Dynamics of carbon and nitrogen stabilization in mineral soil layers of forests regrowing after harvest

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- Soils can quickly stabilize new carbon (C) and nitrogen (N) in northern forests of all ages
- Controls on soil C and N stabilization can help to parameterize forest ecosystem models and improve projections of C and N cycling under various future scenarios and management decisions

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http://www.nsrcforest.org

Project Summary

Rationale: Soil organic matter (SOM) accounts for the largest pools of carbon and nitrogen in the Northern Forest and the stabilization of SOM can help to mitigate climate change through C sequestration and protect downstream surface water quality by controlling N concentrations. SOM stabilization may vary with forest age due to differing N demands and C inputs during forest regrowth. Better understanding SOM stabilization and its controls in forests of different age is increasingly important for future projections of forest health and management decisions.

Methods and Outcomes: We used stable isotopes to trace C and N from plant material (sugar maple leaf litter) into stable soil organic matter associated with clay mineral particles in soils from White Mountain region (New Hampshire) forests of four age classes (~20 years to old growth). We used nanoscale isotopic imaging analysis to identify where on soil particles new SOM formed and with what soil minerals it was associated. We will incorporate results into the ongoing development of the Spe-CN forest ecosystem model of C and N cycling. Beneficiaries of this research include land managers interested in projecting forest C sequestration or N retention under different future scenarios of changes in climate, tree species composition, or N deposition

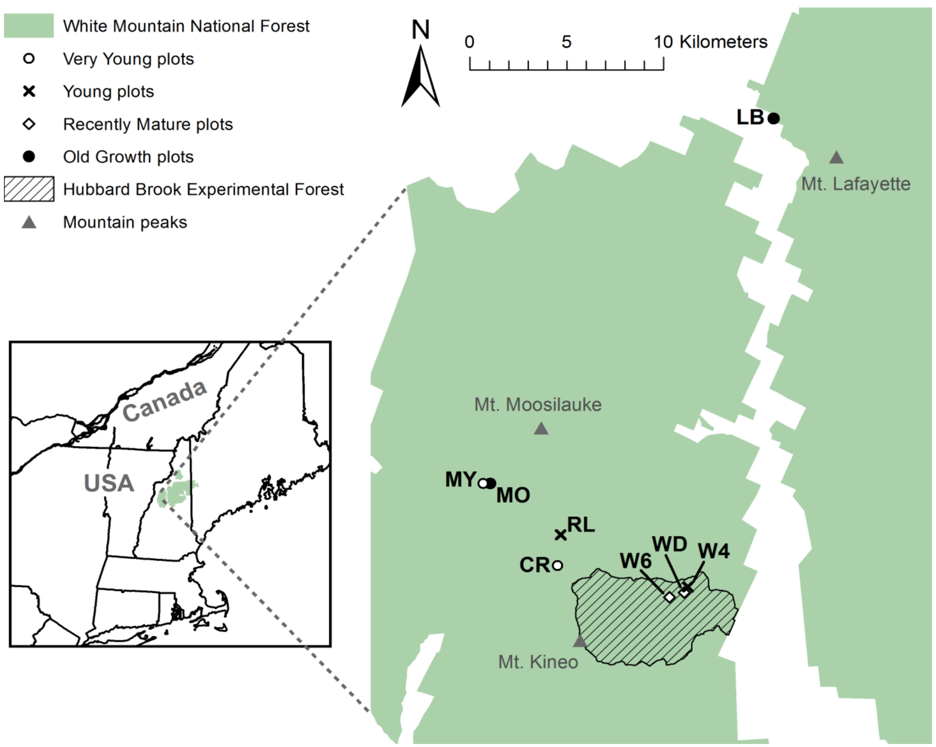
Background and Justification

- Soils have the largest amounts of organic matter (therefore both C and N) in the Northern Forest ecosystem
- Stabilization of SOM provides important ecosystem functions
  - Sequestration of C that keeps CO_2 out of the atmosphere and helps to mitigate climate change
  - Retention of N that could otherwise be lost to runoff and negatively affect downstream water quality
- Forests regrowing after harvest access N from SOM and may affect the SOM stabilization potential
- The storage of C and N in SOM over the long-term is poorly understood, especially given different future scenarios of climate change, tree species change, and air quality controls leading to different levels of atmospheric N deposition

Methods: 1

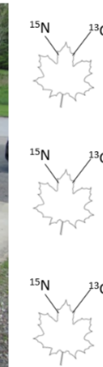
- Eight northern hardwood study plots in the White Mountain region of New Hampshire across a forest age chronosequence (*map*)
  - Four age classes: Very Young (~20-25 years), Young (~45 years), Recently Mature (~100 years), Old Growth (>> 200 years)
- Subsurface soils (upper 10cm of mineral B horizon) was sampled in two depth increments

Sampling soil and measuring tree diameter at plots in the White Mountains



Methods: 2

- Subsamples of fresh soil were mixed with ^{15}N- and ^{13}C-labeled maple leaf litter and incubated for 10 days to produce new, labeled SOM through decomposition and microbial turnover
- Clay-sized soil particles were separated and taken for imaging and isotopic analysis
- Elemental composition (iron and aluminum) of mineral particles were measured with NanoSIMS to develop relationships of SOM stabilization with mineralogy

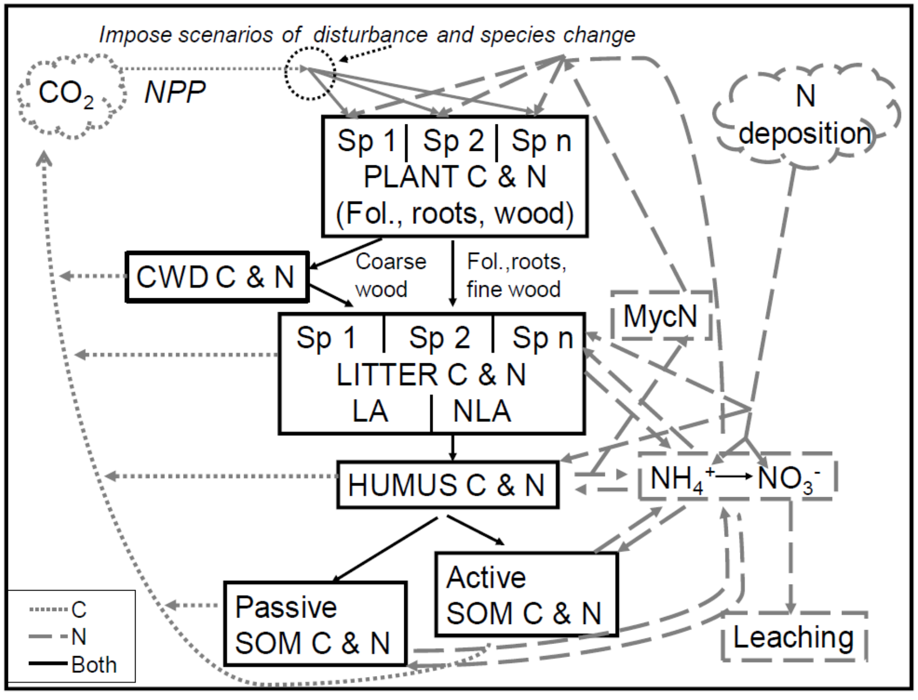


Isotopically-labeled maple leaves were produced by fertilizing potted saplings with ^{15}N-labled ammonium sulfate and fumigating them with ^{13}C-labeled carbon dioxide in this small greenhouse

Cameca NanoSIMS 50L instrument

Photo: Lehrstuhl für Bodenkunde, Technische Universität München

Methods: 3

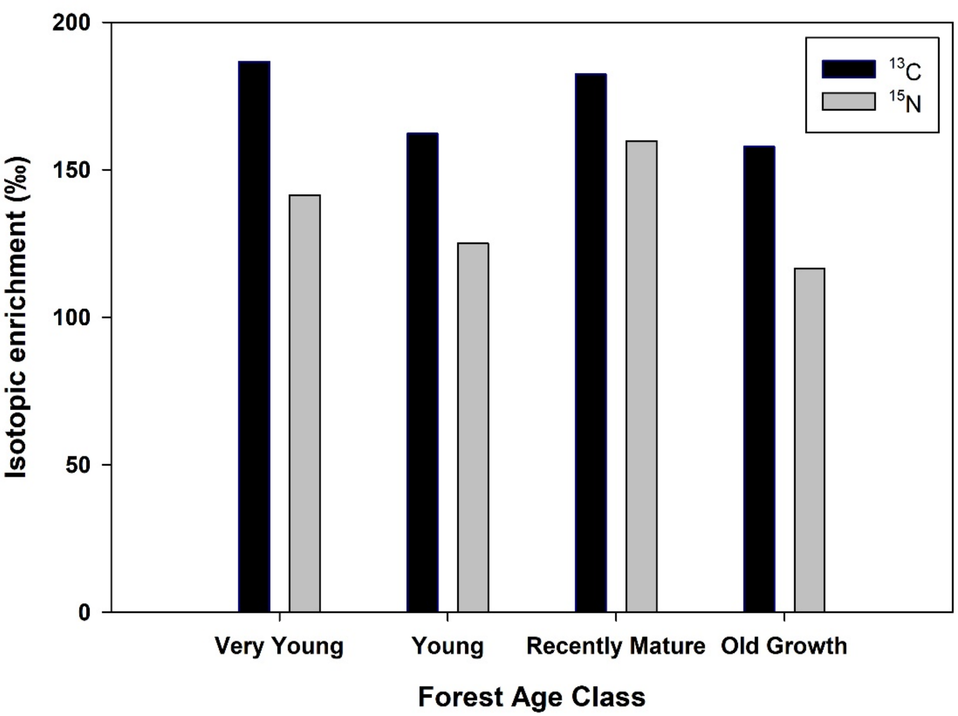


Structure of the Spe-CN forest ecosystem model

- Results will be incorporated into the Spe-CN forest ecosystem model's C and N stabilization routine
- Mineralogy is thought to affect SOM stabilization (stabilized C and N associated with certain iron and aluminum fractions) and would affect the accumulation and turnover in the Passive and Active SOM pools (lower boxes in model figure)

Results: C and N stabilization - 1

- Rapid stabilization of new SOM (indicated by isotopic enrichment due to tracer incorporation) occurred on clay particles in soils of all forest age classes (*figure below*), with no significant differences between the age classes.

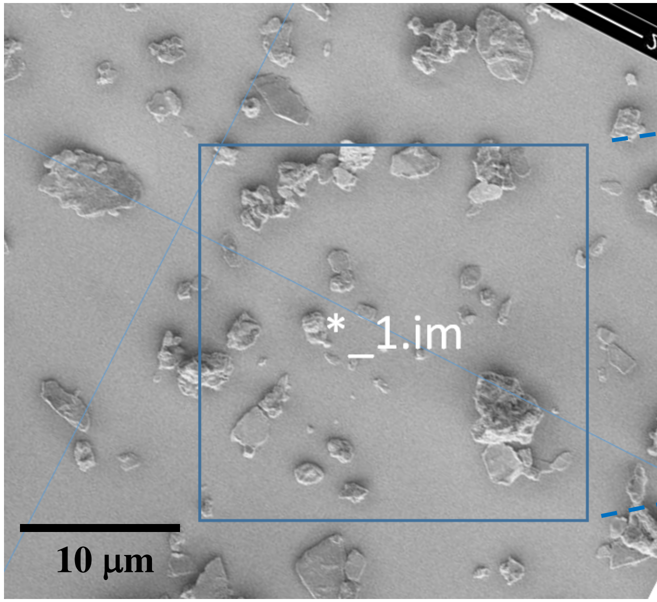


Isotopic enrichment values of clay-associated SOM after 10 days of incubation with isotopic tracer-containing maple leaf litter. Background values are ~-26‰ for $\delta^{13}C$ and ~7‰ for $\delta^{15}N$

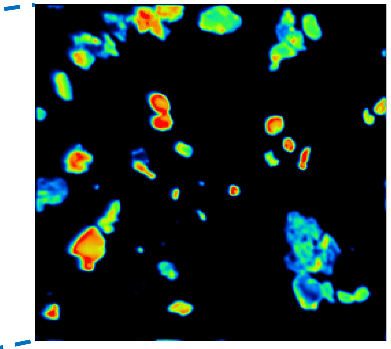
Results: C and N stabilization - 2

- Stabilization of tracer ^{15}N on clay particles was positively correlated with the C:N ratio of the clay-associated SOM (P<0.045). Stabilization of ^{13}C on clay particles was positively (though nonsignificantly, P>0.24) correlated with C:N of the clay fraction.
  - Soils with lower C:N ratios may have a lower capacity to stabilize new SOM, especially SOM rich in N.

Results: C and N stabilization - 3

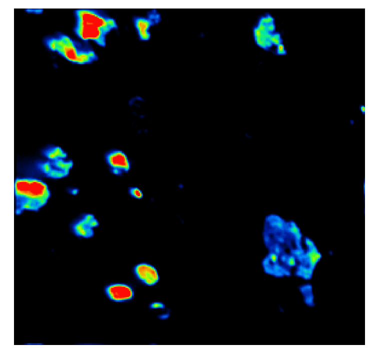


Scanning electron micrograph of clay soil particles



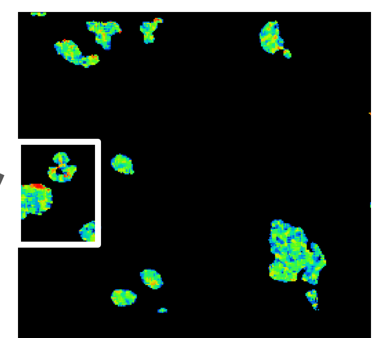
Oxygen – ^{16}O

(defines particles)



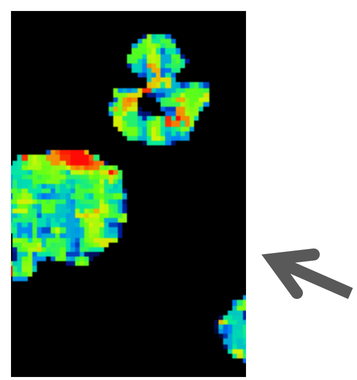
Carbon– ^{12}C

(organic matter coverage)



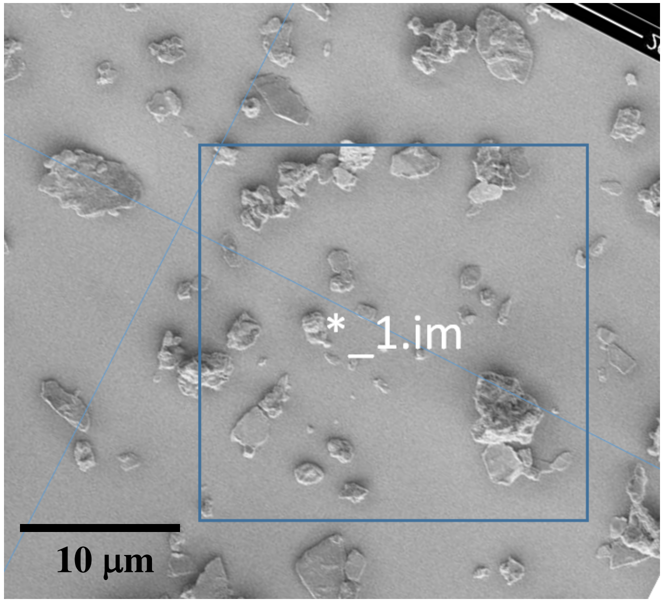
Nitrogen– $^{15}N/^{14}N$

(tracer = newly stabilized organic N)

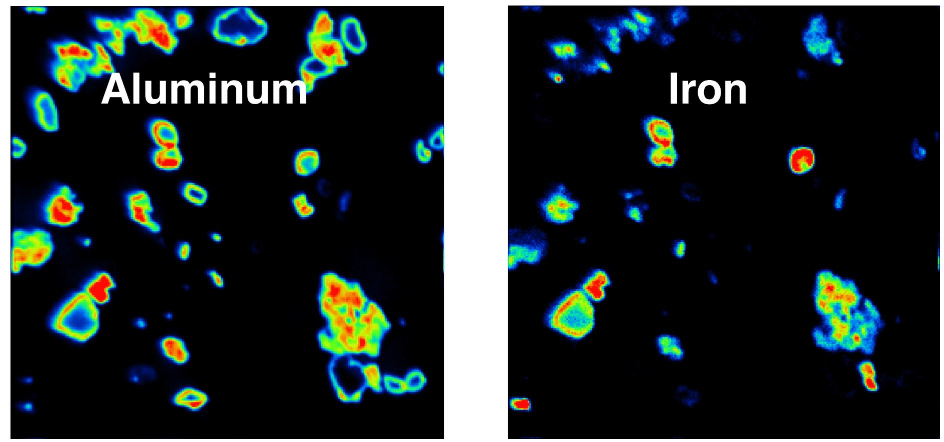


NanoSIMS images show spatial elemental and isotopic tracer composition of particles. Presence of oxygen clearly defines spatial boundaries of particles, while 12C shows where organic matter is present. Hotspots of isotopic enrichment (shown here as the ratio of 15N:14N) show where new SOM was stabilized. Areas of SOM stabilization can be quantified in two dimensions.

Results: C and N stabilization - 4



Scanning electron micrograph of clay soil particles



Organic matter coverage on particles and the location of tracer stabilization can be compared to underlying mineralogy, such as aluminum and iron contents.

In an effort to generalize or broaden the applicability of this information, we are using this data to determine how well the NanoSIMS data correlates to more common and easily obtainable data such as oxalate extractable iron and aluminum in whole soils or clay fractions.

Outreach efforts

- Our study highlights the importance of soil pools for potential long-term retention of C and N. The capacity of forest soils to store C and N is likely to become an increasing important consideration for forest managers or landowners.

- We presented results from this project at the 2018 joint North American Forest Soils Conference – International Symposium on Forest Soils, which included broad representation of parties interested in basic and applied forest soil research

- We are planning a general article that will discuss the role of the Northern Forest in storing C and N (emphasizing soil), including how it might change under differing future scenarios. Forest managers and landowners will be reached by publishing in a magazine such as *Northern Woodlands*.

Implications and applications in the Northern Forest region

- Forest soils can rapidly store C and N inputs in stable mineral-associated SOM in age classes from two decades post harvest to old growth.

- Our results will aid models by increasing our understanding of the controls on SOM stabilization, such as soil mineralogy and C:N ratio.
  - The latter is especially relevant to the forests of the Northeast, where N saturation may be manifested in soils.
  - Improved models are useful to forest managers or landowners concerned with how management decisions may affect C and N balances under future scenarios.

View of Franconia Notch, White Mountains, NH
Photo: Ashley Lang

Future directions

- Our work on incorporating controls on SOM formation and stability into the Spe-CN forest ecosystem model will continue.

- We will further explore the applicability of the method of incubating soils with isotopically-labeled material to produce labeled SOM for use in field studies designed to assess longer term SOM stability. A pilot study was conducted on this as part of a National Science Foundation-funded Research Experience for Undergraduates project that had potentially promising results.

List of products - 1

Conference presentations:

- Northeastern Ecosystem Research Cooperative, March 2017; Saratoga Springs, NY
- Hubbard Brook Ecosystem Study Annual Cooperators Meeting, July 2017; Woodstock, NH
- BIOGEOMON International Symposium on Ecosystem Behavior, August 2017; Litomyšl, Czech Republic
- North American Forest Soils Conference – International Symposium on Forest Soils, June 2018, Quebec City, Canada

Guest seminar:

- Technical University of Munich (“Soil Talks” series), November 2016, Freising, Germany

Research Experience for Undergraduates:

- Melisa Bohlman (University of Arizona), Cary Institute of Ecosystem Studies REU program, summer 2017 (Project Title: “Relative stability of nitrogen in soil organic matter depends on sources of input”)
- Paulina Murray (Siena College), Cary Institute of Ecosystem Studies REU program, summer 2018 (Project Title: “Mature versus old growth: carbon and nitrogen dynamics with forest soil organic matter ”)

List of products - 2

Peer-reviewed publications

- Two publications anticipated: one on controls on SOM stabilization including nanoscale analysis (expected completion 2019), and one including updates of Spe-CN model with mineralogy and control on SOM formation/stability (expected completion 2020)

Stakeholder-targeted publication

- Paper for general audience about scenarios of future forest C and N cycling and the importance of soils (expected 2019)