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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 (^{26}Mg ^{44}Ca) tracing experiment

Gregory van Der Heijden, Arnaud A. Legout, Etienne Dambrine, Salim Belyazid

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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 dysmuder, and the soil parent material is granite. The present study focuses on a 80m² 35-yr-old beech plot.

Horizon	Depth cm	Da TF	C/N	Soil Texture			Soil cationic exchange capacity							
				Sand %	Silt %	Clay %	ECEC cmolc/kg	S/T %	Mg cmolc/kg	Ca cmolc/kg	K cmolc/kg	Al cmolc/kg	H 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	15.7	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	15.7	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

	Concentration meq.L ⁻¹	Flux kg.ha ⁻¹	Isotopic composition ‰	‰
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 ₂ O (² H)	-	-	99.85	2.37E+04

Tab. 2 Composition of the tracer solution

(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 ²⁶Mg and ⁴⁴Ca tracer uptake: biomass samples were collected at different heights, dried at 65°C, milled and digested in HNO₃.

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, NH₄, Na) and anions (NO₃, SO₄, PO₄, 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).

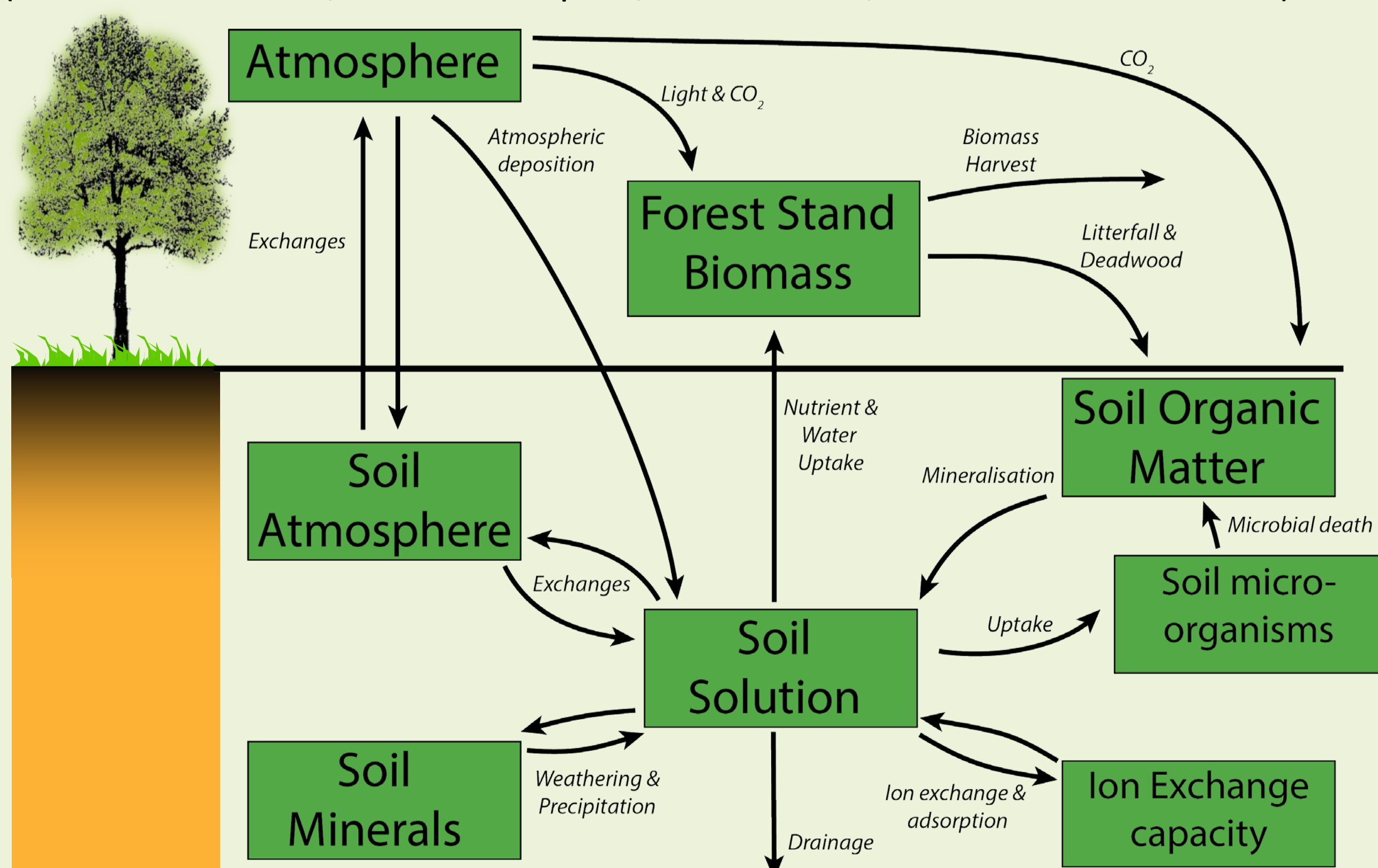


Figure 1: Schematic description of the NUTSFOR biogeochemical model

3. Results

3.1. Elemental chemistry simulations

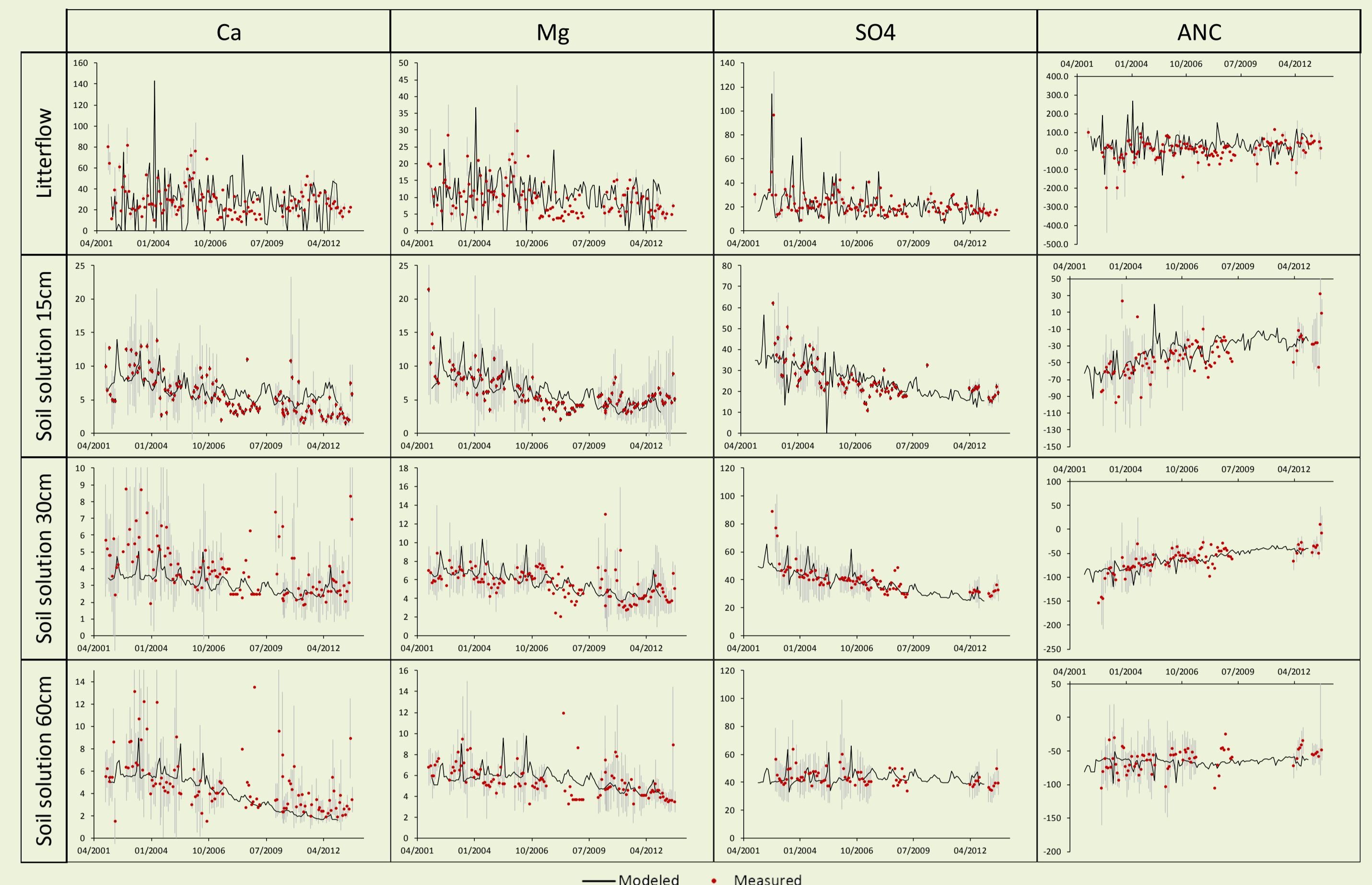


Figure 2: Measured (red dots) and simulated (continuous line) Ca, Mg, SO₄ concentrations (µmol.L⁻¹) and ANC (µmol.L⁻¹) by the NUTSFOR model in the beech plot at the Breuil-Chenue experimental site over the 2002-2012 period. Litterflow was collected with zero-tension lysimeters underneath the litter layer, soil solution was collected with tension-cup lysimeters at 15, 30 and 60 cm depth.

3.2. Simulating the multi-isotopic tracing experiment

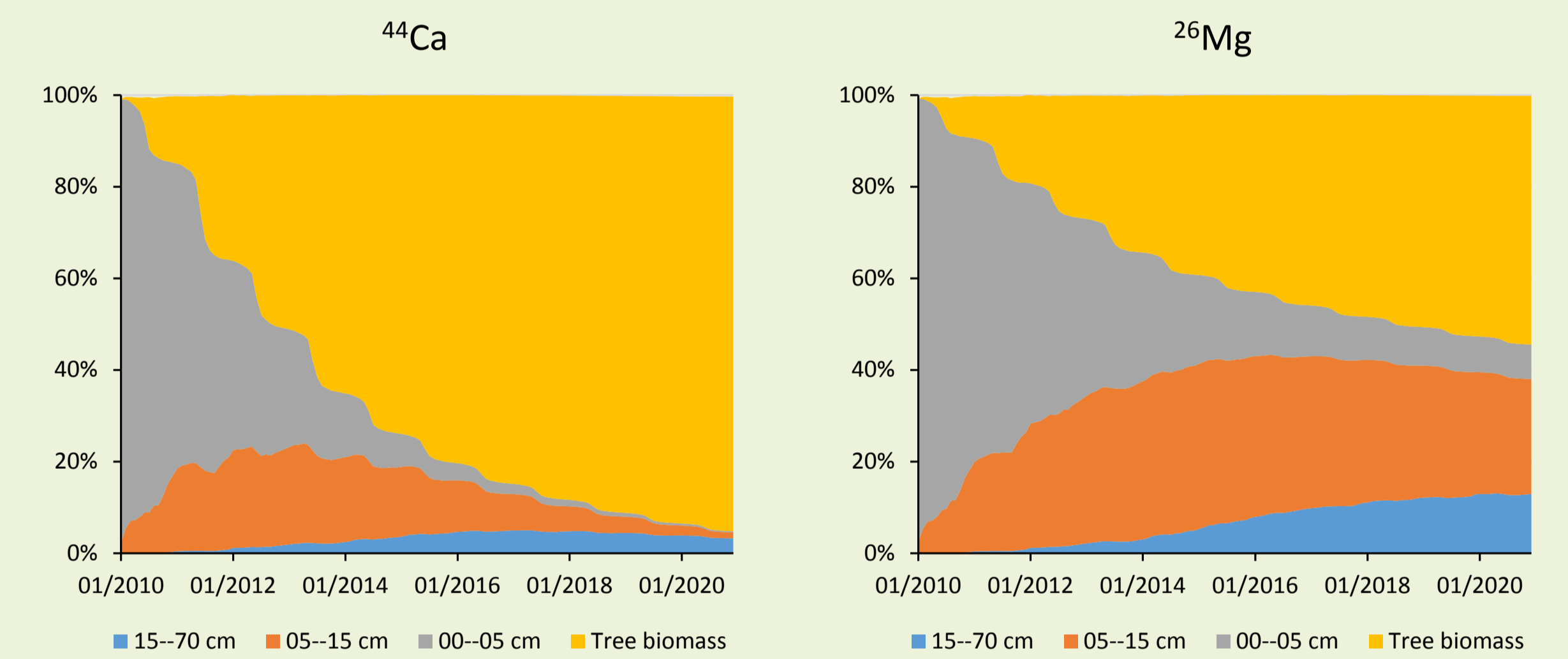


Figure 3: Simulation of the multi-isotopic tracing experiment in the beech plot of the Breuil-Chenue experimental site: ⁴⁴Ca and ²⁶Mg recovery in the different ecosystem compartments over a 10 year period, expressed in percentage of applied tracers.

3.3. Tracer recovery: experimental vs. modeled data

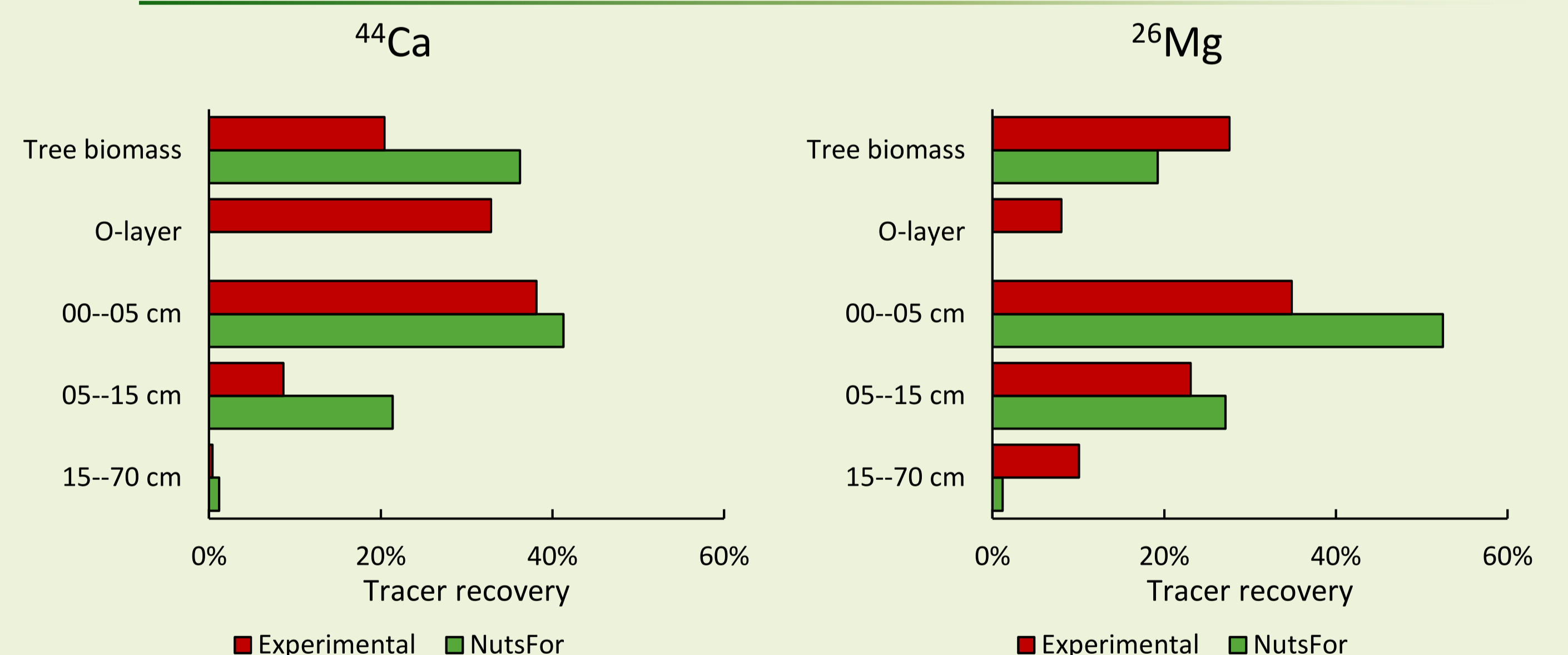


Figure 4: Measured and simulated ⁴⁴Ca and ²⁶Mg recovery in the different ecosystem compartments 2 years after the application of tracers, expressed in percentage of applied tracers.

4. Conclusions

- NutsFor a model to simulate biogeochemical cycling in forest ecosystems and stable isotope tracers was successfully developed.
- NutsFor simulated correctly elemental chemistry of solutions from throughfall to soil solutions.
- 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.
- 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

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