A general framework for modelling the vertical organic matter profile in mineral and organic soils

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INTRODUCTION

Vertically explicit soil organic matter (SOM) models describe SOM concentration as a function of depth by means of a diffusion-advection-reaction equation. An important assumption behind these models is that the volume of soil elements is constant over time, i.e. not affected by SOM dynamics, an assumption which is in general invalid. With increasing SOM content, SOM dynamics have stronger effects on the total volume of soil elements, both due to the volume of the organic matter itself and because of associated bulk density changes. The volume changes have several important consequences for modelling the SOM profile: 1) Input or loss of SOM does not translate directly to changes in SOM concentration; 2) The concentration of one SOM pool is influenced by the dynamics of others; 3) Vertical shifts occur with respect to a fixed reference frame.

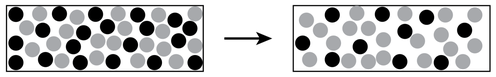
We present a mathematical framework to account for these volume changes in a vertically explicit SOM model. This approach is more realistic and allows SOM profile models to be extended to the surface organic layer.

HOMOGENEOUS SOIL LAYER WITHOUT TRANSPORT

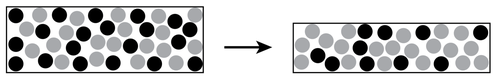
How do SOM dynamics affect volume of soil elements?

Below a hypothetical soil layer consisting of 50% minerals (gray) and 50% SOM (black). The figures illustrates the effects of removal of half of the SOM (e.g. due to decomposition) under three assumptions regarding total volume.

Constant total volume. Bulk density decreases with SOM concentration.



Constant bulk density Total volume decreases due to loss of organic matter



Variable bulk density & variable total volume. Total volume decreases due to loss of organic matter and bulk density increase

Differential equation for SOM concentration

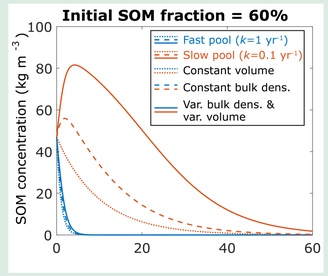
$$\frac{dc_i}{dt} = \rho_b \gamma_i$$

$$\frac{dc_i}{dt} = \rho_b \gamma_i - c_i \sum_{i=1}^{N} \gamma_i$$

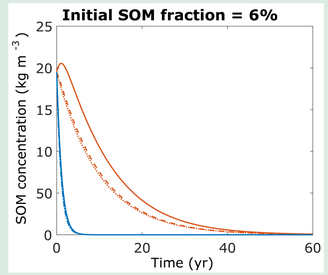
$$\frac{dc_i}{dt} = \rho_b\, \gamma_i - c_i \left(\sum_{i=1}^{N} \gamma_i - \frac{1}{\rho_b} \frac{d\rho_b}{dt} \right)$$

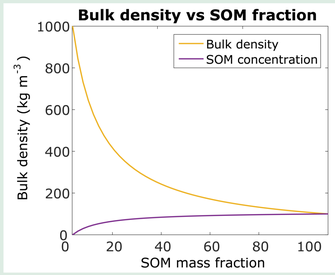
c_i: concentration of pool i
γ_i: relative mass change of pool i
ρ_b: bulk density
t: time
N: no of SOM pools

How do volume changes affect SOM concentration dynamics?



Left: concentration vs time for a hypothetical mixture of two SOM pools decaying according to first order kinetics. The assumption regarding volume changes has strong effects depending on the initial concentration of the pools. Bulk density is modeled as a function of total SOM fraction (below).





FULL SOM PROFILE WITH TRANSPORT

Vertical migration due to volume changes

To account of vertical shifts we introduce the *particle flux* ω: a flow field equal to the volume change integrated over the profile.

Root input & decomposition

$$\omega_{dM}(z) = \int_0^z \sum_{i=1}^{N} \gamma_i \, dz'$$

Total particle flux

$$\boldsymbol{\omega = \omega_{d\Delta M} + \omega_{BD} + \omega_{AGL}}$$

Litter deposition

$$\omega_{AGL} = \sum_{i=1}^{N} \frac{I_i^{AGL}}{\rho_b^{AGL}}$$

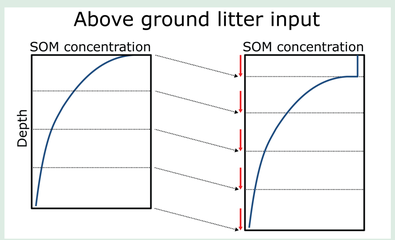
Bulk density change

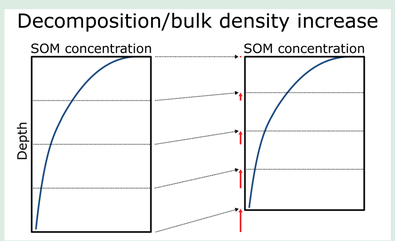
$$\omega_{BD}(z) = -\frac{1}{\rho_b} \int_0^z \frac{d\rho_b}{dt} dz'$$

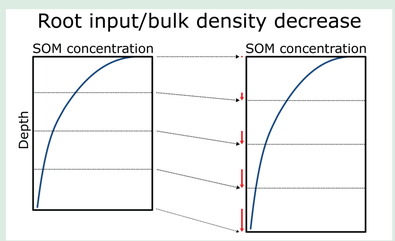
PDE for SOM concentration

$$\frac{\partial c_i}{\partial t} = \frac{\partial}{\partial z}\left[D \frac{\partial c_i}{\partial z} \right] - \frac{\partial \omega c_i}{\partial z} - L_i + I_i$$

Diffusion | Particle flux | Loss | Input



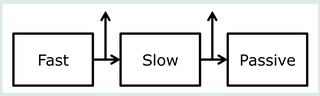


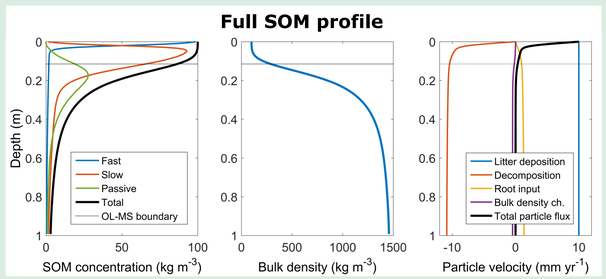


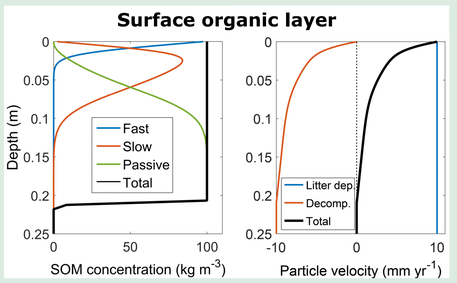
Particle fluxes Vertical shifts in the profile relative to the surface resulting from volume changes. Above ground litter deposition causes a downward particle flux constant with depth. Root litter input and bulk density decrease cause a depth dependent downward flux, decomposition and bulk density increase cause a depth dependent upward flux

Example simulations

We combined the new PDE with a three-pool serial decomposition model. Steady-state results are shown for a organic layer only, without SOM diffusion (right) and a full profile including diffusion and root input (below).







Symbols

c_i: concentration of pool i
γ_i: relative mass change of pool i
ρ_b: bulk density
t: time
N: no. of SOM pools
z: depth
ω: particle flux
D: diffusivity
L_i: loss of SOM pool i
I_i: input of pool i

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Look me up!
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