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UFZ HELMHOLTZ Centre for Environmental Research

Accounting for microbial dynamics to simulate soil functions under agricultural management

Session SSS5.3; Thu 26 May 16:23-16:30

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Content of this display:

- identification of biological processes relevant for modelling soil functions
- example on how to integrate microbial activity within our systemic soil model BODIUM (see also Session SSS10.1)
- a comparison with a classical approache on modeling SOM turnover
- a discussion on general challenges and ongoing developments

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Navigation

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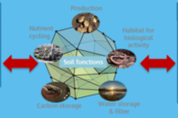
Introduction

changing climate

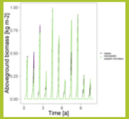
- increasing temperature
- less precipitation
- extreme events
- ...

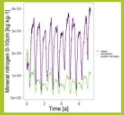


soil management

- crop rotation
- fertilizing
- tillage
- plant protection
- irrigation
- ...

Example





Simulation model

Discussion

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Modeling of soil functions in agricultural systems

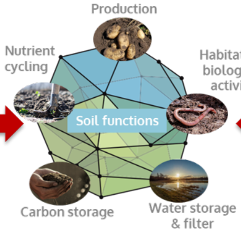
We aim to predict the 5 **soil functions**

1. Production
2. Habitat for biological activity
3. Water storage & filter
4. Carbon storage
5. Nutrient cycling

and the dynamic effects of **soil management** and **climate change**.

changing climate

- increasing temperature
- less precipitation
- extreme events
- …

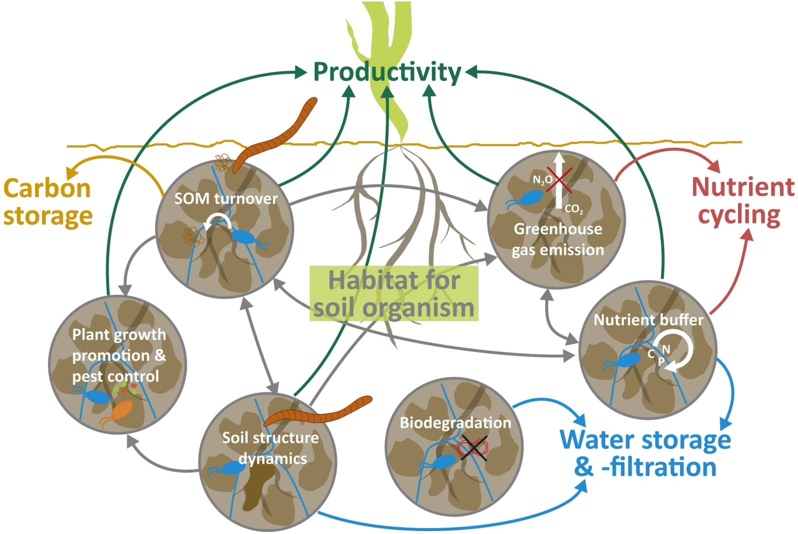


soil management

- crop rotation
- fertilizing
- tillage
- plant protection
- irrigation
- …

For doing so, we develop a systemic soil model based on **data from long-term field** and other experiments, **process knowledge** received from available sources (e.g. literature) and by learning from the **discrepancy between observations and predictions**.

Biological processes in soil models



One major challenge is the representation of **biological processes** in soil models.

Here, we identified the main biological processes driving the soil functions we are interested in.

The main task for integrating these processes into soil models is to transfer the process knowledge between different spatial and temporal scales.

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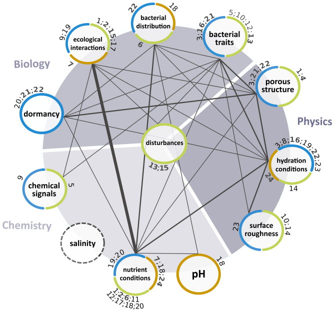
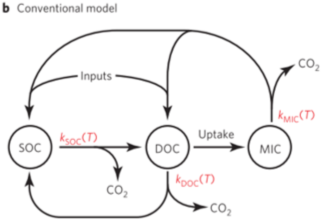
Different scales for modelling microbial activity

Microbial models at the **microscale**:

- high level of detail - very specific
- local heterogeneity in conditions
- specific species
- explicit microbial processes (growth, dispersal,...)
- less consideration of feedbacks
- usually parameterized with lab experiments

Review on **spatially explicit** microbial soil models at the microscale: KÃ¶nig, et al., **2020**, *Front.Ecol.Evol*





Allison, et al., **2010**, *NatGeoSci*

Microbial representation at **profile / landscape scale**:

- simplified assumption - generalizable
- pool concept with implicit microbial activity within rate parameters
- rather homogeneous conditions (for microbes)
- no interactions
- usually parameterized by fits of time series data

Scale transfer in soil science

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Macro-scale phenomena are often driven by **micro-scale processes**, thus, a scale transfer is needed to unterstand and predict those phenomena.

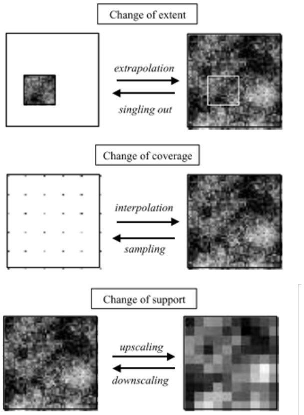
In soil science, this is especially challenging as soil is highly **heterogeneous and dynamic**, and many processes are interrelated and **feedback** to each other.

The appropriate scaling method depends on the specific research problem.

For mechanistic models, we need to **upscale process understanding** rather than measured parameter rates.

In the following, we present a concept of integrating small-scale mechanisms of microbial physiology to our profile-scale systemic soil model BODIUM.

Bierkens, et al., **2000**: Upscaling and Downscaling Methods for Environmental Research



Our model: BODIUM

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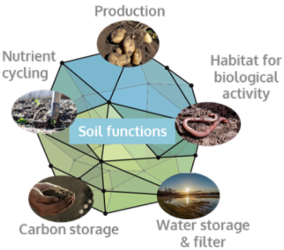
Aim:
To understand and predict the long-term effect of **management** and climate change on **soil functions**



- operates on 1D profile scale
- consisting of list of **nodes** with
- dynamic volume and mass depending on dynamics of
- different components (see next slide)
- communication between nodes
- daily timesteps with higher resolution in specific cases (e.g. rainfall events)

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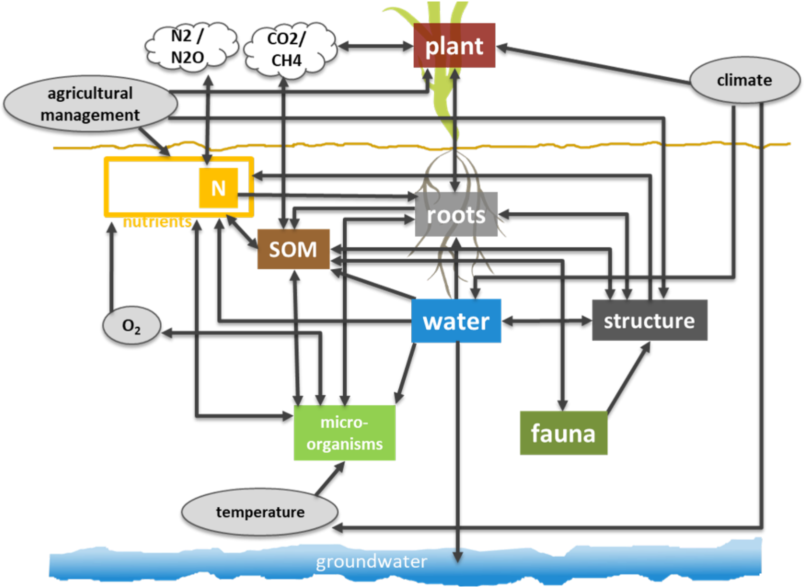
Current version

The current model version involves the components water, SOM & microorganisms, nitrogen, structure, fauna (earthworms), and a plant growth module.

Note that plant and groundwater are not part of the soil nodes, but connected to the top and bottom node, respectively.

See also display vPico 11129 for more information on the BODIUM model.



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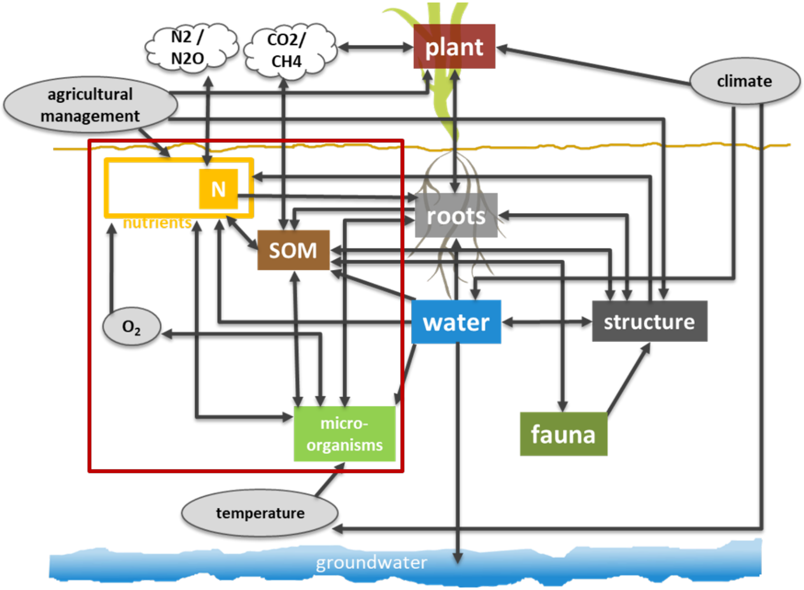
On the next slides, we focus on the components involving **SOM turnover** and **nitrogen cycle**.



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SOM modeling: traditional pool approach

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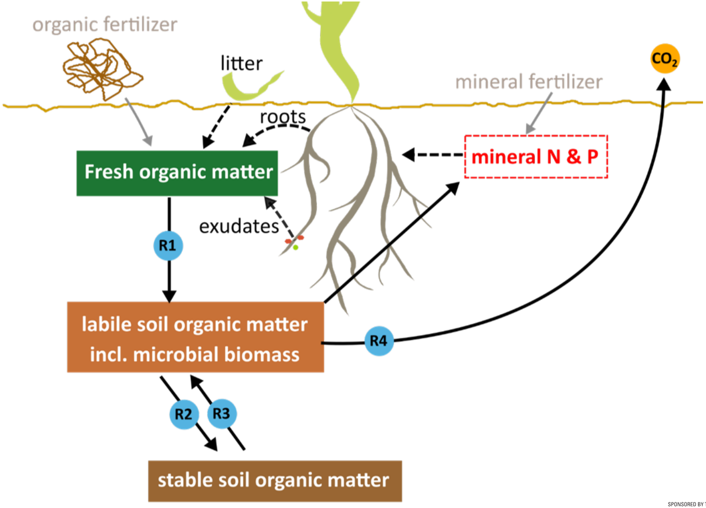
The classic approach usually consists of 3 or more pools of organic matter (OM), the turnover based on fixed maximum rate parameters with the actual dependent on temperature and water content.

This simplified description showed good results in many studies to predict stabilized carbon on well-known field sites.

However, a **thorough fitting** of the rate parameters is needed. The approach is less suitable if this is not possible, and can also not capture a dynamic response to environmental changes.

For providing this, a **mechanistic approach** is necessary.



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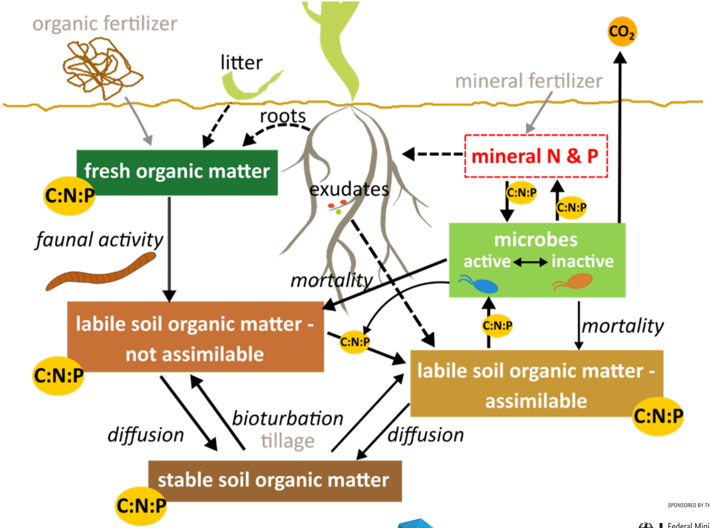
SOM modeling: including explicit microbial activity

Our mechanistic approach includes explicit nutrient-limited **microbial growth** and **stoichiometric** dependencies.

We distributed the labile pool into a microbial pool, a labile OM pool which is assimilable, and a labile OM pool which is not assimilable.

Each pool, except for the microbial pool, has a **flexible C:N:P ratio** and the imbalance to the static microbial C:N:P ratio dedicates mineralization, immobilization, and respiration rates.

The microbial pool is further distinguished into active and inactive microbes, the change of status depends on environmental conditions.



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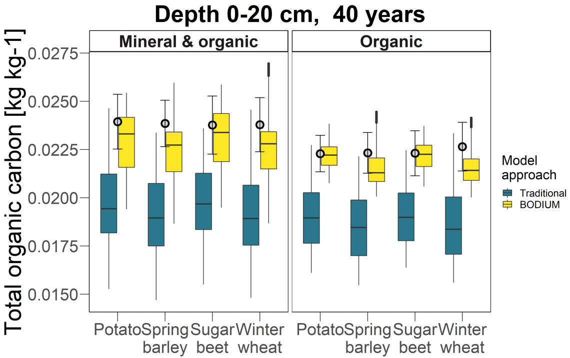
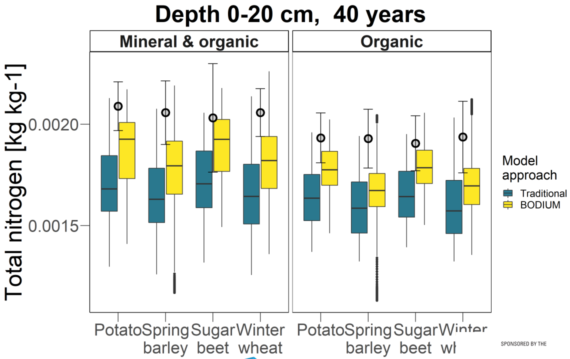
Comparison: traditional vs. mechanistic/BODIUM

To **explore the potential** of the mechanistic approach, we simulated 40 years of two different treatments of the static fertilization experiment in Bad Lauchstädt (Germany) with both approaches and compared the outcome (bars) with observed data (points) - for total organic carbon and nitrogen on this slide. Note that 4 experimental plots with asynchronous crop rotation are simulated such that each crop growths every year on a different plot.

Generally, BODIUM performed better although nitrogen is still underestimated.





What about other soil functions?

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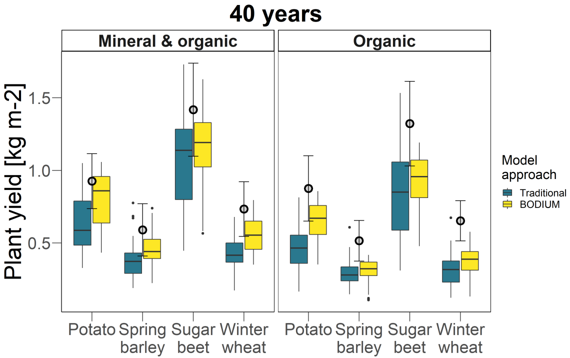
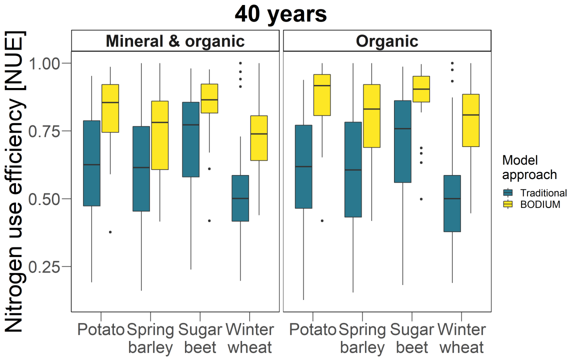
The simulated plant yield of BODIUM fits the observed data better as well. The nitrogen use efficiency (describing the ratio between nitrogen used by plants and nitrogen leached to groundwater) is higher in the BODIUM simulations, because the **nitrogen buffer** ability of microbes is depicted with this approach. Further, it may indicate overestimation of nitrate leachate in traditional approaches, with implications for soil water quality modeling.





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Soil structure effects

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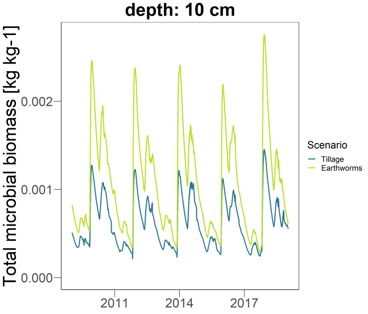
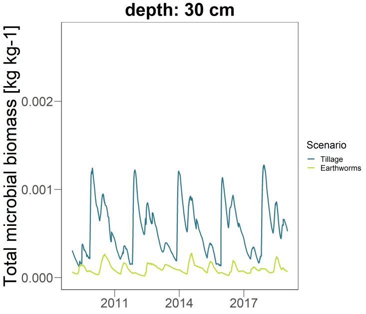
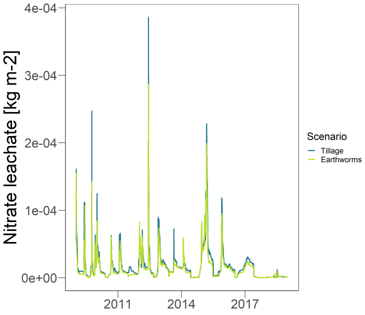
Another feature of BODIUM is the simulation of dynamic soil structure. Here, we compared a scenario with tillage events (biopore destruction, mixing, aeration) with a scenario without tillage but earthworms (biopore increase, no mixing).

The effects on the microbial biomass is highly depth dependent, mainly due to differences in carbon distribution and aeration.

Although the yield in both simulations is quite similar (not shown), in the tillage scenario more nitrate is leaching to the groundwater.







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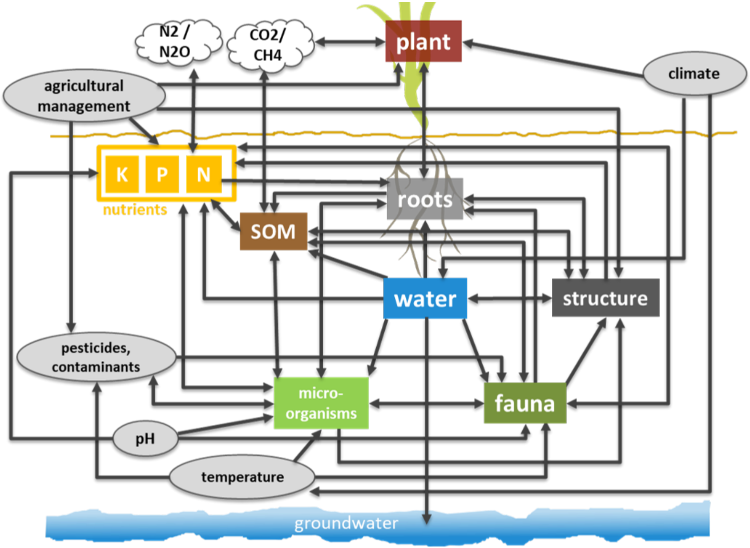
Future extensions

Several extensions of the model are in development or planned for the future.
Regarding biological processes, this includes:

- P availability and mobility
- dynamic F:B ratio
- Impact of tillage and compaction (e.g. on biological habitats)
- catch crops
- bioturbation
- faunal feedback with fertilization
- fauna-microbe interactions
- potential for degradation of organic compounds
- microbial biodiversity



A lot of questions...

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- How to integrate a dynamic F:B ratio resulting in a flexible microbial C:N ratio?
- What if P enters the game?
- How to represent functional diversity?
- How to define habitat quality in terms of different pore sizes?
- What microbes-fauna interactions need to be implemented?
- What about other microbial functions relevant for agriculture? (Pest control, pesticide degradation,. . .)

A lot of questions…

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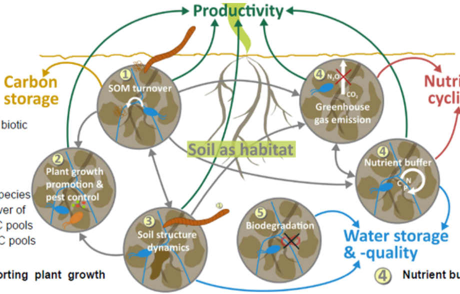

① SOM turnover

- respiration and mineralization
- transfer rates between biotic and abiotic C pools
- C stabilization

? specific food-webs
? functional groups vs. species
? faunal effects on turnover of and transfer between C pools
? quantification of biotic C pools

② Biodiversity supporting plant growth & pest control

- suppression of pathogens as function of biodiversity
- plant growth promotion

? plant-specific microbiome vs. crop rotation
? taxonomic vs. functional diversity
? quantification of functional diversity
? effect of extreme conditions in arable fields on soil organisms
? 'Good guys' vs. 'Bad guys'
? relationship between biodiversity and plant growth promotion
? impact of land use on biodiversity

③ Soil structure dynamics

- macropore generation by roots and fauna
- root growth dynamics
- bioturbation
- swelling and shrinking
- land use (tillage, compaction)

? different faunal life forms (endogeic, anecic)
? definition of habitat quality for microorganisms
? structure stabilization by enchytreids and/or fungi
? faunal effects on distribution of smaller organisms

⑤ Biodegradation

- residence time of pollutants in topsoil
- degradation activity of microorganisms

? specialists for specific pollutants
? efficiency in presence of easier degradable C-sources
? toxic effects of pollutants

④ Nutrient buffer & GHG emissons

- mineralization and denitrification
- temporal nutrient storage in microbial biomass
- nitrogen fixation by legumes
- supply and reversible sorption of cations (K, Mg) and P
- oxygen dynamics (anaerobic balloon)
- leaching of nutrients

? flexible microbial C/N ratios
? fauna as regulator of mineralization
? mycorrhiza and saprophytic fungi
? reduction of nitrate to N_2
? N fixation by free-living bacteria and fungi

Assessing all the soil

functions driven by biological processes is a huge challenge, which needs the whole **soil science community** to work together and integrate experimental and theoretical research.

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Thanks for your interest!

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