The Coupled Nature of C and N Cycles in Forest Ecosystems: Evidence and Uncertainties

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C & N: Joined by a Shared Set of Biological Reactions

**NITROGEN**

- **N Fixation** Principal *biological* source, high carbon cost
- **Photosynthesis and Respiration** Both Related to Plant N Concentrations
- **Decomposition & Mineralization**
  - \( f \) [litter N and Carbon quality]

**CARBON**

- **N Losses**
  - \( f \) [Soil C:N, Plant Demand]
- **CO₂**
- **DOC**
- **CO₂**
- **CO₂**
- **Organic matter**

**Doc**: DOC
ANPP in Most Eastern U.S. Temperate Forests Scales with N Status, not LAI.
AVIRIS-Predicted Foliar Chemistry Used to Estimate Soil Nitrogen Cycling

![Map and Graph](image)

Ollinger et al. 2002
Disturbance History and Species Effects

Hardwoods

- Undisturbed
- Cut or Burned

Conifers

- Undisturbed
- Cut or Burned

Foliar % N

N Mineralization (kg ha\(^{-1}\) yr\(^{-1}\))

Species: Yellow Birch, Beech, Red Maple, Sugar Maple, Balsam fir, Hemlock, Red spruce
Nitrogen availability is a key constraint on carbon cycling in terrestrial ecosystems and it is largely in this capacity that the role of nitrogen in the climate system has been considered. Nevertheless, broad-scale analyses rarely include spatial variation in plant N status as a driving variable. **WHY?**

1. **Uncertainty about how leaf-level photosynthesis-nitrogen relationships aggregate to whole canopies and ecosystems.**

2. **There are no methods to remotely sense canopy nitrogen concentrations at broad spatial scales.**
APPROACH: Continental synthesis of CO$_2$ Flux data, field measurements, imaging spectroscopy and global satellite sensors
Is there hope for continental-scale detection of canopy N?

Dashed Line: Leaf-level trend from Wright et al. 2004 global leaf traits data set.

Wind River Experimental Forest, WA
Willow Creek, WI
Howland, ME
Bartlett Experimental Forest, NH
Harvard Forest, MA
Niwot Ridge, CO
Morgan Monroe State Forest, IN
Duke Forest Deciduous, NC
Duke Forest Pine, NC
Donaldson Tract, FL

R² = 0.65
R² = 0.83

Canopy %N

CA max (area) (μmolC m⁻² s⁻¹)

CA max (mass) (μmol gFoliage⁻¹ s⁻¹)
CANOPY % N AND FULL SPECTRUM REFLECTANCE

AVIRIS spectra from 143 Field plots, by %N class
Canopy N and MODIS Shortwave Albedo

\[ R^2 = 0.88 \]

U.S. Sites
Canadian Sites

MODIS Shortwave Albedo
Mid Growing Season Average

Ollinger et al. 2008, PNAS
Extension to other biomes using FLUXNET
**Extension to other biomes using FLUXNET**

LAI is *NOT* an underlying driver.

![Graph showing MODIS Albedo (2000-2008 growing season avg) vs LAI](image)
AVIRIS reflectance (left) used to calculate shortwave surface albedo (right).

\[ R^2 = 0.92 \]
Landscape-scale patterns of %N and canopy structure

At 20 m spatial resolution, the N-based relationship holds.

No effect of canopy surface roughness (Rugosity)
DOES NITROGEN PLAY A PREVIOUSLY UNRECOGNIZED ROLE IN THE CLIMATE SYSTEM?

- C cycle effects and albedo effects typically viewed as separate mechanisms.

- Our results indicate that they are more intimately related and are linked via plant nitrogen status.

- This suggests a potential feedback in the climate system involving the N cycle as a regulator of both C cycling AND energy exchange.
Nitrogen Deposition and Mid-Summer Shortwave Albedo

![Graphs showing relationship between nitrogen deposition and mid-summer shortwave albedo for evergreen and deciduous trees.](image)

- Evergreen:
  - Scatter plot with a linear regression line.
  - R² = 0.31

- Deciduous:
  - Scatter plot with a linear regression line.
  - R² = 0.31
WHY ARE NITROGEN AND ALBEDO RELATED?

• Co-variation between leaf N concentrations and canopy structure?

• Co-variation between nitrogen and the cellular structure needed to support different rates of photosynthesis?
Leaf-Level Spectra from a Sub-set of Sites  
(MMSF, Niwot, Fraiser, GLEES)

Multiple regression of albedo vs. leaf %N and LMA: $R^2 = 0.84$
Take Home Messages:

1. Carbon and Nitrogen, and maybe even energy, are coupled in many terrestrial ecosystems.

2. We should do remote sensing/imaging spectroscopy to learn about how nature works, not just for the sake of doing more remote sensing.
Interactions between biogeochemical cycles and tree species composition

Influence of Sugar Maple on the Nitrogen Cycle

Plourde et al. 2007