Geophysical Research Abstracts
Vol. 19, EGU2017-4548, 2017
EGU General Assembly 2017

Data-Driven Microbial Modeling for Soil Carbon Decomposition and Stabilization

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Microorganisms have long been known to catalyze almost all the soil organic carbon (SOC) transformation processes (e.g., decomposition, stabilization, and mineralization). Representing microbial processes in Earth system models (ESMs) has the potential to improve projections of SOC dynamics. We have recently examined (1) relationships of microbial functions with environmental factors and (2) microbial regulations of decomposition and other key soil processes. According to three lines of evidence, we have developed a data-driven enzyme (DENZY) model to simulate soil microbial decomposition and stabilization. First, our meta-analysis of 64 published field studies showed that field experimental warming significantly increased soil microbial communities abundance, which is negatively correlated with the mean annual temperature. The negative correlation indicates that warming had stronger effects in colder than warmer regions. Second, we found that the SOC decomposition, especially the transfer between labile SOC and protected SOC, is nonlinearly regulated by soil texture parameters, such as sand and silt contents. Third, we conducted a global analysis of the C-degrading enzyme activities, soil respiration, and SOC content under N addition. Our results show that N addition has contrasting effects on cellulase (hydrolytic C-degrading enzymes) and ligninase (oxidative C-degrading enzymes) activities. N-enhanced cellulase activity contributes to the minor stimulation of soil respiration whereas N-induced repression on ligninase activity drives soil C sequestration. Our analysis links the microbial extracellular C-degrading enzymes to the SOC dynamics at ecosystem scales across scores of experimental sites around the world. It offers direct evidence that N-induced changes in microbial community and physiology play fundamental roles in controlling the soil C cycle. Built upon those three lines of empirical evidence, the DENZY model includes two enzyme pools and explicitly characterizes two classes of extracellular enzyme activities: one that degrades organic molecules containing both C and N (e.g., chitin or protein) and another that degrades only C (e.g., cellulose). The DENZY model assumes that the microbes allocate resources to different enzyme pools so as to exactly satisfy microbial CN ratio stoichiometry in response to changes in climate conditions and soil attributes. The DENZY model can simulate differential effects of nitrogen fertilization on the two groups of enzymes and thus soil respiration and SOC dynamics. We will select field experimental sites to test the DENZY model. With increasing amounts of available observations and data synthesis, this DENZY model will be better parameterized and have a potential to reveal how responses of microbial enzymes to environmental changes regulate soil carbon decomposition and stabilization.