SOIL RESPIRATION AND NET N MINERALIZATION ALONG A CLIMATE GRADIENT IN MAINE

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Abstract: Our objective was to determine the influence of temperature and moisture on soil respiration and net N mineralization in northeastern forests. The study consisted of sixteen deciduous stands located along a regional climate gradient within Maine. A significant portion of the variance in net N mineralization (41 percent) and respiration (33 percent) was predicted by temperature. The fraction of explained variance (r^2) was much higher when data were partitioned by region or by individual sites (as high as 80 percent). This suggests that temperature is a strong predictor of respiration and net N mineralization within climate zones, but additional environmental factors become important at a larger landscape scale. The slope of the relationship between respiration and temperature was significantly greater in the Northern and Central regions than in the Southern and Coastal regions, suggesting that soil biota are more sensitive to temperature in the former. Soil moisture was a poor predictor, probably because moisture is infrequently and transiently limiting in these forests.

INTRODUCTION

The continuing accumulation of greenhouse gases has led scientists to predict a global warming of 2 to 4 °C (Hansen et al. 1988). Because New England is at a relatively high latitude, this climate effect should be amplified, resulting in a 4 to 8 °C increase in mean annual air temperature in that region (Hengeveld and Skinner 1993). Changes in precipitation patterns are less certain but significant increases or decreases could occur (Manabe and Wetherald 1986). New England forests will be subject to potentially significant effects of these projected climatic shifts, ranging from almost immediate changes in biogeochemical cycling and phenology, to longer term changes in forest composition and productivity across the Northeast landscape.

The ability of forest vegetation to respond to changes in climate, such as increased temperatures, will depend upon the resources available to them, such as water and nutrients (Luxmoore et al. 1993, Pastor and Post 1988). Thus, it is essential that we understand how climate change will affect nutrient availability in forests. In order to predict the potential effects of climate change, we must first understand how climate currently influences soil nutrients. The Maine Gradient Study was initiated in 1993 to evaluate the effects of temperature and moisture on carbon (C) and nitrogen (N) mineralization, which are indicators of nutrient availability. We established a network of sixteen sites across the four climate regions of Maine (Briggs and Lemin 1992) and measured soil respiration, soil air CO_2 concentration, net N mineralization and nitrification, litterfall mass and chemistry, foliar chemistry and litter decomposition (Delaney et al. 1995). In this paper we focus on the soil respiration and net N mineralization results.

METHODS

Study Sites

In order to make comparisons among sites in the Gradient Study, we tried to minimize differences among sites in terms of soil and vegetation characteristics. Thus, all sites had to satisfy a set of criteria. Candidate sites were identified along a transect within each of the four climate regions (Figure 1). An extensive site selection procedure was used to reduce the over 300 candidate sites to the chosen 16 sites. Soils at all sites are moderately well-drained to well-drained Spodosols (Typic or Lithic Haplorthods) with well-developed, mor-type forest floor. Stands are dominated by a combination of sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), American beech

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(*Fagus grandifolia* Ehrh.) or red oak (*Quercus rubra* L.). Mean age of the overstory is between 80 - 150 years old and basal area is between 25 and 35 m^2 ha^{-1}.

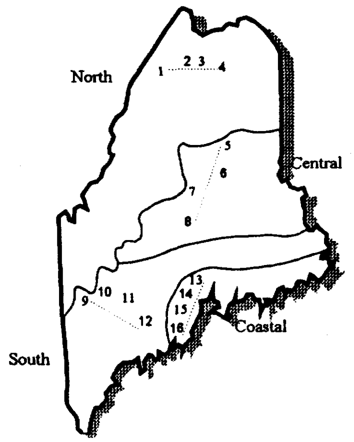

Figure 1. Location of Maine Gradient Study sites.

Sampling

At each of the 16 sites three 15 x 15 m study plots were established. Automated weather stations at central locations in half the sites continuously recorded air temperature, soil temperature at 5 and 35 cm soil depth, and throughfall volume. Linear interpolation was used to estimate these parameters at the remaining sites. Each of the sites was visited monthly from May through November in 1993 and 1994. During each visit air temperature, soil temperature, soil water content, and soil respiration (Zibilske 1995) were measured in each plot. At the same time, N mineralization was estimated using buried bags (Hart et al. 1995). Ammonium and nitrate were extracted for 30 hours in 1N KCl before determination by phenol nitroprusside and cadmium reduction, respectively.

Statistical Analysis

Least-squares linear regression and Pearson's correlation were performed on log-transformed data. Temperature and moisture were the independent variables and soil respiration and net N mineralization were the dependent variables. Temperature response curves of soil from each site were compared using analysis of variance with a significance level of 0.05 (Meredith and Stehman 1991).

RESULTS AND DISCUSSION

Data from the eight weather station sites confirmed that our experimental design successfully captured a broad range of climate conditions (Figure 2). Mean annual precipitation ranged from 90.1 cm at site 1 to 139.6 cm at site 16. Mean annual air temperature ranged from 2.0 °C at site 1 to 6.2 °C at sites 12 and 16. This 4 °C difference is within the projected range of temperature increase from global warming (Hengeveld and Skinner 1993).

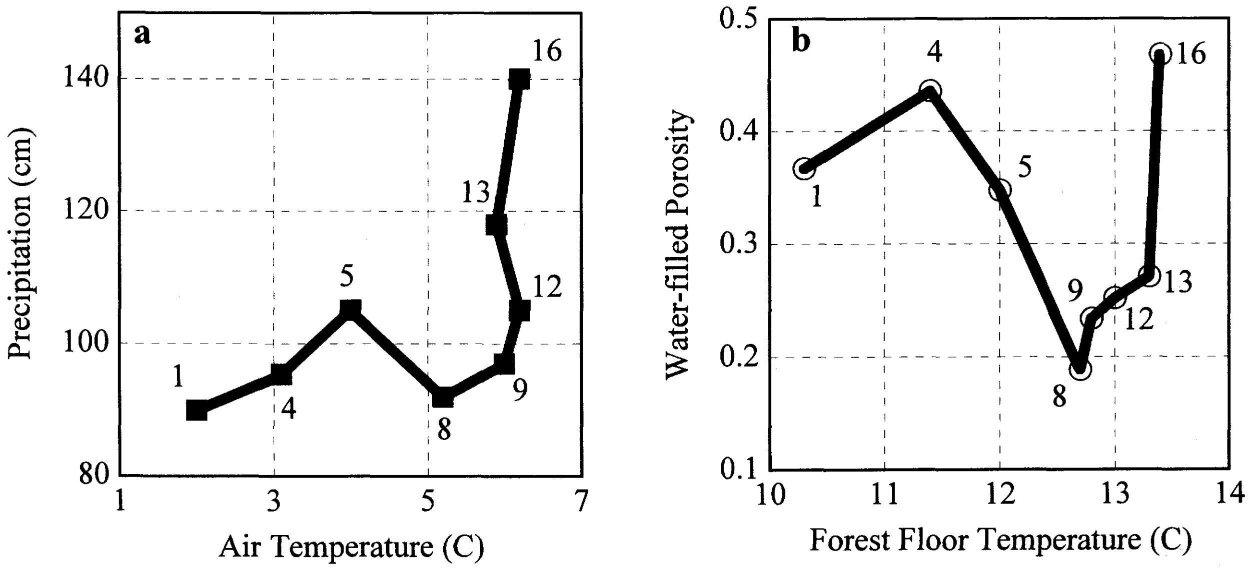

Figure 2. The location of the eight weather station sites on a climate surface. The surfaces are (a) annual precipitation vs. mean annual air temperature, and (b) mean annual water-filled porosity (% of saturation) vs. mean growing-season (May - Oct.) soil temperature at 5 cm below the surface of the Oe.

Although precipitation and air temperature define the regional climate conditions of each of the sites, soil biota will be most responsive to soil environmental factors, such as soil temperature and water content. Water-filled porosity, the fraction of pore space that is water-filled, was greater than 0.3 in sites 1, 4, 5 and 16 and less than 0.3 in sites 8, 9, 12 and 13. Note that the two northern sites exhibited a high water-filled porosity even though precipitation inputs were relatively low. This may be a result of cooler temperatures in the northern region limiting evapotranspiration of soil moisture. Mean growing season forest floor temperature (May through October at 5 cm below the surface of the Oe) increased from 10.3 to 13.4 °C from site 1 to site 16.

Soil respiration values ranged from 0.034 to 0.557 g CO_2 m^{-2} hr^{-1} with the highest rates in July and August and the lowest rates in November. Soil respiration from all sites and all dates was significantly correlated with soil temperature (Figure 3a; $r^2 = 0.33$; $p < 0.01$), but not with water-filled porosity ($r^2 = 0.03$; data not shown). Thus, temperature apparently influenced soil respiration at these sites, whereas soil moisture did not within the range of moistures we observed.

One of the unique aspects of this data set is that it represents the response of soil respiration over a wide geographic and climatic range. Most other soil respiration studies have used only a single site or adjacent sites (Reiners 1968; Bowden et al. 1993; Hanson et al. 1993; Peterjohn et al. 1994; Toland and Zak 1994). Performing correlations on data subdivided by region or by site revealed a noteworthy trend (Table 1). With a few exceptions, the strength of the correlations between temperature and either soil respiration or net N mineralization decreased as the spatial scale of the measurements increased. This suggests that temperature can be a strong predictor of soil respiration at individual sites, but is weaker at the landscape scale. Thus, at larger scales additional environmental parameters may be required.

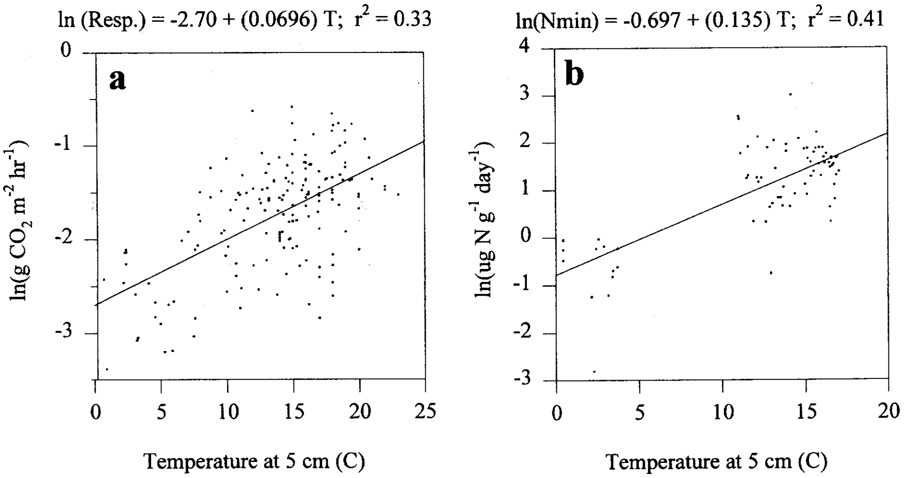

Figure 3. Linear regressions of (a) ln(soil respiration, g CO_2 m^{-2} hr^{-1}) and (b) ln(net N mineralization, μg N g^{-1} day^{-1}) versus forest floor temperature. Both regressions are significant ($p < 0.01$). Soil respiration data is for 1993-94 whereas net N mineralization data is for 1993 only.

Table 1. Adjusted-r^2 values from linear regressions of ln (soil respiration) and ln (net N mineralization) vs. forest floor temperature for the entire data set and for data grouped by region or site.

	Soil Respiration	Net N Mineralization
All points	0.33	0.41
By Region		
Northern	0.49	0.54
Central	0.53	0.46
Southern	0.27	0.80
Coastal	0.11	0.56
By Site		
1 through 16	0.20 to 0.74	nsd*

*nsd = not sufficient data

The slopes and y-intercepts of the ln (respiration)-vs-temperature curves from each of the four climate regions were compared using analysis of variance to determine if the soil biota in each region responded to temperature changes in the same way. In other words, we wanted to know if the temperature response of soil biota from each region was governed by a unique equation or if there was one equation that can be applied to all regions. There were no significant differences in either y-intercept or slope among the four regions ($p = 0.11$; $n = 4$). However, when the North and Central regions were combined and compared to the combined South and Coastal regions, there was a significant difference in slope ($p < 0.05$; $n = 8$). Apparently soil biota in the North/Central regions are more sensitive to temperature (have a steeper slope) than soil biota from the South/Coastal regions (Figure 4). Peterjohn et al. (1994) combined data from a number of soil respiration studies in temperate deciduous forests (most of which were at lower latitudes) and reported a higher slope (0.113 compared to 0.0862 and 0.0627 in our study) and a lower y-intercept value (-3.89 compared to -2.84 and -2.52 in our study).

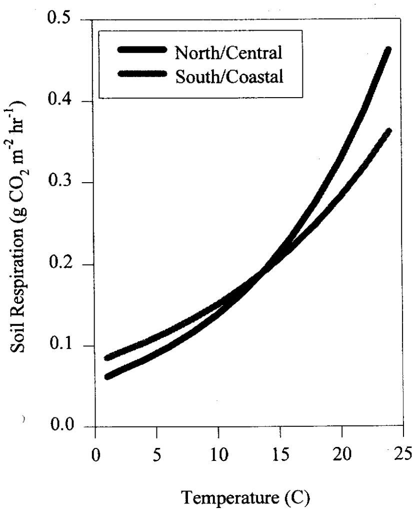

Figure 4. Soil respiration as a function of temperature {North/Central = exp (-2.84 + 0.0862*T); South/Coastal = exp (-2.52 + 0.0627*T)}.

Net N mineralization ranged from -1.56 to 12.79 μg N g^{-1} day^{-1} in 1993 and was significantly correlated with temperature (Figure 3b; $r^2 = 0.41$; $p < 0.01$). This range of N mineralization rates is typical for northern hardwood forests (0.5 to 16 μg N g^{-1} day^{-1}; Zak and Pregitzer 1990; Simmons et al. 1995). Correlation with water-filled porosity was not significant. However, when measurements from November were omitted (a period when soil activity is not expected to be limited by water because of very low temperatures), then a weak correlation became apparent ($r^2 = 0.10$; $p < 0.05$; data not shown). Thus, it appears that temperature had a significant effect on net N mineralization and soil water content had a weak effect during the relatively drier growing season.

Similar to soil respiration, the strength of the correlation of net N mineralization with temperature was greater within regions than in the combined data set (Table 1). This suggests that additional environmental parameters may be required to more accurately predict net N mineralization at the landscape scale. Correlations for each site were not attempted because there was not a large enough number of data points for each site in 1993.

SUMMARY AND CONCLUSIONS

Temperature was significantly correlated with soil respiration and net N mineralization at the regional level. Together with supporting evidence from laboratory studies by other researchers, this suggests that both C and N mineralization of northern hardwood forests in Maine have the potential to increase in response to global warming. The actual response of C and N mineralization will depend on a number of interacting factors including the response of foliar C:N ratios, litter C:N ratios, soil nutrient availability and soil C inputs. At the same time plants and soil biota will be exposed to elevated atmospheric CO_2 concentrations and continued inputs of N from atmospheric deposition. Regional differences in the relationship between soil respiration and temperature exist and should be investigated further in other locations. Moisture was not an important limiting factor for C or N mineralization in these forests, probably because the forest floor remained moist most of the year.

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