Towards more accurate and more useful models of soil organic carbon

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Biochar application and enhanced weathering for increasing soil carbon storage: the story never ends?
Antwerp, November 14th 2024

Take-home message:

Despite >30 years of soil carbon models

➔ none can accurately project future changes

1980ties knowledge …

- Soil organic matter is formed from plant residues

- In soils: decay products condense into macromolecules (humic acids, fulvic acids) ➔ very stable compounds = humification

- Lignin content (and other recalcitrant molecules e.g. tannins) controls plant residue decomposition rate

- Clay soils are richer in soil carbon ➔ clays stabilize soil organic matter

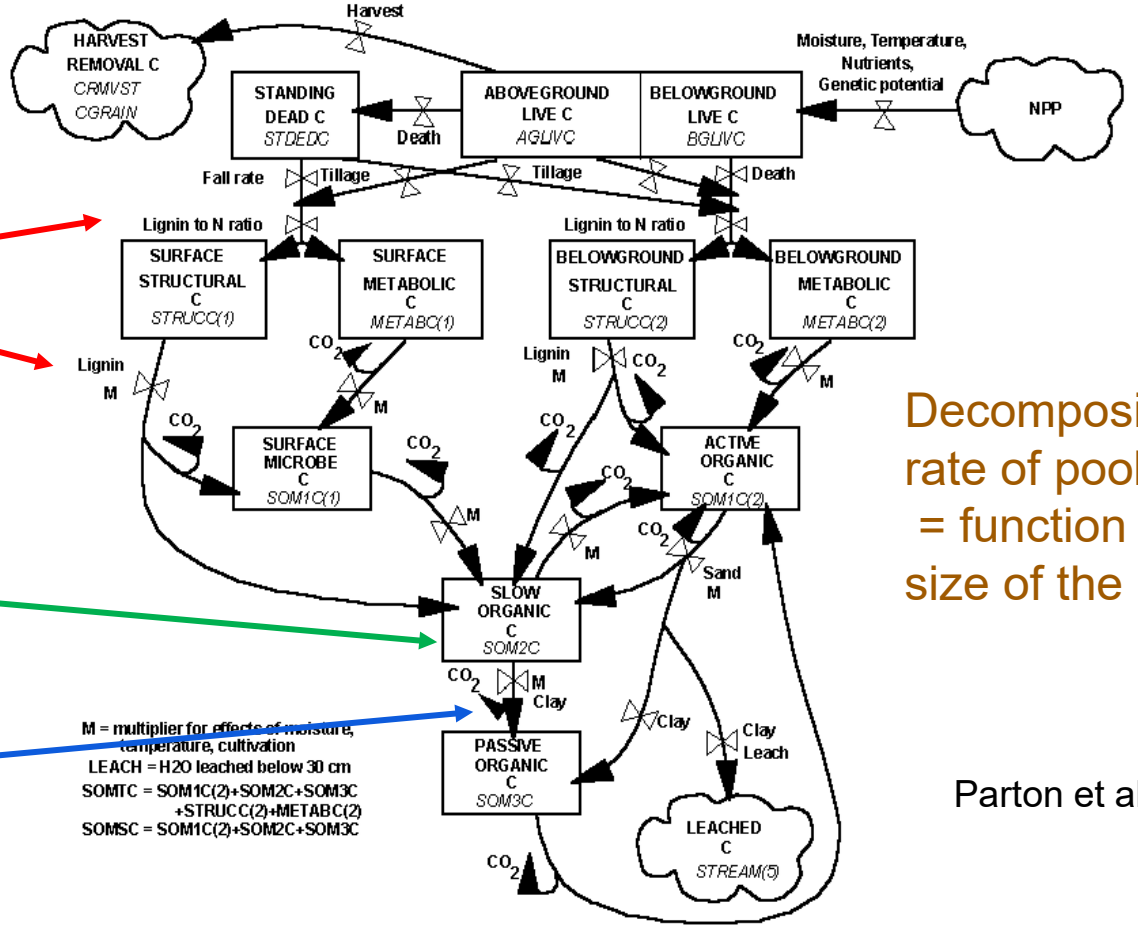
1980ties knowledge ➔ 1st generation models: Roth-C & Century

Knowledge:

Decomposition rate depends on lignin content

Humification forms stable compounds

Clays stabilize soil carbon

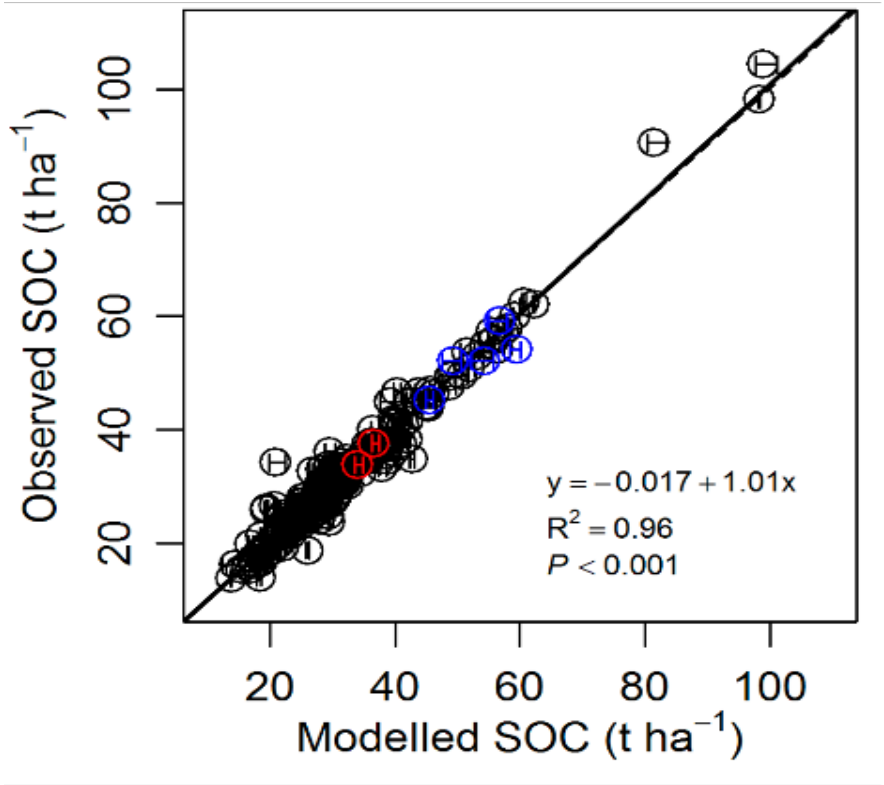


Decomposition rate of pools = function of size of the box

Parton et al. 1993

Models work well:

Optimized model parameters across 90 experiments:



Luo et al. *Biogeosciences*, 2015.

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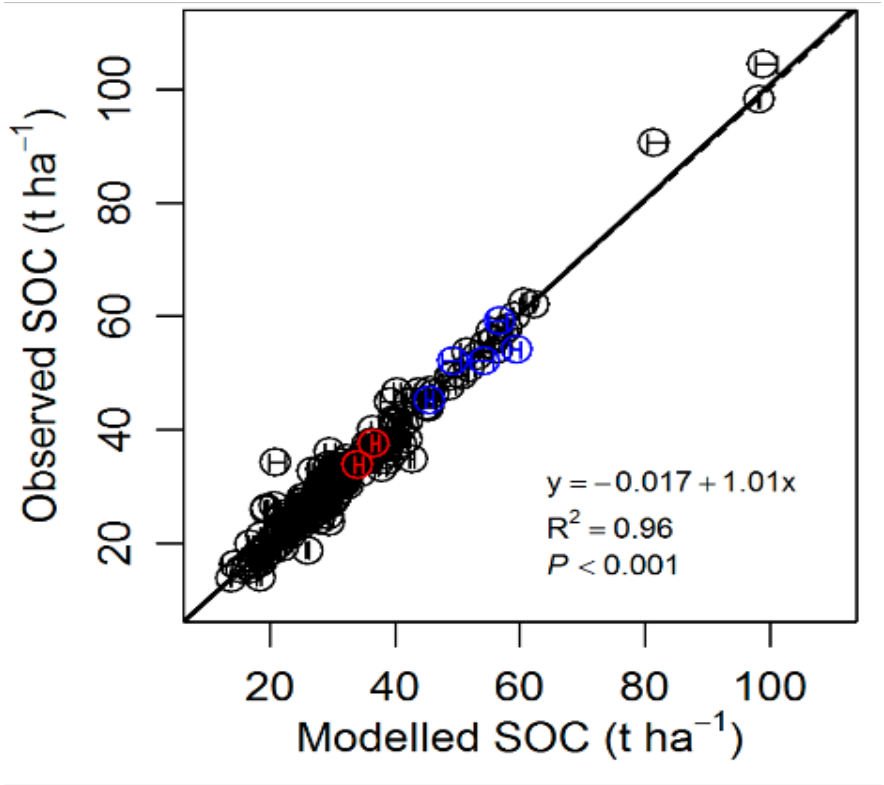


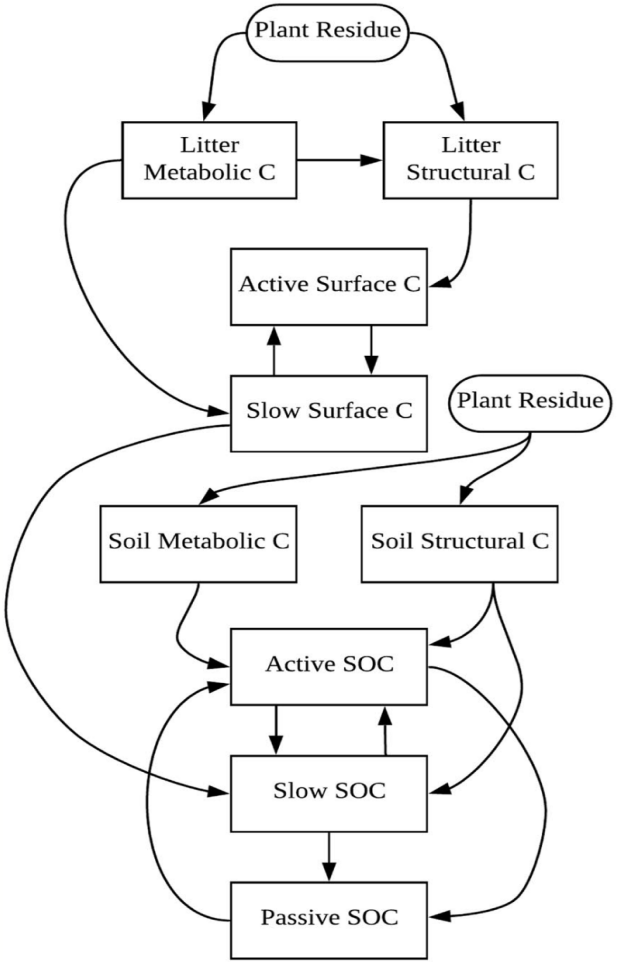
Luo et al. *Biogeosciences*, 2015.

- Model = great when parameters are ‘optimized’ per site

➔ logical with so many parameters to play with and only total soil carbon as test data

- 1st Problem = ‘virtual pools’

➔ pool sizes and parameters of flux equations are impossible to measure



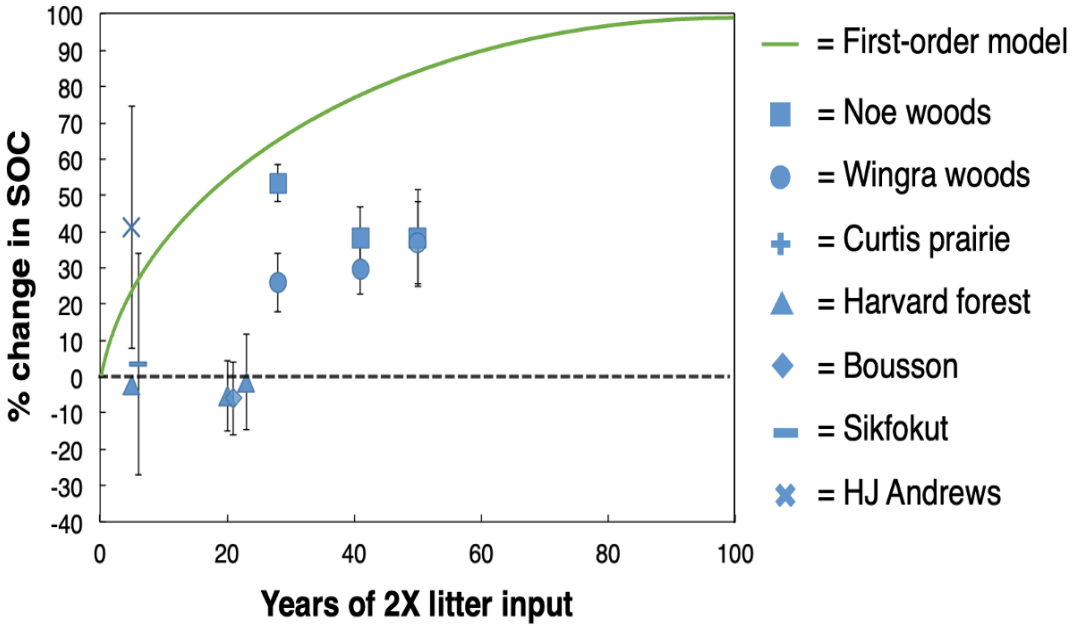
Berardi et al. *GCB Bioenergy*, 2020.

Models fail

when not fitted to data

or when growth conditons / plant inputs change

Litter manipulation experiments:



Lajtha et al. *Biogeochemistry*, 2014

Georgiou et al. *Nature Comms*, 2017.

Second problem: new knowledge ➔ basic assumptions are wrong!

1. Humic substances do not exist (artifacts)
   - ➔ we don’t need unmeasurable active, slow, passive pools
   - ➔ we need measurable pools

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   - ➔ we need measurable pools

2. Soil organic matter = mainly microbial, not plant-derived;

\+ Lignin decomposes as fast as other molecules (in soils)

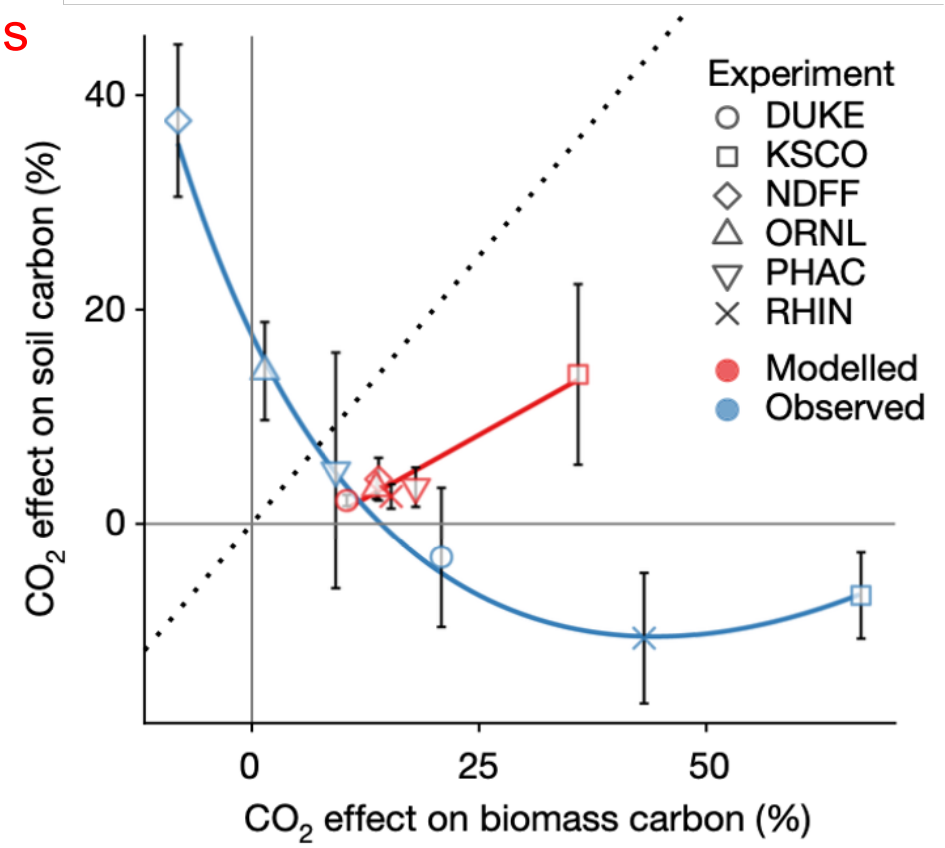
- model needs a microbial engine
- degradability of molecules is irrelevant (except biochar)
- other stabilization mechanisms: minerals, physical protection

3rd problem:

model lacks plant-microbe interactions

Increased plant inputs can *reduce* soil organic matter ('priming' and nutrient mining)

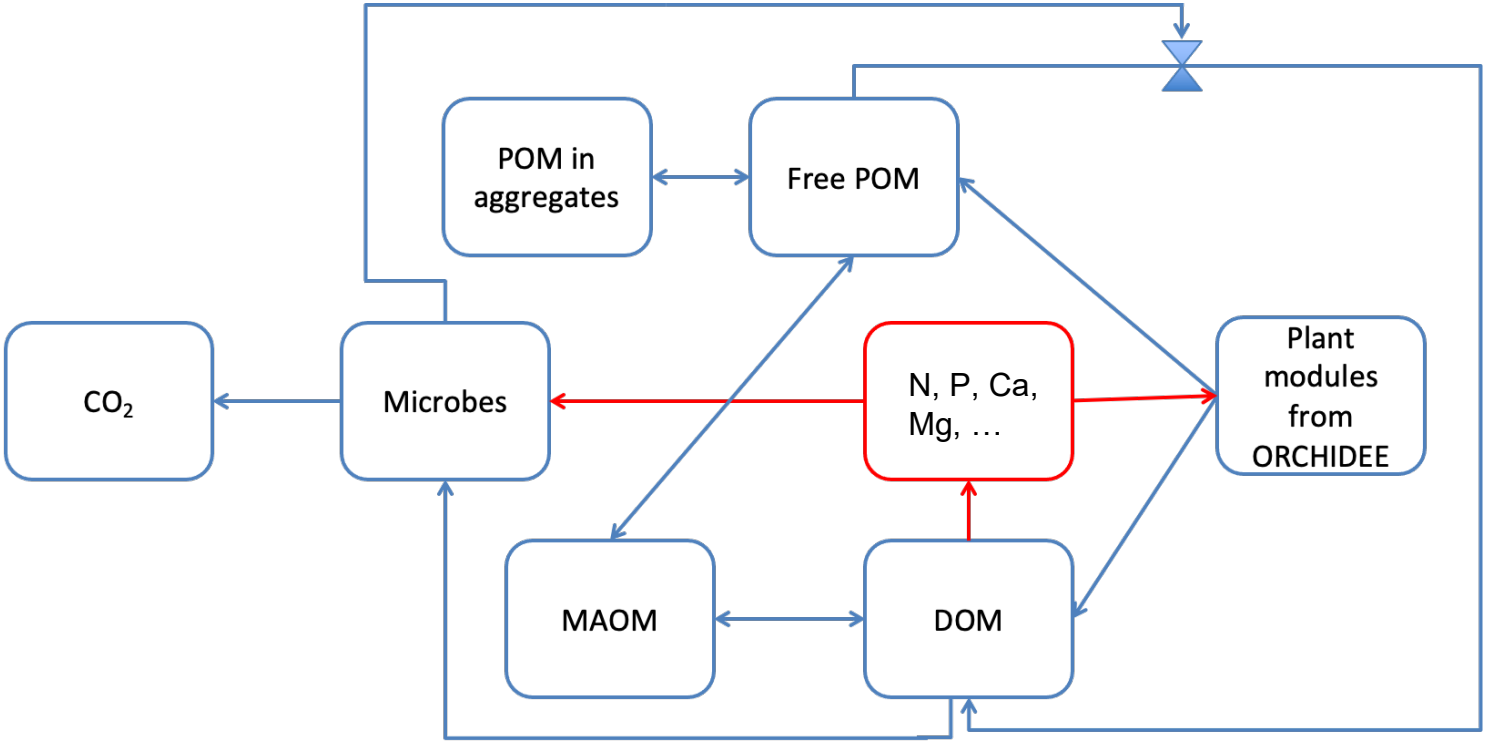
➔ models need nutrient cycles and plant-microbe interactions



Terrer et al. *Nature*, 2021.

New generation soil carbon models (MEMS; Millenial-2)

New structure ➔ measurable pools; microbes; nutrients



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New knowledge included: protection inside aggregates; microbes as engines of long-term stabilization; …

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Models have improved a lot, but major shortcomings remain

➔ Models not suited for carbon (regenerative farming), biochar amendment, enhanced weathering, …

New generation soil carbon models: What is lacking?

1. Dynamic modelling of soil structural changes: aggregate turnover and feedbacks to plant & microbial activity (water, oxygen, erosion) (needed for carbon farming & biochar)

2. Dynamic geochemistry: interactions with soil organic matter, pH, base cations (needed for enhanced weathering)

3. Dynamic nutrient retention & exchange capacity (needed for biochar, carbon farming, enhanced weathering)

Take-home message:

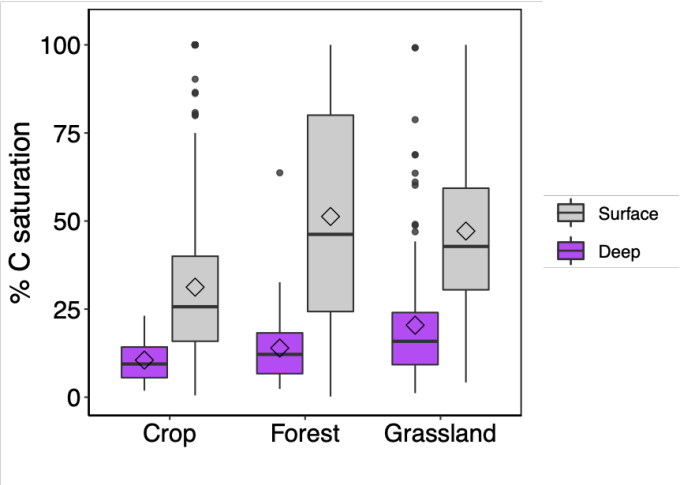
Despite >30 years of soil carbon models

➔ none can accurately project future changes

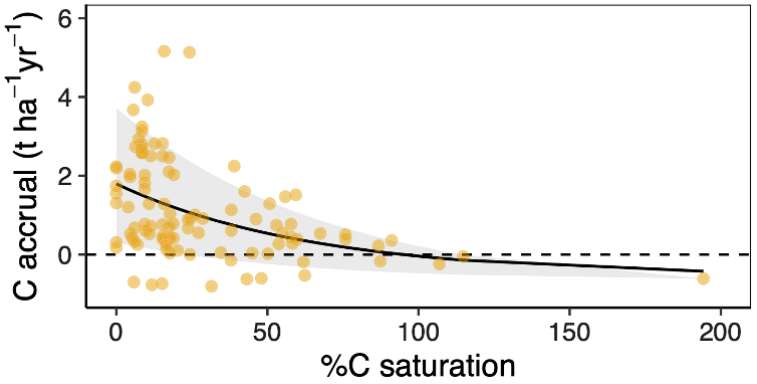
(but we're getting closer)

Implicit representations lack ability to model carbon saturation

Geochemical controls and carbon saturation must be explicitly represented in models to capture select soil carbon responses.



Agricultural lands and **deeper soil layers** are furthest from saturation.



Soils further from saturation may achieve **higher accrual rates**.

Georgiou et al. *Nature Comms*, 2022.