The Berkeley Lab Belowground Biogeochemistry SFA: Overview and Results of Five Years of Deep Soil Warming

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BER Program: TES
Project: Belowground Biogeochemistry SFA (lead: LBNL)
Project Websites:
https://eesa.lbl.gov/projects/terrestrial-ecosystem-science/
https://tes.lbl.gov/

Project Abstract:

In the Berkeley Lab Terrestrial Ecosystem Science SFA, we research the role of soils in terrestrial biogeochemistry and the Earth system. Our goals are to improve process-level understanding of ecosystem-climate interactions and to develop predictive capacity suitable for Earth system models. SFA research integrates field, laboratory, and model experiments to characterize how biotic and abiotic processes influence soil carbon cycling, and may shape ecosystem responses to a warming climate. We are warming the whole soil profile to +4ºC in a well-drained coniferous forest (Blodgett Forest), and are setting up a second deep-soil warming experiment in a coastal grassland (Point Reyes). At each site, we are studying the influence of soil depth, mineralogy, biota, and climate on soil carbon dynamics. We are using results from field and lab studies to guide model development in a framework for Biogeochemical Transport and Reactions (BeTR), for the DOE E3SM land model and others.

In the first two years of the Blodgett forest warming experiment, soil respiration increased by 35% from all depths (Hicks Pries et al. 2018). After five years of warming, there is no significant attenuation trend; there is still a sustained, 30% increase in soil CO_2 efflux due to increased production throughout the soil profile (Soong et al. 2021). Moreover, subsoil (below 20 cm) carbon stocks were 33% lower in heated plots. This loss of subsoil carbon was primarily from unprotected particulate organic matter. The observed decline in subsoil carbon stocks is evidence for a positive carbon-climate feedback, which could not be concluded based on increases in CO_2 efflux alone. The high sensitivity of subsoil carbon, and the different responses of soil organic matter pools, suggest that models must capture these heterogeneous soil dynamics to accurately predict future feedbacks to warming.

Additional posters will present research on Blodgett microbiology (presented by Alves) and Point Reyes site characterization and experimental design (presented by Pegoraro and Rowley).

Publications

Hicks Pries, Castanha, Porras, and Torn. 2017. The whole soil carbon flux in response to warming. *Science* DOI: 10.1126/science.aal1319

Soong, Castanha, Hicks Pries, Ofiti, Porras, Riley, Schmidt, and Torn. 2021. Five years of whole-soil warming led to loss of subsoil carbon stocks and increased CO2 efflux. *Science Advances*, DOI: 10.1126/sciadv.abd1343

Title: Integrated Site Characterization for a New Whole-Soil Warming Experiment in a California Grassland

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Project Abstract:

The LBNL Belowground Biogeochemistry SFA is establishing a whole-soil warming experiment in a coastal California grassland. The objective of this study was to characterize soil physico-chemical properties and seasonal hydrological dynamics along the Point Reyes warming experiment catena and vertical soil profile.

To temporally and spatially characterize the site we used remotely sensed measurements of plant properties and topography, and geophysical measurements of soil and sediment heterogeneity over a multi-month period. To calibrate our interpretations of the geophysical data we installed shallow groundwater monitoring wells and characterized soil cores (~1 m) at strategic locations for soil properties and microbial composition. Soil mineralogy was also determined by synchrotron-based X-ray diffraction. To our knowledge, this kind of integrated characterization has not been completed prior to the beginning of an ecosystem climate-change experiment, and it has had an impact on site understanding and experimental design.

Geophysical surveys by electrical resistivity tomography (ERT) and electromagnetic induction (EMI) revealed levels of heterogeneity within the study site that were not apparent either from surface observations or through traditional soil coring. We are testing whether the observed soil texture, and its pattern with depth, can be extrapolated to the site using ERT. The instrumented shallow piezometers have shown that water table fluctuations at the site are more dramatic than was expected. In the wet season, the water table rises as high as ~0.8 m below the ground surface in the vicinity of the study plots, well within the ~ 120 cm vertical region of interest (and heating) for this project.

These results have brought into focus important processes, such as redox variation, while the water table fluctuations will allow us to investigate the coupling between temperature and interannual moisture variations. The integrated picture informs the design of the heating treatments and the experimental layout, and will make the interpretation of future experimental results more robust. We will implement a regression design with multiple heating levels (+3 and +6 °C), and minimize intra-block variation and locate blocks across the landscape based on ERT and EMI results to explore the natural gradient in moisture, parent material, and vegetation. This will allow us to better elucidate the impacts of soil warming on ecosystem dynamics and threshold responses. In addition, by better incorporating the site hydrology in our understanding we will create a stronger connection between this project and other BER-funded efforts on water impacts and coastal exports.

Title: Microbial Exoenzyme Kinetic Traits Vary with Soil Depth but Have Similar Temperature Sensitivities Through the Soil Profile

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Project: Belowground Biogeochemistry SFA (lead: LBNL)

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Project Abstract: The microbial mechanisms controlling soil organic matter (SOM) decomposition with warming are not well understood, particularly in subsoils, although they contain over 50% of global soil carbon. Deep soils have different physicochemical properties, nutrient inputs, and microbiomes, but it is not known if these lead to different SOM dynamics and temperature responses. In the LBNL Belowground Biogeochemistry SFA, 4.5 years of whole-profile soil warming at Blodgett Forest, CA, have led to higher microbial growth rates and modest depth-dependent changes in microbiome composition and metabolic potential. However, microbiomes in deeper soils have lower growth rates, carbon use efficiency, and potential to produce carbohydrate-active enzymes. We hypothesized that kinetics and temperature sensitivity of microbial exoenzymes, which mediate SOM depolymerization, vary with soil depth, reflecting adaptation to distinct substrate and temperature regimes. We determined the Michaelis-Menten (MM) kinetics of three ubiquitous enzymes involved in carbon (C), nitrogen (N) and phosphorus (P) acquisition at six soil depths to 90 cm, and their temperature sensitivity between 4-50°C based on Arrhenius and Macromolecular Rate Theory (MMRT) models. Maximal enzyme velocity ($V_{\max}$) decreased strongly with depth for all enzymes, on a soil mass or microbial biomass basis, whereas their affinities increased, indicating adaptation to lower substrate availability. However, microbial biomass-specific catalytic efficiencies (CE) of C- and N-acquiring enzymes also decreased with depth, indicating that deep soil microbiomes encode enzymes with intrinsically lower turnover and/or produce less enzymes per cell, likely reflecting distinct life strategies. $V_{\max}$ and CE increased with warming, leading to higher SOM decomposition potential at all depths. This temperature sensitivity was similar through the soil profile based on Arrhenius/Q_{10} and MMRT models, similar to what has been observed for soil respiration. However, temperature sensitivity varied between enzyme types in a depth-dependent manner, implying changes in the

potential for depolymerization of different SOM compounds with warming down the profile. We are currently investigating the temporal and temperature responses of microbial trait distributions and expression as a function of depth, based on multi-omics approaches, and linking them to experimentally verified functional properties. Our results indicate that soil microbiomes have distinct functional traits and life strategies at depth, which may be fundamental determinants of biogeochemical cycling and responses to warming. In particular, enzyme kinetics and thermodynamics may represent inherent traits of soil microbiomes at depth, and prompt a more detailed, depth-resolved representation of enzyme-mediated processes in models of SOM dynamics.