Carbon and nitrogen dynamics in a soil profile: Model development

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Research motivation,

Model development and novelties:
  ✓ Moisture dynamics,
  ✓ Solute transport and nutrient turnover (carbon),
  ✓ Solute transport and nutrient turnover (nitrogen),

Model capabilities: results of synthetic scenarios,

Model application to a restored riparian ecosystem.
Motivation

• Identify the most important parameters involved in the carbon and nitrogen transformation in the soil,
• how these parameters affect the natural nutrient transformations,
• obtain the vertical distribution of SOM and nutrients in the soil profile.

To this end, we have developed an extended version of the mechanistic batch model of Porporato et al. (*Adv. Water Res.*, 26, 45-58, 2003).

Main new features concern the following points:

• Soil compartments,
• Water and solute transport,
• Nutrient pools,
• Biochemical transformations.
Rainfall (+ added litter)

T OP SOIL
(Nitrate uptake + added litter)

E₁ Zr₁ n₁ V₁

ROOT ZONE
(Nitrate uptake + added litter)

E₂ Zr₂ n₂ V₂

E₃ = 0
Zr₃ n₃ V₃

PARENT MATERIAL

h

Water table

E₄ = 0
Zr₄ n₄ V₄

1ˢᵗ, 2ⁿᵈ and 3ʳᵈ soil compartments
(unsaturated and variably saturated conditions \( \theta_r \leq \theta \leq \theta_{sat} \))

4ᵗʰ soil compartment
(saturated conditions \( \theta = \theta_{sat} \))

- Organic C (litter, humus and biomass)
- Organic N (litter, humus and biomass)
- Inorganic C (CO₂)
- Dissolved carbon
- Dissolved nitrogen
- Inorganic N (ammonium and nitrate)

- Organic C (humus and biomass)
- Organic N (humus and biomass)
- Inorganic C (CO₂)
- Dissolved carbon
- Dissolved nitrogen
- Inorganic N (ammonium and nitrate)
• Water budget approach, accounting for infiltration and evapotranspiration.

• Moisture content of each soil compartment is computed using a mass-balance approach for each compartment.

\[
\Delta s_i = \left[ I_i(s,t) - E_i(s,t) - L_i(s,t) \right] \Delta t / (n_i Z_i)
\]

• Moisture dynamics is controlled by climate—precipitation and evapotranspiration—and soil physical properties.

- \( i \) = soil compartment;
- \( c \) = canopy interception;
- \( P \) = precipitation;
- \( I_i \) = Infiltration;
- \( L_i \) = leakage;
- \( S_{fc_i} \) = soil field capacity water content;
- \( E_i \) = evapotranspiration;
- \( n_i \) = soil compartment porosity;
- \( Z_i \) = soil compartment thickness;

\( q_{tv} \) = threshold value (max. leakage to the aquifer);
SOIL MOISTURE DYNAMICS

A dimensionless parameter $F$ is used to define whether leakage or infiltration dominate the dynamic of soil moisture:

$$F = \frac{\langle P \rangle - \langle E \rangle}{q_{tv}}$$

$\langle \rangle$ refers to the average daily precipitation and evapotranspiration

$F >> 1$
Net infiltration larger than leakage. Soil profile permanently saturated.

$F << 1$
Soil profile drains quickly and water saturation is low.

$F = 1$
Soil moisture is sensitive to climatic conditions, showing inter-annual variability depending on the actual precipitation rate.
Overall soil carbon turnover network: (New pools and processes added)

ADD = litter input rate;
DEC_{l,h} = C fluxes leaving litter and humus pools (microbial decomposition);
MOB_{l,h} = dissolution rates of litter and humus pools;
BIO = biomass uptake rate of DOM.

\[ DEC_l = \phi_d(s)k_lC_bC_l, \]
\[ DEC_h = \phi_d(s)k_hC_bC_h, \]
\[ BD = k_dC_b, \]
\[ MOB_l = k_{c,l}C_l, \]
\[ MOB_h = k_{c,h}C_h, \]
\[ BIO = \gamma_d(s)k_{DC}C_dC_b, \]
\[ \frac{dCO_{2,i}}{dt} = r_r \left( DEC_{l,i} + DEC_{h,i} + BIO_i \right). \]
Overall soil nitrogen turnover network: (New pools and processes added)
N availability controls the SOM turnover rate and dynamics (limiting factor). The model is designed to maintain the biomass C/N constant:

\[
\frac{d(C/N)_b}{dt} = \frac{dC_b}{dt} = \frac{dN_b}{dt} = 0
\]

To do so, only 2 variables were originally used:

- \( \Phi \): controls the net N flux from/to the mineral pools -mineralization or immobilization-,
- \( \varphi \): used to reduce SOM decomposition rate when immobilization is not sufficient to cover the N deficit.

We have updated the model using one additional variable:

- \( \Gamma \): controls the net flux among mineral nitrogen pools and DOM.

(details in Brovelli et al., In preparation)
Microbial decomposition, nitrification and denitrification processes are influenced by a dimensionless factor which accounts for the soil moisture effect:

**Microbial decomposition (DEC)**

\[
f_a(s) = \begin{cases} 
\frac{s}{s_w} & \text{if } s \leq s_{fc} \\
\frac{s_{fc}}{s} & \text{if } s > s_{fc}
\end{cases}
\]

**Nitrification (NIT)**

\[
f_n(s) = \begin{cases} 
\frac{s}{s_{fc}} & \text{if } s \leq s_{fc} \\
\frac{1-s}{1-s_{fc}} & \text{if } s > s_{fc}
\end{cases}
\]

**Denitrification (DENIT)**

\[
f_{dn}(s) = H(s - s_{fc})\left(\frac{s - s_{fc}}{1-s_{fc}}\right)^{1.5}
\]

*(H : Heaviside step function)*
SYNTHETIC RESULTS EXAMPLES AND MODEL CAPABILITIES

Daily / mean monthly rainfall, stochastically generated or measured.
SYNTHETIC RESULTS EXAMPLES AND MODEL CAPABILITIES
Specific objectives:
- to evaluate the nutrient buffer capabilities of this SPECIFIC riparian system,
- to evaluate nitrate fluxes (i.e. atmospheric deposition, leakage to the aquifer, etc.),
- to understand the effects of restoration processes over nutrient turnover.

Wednesday 5th May, 17:30 – 19:00. Session HS3.1. Hall A (board A52).

“Carbon and nitrogen dynamics in a soil profile: Model insights and application to a restored Swiss riparian area” (Brovelli et al.). Poster EGU2010-5630.
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Thanks for your attention !!