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Title: Long-term soil warming and Carbon Cycle Feedbacks to the Climate System

Study period: 2010-2013

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The primary objective of the proposed research was to quantify and explain the effects of a sustained *in situ* 5°C soil temperature increase on net carbon (C) storage in a northeastern deciduous forest ecosystem.

The research was done at an established soil warming experiment at the Harvard Forest in central Massachusetts – Barre Woods site established in 2001.

In the field, a series of plant and soil measurements were made to quantify changes in C storage in the ecosystem and to provide insights into the possible relationships between C-storage changes and nitrogen (N) cycling changes in the warmed plots. Field measurements included: 1) annual woody increment; 2) litterfall; 3) carbon dioxide (CO_2) efflux from the soil surface; 4) root biomass and respiration; 5) microbial biomass; and 6) net N mineralization and net nitrification rates.

This research was designed to increase our understanding of how global warming will affect the capacity of temperate forest ecosystems to store C. The work explored how soil warming changes the interactions between the C and N cycles, and how these changes affect land-atmosphere feedbacks. The findings of the study have been documented in a set of peer-reviewed papers published between 2010 and 2013 – listed below.

The core research question that framed the projected – What are the effects of a sustained *in situ* 5°C soil temperature increase on net carbon (C) storage in a northeastern deciduous forest ecosystem? - was addressed in Melillo et al., *PNAS*, 2011. The findings are summarized as follows:

Soil warming has the potential to alter both soil and plant processes that affect carbon storage in forest ecosystems. We have quantified these effects in a large, long-term (7-y) soil-warming study in a deciduous forest in New England. Soil warming has resulted in carbon losses from the soil and stimulated carbon gains in the woody tissue of trees. The warming-enhanced decay of soil organic matter also released enough additional inorganic nitrogen into the soil solution to support the observed increases in plant carbon storage. Although soil warming has resulted in a cumulative net loss of carbon from a New England forest relative to a control area over the 7-y study, the annual net losses generally decreased over time as plant carbon storage increased. In the seventh year, warming-induced soil carbon losses were almost totally compensated for by plant carbon gains in response to warming. We attribute the plant gains primarily to warming induced increases in nitrogen availability. This study underscores the importance of incorporating carbon–nitrogen interactions in atmosphere–ocean–land earth system models to accurately simulate land feedbacks to the climate system.

A second critical question addressed in this research – What are the effects of a sustained *in situ* 5°C soil temperature increase on nitrogen (N) cycling in a northeastern deciduous forest ecosystem? – was addressed in Butler et al., *Oecologia*, 2012. The findings are summarized as follows:

Global climate change is expected to affect terrestrial ecosystems in a variety of ways. Some of the more well-studied effects include the biogeochemical feedbacks to the climate system that can either increase or decrease the atmospheric load of greenhouse gases such as carbon dioxide and nitrous oxide. Less well-studied are the effects of climate change on the linkages between soil and plant processes. Here, we report the effects of soil warming on these linkages observed in a large field manipulation of a deciduous forest in southern New England, USA, where soil was continuously warmed 5°C above ambient for 7 years. Over this period, we have observed significant changes to the nitrogen cycle that have the potential to affect tree species composition in the long term. Since the start of the experiment, we have documented a 45% average annual increase in net nitrogen mineralization and a three-fold increase in nitrification such that in years 5 through 7, 25% of the nitrogen mineralized is then nitrified. The warming-induced increase of available nitrogen resulted in increases in the foliar nitrogen content and the relative growth rate of trees in the warmed area. *Acer rubrum* (red maple) trees have responded the most after 7 years of warming, with the greatest increases in both foliar nitrogen content and relative growth rates. Our study suggests that considering species-specific responses to increases in nitrogen availability and changes in nitrogen form is important in predicting future forest composition and feedbacks to the climate system.

In order to gain a better understanding of the role of microbes in response to soil warming, we used three soil warming experiments, including the one at Barre Woods, to explore microbial mechanisms that control soil organic matter decomposition. The findings of this work are summarized as follows:

Soils are the largest repository of organic carbon (C) in the terrestrial biosphere and represent an important source of carbon dioxide (CO_2) to the atmosphere, releasing 60–75 Pg C annually through microbial decomposition of organic materials[1,2]. A primary control on soil CO_2 flux is the efficiency with which the microbial community uses C. Despite its critical importance to soil–atmosphere CO_2 exchange, relatively few studies have examined the factors controlling soil microbial efficiency. Here, we measured the temperature response of microbial efficiency in soils amended with substrates varying in lability. We also examined the temperature sensitivity of microbial efficiency in response to chronic soil warming *in situ*. We find that the efficiency with which soil microorganisms use organic matter is dependent on both temperature and substrate quality, with efficiency declining with increasing temperatures for more recalcitrant substrates. However, the utilization efficiency of a more recalcitrant substrate increased at higher temperatures in soils exposed to almost two decades of warming 5 °C above ambient. Our work suggests that climate warming could alter the decay dynamics of more stable organic matter compounds, thereby having a positive feedback to climate that is attenuated by a shift towards a more efficient microbial community in the longer term.

Publications:

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