# NUTSFOR a process oriented numerical model to simulate biogeochemical cycling and tree nutrition in forest ecosystems – Model development and testing using data from a multi-isotopic (26Mg 44Ca) tracing experiment

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# NUTSFOR a biogeochemical cycling and tree nutrition model for forest ecosystems: Simulating elemental chemistry and stable isotope ($^{26}Mg$, $^{44}Ca$) tracing

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## 1. Context and objectives

**Reduced atmospheric deposition and intensified biomass harvest is likely to put soil fertility at risk**

- **Numerical models are important and useful tools** to help predict how forest ecosystems may respond to **change in atmospheric deposition** and/or **silvicultural practices**. They are also important research tools which help decipher the role of different processes in biogeochemical cycles.
- New tools such as **stable isotope tracers** have been developed in past decades to better experimentally study forest ecosystem biogeochemistry and nutrient sources for trees. Existing models have not yet integrated these isotopic tools to i) **test the hypotheses and model concepts** and ii) develop models to **better simulate ecosystem processes**.

**Objectives**

- Develop a novel numerical model to simulate the biogeochemical cycling of nutrients and stable isotope tracers in forest ecosystems.
- Test the model's capability to simulate elemental chemistry and isotope ratios using the monitoring data from the Breuil-Chenue experimental site where a multi-isotopic tracing experiment was carried out in April 2010.

## 2. Material and Methods

### 2.1. Study site

The experimental site of Breuil-Chenue forest (hereafter named Breuil site) is located in the Morvan Mountains, Burgundy, France. The soil (Tab. 1) is an Alocrisol, the humus type is a dysmoder, and the soil parent material is granite. The present study focuses on a 80m² 35-yr-old beech plot.

| | | | | Soil Texture | | | Soil cationic exchange capacity | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Horizon | Depth | Da TF | C/N | Sand | Silt | Clay | ECEC | S/T | Mg | Ca | K | Al | H |
| | cm | | | % | % | % | cmolc/kg | % | cmolc/kg | cmolc/kg | cmolc/kg | cmolc/kg | cmolc/kg |
| A1/E | 0-5 | 0.50 | 18.0 | 57.6 | 21.8 | 20.6 | 8.66 | 19.44 | 0.23 | 0.54 | 0.37 | 6.30 | 0.83 |
| A1-A1/Bp | 5-10 | 0.64 | 18.1 | 60.2 | 21.5 | 18.4 | 7.23 | 10.88 | 0.13 | 0.15 | 0.22 | 6.05 | 0.42 |
| Sal 1 | 10-15 | 0.67 | 18.1 | 58.0 | 23.6 | 18.4 | 5.43 | 7.88 | 0.08 | 0.07 | 0.14 | 4.85 | 0.18 |
| Sal 2 | 15-25 | 0.89 | 17.9 | 60.0 | 24.1 | 16.0 | 4.08 | 5.75 | 0.04 | 0.02 | 0.10 | 3.79 | 0.12 |
| Sal 2 | 25-40 | 0.90 | 17.1 | 57.8 | 24.7 | 17.5 | 3.13 | 7.38 | 0.03 | 0.02 | 0.08 | 2.73 | 0.09 |
| Sal 3 | 40-55 | 1.08 | | 55.7 | 25.8 | 18.5 | 3.11 | 8.06 | 0.02 | 0.01 | 0.09 | 2.62 | 0.08 |
| II Sal 4 | 55-70 | 1.05 | | 57.3 | 25.3 | 17.5 | 3.32 | 8.06 | 0.03 | 0.02 | 0.09 | 2.80 | 0.10 |

*Tab. 1 Physical and chemical properties of the soil profile*

### 2.2. Multi-isotopic tracing experiment

In April 2010, the isotope tracer solution (Tab. 2) was sprayed on the forest floor of the tracing plot representing a ~16 mm rainfall event. Rainfall, throughfall and soil solutions were collected at a 28-day time step. Soil cores were sampled every 28 days (8 soil profiles; 0-60cm, thickness 5cm). Soil cationic exchange capacity (CEC) extractions using ammonium acetate (1 mol.L-1) were carried out on the soil samples. Five trees were felled in 2012 to estimate total $^{26}Mg$ and $^{44}Ca$ tracer uptake: biomass samples were collected at different heights, dried at 65°C, milled and digested in $HNO_3$.

| | Concentration | Flux | Isotopic composition | |
|---|---|---|---|---|
| | $meq.L^{-1}$ | $kg.ha^{-1}$ | % | δ‰ |
| $NO_3^-$ ($^{15}N$) | 26.7 | 1 | 99 | 2.69E+07 |
| $Ca^{2+}$ ($^{44}Ca$) | 9.6 | 0.53 | 96.45 | 1.26E+06 |
| $Mg^{2+}$ ($^{26}Mg$) | 29.6 | 0.96 | 99.25 | 1.09E+06 |
| $H_2O$ ($^2H$) | - | - | 99.85 | 2.37E+04 |

*Tab. 2 Composition of the tracer solution*

### 2.3. NUTSFOR model description

NUTSFOR is a process-oriented model, based on model concepts from both the Nutrient Cycling Model (NuCM) and the ForSAFE model, that simulates nutrient cycling of major cations (Ca, Mg, K, Al, $NH_4$, Na) and anions ($NO_3$, $SO_4$, $PO_4$, Cl,) and a stable isotope tracer for each element at the scale of an ecosystem. The ecosystem is represented as a series of vegetation and soil components or pools (soil adsorbed ions, soil mineral pool, soil solution, litter and tree biomass).

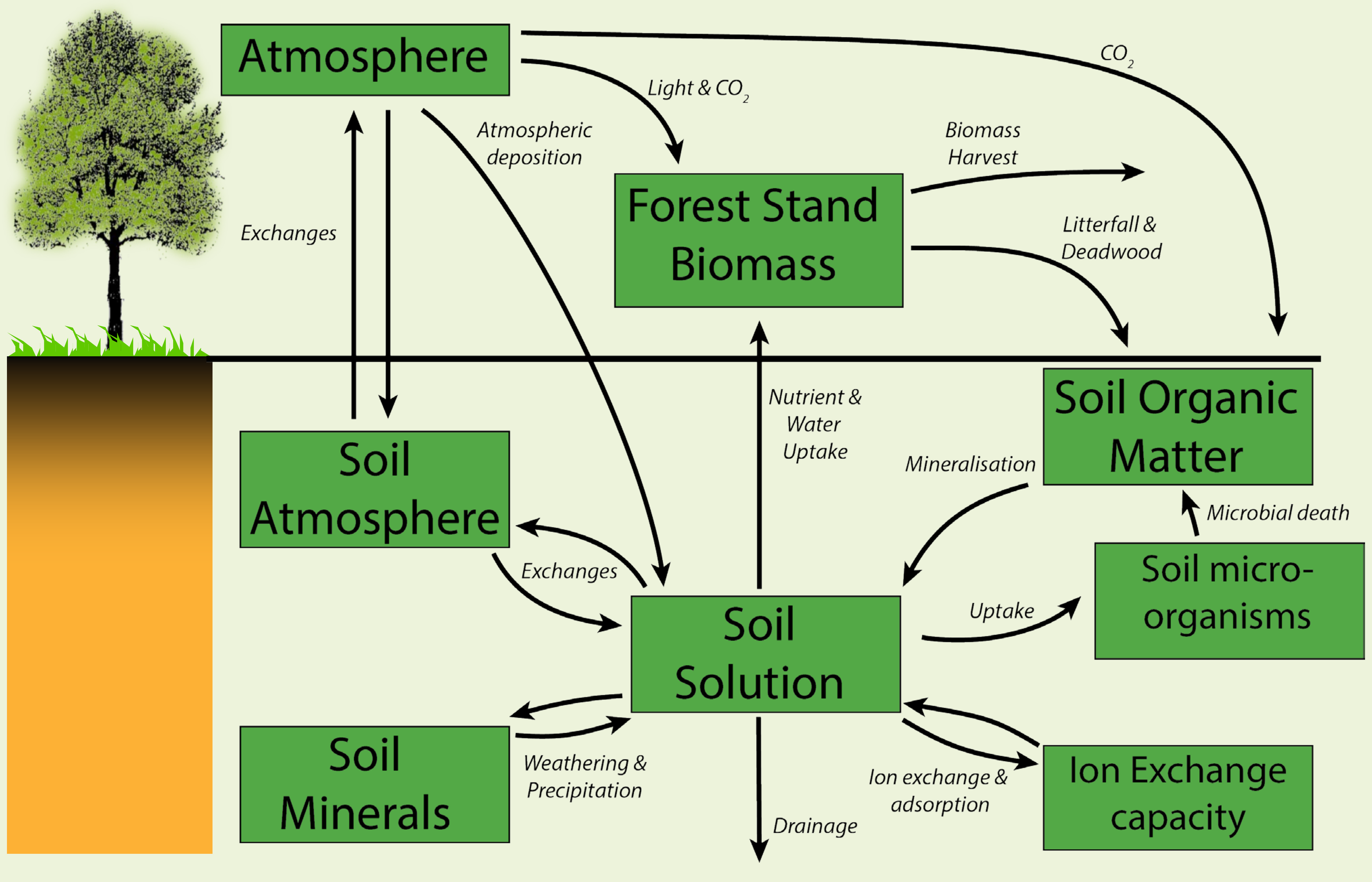


*Figure 1: Schematic description of the NUTSFOR biogeochemical model*

## 3. Results

### 3.1. Elemental chemistry simulations

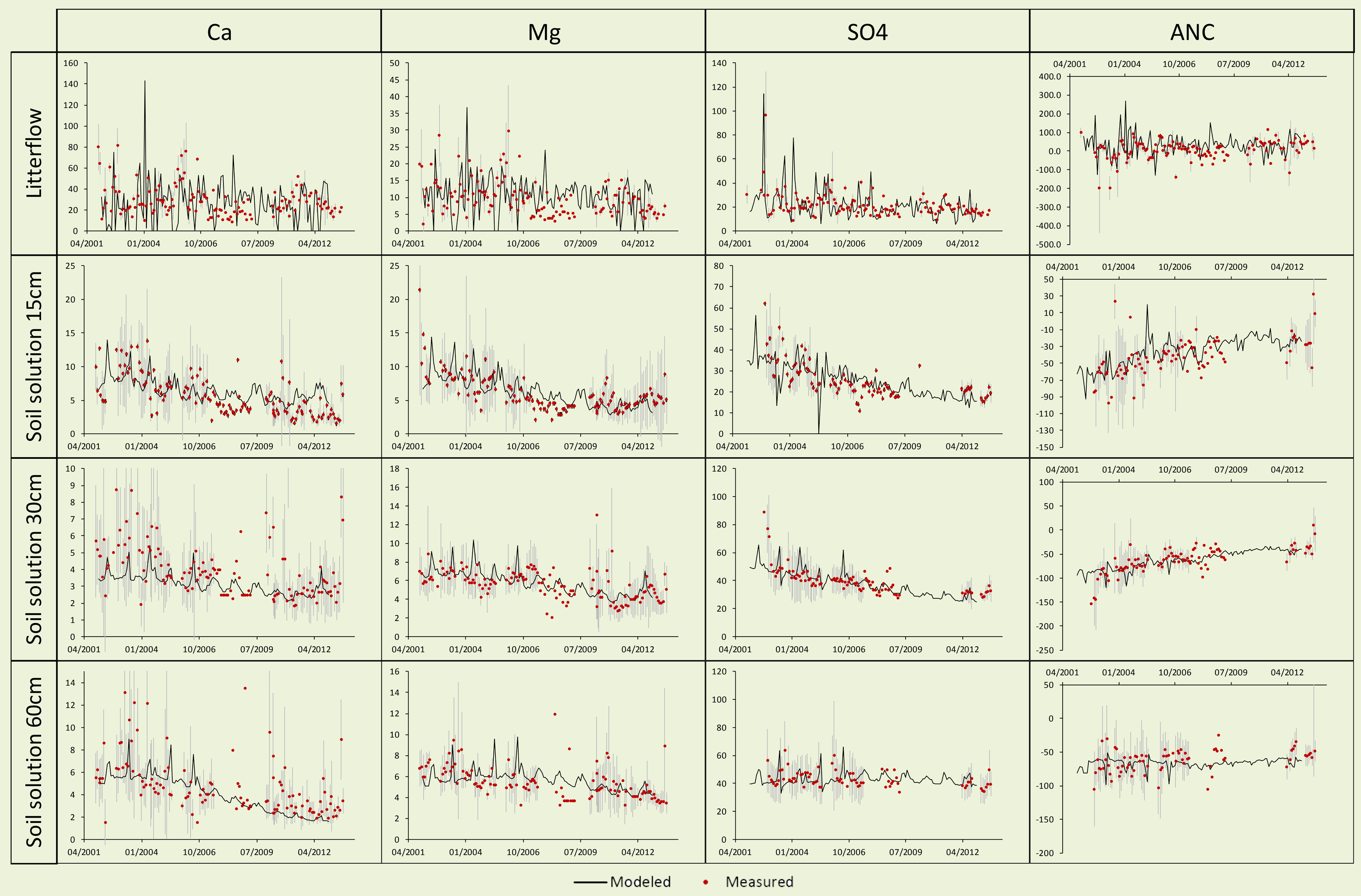


*Figure 2: Measured (red dots) and simulated (continuous line) Ca, Mg, $SO_4$ concentrations (µmol.L[-1]) and ANC (µmol$_c$.L[-1]) by the NUTSFOR model in the beech plot at the Breuil-Chenue experimental site over the 2002-2012 period. Litterflow was collected with zero-tension lysimeters underneath the litter layer, soil solution was collected with tension-cup lysimeters at 15, 30 and 60 cm depth.*

### 3.2. Simulating the multi-isotopic tracing experiment

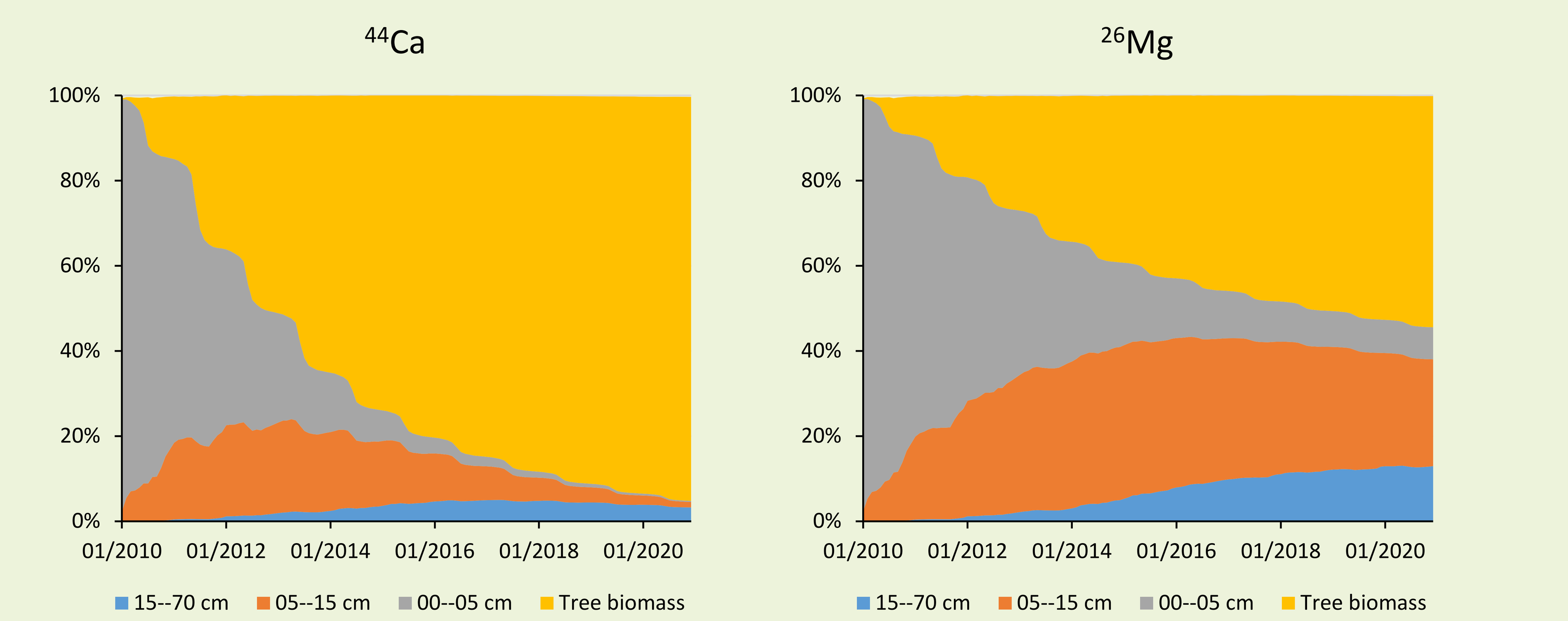


*Figure 3: Simulation of the multi-isotopic tracing experiment in the beech plot of the Breuil-Chenue experimental site: $^{44}Ca$ and $^{26}Mg$ recovery in the different ecosystem compartments over a 10 year period, expressed in percentage of applied tracers.*

### 3.3. Tracer recovery: experimental vs. modeled data

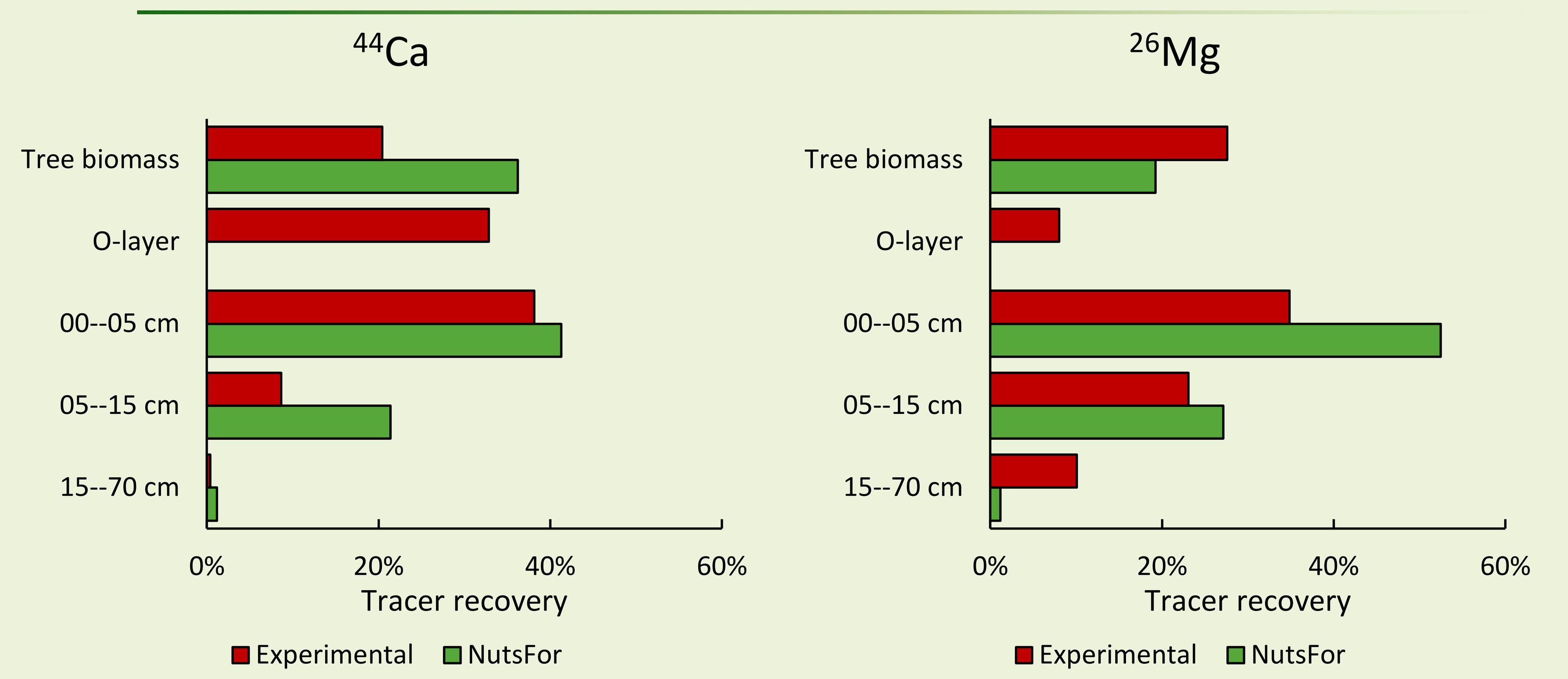


*Figure 4: Measured and simulated $^{44}Ca$ and $^{26}Mg$ recovery in the different ecosystem compartments 2 years after the application of tracers, expressed in percentage of applied tracers.*

## 4. Conclusions

1. NutsFor a model to simulate biogeochemical cycling in forest ecosystems and stable isotope tracers was successfully developed.
2. NutsFor simulated correctly **elemental chemistry of solutions** from throughfall to soil solutions.
3. The simulated **vertical transfer of Mg and Ca tracers** in the soil profile was **slow yet faster than measured transfer** in the multi-isotopic tracing experiment.
4. NutsFor **failed to reproduce the observed different behaviors of Mg and Ca**: simulated Mg tracer moved more slowly in the profile due to immobilization in the soil microbial biomass

## 5. Future NutsFor developments

1. Cationic exchange capacity in the organic layer
2. Root to canopy Mg and Ca allocation module
3. Isotope fractionation processes (natural isotope ratio variation studies)

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