Understanding litter input controls on soil organic matter turnover and formation are essential for improving carbon-climate feedback predictions for Arctic, tundra ecosystems

Project Overview

The Arctic region has been an important net sink of carbon (C) over recent millennia because decomposition has been limited by cold, wet conditions. As a result, Arctic soils have accumulated an estimated 1672 Pg of soil C, which is roughly equal to the total amount of C that is contained in all other soils across the globe combined (Post et al. 1982). However, climate warming could turn the Arctic into a net C source as soil organic matter (SOM) decomposition accelerates and permafrost thaws. In addition to temperature-driven acceleration of decomposition, several additional processes could either counteract or augment warming-induced SOM losses. For example, increased plant growth under a warmer climate will increase organic matter inputs to soils, which could fuel further soil decomposition by microbes, but will also increase the production of new SOM. Whether Arctic ecosystems store or release carbon in the future depends in part on the balance between these two counteracting processes, which this project focuses on. By differentiating SOM decomposition and formation and understanding the drivers of these processes, we will better understand how these systems function.

(1) Field investigation of SOM priming and formation with labile substrate addition

Rapid climate warming in the Arctic threatens to destabilize vast stocks of soil carbon (C) that have accumulated over millennia, which could amplify the C-climate feedback. However, climate-induced shrub expansion may counteract these losses if their higher-quality litter is efficiently incorporated into microbial products and stabilized within the soil. On the other hand, increased C inputs could stimulate microbial decomposition of old soil organic matter (SOM) through priming mechanisms. We investigated whether inputs of low molecular weight carbon (LMW-C) induced SOM priming or stabilization in soils underlying *Eriophorum vaginatum*, a ubiquitous tussock-forming sedge, and *Betula nana,* a dominant shrub that is expanding its range and coverage across the Arctic.

(2) Laboratory investigation of SOM priming and formation with labile substrate and short-term nutrient additions:

To test whether nutrient additions influence SOM priming and formation, we performed a laboratory experiment with soils associated with *B.nana and E.vaginatum*. Our experiment consisted of three treatments: ^{13}C-enriched glucose, ^{13}C-enriched glucose + ammonium nitrate, and a water-only control. We tracked ^{13}C-CO_2, ^{13}C-microbial biomass, and ^{13}C-soil C over 25 days.

(3) Laboratory investigation of SOM priming and formation with long-term nutrient additions:

What is the persistence of SOM priming with nutrient additions? We utilized soils from the long-term fertilization plots at Toolik Lake (initiated in 1989) to examine whether SOM priming, that we previously observed with short-term fertilization (#2 above), actually persists with consistent, long-term nutrient inputs. We performed the same experiment described above with soils that had been fertilized since 1989 and control (no nutrient addition). Our experiment consisted of three treatments: ^{13}C-enriched glucose, ^{13}C-enriched glucose + ammonium nitrate, and a water-only control. We tracked ^{13}C-CO_2, ^{13}C-microbial biomass, and ^{13}C-soil C over 25 days.

(4) The influence of litter chemistry and temperature on SOM priming and formation (Laboratory and Field Investigation):

We have successfully labeled both *E. vaginatum* and *B. nana* with enriched ^{13}C and ^{15}N and have used leaf litter in both laboratory and field experiments. In all of these experiments we hope to gain a better understanding on leaf litter C and N fate in arctic soils. We have completed a laboratory incubation with isotopically labeled *E. vaginatum* leaf litter. We sampled soils along a landscape gradient and enormous spatial heterogeneity in dissolved nutrients, microbial biomass, and soil texture allowed us to examine potential mechanisms controlling decomposition. We incubated each soil core separately with *E.* vaginatum leaf litter and tracked decomposition and leaf litter C an N stabilization over 150 days. In August 2015, we set up a decomposition experiment in long-term warming and fertilization plots at Toolik Lake. We are tracing the fate of litter C and N into soils with isotopically labeled (^{13}C and ^{15}N) *B.nana* leaf and wood litter. We completed the first harvest of this experiment in August 2016 and will collect the final harvest of this experiment in July 2017. We plan to complete laboratory analysis of these samples during the next reporting period.

(5) From Roots to Rivers: Tracking the fate of dissolved organic matter through Arctic tundra soils

Last fall we conducted an experiment at Imnavait Creek, AK (ten miles north of Toolik Lake Field Station) to assess how dissolved organic carbon is mobilized and transported through Arctic hillslopes to adjacent streams. We used bromide (a conservative tracer) and tension lysimeters to determine whether preferential flow paths exist in the organic soil layer (12 cm deep) or along the permafrost interface (~25 cm deep). We collected pore water from both soil depths and analyzed functional chemistry with proton-nuclear resonance mass spectrometry (^{1}H-NMR) and optical properties using excitation-emission matrices (EEMS). We also visualized permafrost topography and transitions between organic and mineral layers using ground-penetrating radar. Together, these studies enhance our understanding of dissolved organic carbon chemistry and mobility as permafrost thaws (Figure 2).

Significant Results:

1. We did not find evidence of priming, defined as an increase in the decomposition of native SOM stocks, from soils underlying either vegetation type. However, LMW-C conversion to CO_2 was twice as high in soils underlying *E. vaginatum* than *B. nana,* and LMW-C stabilization efficiencies were 150% greater in soils underlying *B. nana.* Our results highlight the resilience and extraordinary C storage capacity of these soils, and suggest shrub

expansion may partially mitigate C losses from decomposition of old SOM as Arctic soils warm (Figure 1).

2. We found that N addition stimulated SOM priming in *E.vaginatum* soils but not *B.nana* soils. Microbial glucose utilization was also higher in *E.vaginatum* soils. This suggests that SOM priming is dependent on dissolved N concentrations and vegetation type. *E.vaginatum* soils are associated with lower dissolved nutrients and lower microbial biomass presumably a result of greater microbial nutrient limitation. We plan to submit this manuscript for publication during the next reporting period.

3. Twenty+ years of fertilization has decreased the amount of SOM decomposition and shifted SOM chemistry. Additional N additions did not stimulate SOM priming in soils that have been fertilized for over 20 years. This suggests that SOM priming may be a transient response and not persist with consistent nutrient additions. We found that 20+ years of fertilization caused a substantial shift in SOM chemistry towards a greater abundance of recalcitrant, aromatic C. Consequently, the fertilized plots have lower microbial biomass, lower dissolved C, and significantly lower respiration. It has been previously documented that fertilization (in these same plots) leads to a significant reduction of SOM C stocks, despite having much higher aboveground productivity. Our results suggest that nutrient additions can destabilize old SOM (SOM priming) leading to a decrease in soil C stocks, but this effect does not persist. Higher aboveground productivity and decreased SOM decomposition in soils associated with long-term fertilization may lead to SOM accumulation over time and the soil C stocks may rebuild. This manuscript is currently in preparation and we plan to submit for publication during the next reporting period.

4. N/A

5.Permafrost-inluenced soils were significantly enriched in aromatic C, soluble microbial byproducts, and humic-type materials, while organic soils had higher proportions of fulvic acids. Molecular diversity was also higher in pore waters collected at the permafrost interface relative to those collected in the upper organic layer. Rates of solute transport along the permafrost interface were similar to those through porous organic soils, suggesting permafrost thaw could mobilize SOM across the landscape. We plan to submit this manuscript during the next reporting period.

<u>Modeling</u>

Background/Question/Methods

The incorporation of explicit representation of biological complexity in soil carbon decomposition models may improve our ability to accurately predict terrestrial carbon-climate feedbacks. A new generation of microbe-explicit soil decomposition models (MEMs) are being developed that represent soil biological complexity, but only a few take into account detailed biotic and abiotic components and competitive interactions in the complex soil system. In view of this, we have developed a MEM with a detailed component network, in which competitive interactions and microbial metabolism are explicitly modeled. The model behavior has been tested and is qualitatively consistent with many empirical studies, but further model development and evaluation with experimental data is needed. In this study, we aim to investigate how competitive interactions between microbes and mineral surfaces influence soil organic carbon (SOC) turnover. To explicitly consider microbe-mineral interactions, we further develop the model by incorporating a mineral protection process and a dissolved organic carbon-dependent microbial physiological activity function. Two carbon isotope labeled addition experiments with a varying range of soil properties are used to test, parameterize, and evaluate the model behaviors. Model sensitivity to key parameters is analyzed, and the importance of microbe-mineral competitive interactions in controlling SOC turnover is discussed.

Results/Conclusions

Preliminary results show that the developed MEM is able to well simulate the dynamics of each soil carbon component including the evolutions of carbon dioxide efflux and microbial biomass, and microbe-mineral competitive interactions play a key role in controlling SOC turnover.

Publications

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