Global nitrogen (im)balance: New approaches to the 7th element

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Carbon and nitrogen since LGM

Without this added N, atmospheric CO$_2$ would be ~ 600 ppm higher, or 3 to 4 degrees C warmer.
Missing N sink (s) and missing N source (s) and the global N balance?
1. Global hotspots of gaseous N losses in the terrestrial biosphere – **missing N sink?**
   • C,N, P modeling and natural isotopic constraints

2. N input via rock weathering – **missing N source?**
   • Cases study in natural forests and global calculations

3. Frontiers
Problem: $N_2$ production < $10^{-7}$ of the pool of atmospheric $N_2$
Gaseous $\delta^{15}N$

Terrestrial $\delta^{15}N$ (vegetation, soil)

Denitrification Zone

$\text{NO}_3^-$

Input $\delta^{15}N$

Gaseous $\delta^{15}N$

$\text{f}_{\text{gas loss}}\varepsilon_G$

$\text{f}_{\text{leaching}}\varepsilon_L$

Hydrologic $\delta^{15}N$

$\text{f}_{\text{gas}} = \frac{\delta^{15}N_{TB} - \delta^{15}N_I + \varepsilon_L}{\varepsilon_L - \varepsilon_G}$

(Houlton et al., PNAS, 2006; Houlton et al., PNAS, 2007; Houlton and Bai, PNAS, 2009; Bai and Houlton, GBC, 2009)
$$f_{gas} = \frac{\delta^{15}N_{soil} - \delta^{15}N_I - (\epsilon_{NH3} - \epsilon_L) \times f_{NH3} - \epsilon_L}{\epsilon_G - \epsilon_L}$$

Houlton and Bai, *PNAS*, 2009
Denitrification gas loss fractions

\[
f_{\text{gas}} = \frac{\delta^{15} N_{\text{soil}} - \delta^{15} N_I - (\varepsilon_{\text{NH}_3} - \varepsilon_L) \times f_{\text{NH}_3} - \varepsilon_L}{\varepsilon_G - \varepsilon_L}
\]

Bai, Houlton and Wang, *Biogeosciences*, in press
Denitrification fluxes

\[
f_{\text{gas}} = \frac{\delta^{15}N_{\text{soil}} - \delta^{15}N_I - (\epsilon_{\text{NH}_3} - \epsilon_L) \times f_{\text{NH}_3} - \epsilon_L}{\epsilon_G - \epsilon_L}
\]


Bai, Houlton and Wang, *Biogeosciences*, in press
\( \text{NO}_x \) *
11 – 20 Tg
*(cut in half with canopy)

\( \text{N}_2\text{O} \)
7 – 13 Tg

\( \text{N}_2 \)
15 – 27 Tg

Bai, Houlton and Wang, *Biogeosciences*, in press
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Global distribution of “fixed” N

- **Biosphere**: 1%
- **Rock N**: 99%
Have we been working with the right N cycle?
Study Sites

<table>
<thead>
<tr>
<th></th>
<th>N-rich rock</th>
<th>N-poor rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geology:</td>
<td>Mica Schist</td>
<td>Diorite</td>
</tr>
<tr>
<td>Elevation:</td>
<td>1750 m</td>
<td>1500 m</td>
</tr>
<tr>
<td>N deposit:</td>
<td>&lt; 1kg ha(^{-1})</td>
<td>&lt; 1kg ha(^{-1})</td>
</tr>
<tr>
<td>Aspect:</td>
<td>NE &amp; N</td>
<td>N</td>
</tr>
<tr>
<td>Precip:</td>
<td>1520 mm</td>
<td>1400 mm</td>
</tr>
<tr>
<td>Temp:</td>
<td>9° c</td>
<td>10.5° c</td>
</tr>
<tr>
<td>Rock:</td>
<td>682 ppm</td>
<td>55 ppm</td>
</tr>
</tbody>
</table>

Species sampled:
- *Abies concolor* (White Fir)
- *Pinus lambertiana* (Sugar Pine)
- *Pinus ponderosa* (Ponderosa Pine)
- *Calocedrus decurrens* (Incense Cedar)
Total N in Plant Foliage

**p < 0.05**

**p < 0.01**

***p < 0.001

n=12

n=9

n=12

n=9

n=10

Ponderosa Pine

Morford, Houlton, and Dahlgren, *Nature*, 2011
$\delta^{15}N$ of Plant – Soil – Rock System

N-rich rock

N-poor rock

Morford, Houlton, and Dahlgren, *Nature*, 2011
### Estimated N Inputs

<table>
<thead>
<tr>
<th></th>
<th>Isotope balance</th>
<th>Isotope balance with fractionations</th>
<th>Uplift</th>
<th>Lab weathering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction of total N inputs via rock weathering</td>
<td>1.22</td>
<td>0.30</td>
<td>0.47</td>
<td>0.64</td>
</tr>
</tbody>
</table>

3 to 10 Kg N/ha/yr, or ~ doubling of N inputs

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Morford, Houlton, and Dahlgren, Nature, 2011
Global Flux – $^{10}\text{Be}$ and average N

Erosion Rate: 218 m per Mya
Assumptions:
- Earth land surface = 150,000,000 km$^2$
- Rock Density: 2750 kg / m$^3$
- Rock N content (400 - 500 ppm)
- Chemical Depletion Factor: 0.25 - 0.30

N Denudation: Physical + Chemical (Tg yr-1)
- Low: 48
- High: 64

Chemical Weathering (Tg yr-1):
- Low: 12
- High: 19

Rock N in Forests: 4 – 6 Tg
(c.f. N deposition to forests: 2 - 6 Tg)

Potential rock N contribution to carbon sequestration in forests: 0.2 - 0.9 Pg*
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Scientific frontiers

- N saturation vs. progressive N limitation – interactions of C, N, P cycles?
- Global inputs via rock weathering: patterns, mechanisms and fluxes?
- Coupled satellite/observations of N cycle fluxes – how to link?
- How did the N cycle respond to past change?
Example: isotopic modeling and satellites

Bai, Houlton and Wang, *Biogeosciences*, in press
Example: Paleo-markers of C x N x Climate

Source: [hkp://hawaiian-islands.chryslerprowler.co.uk/hawaiian-islands/](http://hawaiian-islands.chryslerprowler.co.uk/hawaiian-islands/)

Credit: Sara Enders
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