Modelling dynamic interactions between soil structure and soil organic matter

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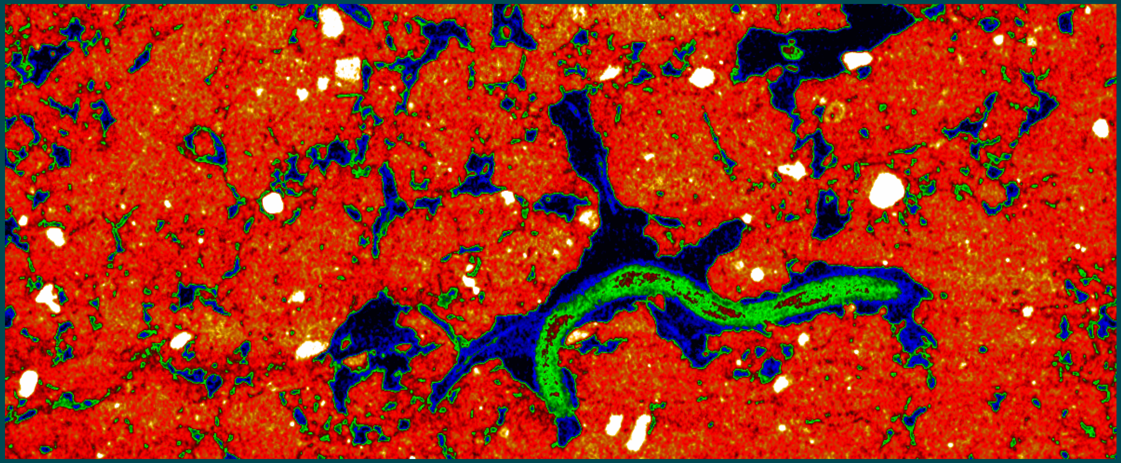


X-ray image courtesy of John Koestel (SLU, Soil and Environment)

Background

- Models of SOM turnover and storage are potentially useful tools to assess the potential for C sequestration in agricultural soils

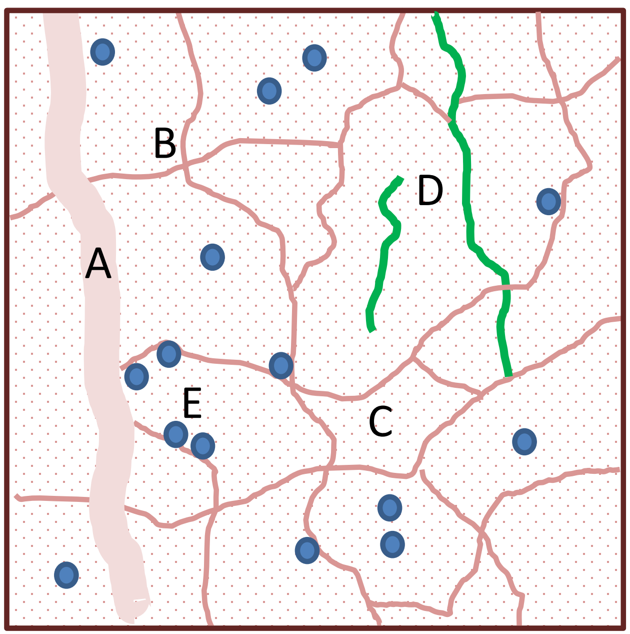
- Two-way interactions between SOM and soil structure should be explictly considered in these model approaches, because:
  - Soil structure influences SOM decomposition (”physical protection”)
  - SOM influences soil structure, soil physical properties, soil hydrological processes and, therefore, crop growth and C inputs to soil.

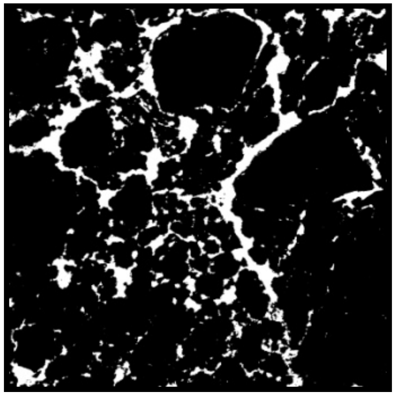
- We present here a new approach to model the dynamic interactions between soil structure and soil organic matter turnover and storage
  - More details can be found in a paper (Meurer et al., 2020) that we have recently submitted to *Biogeosciences*

Conceptual approach

- The modelling approach focuses on simple measures of soil structure, emphasizing the soil pore space
  - Soil volume (layer thickness), porosity/bulk density, pore size distribution, soil water retention curves
  - Allows straightforward links to models of soil hydrology and crop growth
- ”Aggregation” is modelled …

  ….. but **not** aggregates



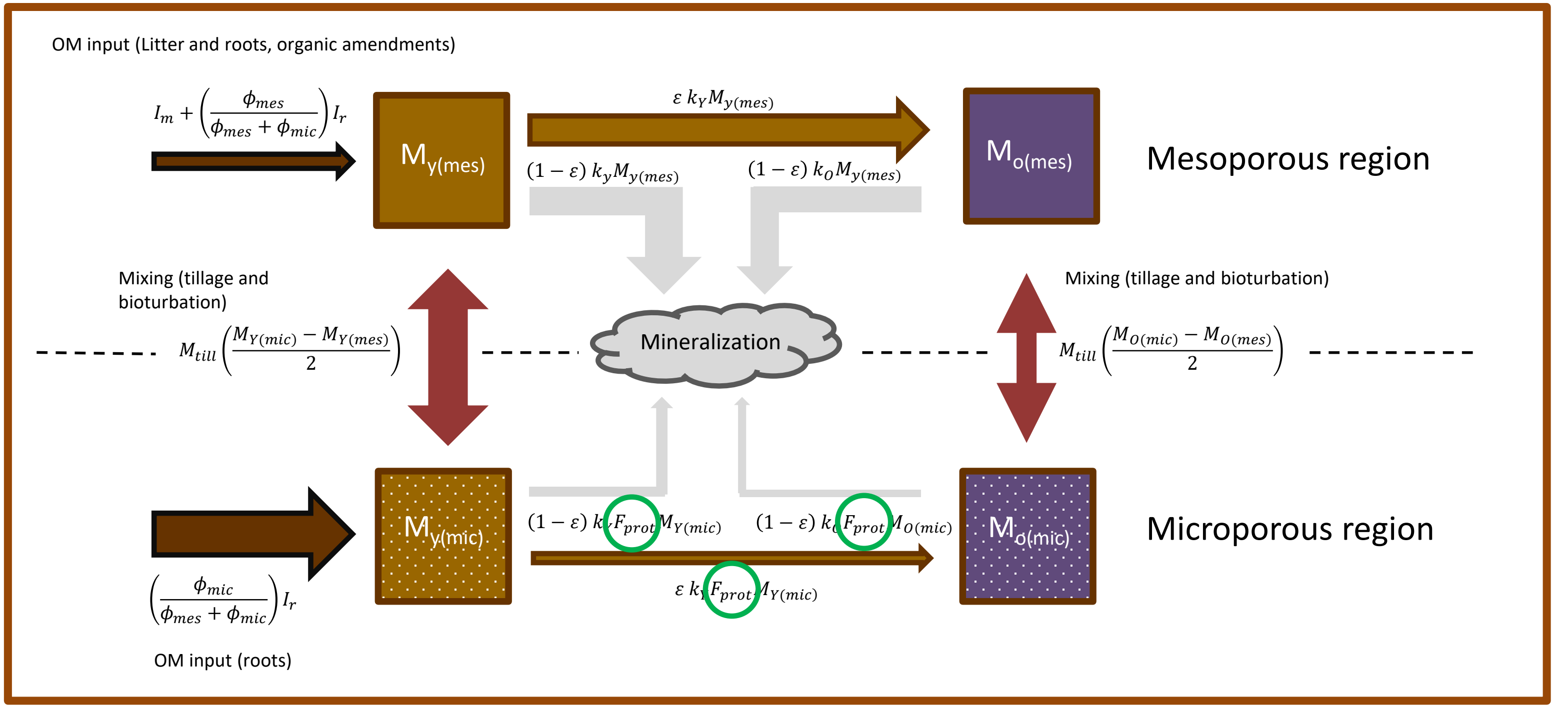


i.) the soil pore space comprises macropores (A), mesopores (thin lines, B) and micropores (dotted regions, C). In the current model version, organic matter is only stored in mesoporous and microporous soil regions.

ii.) there are two types (qualities) of organic matter: particulate organic matter (POM e.g. decaying roots; green lines, D), and microbially-processed organic matter (blue circles, E), both of which are stored either in contact only with micropores (and therefore partially protected from decomposition) or in contact with mesopores.

The influence of soil structure on SOM

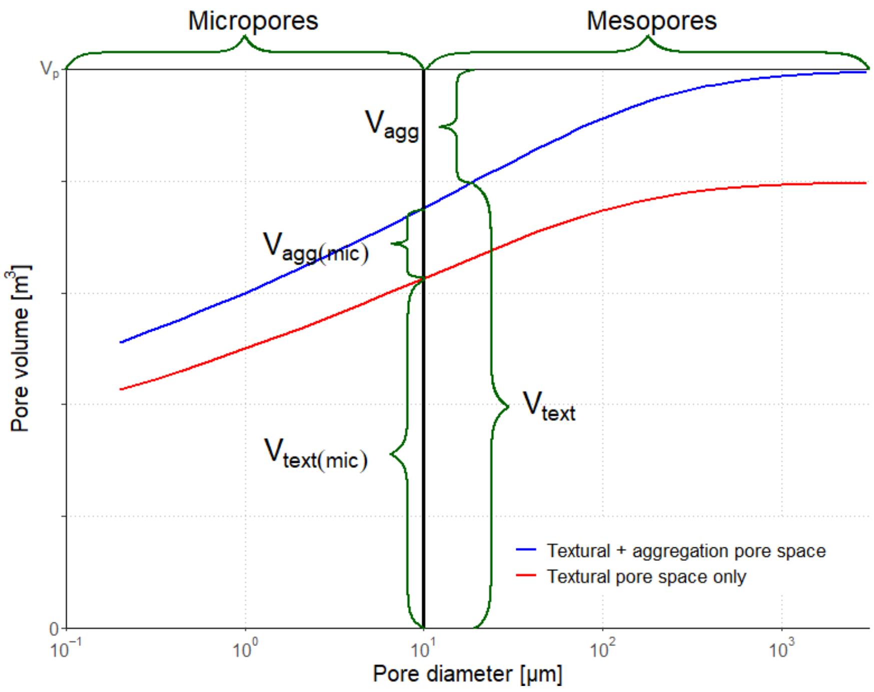
- SOM turnover is modelled with the ICBM model* extended to two pore regions
    - Decomposition rates in the micropores are reduced by a protection factor (see green circles in figure)
    - Root-derived OM is added to the two pore regions in proportion to their relative volumes; organic amendments and above-ground litter are added to the mesopore region
    - Exchange of OM between the pore regions by tillage mixing and faunal bioturbation is modelled



*Andrén, O., Kätterer, T. 1997. ICBM: the introductory carbon balance model for exploration of soil carbon balances. Ecological Applications, 7, 1226-1236.

The influence of SOM on soil structure

- Changes in SOM stocks in the two pore regions alter the volume of aggregation pore space, and thus soil volume, porosity, pore size distribution and water retention



- The total soil pore volume comprises a constant volume of textural pores V_{text} and an aggregation pore volume, V_{agg}, which is assumed to be a linear function of the volume of organic matter*
- The textural porosity is partitioned between the micropores and mesopores as a function of the particle size distribution

*Emerson, W., McGarry, D. 2003. Australian J. Soil Res., 41, 107-118
Boivin, P., et al. 2009. European J. Soil Sci., 60, 265-275
Johannes A., et al. 2017. Geoderma, 302, 14-21.

The model has been tested against data taken from the ongoing Ultuna long-term ”frame” trial (RAM-56), which started in 1956

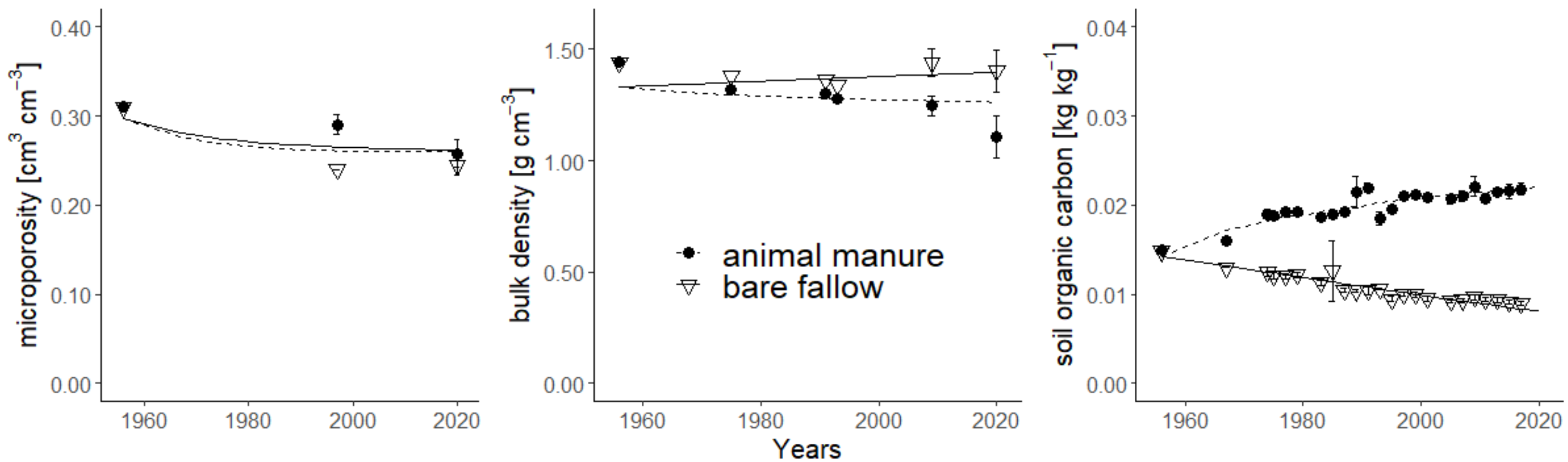
RAM-56 Organic matter trial

Data taken from two treatments (bare fallow and animal manure)

- Organic carbon every second year
- Bulk density on seven occasions
- Soil surface elevation (once, in 2009)
- Soil water retention on three occasions

Results

- After simultaneous calibration of four parameters, the model could accurately match the measurements in both treatments during the experiment



Observed (symbols; bars show standard deviations) and simulated (lines) microporosity, bulk density and soil organic carbon concentration for the fallow and animal manure treatments.

<u>Data from:</u>

Kirchmann, H. et al., 1994. Dept. Soil Sciences, Reports and Dissertations 17, Swedish University of Agricultural Sciences, Uppsala, Sweden.

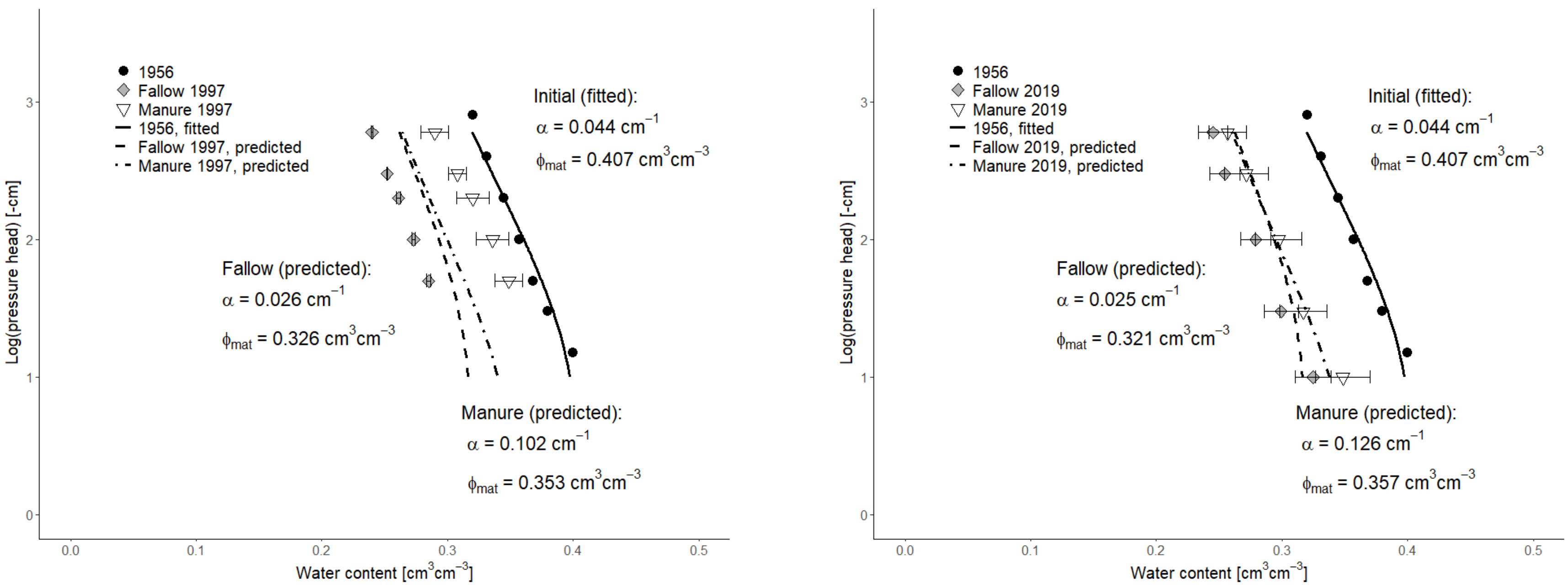
Gerzabek, M., et al., 1997. European Journal of Soil Science, 48, 273-282.

Kirchmann, H., Gerzabek, M. 1999. Journal of Plant Nutrition and Soil Science, 162, 493-498.

Kätterer, T., et al., 2011. Agriculture, Ecosystems and Environment, 141, 184-192.

Results

- The model accurately predicted the water retention curves measured in both treatments in 2019 (right-hand figure) ….
- … but failed to do so for the data measured in 1997: is this a sign of model error or just spatial variability? (only 4 replicates were measured)



Observed (symbols; bars show standard deviations) and simulated (dashed and dotted lines) soil water retention curves in the fallow and animal manure treatments. The measurements used as the initial condition in 1956 are also shown, together with a fitted curve. Van Genuchten's *n* was fixed at 1.073 for all water retention curves.

Conclusions and outlook

- This approach to modelling the interactions between SOM storage and turnover and soil structure seems promising
    - Based on soil pore space properties rather than ”aggregates”, which allows straightforward coupling to soil hydrology and plant growth modules in soil-crop models
    - Potentially useful tool to investigate the role of tillage and bioturbation for C sequestration
    - The results of a sensitivity and uncertainty analysis are presented in Meurer et al. (*Biogeosciences*, submitted)
- Some processes relevant to C sequestration are still missing
    - Carbon saturation (chemical stabilization)