Exploring the impacts of belowground plant traits on the permafrost carbon-climate feedback

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Tundra is nutrient limited
Permafrost nitrogen

Early summer
- Vegetation
- Active layer
- Permafrost

Late summer
- Vegetation
- Active layer
- Permafrost

![Graph showing temporal changes in bulk soil N (%)](Mack unpubl. data)

- Time

We collected preliminary data on permafrost N release from northeastern Siberia Orthel soil profiles frozen during the Pleistocene. Average release was 15 times higher from permafrost soil than from texturally similar mineral soil in the active layers of the same sites. Allocation of biomass to woody tissue is 10-100 times higher in shrub than in graminoid tundra, and shrub litter tends to produce the most recalcitrant litter. The potentially labile C pool from this 1-cm layer—C likely to be released as CO$_2$ over 150 yr—was two to 16 times greater in permafrost than active soils. Cumulative N release was positively related to total N concentration, and this labile N pool—was two to 16 times greater in permafrost than active soils. Nitrogen released at thaw was comprised of equal parts D$_N$ and DIN and a very small amount of NO$_3$-, which is then subject to the fates outlined above. We refer to further enzymatic processing. When permafrost thaws, SON is subject to microbial decomposition, and a fraction is released as DON and DIN, which is then subject to the fates outlined above.

In the field, labile N may be immobilized by microbes, taken up by plants either directly or indirectly via mycorrhizal symbionts, nitrified and/or denitrified to a partially or completely reduced N gas, or transferred to aquatic ecosystems via hydrological loss. Although microbial immobilization is the most likely immediate fate in low N systems, plants are the winners of plant-microbe competition in the long run because of temporal niche differentiation.
Coupled C and N cycling

Net Ecosystem Carbon Balance
Heterotrophic Respiration & Other C Losses

Net Primary Production

↑ CO₂

↑ Temperature

Permafrost Thaw

NO₃⁻

DON

NH₄⁺

Permafrost SOM Decomposition

Loss
Do belowground traits dictate nutrient uptake as permafrost thaws?

**Hypothesis:** Permafrost N will be acquired by plants with
• roots that can grow *deep* and stay active *late*
• *mycorrhizal symbionts* that forage at the thaw boundary

**Goals:** Characterize species rooting profiles & determine whether there is active uptake of deep N when thaw depths are deepest
Project scope

• Intensive experimental sites
• Extensive regional survey sites
• Regional modeling with TEM
Warming at Toolik yields conditions similar to Eight Mile Lake

<table>
<thead>
<tr>
<th>Variable</th>
<th>Toolik</th>
<th>Toolik greenhouses</th>
<th>EML</th>
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</thead>
<tbody>
<tr>
<td>Mean annual temperature</td>
<td>-7.0°C</td>
<td>-6.0°C</td>
<td>-1.0°C</td>
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<tr>
<td>Surface permafrost temperature</td>
<td>-5.0°C</td>
<td>-4.0°C</td>
<td>-0.7°C</td>
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<tr>
<td>Average active layer depth</td>
<td>~40 cm</td>
<td>~60 cm</td>
<td>~60 cm</td>
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*Conditions at EML are close to those predicted for Toolik Lake by 2100*
Exploring deep roots and deep N

• Research at Eight Mile Lake on belowground root traits and deep N uptake was recently published in Journal of Ecology

• Finishing a manuscript exploring how mycorrhizal fungi may be an important mechanism for dwarf shrub access to deep N
Focus at and near Toolik Field Station

Experimental site

Regional survey
Effects of experimental warming

LTER warming experiment: aboveground vascular plant biomass 2016
Effects of experimental warming

Trend in late season thaw depth

Thaw depth during our harvest
Methods overview

Deep Isotope addition
Fate of the tracer

Aboveground

Belowground
Fine root profiles

Dry root biomass (g m-2)

Depth (cm)

Ambient

Warmed

Rubcha  Carbig  Betnan/Salpul  Pedfri
Erivag  Betnan  Ericoid  Unknown
Rooting plasticity and acquisition of permafrost N

**Rooting plasticity**

![Graph showing rooting depth vs. max thaw depth](image1)

- $R^2 = 0.43$, $p < 0.05$
- $R^2 = 0.50$, $p < 0.01$
- $R^2 = 0.67$, $p < 0.001$

**Deep N acquisition**

![Graph showing mean rooting vs. mean atom % enrichment](image2)

- Ambient: $R^2 = 0.687$
- Warmed: $R^2 = 0.466$
Rooting plasticity and acquisition of permafrost N
Plant acquisition of permafrost N

Variable importance explaining fine root isotope enrichment

- Proximity to deep N affords the greatest uptake more so than biomass or root length

Deep N acquisition by fine roots
Plant acquisition of permafrost N

Aboveground harvest

Aboveground harvest: % isotope recovered
Next steps: the role of mycorrhizal fungi

- Molecular characterizations:
  - Fungal depth profiles
  - Fungal connection between rooting zone and thaw front
    - Root DNA
    - Thaw front RNA
EML: fungal connection to the thaw front

Root and permafrost thaw front fungi

Fungal connection to the thaw front

Root DNA: 215, 34, 2
Soil RNA: 15, 115
Soil DNA: 51

Connectivity index for different plots:
- Behan
- Empng
- Leddec
- Vaculi
- Vacvit

Plot categories:
- Shrub
- Tussock
EML: fungal-connection effect on deep N access

Fungal connection to the thaw front and percent tracer recovered

Taxon-specific fungal access to deep N

- OTU110 UK_Helotiaceae
- OTU33 Cortinarius croceus
- OTU32 Lachnum pygmaeum
- OTU401 Sebacina sp.
- OTU39 UK_Helotiaceae
- OTU37 Lactarius rufus
- OTU1228 Rhizoscyphus ericae
- OTU655 UK_Hyaloscyphaceae
- OTU928 Rhizoscyphus ericae
- OTU880 Rhizoscyphus sp.
- OTU1047 UK_Helotiaceae
- OTU49 UK_Hyaloscyphaceae
- OTU1248 Rhizoscyphus sp.
- OTU273 UK_Agaricomycetes
- OTU179 UK_Helotiaceae
- OTU177 Sebacina sp.
- OTU177 Mycena sp.
Summary

• Thaw depth is an important predictor of belowground dynamics
• Forb, sedge, and deciduous shrub PFTs forage more deeply with increasing thaw
• *R. chamaemorus* and *E. vaginatum* have the deepest roots and the greatest uptake of $^{15}$N
• *E. vaginatum* and *B. nana* showed some tracer recovery in their leaves within 24 hours.
• Mycorrhizal fungi may be an important mechanism of deep N access for shallowly rooted shrubs
Belowground ecology informs predictions for the Arctic

• Long term fate of permafrost N
  • Stimulation of productivity?
  • Allocation, turnover, persistence in ecosystem materials

• Deep N immobilization in fungal biomass
  • Saprotrophs vs. mycobionts
  • Quantification of uptake, turnover, stability of fungal pool

• Linking microbial community dynamics to flux measurements
  • Moving towards absolute not relative abundances
  • Heterogeneity of organisms and environment
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