structure development due to abiotic and biotic drivers
- Soil structure turnover

What is soil structure? – Aggregate perspective



Reprinted from Weil and Brady (2017).

Aggregate perspective is helpful to diagnose structure stability and its influencing factors, such as organic carbon, cations, pre-compression stress, etc.

What is soil structure? – Pore perspective

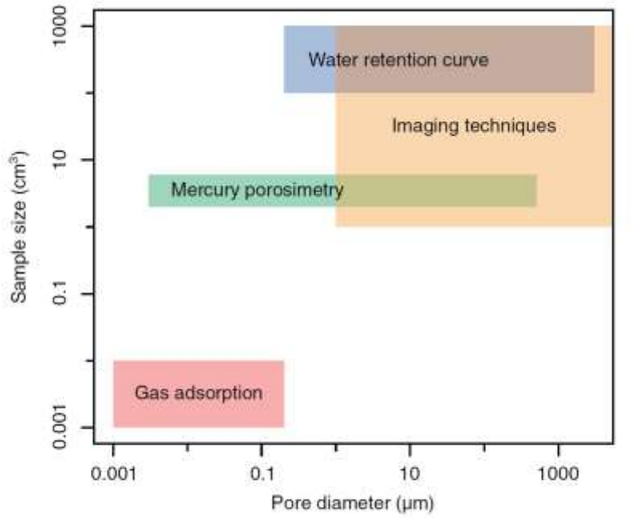
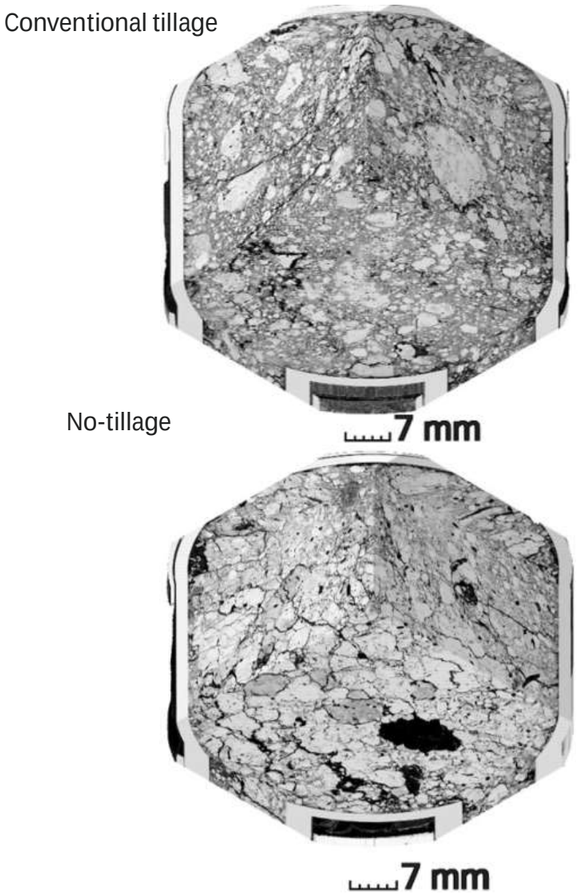
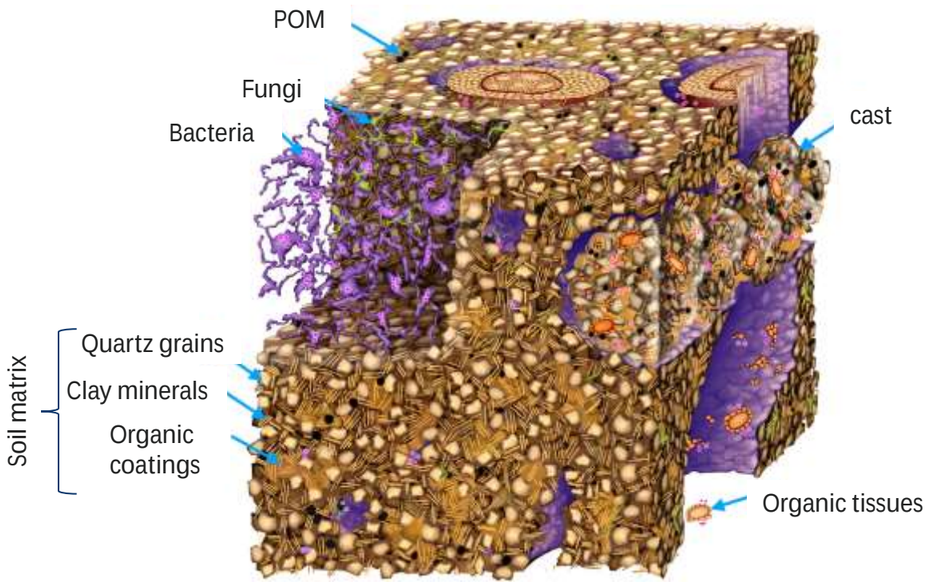


Fig. 2. Comparison of the sample sizes and pore sizes investigated with the different methods to characterize soil pore space. Both axes are represented with a logarithmic scale.

Reprinted from Rabot et al. (2021).



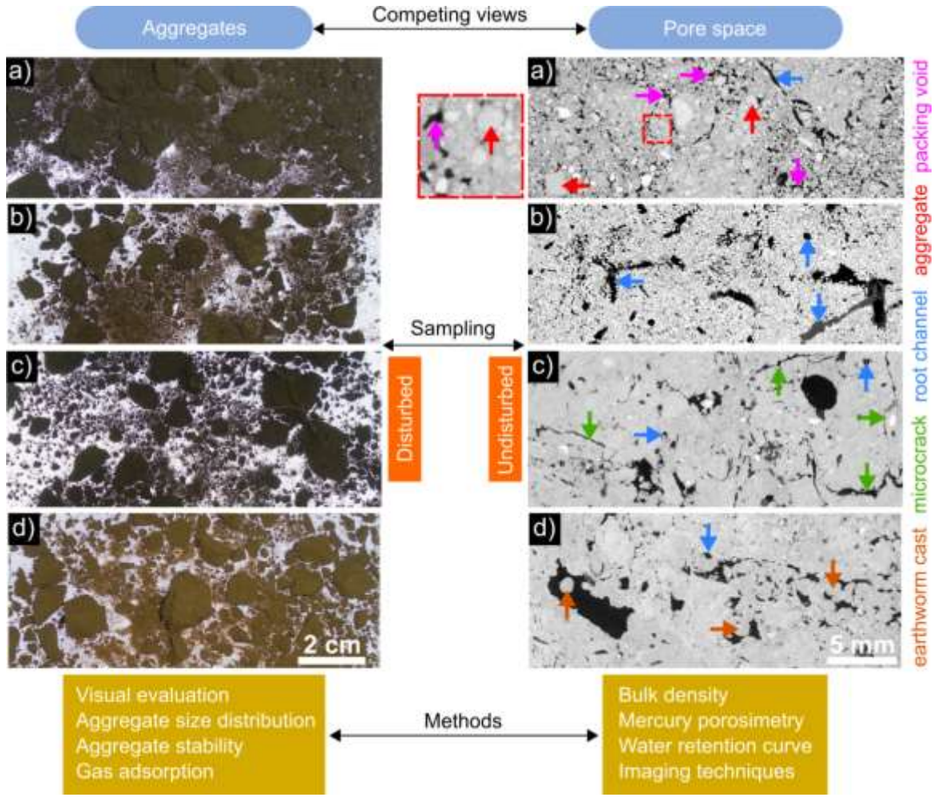
Structural organization of fine textured soils



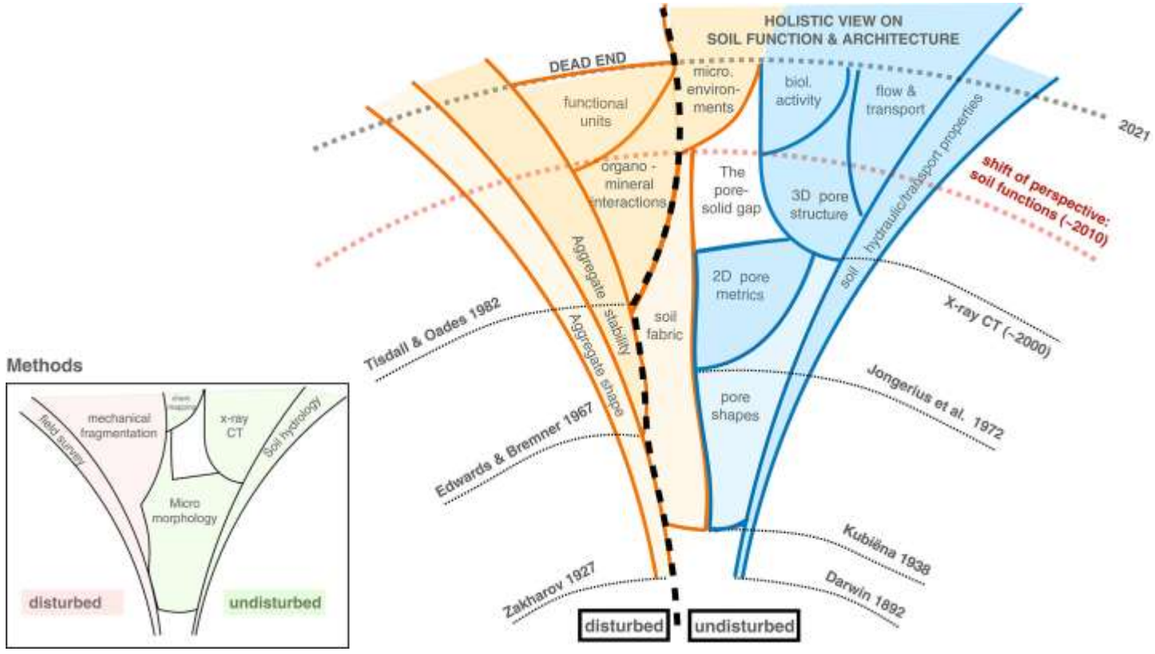
Reprinted from Vogel et al. (2022).

Pore perspective is helpful to describe matter fluxes and habitats (…, water storage, aeration, rootability)

What is soil structure?

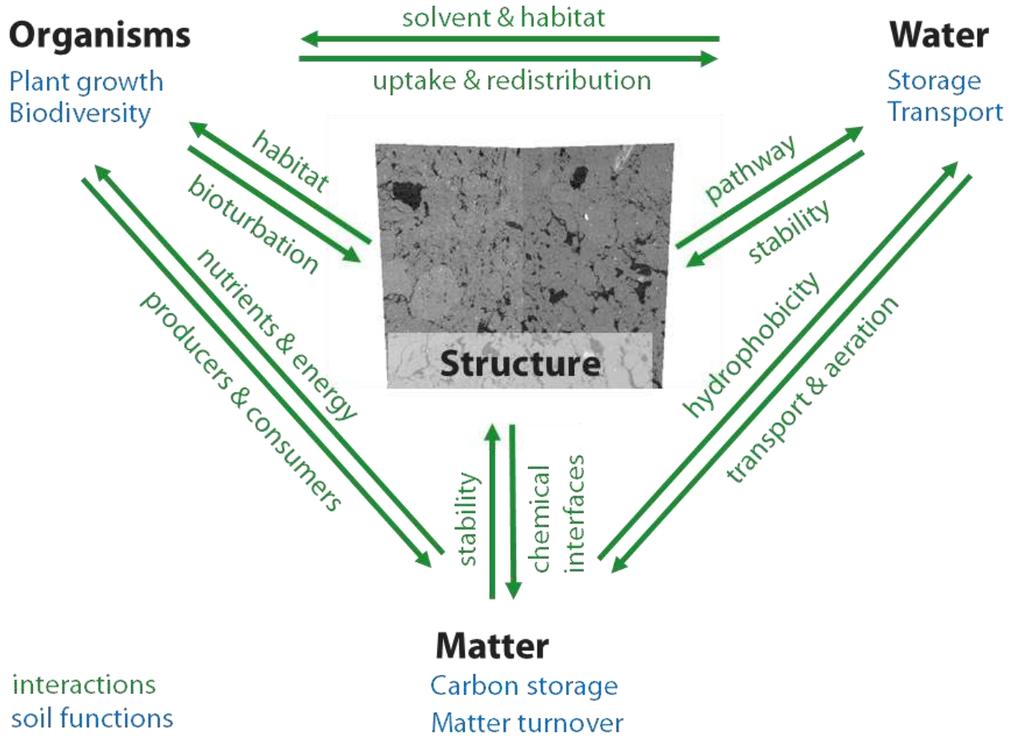


Reprinted from Rabot et al. (2021).



Reprinted from Vogel et al. (2022).

Soil structure – a dynamic soil property which effects multiple soil functions

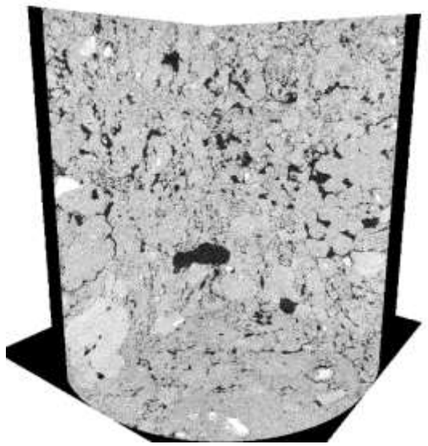


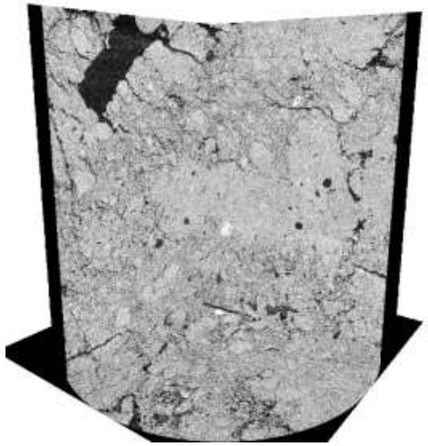
Adapted from Schlüter & Köstel, *Reference Module in Earth Systems and Environmental Sciences: Soil Structure*. Elsevier (2022).

Feedbacks with biological activity – a case study

reduced tillage

conventional tillage

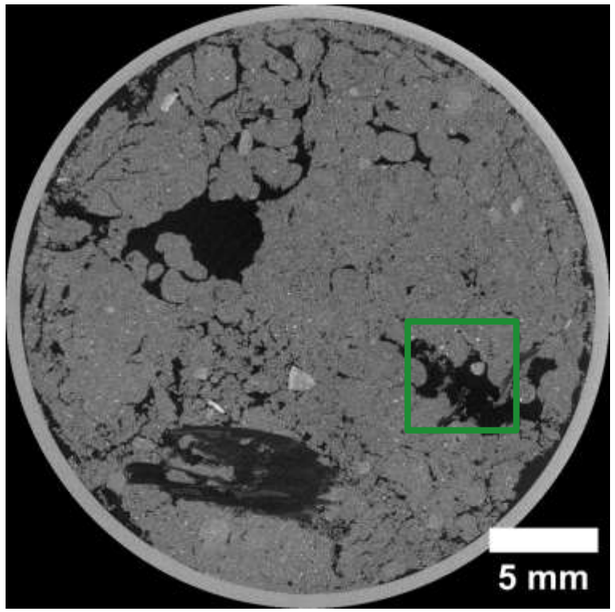




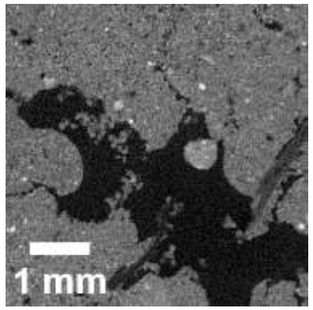
Can we link soil structural indicators to differences in biological activity?

12 years of contrasting land management practices creates different soil structures and thus affect the mineralisation of glucose addition.

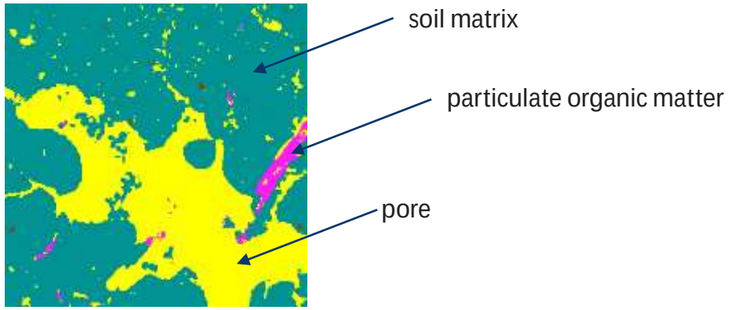
Soil structure indicators



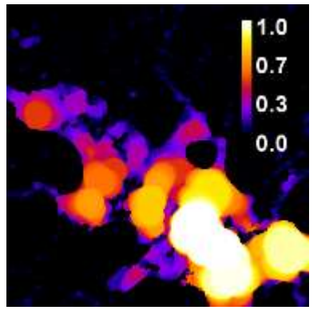
- mean matrix grey value



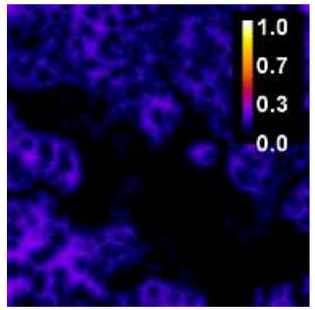
- visible porosity
- pore surface density
- pore connectivity
- POM volume



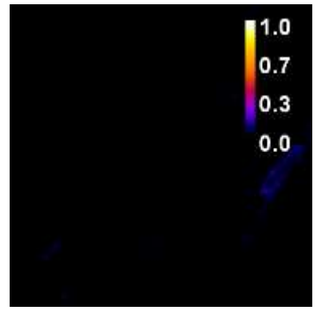
- mean pore size [mm]

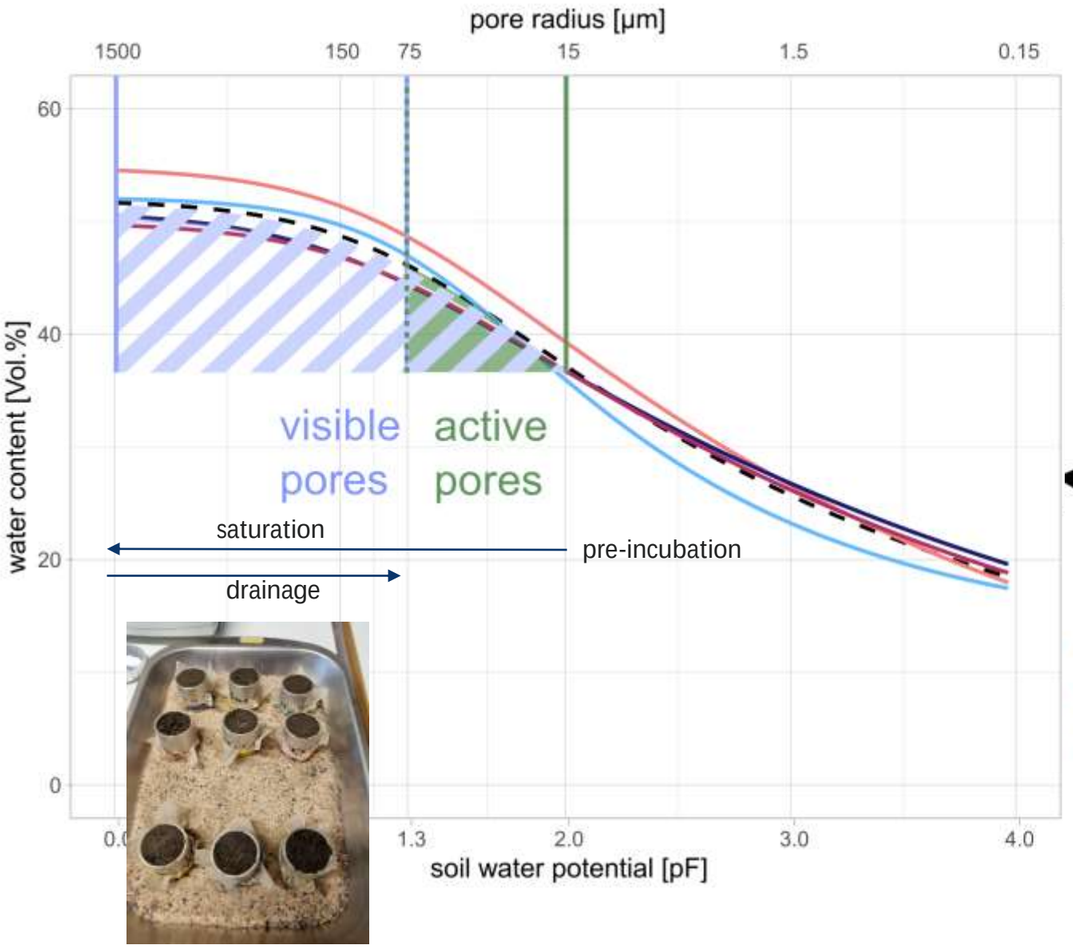


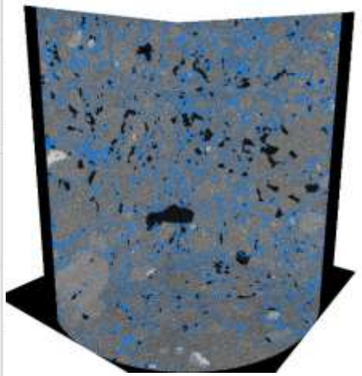
- matrix-pore distance [mm]



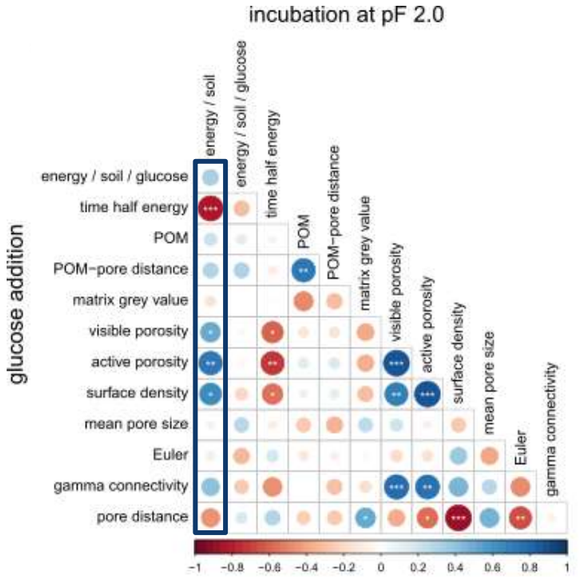
- POM-pore distance [mm]



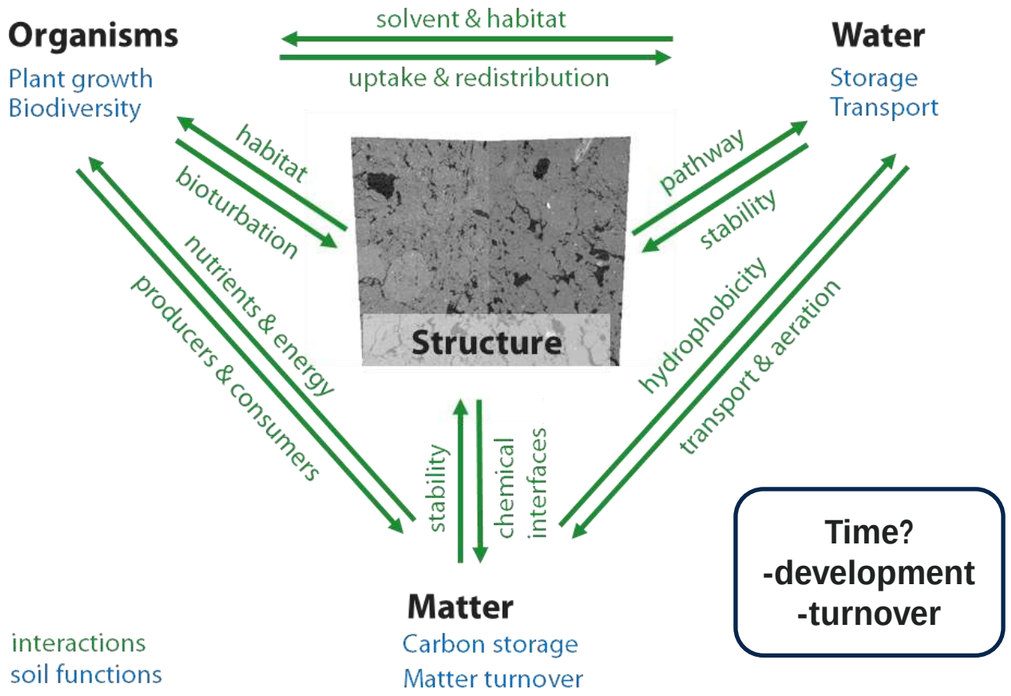




management system
- average
- conventional maize
- conventional wheat
- reduced maize
- reduced wheat



Soil structure is not static, but changing over time



abiotic drivers

- Dry/wet cycles, Freeze/thaw cycles
- Stability: cementing agents, base ions


dessication cracks


Diel et al. (2019): Geoderma

biotic drivers

- Bioturbation
- Stability: SOM, residues


earthworm cast


earthworm burrow

management

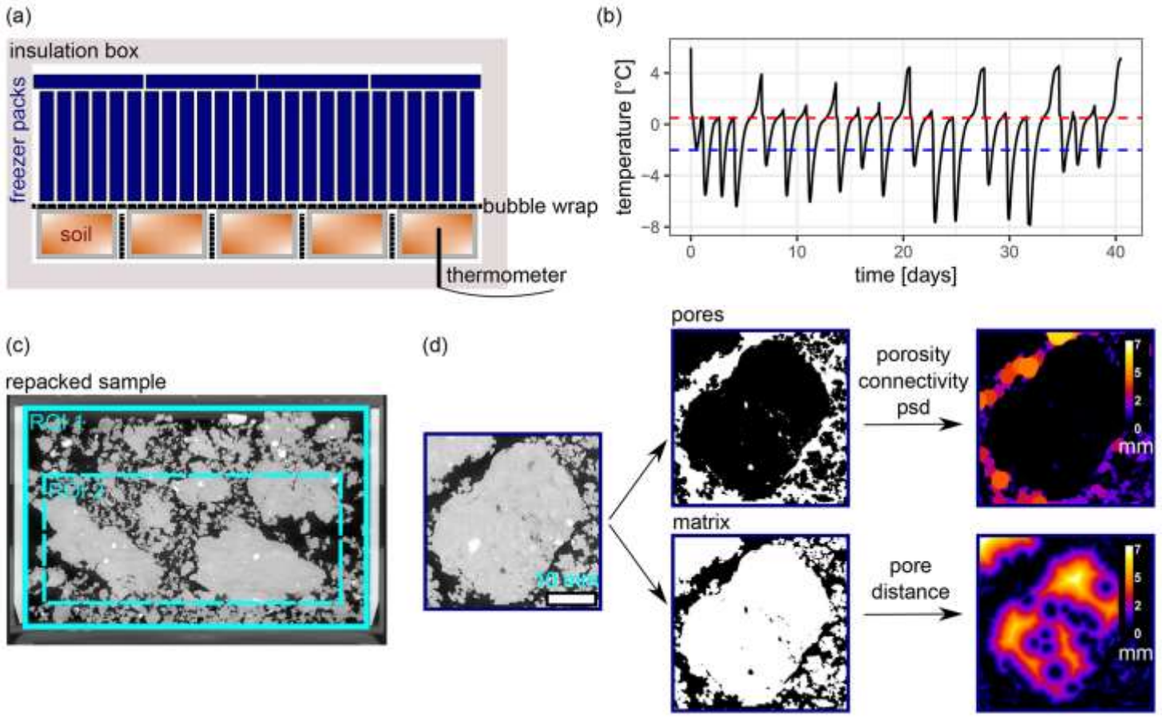
- Tillage, compaction
- Stability: liming, residue management

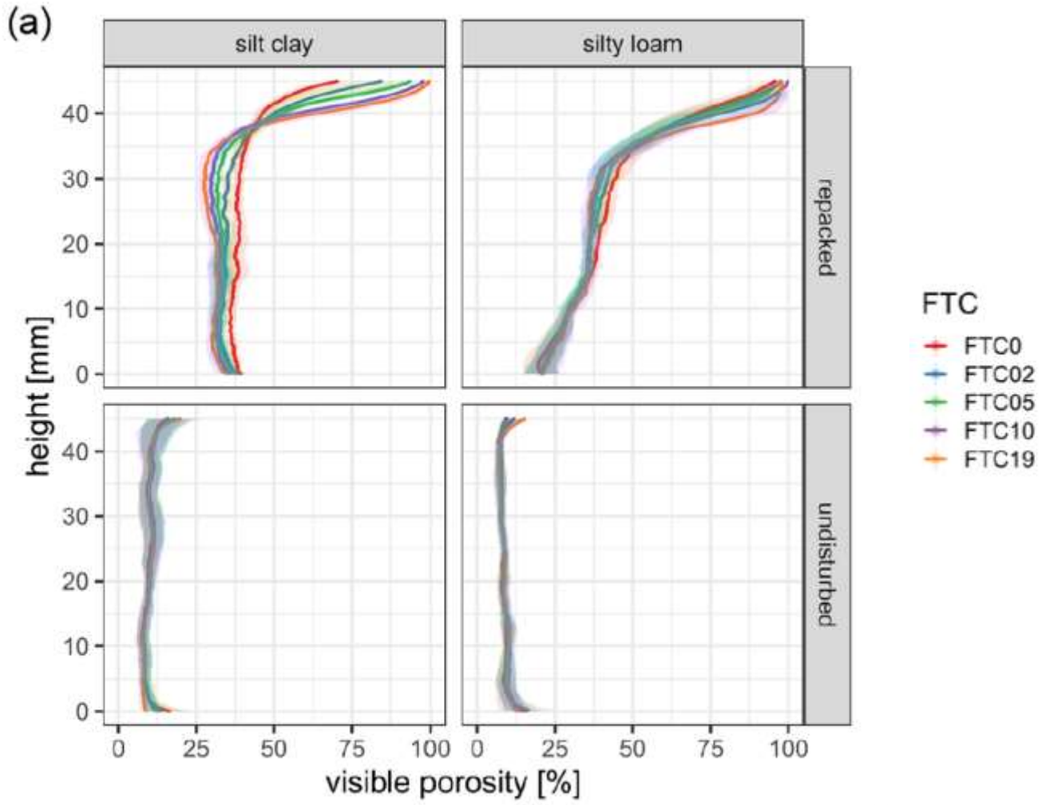

tillage


compaction

Changes in soil structure due to abiotic drivers

Seasonal dynamics: **Freezing-thawing** and wetting-drying

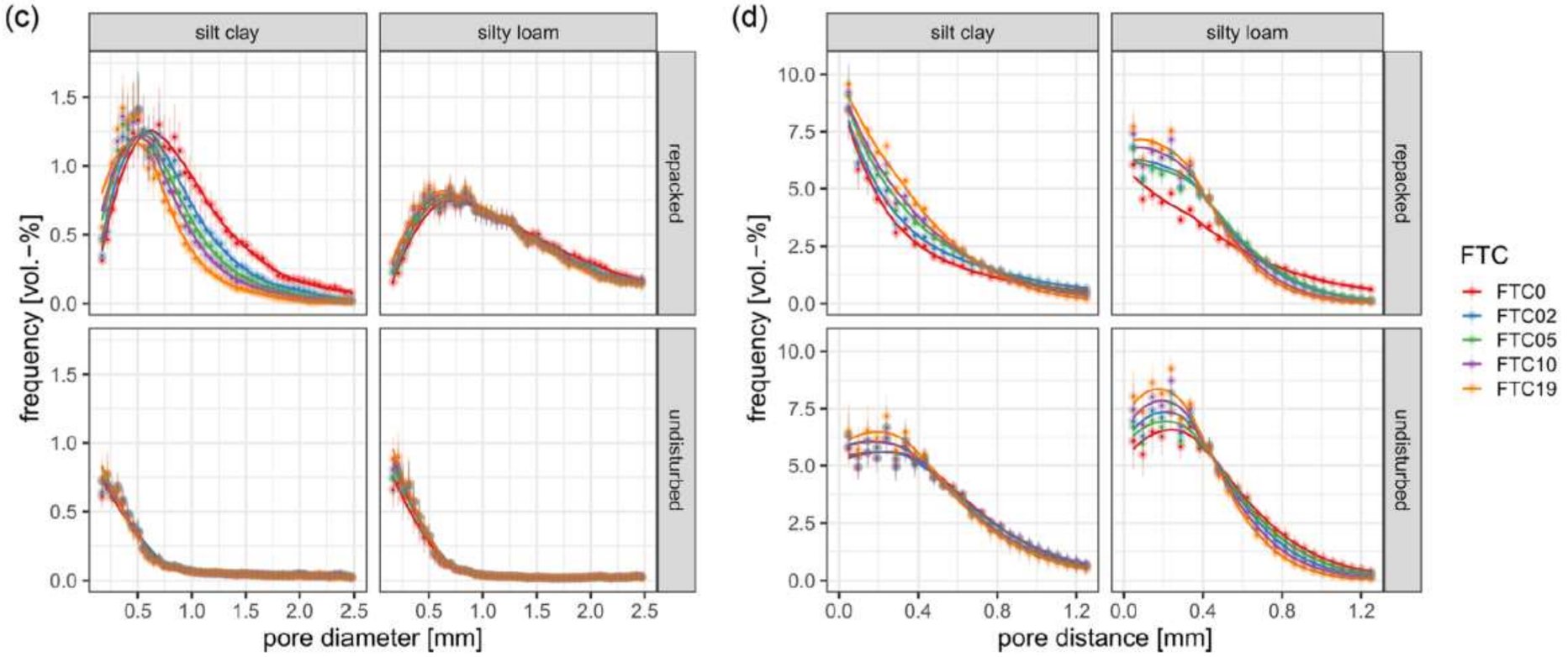




F. Leuther and S. Schlüter , Impact of freeze-thaw cycles on soil structure and soil hydraulic properties. Soil. 7, 179-191 (2021).

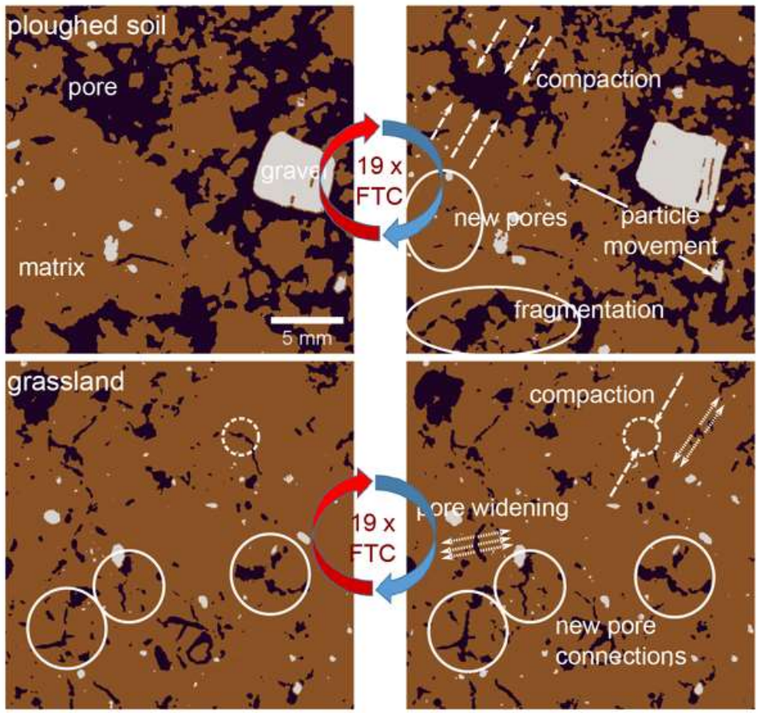
Changes in soil structure due to abiotic drivers

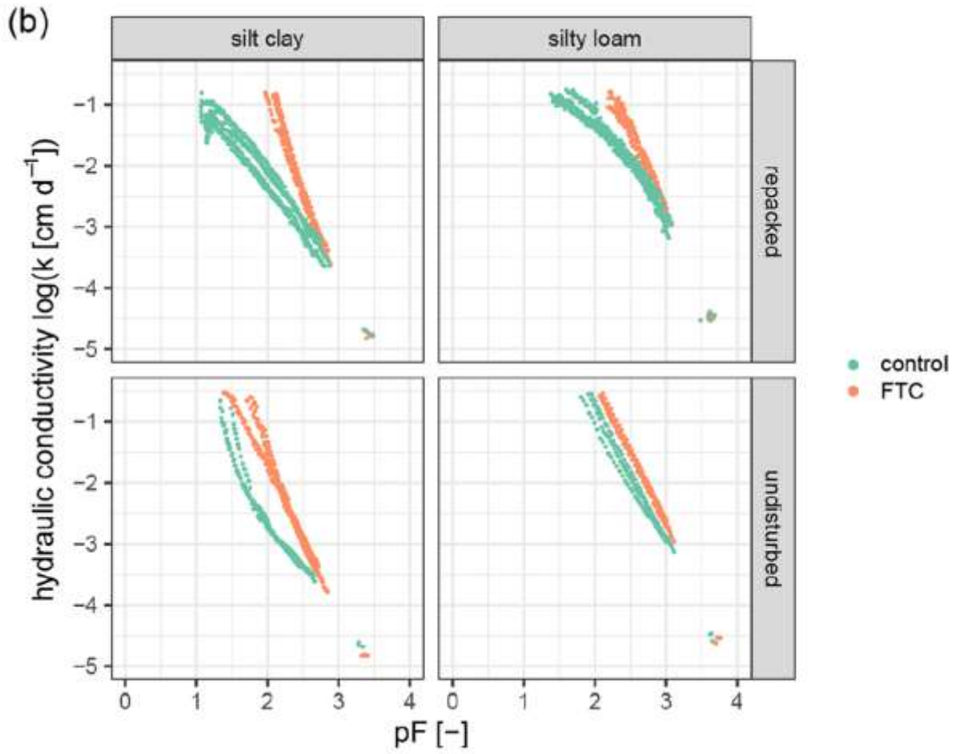
Seasonal dynamics: **Freezing-thawing** and wetting-drying



Changes in soil structure due to abiotic drivers

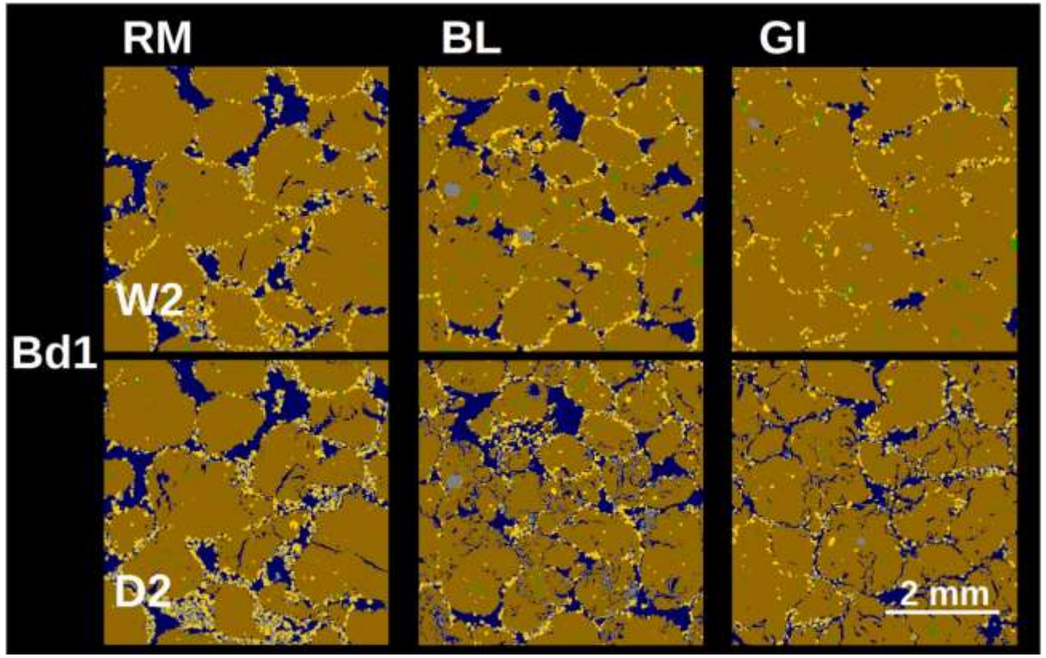
Seasonal dynamics: **Freezing-thawing** and wetting-drying

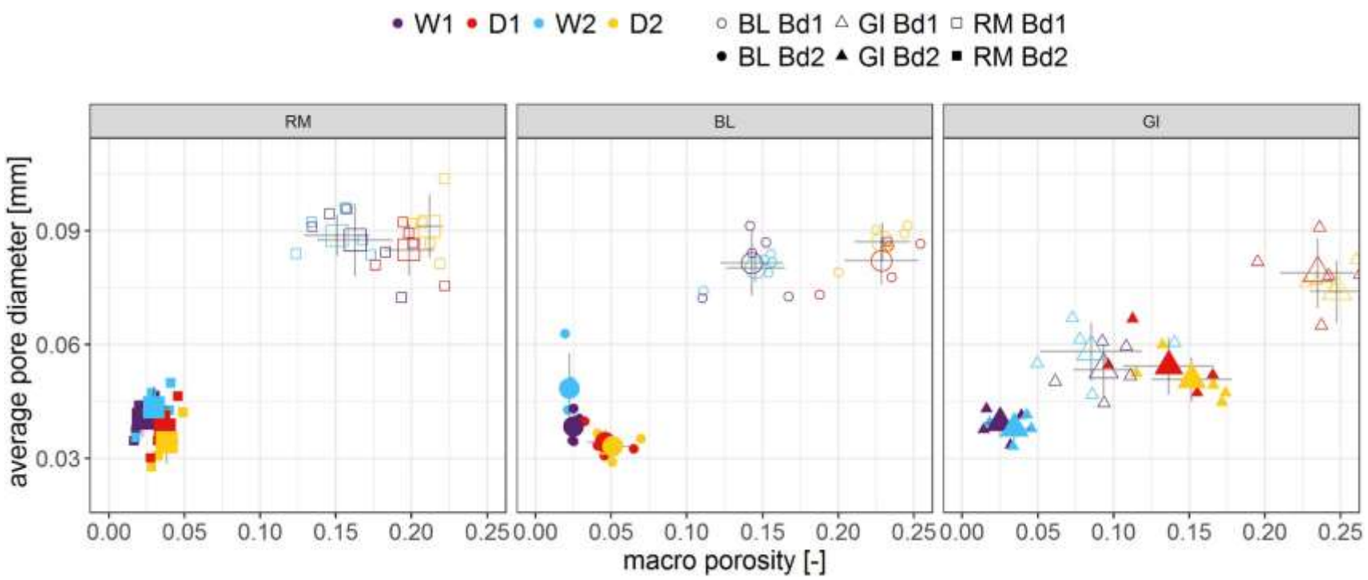




Changes in soil structure due to abiotic drivers

Seasonal dynamics: Freezing-thawing and **wetting-drying**

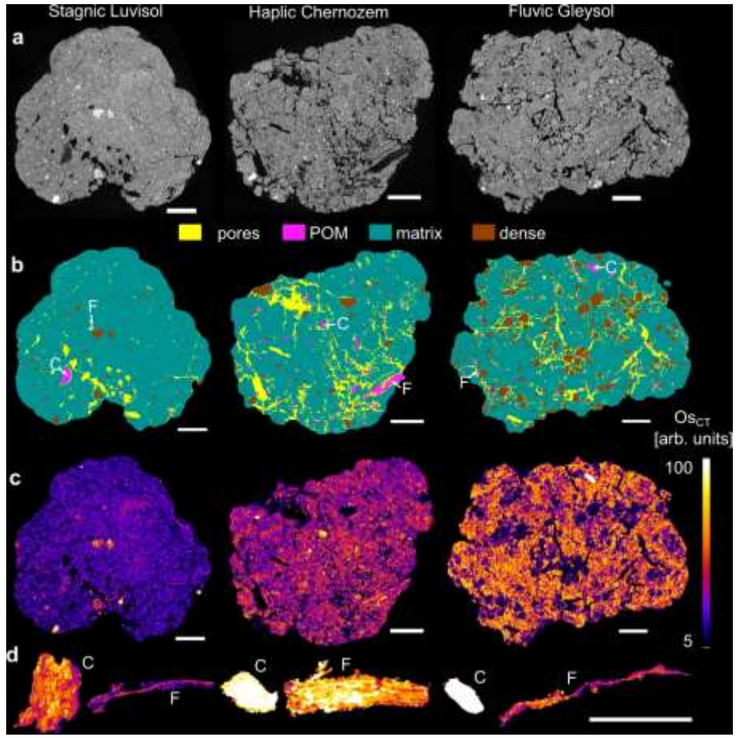


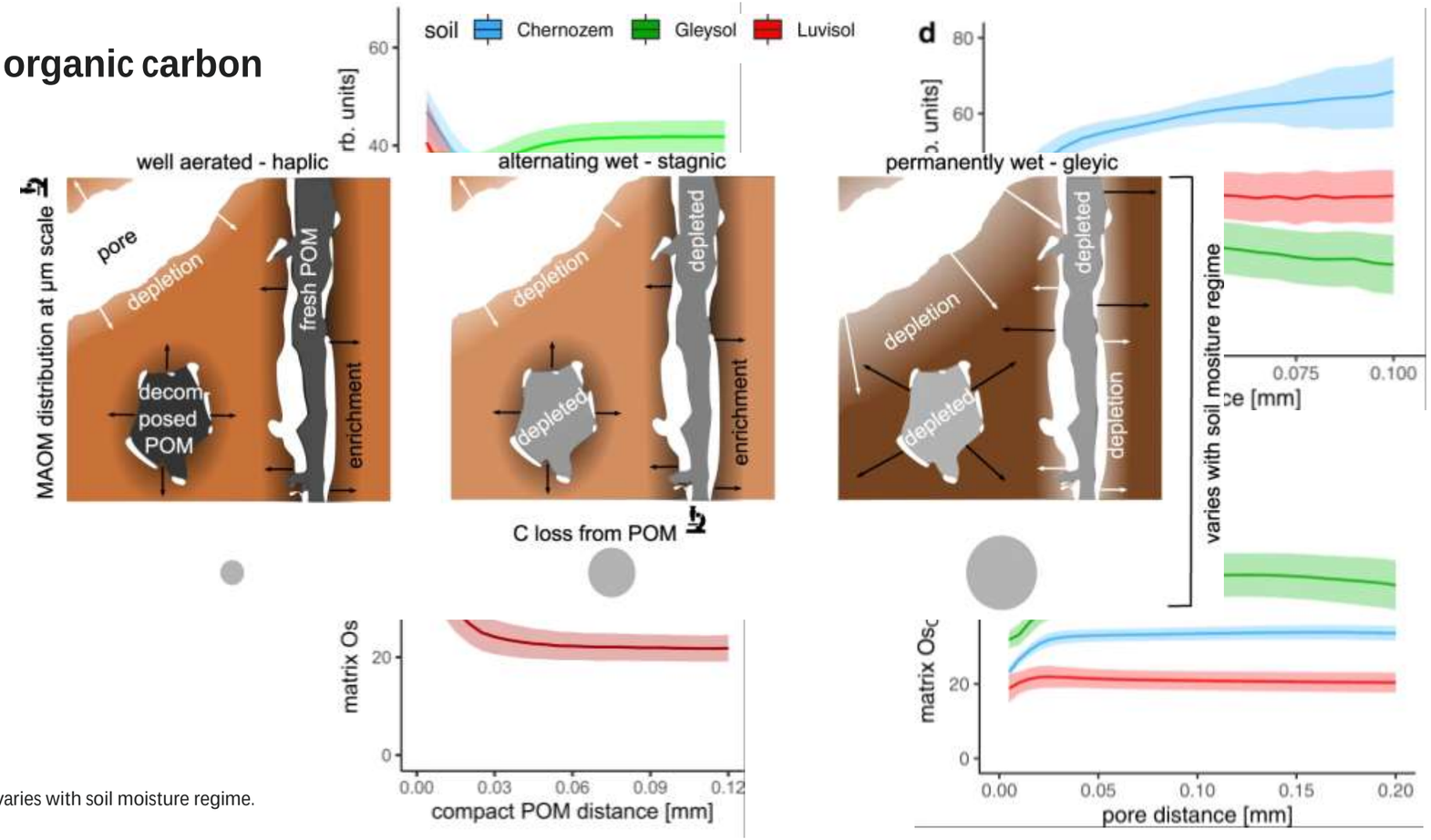


J. Diel et al., Impact of wetting-drying cycles on soil structure dynamics. Geoderma. 345, 63-71 (2019).

Changes in soil structure due to abiotic drivers

Long-term effects: **Soil moisture regime and organic carbon**

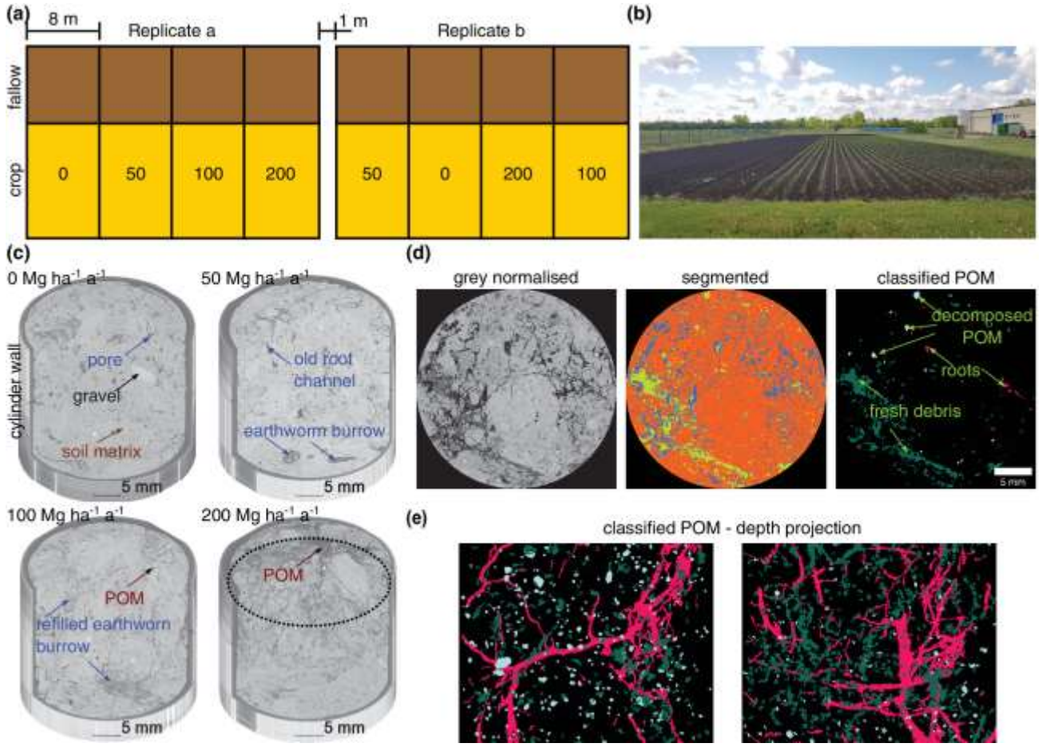


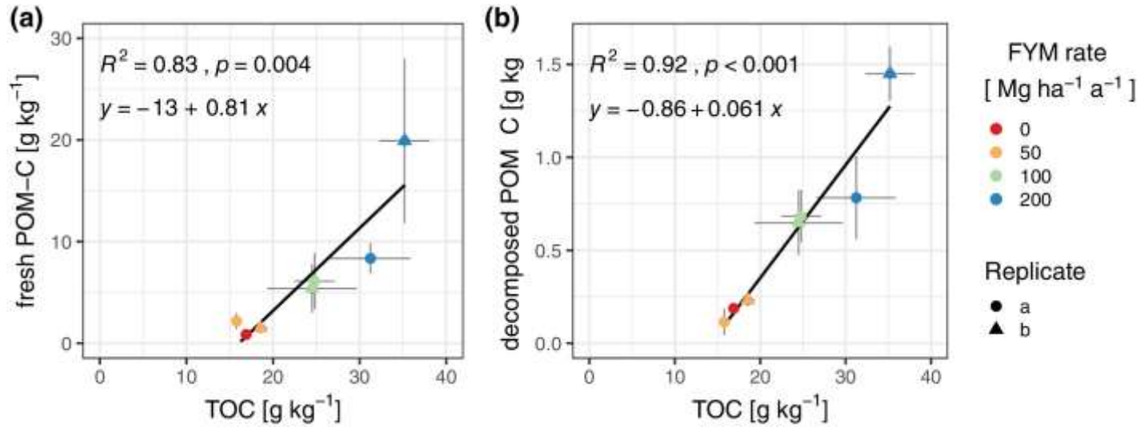


S. Schlüter *et al.*, Microscale carbon distribution around pores and particulate organic matter varies with soil moisture regime. *Nat. Commun.* **13**, 2098 (2022).

Changes in soil structure due to biotic drivers

Long-term effects: **FYM input and organic carbon**

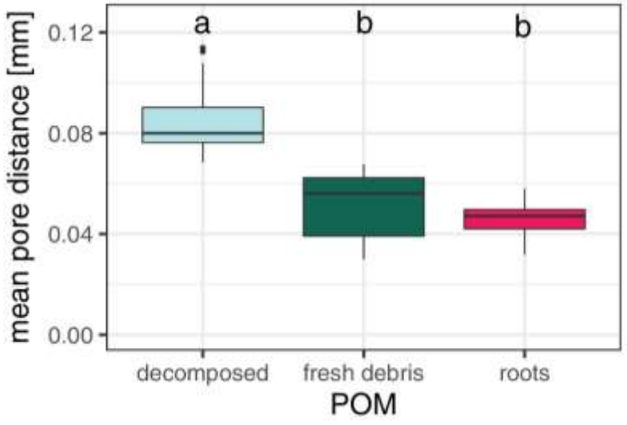


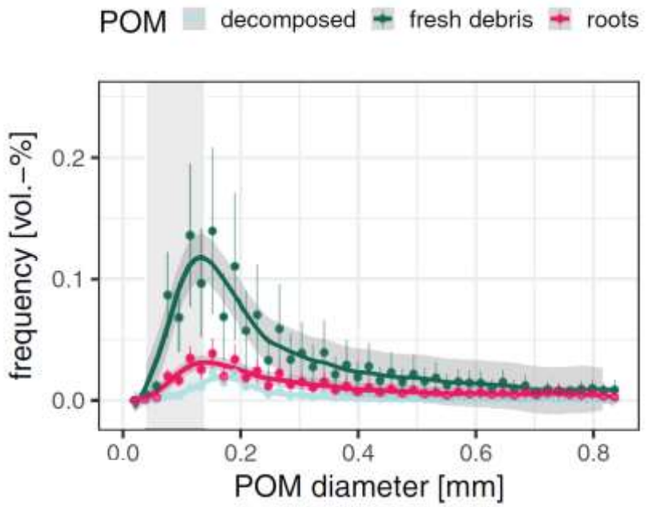


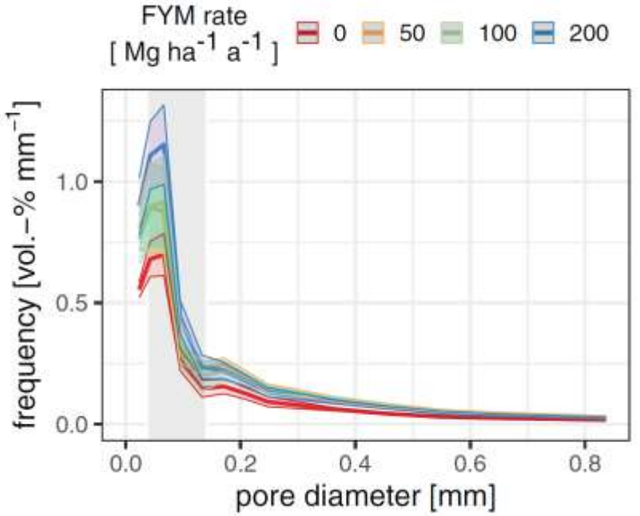
F. Leuther *et al.*, *Response of subsoil organic matter contents and physical properties to long-term, high-rate farmyard manure application.* *Eur. J. Soil Sci.* **73**, e13233 (2022).

Changes in soil structure due to biotic drivers

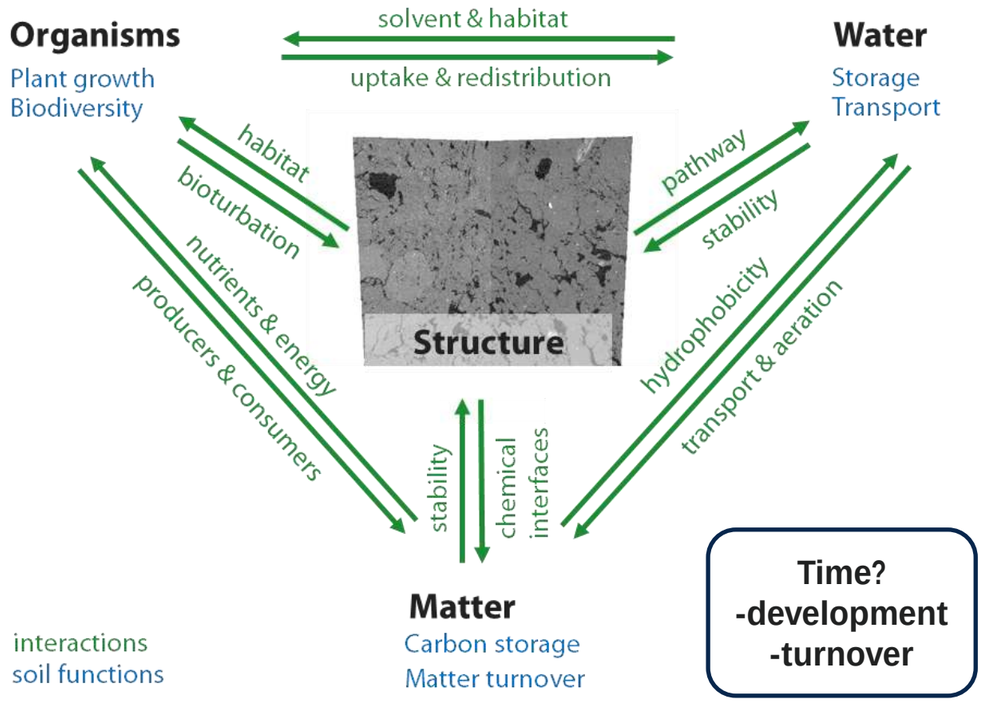
Long-term effects: **FYM input stimulates root growth**





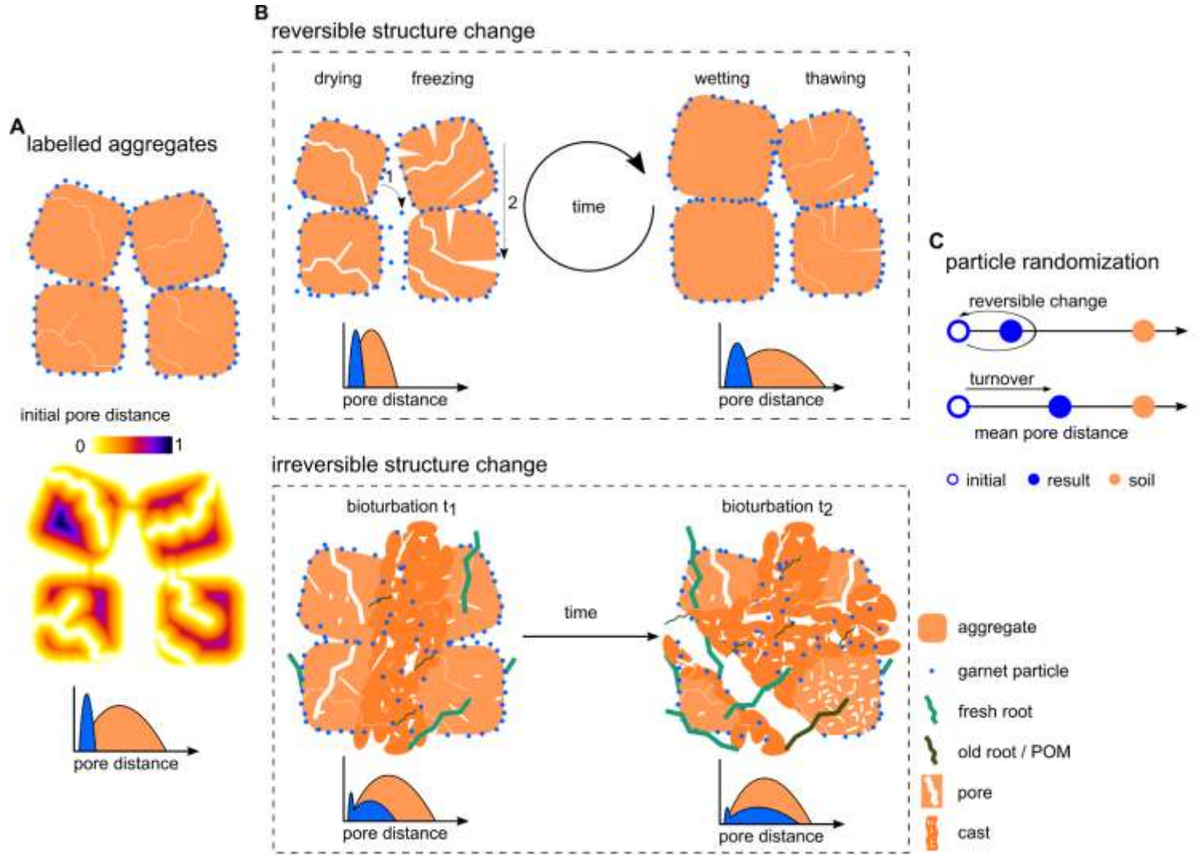


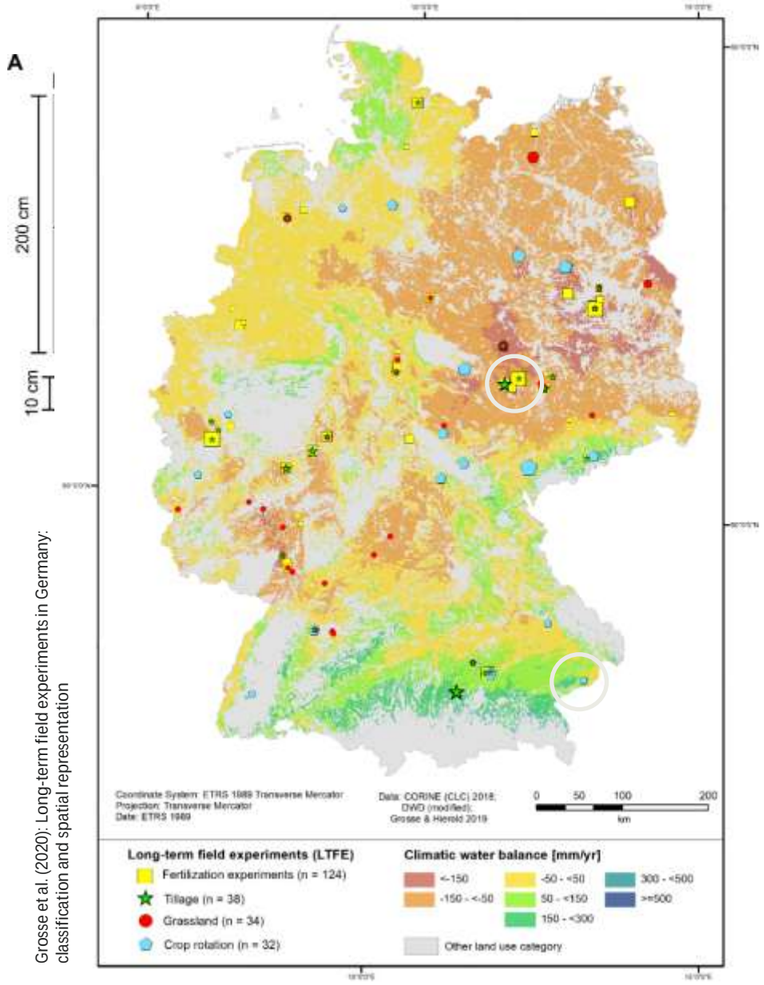
Soil structure and soil functions



Adapted from Schlüter & Köstel, *Reference Module in Earth Systems and Environmental Sciences: Soil Structure*. Elsevier (2022).

Particle randomization as an indicator for turnover

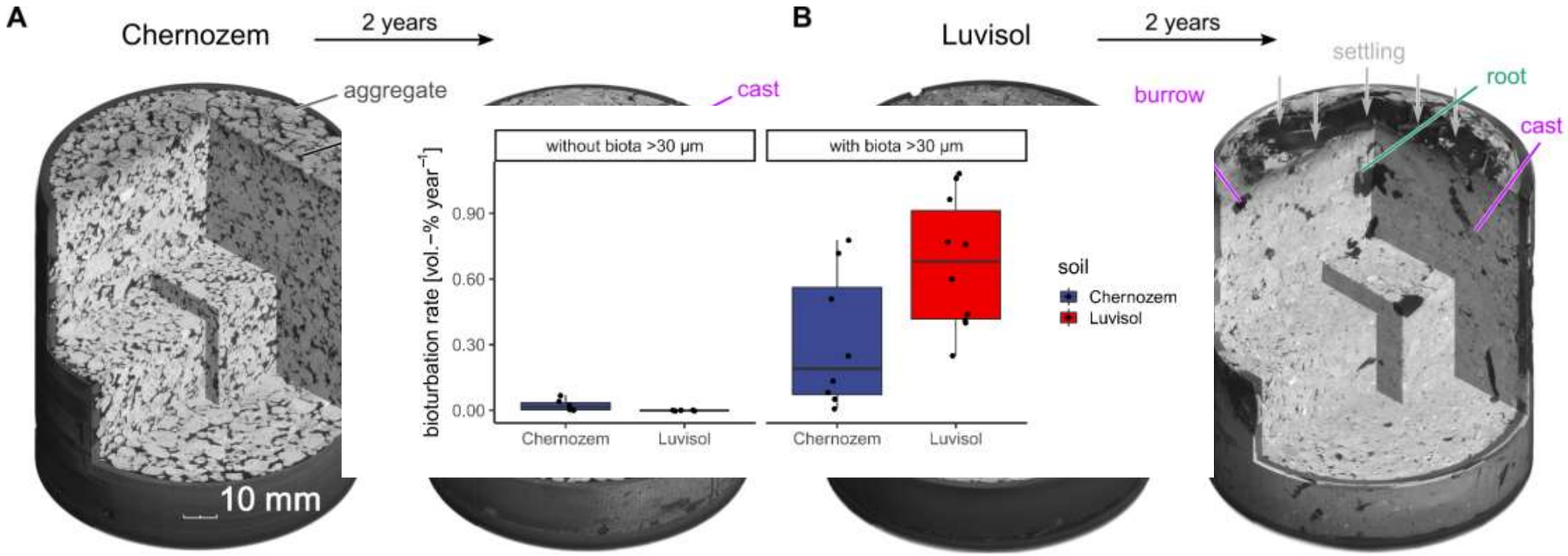




Grosse et al. (2020): Long-term field experiments in Germany: classification and spatial representation

F. Leuther et al. , Structure turnover times of grassland soils under different moisture regimes. Geoderma. 433, 116464 (2023).

Mesocosms



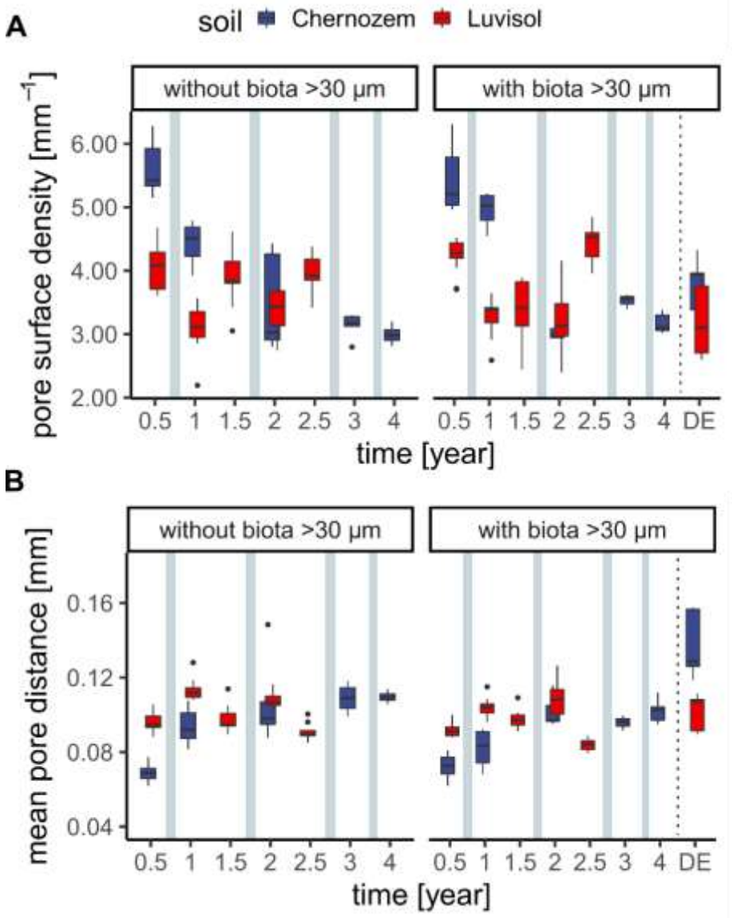
- Chernozem:

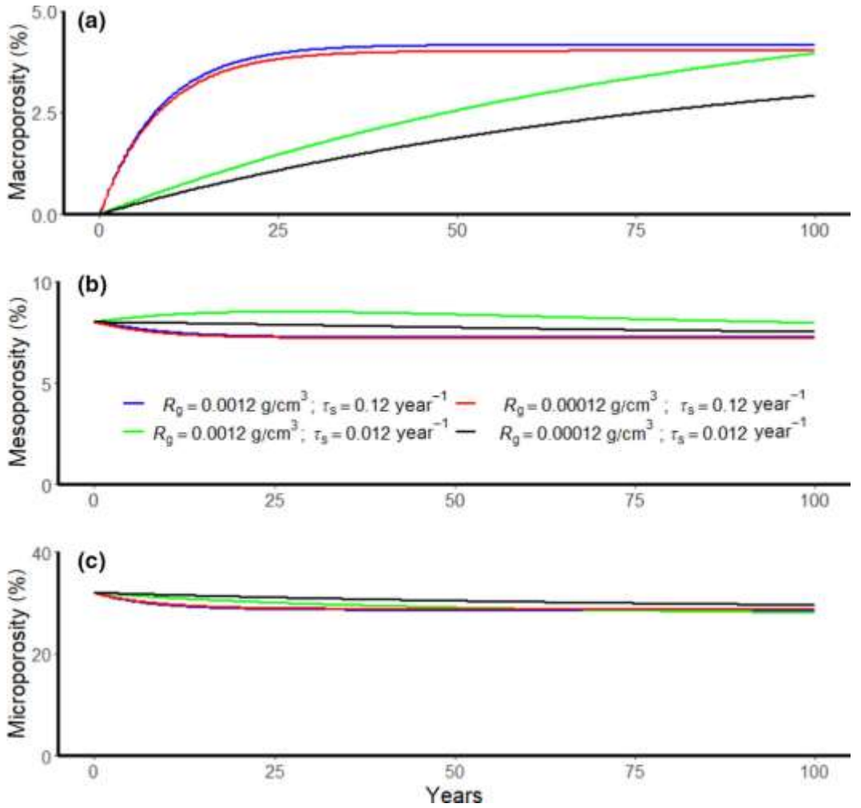
0.0032 $mm^3\ mm^{-3}\ year^{-1}$
→ turnover time 316 years

- Luvisol:

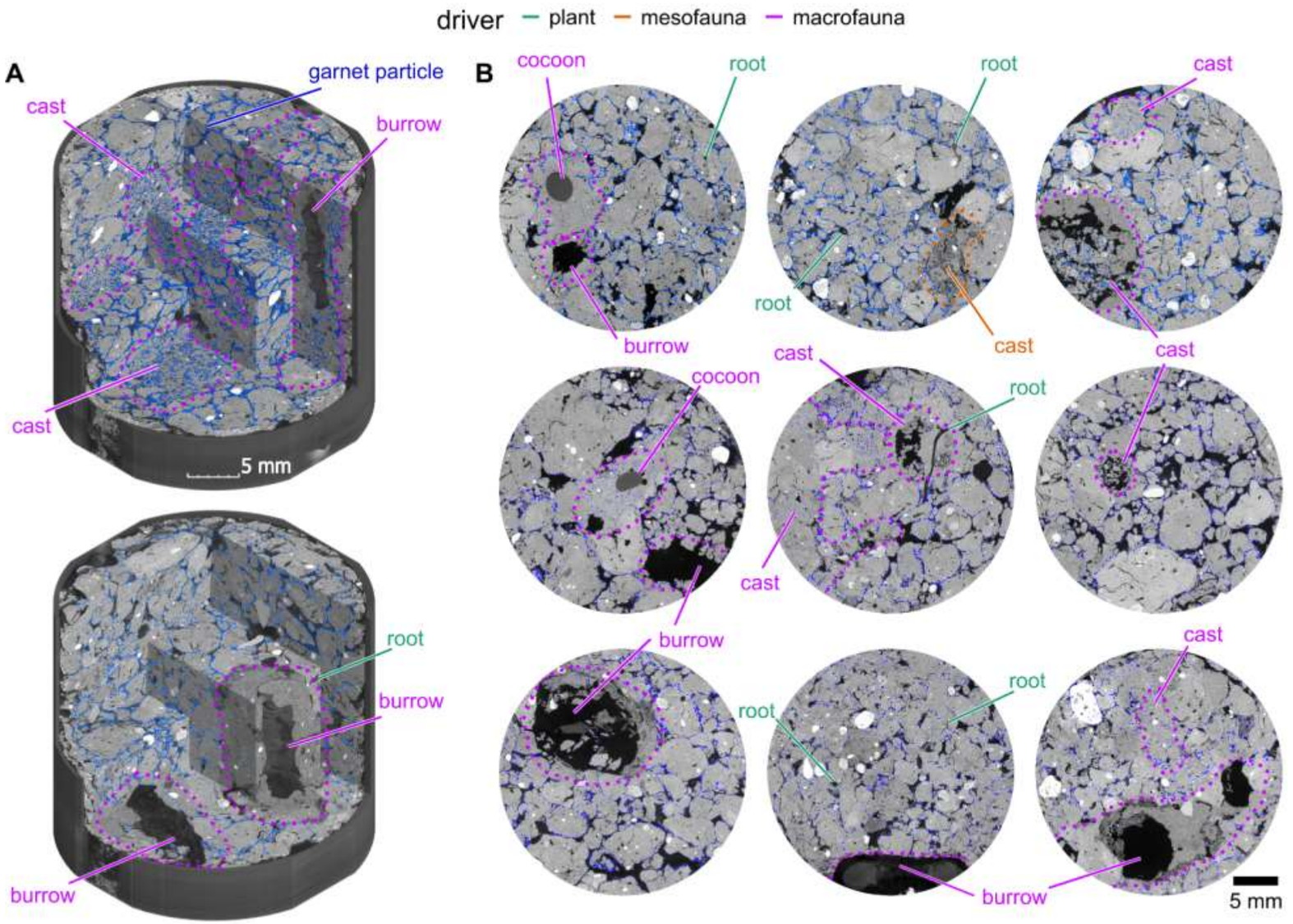
0.0067 $mm^3\ mm^{-3}\ year^{-1}$
→ turnover time 149 years

Soil structure development





Meurer et. al. *A framework for modelling soil structure dynamics induced by biological activity*. Glob. Change Biol. , **26** , 5382-5403 (2020).

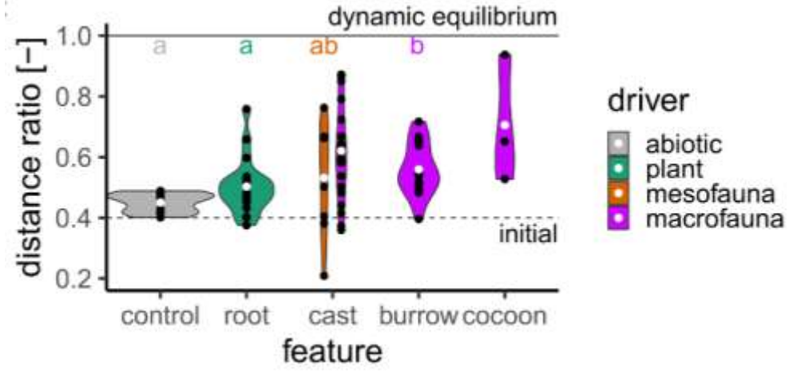


- Chernozem:

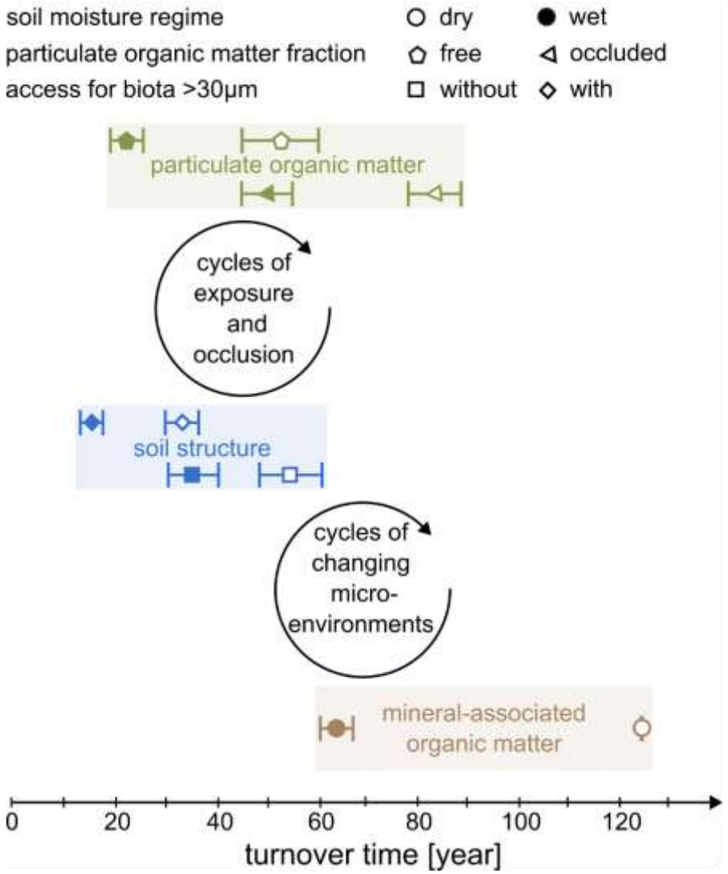
Without biota >30 µm → 54 years
With biota >30 µm → 33 years

- Luvisol:

Without biota >30 µm → 34 years
With biota >30 µm → 16 years



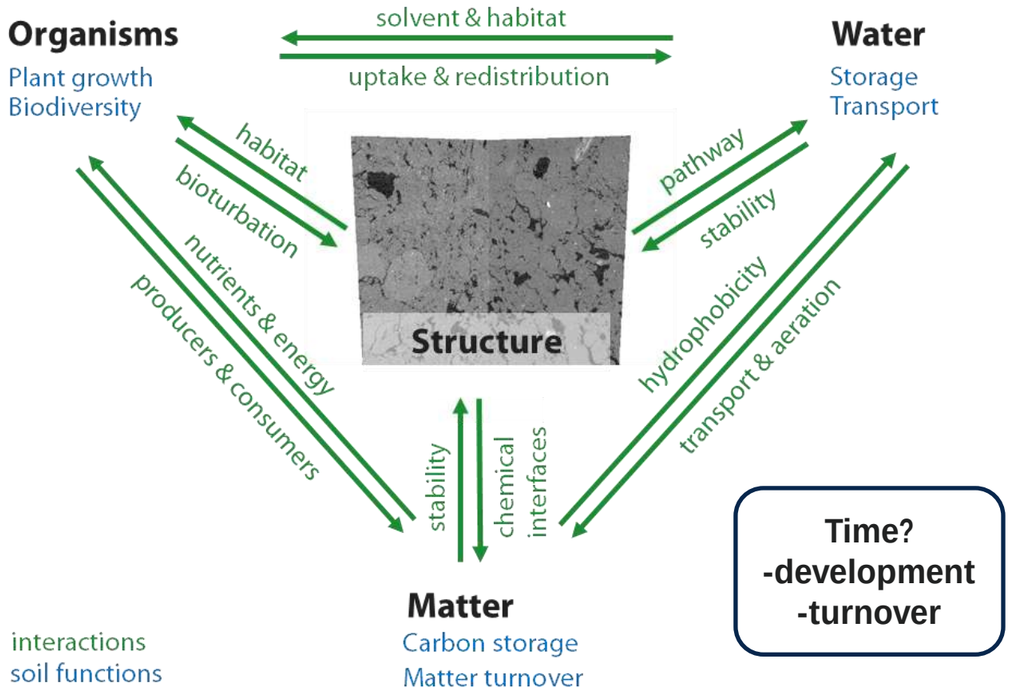
Soil structure and organic matter turnover



Conclusion

- Abiotic drivers cause seasonal fluctuations of soil structure
- Biological activity, in contrast, induced irreversible soil structure turnover
- Turnover time was 16 years under moist conditions (Luvisol) and 33 years under dry climate (Chernozem)
- Long dry spells likely reduced bioturbation in Chernozem
- Similarities in structure and POM turnover times indicate a link between soil structure evolution and physical protection of organic matter in soil

Soil structure is dynamic!



biotic drivers

- Bioturbation
- Stability: SOM, residues

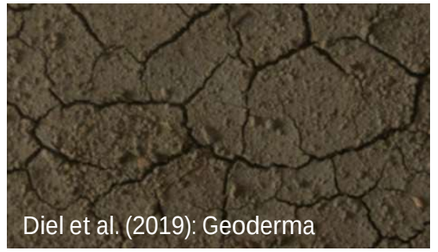

earthworm cast


earthworm burrow

abiotic drivers

- Dry/wet cycles, Freeze/thaw cycles
- Stability: cementing agents, base ions


dessication cracks


Diel et al. (2019): Geoderma

management

- Tillage, compaction
- Stability: liming, residue management


tillage


compaction

Adapted from Schlüter & Köstel, *Reference Module in Earth Systems and Environmental Sciences: Soil Structure*. Elsevier (2022).

Quantifying temporal dynamics of soil structure using X-ray CT scanning

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