Soil denitrification

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Atmospheric deposition
NH4, NO3, H, S, Ca, Mg, K

Uplands: nitrification (hardwoods)  Lowlands: denitrification

N\textsubscript{2}O

DON, DOC, S, Ca, Mg, K

N, S, Ca, Mg, K

DTW

DON, DOC, S, Ca, Mg, K

N\textsubscript{2}O

Soil denitrification: forest ecosystem context

Atmospheric input for wet and dry deposition:
- $H^+$, $NH_4^+$, $NO_3^-$, $SO_4^{2-}$, $Ca^{2+}$, $Mg^{2+}$, $K^+$, $Na^+$, $Cl^-$

Exports:
- Forest Harvesting / Fires
- Litter fall (S, N, Ca, Mg, K)

Soil weathering:
- Ca, Mg, K, P
- & acid buffering

Water movement:
- Soil leaching: $SO_4^{2-}$, $NO_3^-$, $Ca^{2+}$, $Mg^{2+}$, $K^+$, $Al^{3+}$, $Na^+$, $Cl^-$, DOC, DON

Denitrification:
- Increases with increasing soil wetness

Uptake:
- $NH_4^+$, $NO_3^-$, $Ca^{2+}$, $Mg^{2+}$, $K^+$
N application / denitrification rates (g / ha day):
note relationship between de-nitrification and with soil wetness

Denitrification rates (g / ha day)
Modeling soil moisture (pore space fraction) and denitrification (kg / ha day)

Atmospheric deposition

NH₄, NO₃, H, S, Ca, Mg, K

Uplands: nitrification (hardwoods)  Lowlands: denitrification

N₂O

DTW

N, S, Ca, Mg, K

SOIL MOISTURE INDEX (S, pore space fraction)

= f(daily weather, topography, soil permeability, AET)

DENITRIFICATION (eq ha⁻¹ yr⁻¹) = f (N loads, S, T, pH); Heinen, 2006
Soil moisture (pore space fraction) = \(1 - (1 - S_{\text{weather}}^{\text{ridge}})[\frac{1 - \exp(-k \, DTW)}{1 - \exp(-k \, DTW_{\text{ridge}})}]^p\)
Soil moisture (pore space fraction) = $1 - (1 - S_{\text{weather}}^{\text{ridge}}) \left[ \frac{1 - \exp(-1.77 \text{ DTW}_{\text{ridge}})}{1 - \exp(-1.77 \text{ DTW}_{\text{ridge}})} \right]^2$
\( \log_{10} \text{denitrification (g-N ha}^{-1} \text{ day}^{-1} \) \\

Meadow: \( y = 4.32 + 5.33 (1 - S/100) \)

Field: \( y = 4.32 + 7.47 (1 - S/100) \)

Dobbie and Smith (2006)

Slope decreases with earlier onset of anaerobic condition, or with increasing biological oxygen demand within the soil.

Measurement variations and associated uncertainties are high: about ± one order of magnitude.
Denitrification decreases rapidly with increasing depth to water, and decreasing soil moisture content.

\[ \log_{10}(N_2O \text{ flux, g ha}^{-1} \text{ day}^{-1})_{\text{Grassland sandy loam}} = D_p - w (1 - S) \]
Soil denitrification (g/ha day): generalized model

\[ D_{a, \text{uplands}} = \min(D_{\text{pot}}, N_{\text{dep}} + N_{\text{fix}} - N_{\text{uptake}} - N_{\text{imm}}) f_N f_S f_T \]

\[ D_{a, \text{wet areas and flow channels}} = \min(D_{\text{pot}}, N_{\text{dep}} + N_{\text{fix}} - N_{\text{uptake}} - N_{\text{imm}} - D_{a, \text{uplands}}) \frac{\text{catchment area above stream point}}{\text{wet area above stream point}} f_N f_S f_T \]

\[ [\text{NO}_3 - N_{\text{stream}}] = \frac{(N_{\text{dep}} + N_{\text{fix}} - N_{\text{uptake}} - N_{\text{imm}} - D_{a, \text{uplands}} - D_{a, \text{wet areas and flow channels}})}{\text{stream discharge}} \]

\[ f_N = \frac{N_{\text{dep}} + N_{\text{fix}} - N_{\text{uptake}} - N_{\text{imm}}}{14 \cdot 2900 + N_{\text{dep}} + N_{\text{fix}} - N_{\text{uptake}} - N_{\text{imm}}}; \text{ ExpertN} \]

\[ f_S = \exp[-w(1 - S)]; \text{ derived from Dobbie and Smith, 2006} \]

\[ f_T = \exp[- \frac{E_a}{R} (\frac{1}{T} - \frac{1}{288})]; \text{ Arrhenius equation} \]
Denitrification potential increases with increasing soil permeability

\[ D_{\text{pot}} = 100.9 \text{ Sand}_w (\%) + 825 \text{ OM}_w (\%), r^2 = 0.94 \]
DEM + hydrographic features
“Burn” hydrographic features into DEM
Reintroduce hydrographic features
Determine flow directions and accumulations
Determine depth-to-water next to all open water features
Wet-areas mapping, at 10 m resolution:

80-90% field conformance

Blue:
flow channels, previously mapped

Grey to green:
water 0 to 1 m below soil surface
...And Using it for Wet-Areas Coastal Mapping...

Mapping extent of costal wetland features – Point Comeau, NB
…wet areas mapping for enhanced visualization …
Potential denitrification rates in wet areas (RF, RM, RC) and even on fine-textured uplands (RF, RM, RC) far exceed usual atmospheric N deposition rates (<1 to 8 kg N / ha year) for North America.

Texture classes:
- F – fine
- M – medium
- C - coarse

Denitrification rate (kg N/ha/yr)
Modeling potential denitrification rates, at high (10 m) resolution

High resolution mapping of flow channels (blue)

Same area, with depth-to-water overlay

Depth to water (m)

Estimated denitrification rate (kg N ha / year) for the same area, based on depth-to-water and corresponding literature-derived model
Inorganic nitrogen wet deposition from nitrate and ammonium, 2005

Sites not pictured:
AK03 0.3 kg/ha
VI01 1.0 kg/ha

National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu
Upland soil acidification exceedances, eq / ha year related to BEC classes
Upland and wetland soil acidification exceedances, eq / ha year accounting for denitrification in wet areas
Upland and wetland soil acidification exceedances, eq / ha year accounting for denitrification in wet areas
Economic Implications for Nova Scotia

…considering the replenishment of cumulative nutrient depletions and deficits through fertilization and/or liming…

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Product ($/ton)</th>
<th>Application ($/ton)</th>
<th>Transportation ($/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca</td>
<td>125</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Mg</td>
<td>175</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>K</td>
<td>455</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>N</td>
<td>639</td>
<td>45</td>
<td>45</td>
</tr>
</tbody>
</table>
Critical soil acidification load model (steady state):

\[ \text{net acid in} = \text{net acid out}, \]

calculable from known S, N, Ca, Mg, and K inputs and exports

*Upland areas are more sensitive to soil acidification than wet areas*

**Exceedance (in equivalents / ha year) =**

\[ \text{S+N deposition} - \text{base cation input} - \text{N uptake and return} \]
Base cation depletion = loss of exchangeable bases, from rooting zone

Nutrient deficits = nutrient export – site-level inputs (atm. + soil)
CL acidification calculations

\[
\text{CL}_{\text{soil acidification}} = BC_{\text{dep}} + BC_{\text{weathering}} - BC_{\text{uptake}} \\
+ N_{\text{uptake}} + N_{\text{immobilization}} + N_{\text{denitrification}} - ANC_{\text{leach(crit)}}
\]

\[
\text{Exceedance}_{\text{soil acidification}} = N_{\text{dep}} + S_{\text{dep}} - \text{CL}_{\text{soil acidification}}
\]

\[
N_{\text{immobilization}} = 0
\]

\[
N_{\text{denitrification}} = f(N_{\text{dep}}, \text{texture, drainage, topography, weather})
\]
Atmospheric deposition

$\text{H}^+, \text{NH}_4^+, \text{NO}_3^-, \text{SO}_4^{2-}, \text{Ca}^{2+}, \text{Mg}^{2+}, \text{K}^+, \text{Na}^+, \text{Cl}^-$

Ecological Land Classification (DNR)

**Dominant Species:** optimal MAI (tons / ha year)
wood density (ton of biomass /m$^3$ of wood)
nutrient concentrations (N, Ca, Mg, K, P)
in: foliage, branches, stem wood, bark

Soil type (CANSIS)

texture, organic matter, coarse fragments, soil depth,
ratio of exchangeable bases

Bedrock type

4 weathering classes: low, intermediate, high, calcareous
NS Depletion Costs (harvest + acid leach)

NS Nutrient Deficit Costs (harvest only)

Decreased atm. deposition
Outlook

Develop economic implications of N, S, Ca, Mg, K deposition and depletion, in the context of local nutrient supply-demand contexts

Develop model useful for assessing nutrient sustainabilities: uplands, wetlands

Develop model assessing atmospheric deposition and upland-wetland nutrient uptake, exports and losses in relation to water quality issues
Above calculations and maps are approximate
  based on available and fairly generalized information

For operational use in forestry, need to focus on stand-level MAI expectations

Need to conduct more analyses:
  wood, bark, branches, foliage
  wood density, biomass fractions, nutrient concentrations

Develop operational performance tests
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