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Native temperature regime influences soil response to simulated warming

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ABSTRACT

Anthropogenic climate change is expected to increase global temperatures and potentially increase soil carbon (C) mineralization, which could lead to a positive feedback between global warming and soil respiration. However the magnitude and spatial variability of belowground responses to warming are not yet fully understood. Some of the variability may depend on the native temperature regimes of soils. Soils from low temperature climates may release more C than will soils from high temperature climates because soils in cold climates are often C-rich and may experience more warming. We investigated whether soils from low native temperatures respired more than did soils from high native temperatures. We collected intact soil cores from three elevational transects along a latitudinal gradient in the forests of southern Appalachian Mountains. Soil cores were incubated for 292 days at low, medium, and high temperatures (separated by 3 °C each) with diurnal temperature and light regimes that simulated realistic temperature changes likely to occur within the next century. The native temperature regimes of soils negatively influenced soil respiration, such that soils from cold climates respired more in response to experimental warming than did soils from warm climates. Conversely, soils from warm climates mineralized the largest proportion of available soil C and available soil nitrogen in response to warming. Across all soils, modest experimental warming increased soil respiration, the proportion of available soil C that was being respired (respiration/soil C), and the proportion of soil nitrogen that was mineralized (N min/soil N). Taken together, these data suggest that soils from low native temperatures have a greater potential to release C in response to climate warming because the C stocks are larger and respiration rates will be higher than those in soils from high native temperatures.

1. Introduction

Forest ecosystems account for approximately half of the Earth's terrestrial surface and understanding their responses to increased global temperature will be vital toward predicting future climate change feedbacks (Dixon et al., 1994). The amount of carbon dioxide (CO_2) respired from soils is over 11 times larger than the amount of CO_2 released into the atmosphere via anthropogenic processes (Bader and Korner, 2010), and forests account for approximately 40% of global soil C (Dixon et al., 1994). Increasing global temperatures can induce greater soil respiration (Bond-Lamberty and Thomson, 2010), and the presence of a positive feedback between soil carbon (C) release and temperature remains unclear (Campbell et al., 2009; Bader and Korner, 2010). The spatial distribution of C stored in soils will also affect soil C mineralization since climate change is variable at regional scales (CCSP, 2007; Christensen et al., 2007). Our goal was to determine whether the temperature dependent responses of belowground processes are influenced by regional and local variation in the native temperature regimes.

Historical climate has influenced the size and quality of C pools in soils as the biological activity that drives C turnover is temperature dependent (Bottner et al., 2000; Pendall et al., 2004). Soil C pools and turnover rates are also a product of the quantity and quality of inputs from plant litter (Berg, 2000). Aboveground inputs to belowground systems are comprised of simple, easily-decomposed substrates (labile C) as well as complex, structural molecules that are not easily degraded (recalcitrant C), and theoretical studies indicate that these substrates should have different temperature sensitivities (Sierra, 2012). The difference between labile and recalcitrant C pools has important C cycling implications, as many models partition soil C into two or three pools, with varying turnover times ranging from years to millennia (Paustian et al., 1997; Falloon et al., 1998; Tague and Band, 2004; Zhang et al., 2007). In natural systems there is a continuum of soil C recalcitrance, and the proportion of recalcitrant C increases over the course of decomposition during the process of humus formation (Berg, 2000). Humus accumulation is often associated with

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cold climates, such that these ecosystems accumulate C in recalcitrant pools (Hobbie et al., 2000). Since increases in latitude/elevation generally decrease mean annual temperature (Komatsu et al., 2010), forests at high elevations/latitudes contain more stored soil C than do forests at low elevation/latitudes, and this can have important consequences for how soils respond to elevated temperatures (Dixon et al., 1994; Garten and Hanson, 2006; Griffiths et al., 2009).

How soils respond to increasing temperatures will be an important driver of potential carbon-climate feedbacks, but there has been a lack of consensus concerning the temperature sensitivity of soil C cycling. An early meta-analysis suggested that the Q_{10} for soil organic matter decomposition, a change in reaction rate standardized to a 10 °C increase, was the greatest at low temperatures and decreased exponentially with increasing incubation temperature (Kirschbaum, 1995). However, others have also reported that decomposition of a variety of substrates is relatively insensitive to temperature (Katterer et al., 1998), time (Fang et al., 2005), or mean annual temperature (Giardina and Ryan, 2000). In addition, recent work indicates that the intrinsic temperature sensitivity of ecosystem level respiration is uniformly low across all mean annual temperatures (Mahecha et al., 2010). Some of the discrepancies among studies may be due to various experimental designs and protocols that influence soil disturbance, especially when soils are sieved and/or divided into fractions (Thomson et al., 2010). Kinetic theory suggests that temperature sensitivity should increase with soil C recalcitrance, which could limit studies that did not include different soil C pools (Davidson and Janssens, 2006; Sierra, 2012). The incubation time of soils in the laboratory can shift soil C toward recalcitrant stocks as labile C sources are catabolized, and the temperature sensitivity of heterotrophic respiration often increases with soil C recalcitrance (Conant et al., 2008; Hartley and Ineson, 2008). Finally, some mechanistic studies reveal important trends in belowground processes, but may be unrealistic because the magnitude of the experimental warming is often far beyond what soils are expected to experience based on climate change predictions for the next 100 years.

We investigated how variation in the native temperature regimes of soils influences the temperature sensitivity of belowground processes. We approximated field conditions by using relatively large intact microcosms, including the leaf litter layer, and simulating realistic temperature increases. We tracked soil microbial respiration, microbial extracellular enzymatic potential, litter decomposition, and N mineralization. We were able to address regional scale variation in native soil temperatures by collecting soil cores from a latitudinal and elevational range. Our goal was to determine whether rates of C and N cycling in soils from different native temperature regimes, with varying substrate qualities, responded differently to realistic global warming.

2. Methods

2.1. Site description

We sampled soils along three elevational transects in the southern Appalachian Mountains of North Carolina spanning a 135 km north–south range. Three sites were chosen along each transect, with differences in aspect minimized within each transect. The southernmost site was located at the Coweeta Hydrologic Laboratory in Otto, NC (USDA – USFS), and contained the greatest elevation range (~700 m, Table 1). The next largest range (~450 m Table 1) was located in Pisgah National Forest in Avery County, NC, and the final and northernmost site was on Appalachian State University's Gilley Field Station in Watauga County, NC, and contained the smallest elevation range (~ 200 m, Table 1). Soil texture and taxonomy were fairly consistent within sites but varied among sites (Table 1).

2.2. Field collection

PVC tubes 10.3 cm in diameter were inserted into the ground to a depth of 15 cm. Due to the brittle nature of the PVC cores, we necessarily avoided large roots or rocks. We allowed severed fine roots to remain within cores, as fine roots do not vary with elevation in our study region (Davis et al., 2004). Soil cores were carefully excavated from below in order to retain intact soil cores and capped at both ends for transport to the laboratory. Six cores were randomly excavated from each elevation at each site, for a total of 54 cores. Variation in soil characteristics at each site was unavoidable with intact soil cores, but allowed for a better approximation of *in situ* soil response to warming. We chose to use intact soil cores to avoid disturbing soil profiles, as sieving or homogenization can lead to large flushes of microbial activity by altering substrate availability (Thomson et al., 2010). We measured bulk density at three locations per site and monitored soil temperature at 10 cm deep using Hobo data loggers (Onset Computer Corp., Bourne, MA, USA). Soil temperature data were used to characterize the native temperature regimes of each collection site.

In order to standardize starting conditions for microcosm incubations, cores were stored at 4 °C for up to 14 days until all cores were collected. We standardized leaf litter mass among all cores to a mean value of approximately 0.7 g to normalize C inputs into soils during the incubation period. Litter type varied among sites, but all were from mature mixed deciduous stands. We tracked litter decomposition by measuring the initial and final litter mass remaining at the end of the incubation period.

2.3. Laboratory incubation

Three incubators (I-36LL, Percival Scientific Inc., Perry, IA, USA) were programmed with three different diurnal light and

Table 1
Soil collection site parameters.

	Elevation (masl)	Coordinates	Soil texture[a]	Soil taxonomy[a]
Coweeta	1381	35.0320°N, 83.4654°W	Fine-loamy	mesic Humic Dystrudepts
	1189	35.0402°N, 83.4603°W	Fine-loamy	mesic Typic Hapludults
	702	35.0563°N, 83.4324°W	Fine-loamy	mesic Typic Hapludults
Pisgah	1146	35.9190°N, 81.8888°W	Coarse-loamy	mesic Lithic Dystrudepts
	917	35.9180°N, 81.8956°W	Coarse-loamy	mesic Typic Dystrudepts
	701	35.9141°N, 81.9016°W	Coarse-loamy	mesic Typic Dystrudepts
Gilley	1025	36.2907°N, 81.5865°W	Fine-loamy	mesic Typic Hapludults
	973	36.2909°N, 81.5844°W	Coarse-loamy	mesic Typic Dystrudepts
	897	36.2914°N, 81.5828°W	Coarse-loamy	mesic Typic Dystrudepts

[a] Information taken from USDA SSURGO database (Soil Survey Staff, 2010).