INCREASING SOIL TEMPERATURE IN A NORTHERN HARDWOOD FOREST: EFFECTS ON ELEMENTAL DYNAMICS AND PRIMARY PRODUCTIVITY

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Abstract: To investigate the effects of elevated soil temperatures on a forest ecosystem, heating cables were buried at a depth of 5 cm within the forest floor of a northern hardwood forest at the Huntington Wildlife Forest (Adirondack Mountains, New York). Temperature was elevated 2.5, 5.0 and 7.5°C above ambient, during May - September in both 1993 and 1994. Various aspects of forest ecosystem dynamics were studied, including soil solution chemistry (lysimeters at 15 and 50 cm depths), trace gas flux (closed box technique), decomposition of maple and American beech litter, and tree seed germination. A preliminary experiment showed that there was less effect on soil solution chemistry when cables were buried at 5 versus 15 cm depths. The soil warming plots experienced negligible disturbance effects associated with installation of heating cables. Nitrate concentrations were elevated in the highest temperature treatment. Carbon dioxide flux was positively correlated with soil temperature, as was the decomposition rate for American beech litter. In heated plots, germination of *Pinus strobus* (white pine) was positively correlated with soil temperature.

INTRODUCTION

The mean global temperature (MGT) has been increasing for the past 150 years (Houghton et al., 1990), giving possible evidence of the phenomenon of global warming. Current general circulation models (GCMs) suggest that the MGT will continue to rise and could increase 1.5-5.0°C over the next 100 years (Houghton et al., 1990). Global warming is considered to be induced by increasing concentrations of atmospheric water vapor (H_2O), carbon dioxide (CO_2) and other trace gases, including methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs). Concentrations of CO_2, CH_4 and N_2O have been steadily increasing since the mid-1800s (Houghton and Woodwell, 1989). Various predictions have been made as to how regional climates will change if the earth continues to warm (Graham et al. 1990; Houghton et al. 1990). Climate change is likely to occur on a regional scale. For instance, northern latitudes (temperate and boreal) are expected to become warmer and wetter in the future (Houghton et al., 1990). Thus, it is important to understand how different ecosystems may respond to climate change, both biotically and abiotically.

METHODS

Site Description

The study site is located in a 100 year-old birch-beech-maple stand at the Anna and Archer Huntington Wildlife Forest (HF). This northern hardwood forest is located in the central Adirondack mountains of New York State (43°59'N, 74°14'W) near Newcomb. The site is underlain by Spodosols, specifically coarse-loamy, mixed frigid, Typic Haplorthods in the Becket-Mundal association (Somers, 1986). The research area was chosen because of the availability of electrical power, which was required for heating the plots, and additionally, it lies within close proximity to a nearby access road. The biogeochemistry and productivity of HF have also been well characterized by previous studies (Mollitor and Raynal, 1982; David et al., 1982; Shepard et al., 1989).

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Experimental Design

Heating cables were buried in the forest floor to a depth of approximately 5 cm, at 20 cm spacing within four (10 m x 10 m) plots. At 5 cm, three heated plots had soil temperatures of 2.5, 5.0 and 7.5°C, respectively, above ambient (reference plot). Elevated soil temperatures were maintained throughout the field season from approximately mid-May to September 30 for both 1993 and 1994.

Field and Laboratory Methods

Field sampling included measurements of nutrient cycling parameters identified as important to carbon and nitrogen dynamics within a forest ecosystem, and included solid phase (buried soil bags) and soil solution chemistry (lysimetry), trace gases fluxes (CO_2, CH_4 and N_2O), decomposition (litter bags), primary productivity (foliage/litter collection and germination) and soil moisture and soil temperature. Preliminary results from some of these analyses will be presented. Nitrate concentration was determined by ion chromatography, while calcium and magnesium concentrations were obtained by inductively coupled plasma emission (ICP) and potassium by atomic absorption spectrophotometry (AA), respectively (Standard Methods, 1992). Trace gas samples were collected and analyzed according to the methods of Richey (1994). Litter bags containing either maple or American beech leaves were installed in plots during October 1992 and collected at one and two years following installation. After collection, the bags were dried and weighed. A comparison of the weights at collection to the original bag weight was used to determine percent mass remaining. An *in situ* germination experiment, where seeds of ***Pinus strobus*** (white pine) and ***Tsuga canadensis*** (eastern hemlock) were planted in the litter layer (Oa horizon), began in May 1994. A total of fifteen wire mesh boxes were randomly located along a transect one meter from one edge of each plot. Twenty seeds per species were planted in a box, and each species was planted in a total of five boxes per plot (100 seeds/species/plot) with five additional boxes per plot as controls. The box design and planting methods were similar to those described by Dustin (1986).

Disturbance Study

Preceding the soil-warming study, a preliminary experiment was implemented in order to assess the influence of disturbance on soil solution chemistry associated with installing heating cables (McHale and Mitchell, 1995). The study was conducted near the soil-warming site (within 500 m). The main difference between the two studies was that the cables were installed during fall 1991 for the disturbance experiment, whereas installation of heating cables occurred during spring 1992 for the soil warming study. Further details can be found in McHale and Mitchell (1995).

RESULTS AND DISCUSSION

Disturbance

Results of the disturbance experiment showed that simulated cables buried at 15 cm initially produced elevated ion concentrations commonly associated with soil disturbance (Likens et al., 1970; Vitousek et al., 1979; Hornbeck et al., 1986), compared to simulated cables at 5 cm, which exhibited less disruption of elemental cycles due to cable burial (Fig. 1). Plots with no cable installation generally had the lowest ion concentration levels during the disturbance experiment. In comparison, the soil warming reference plot, which had heating cables installed at 5 cm, displayed no evidence of disturbance effects despite cable burial. McHale and Mitchell (1995) suggested that the lack of disturbance effects in the soil warming reference plot could be attributed to the timing of cable installation.

Temperature Treatments

Mean temperatures at 5 cm depth were monitored and recorded continuously throughout the 1993 and 1994 field seasons (Fig. 2). Heated plots were maintained at the specified temperatures, except the 7.5°C plot. At the 7.5°C treatment there was notable deterioration of the heating cables by the end of the 1993 field season and heat treatment was terminated approximately one month before the field season ended in 1994.

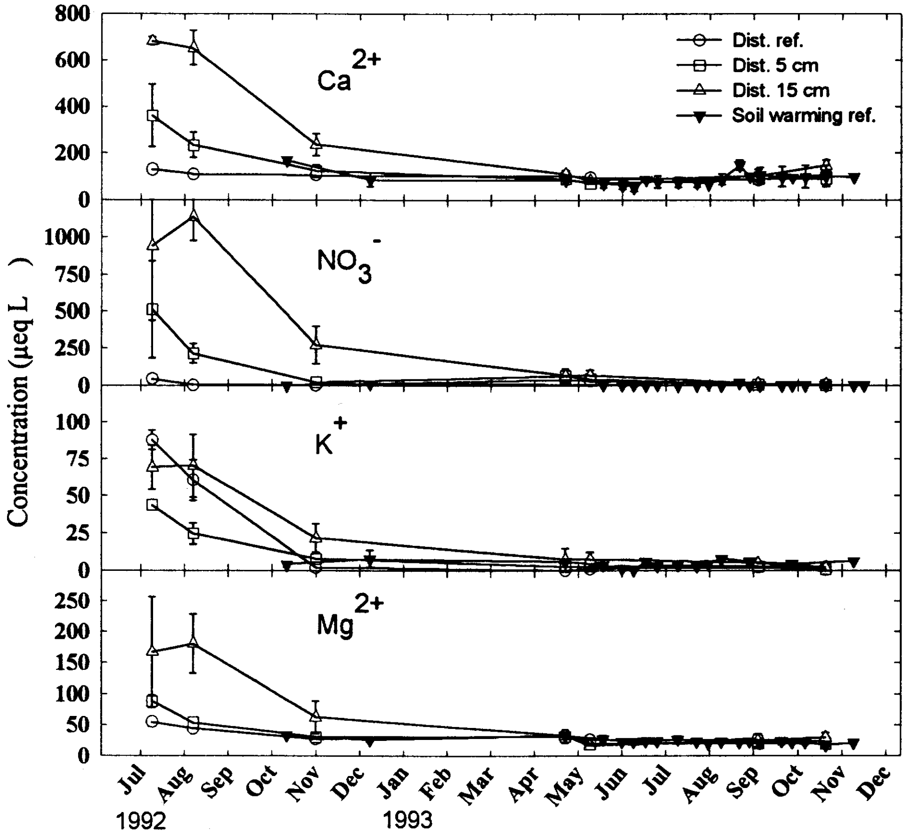

Figure 1. Soil solution chemistry from disturbance plots and soil warming reference plot.

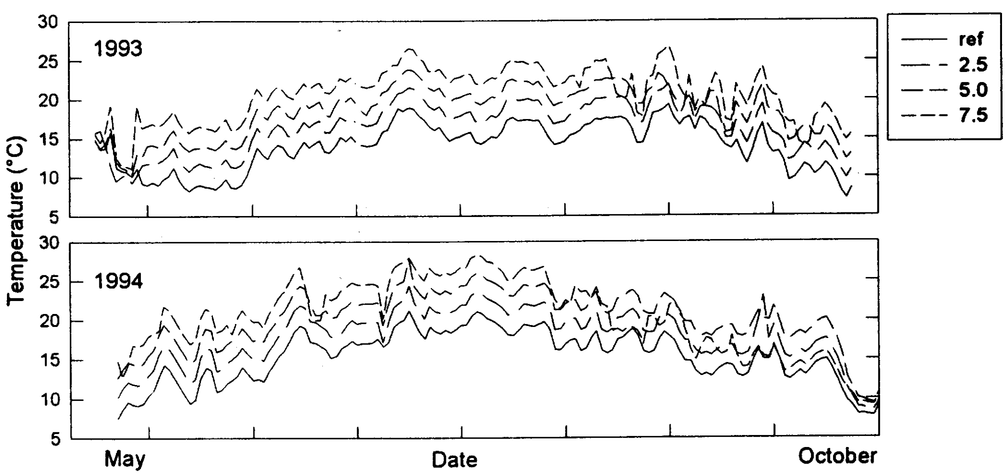

Figure 2. Mean temperatures at 5 cm depth for 1993 and 1994 field seasons.

Soil Solution Chemistry

It was anticipated that raising the soil temperature could produce important alterations of elemental cycles, specifically, soil solution chemistry. Nitrate levels at 15 cm (Bh horizon) and 50 cm (Bs2 horizon) from the 7.5°C plot exceeded all other plot concentrations during early summer and again in late fall of both 1993 and 1994 (Fig. 3). These results suggest that increased soil temperatures increased N mineralization.

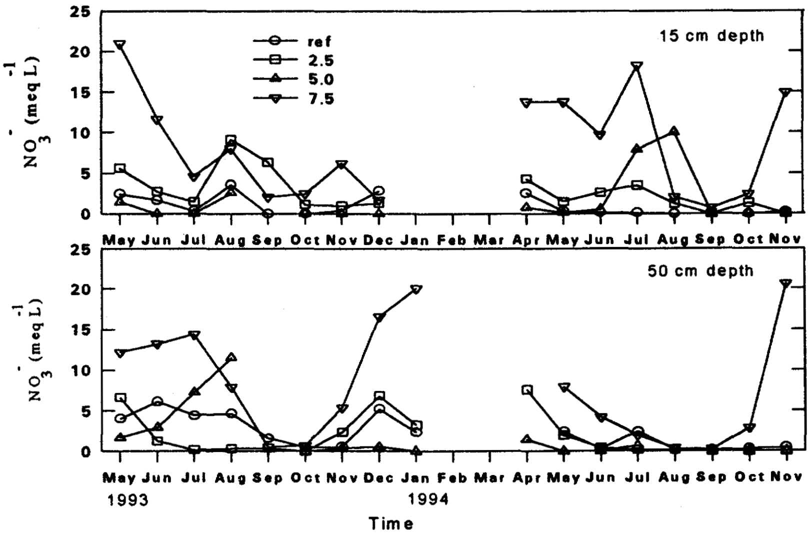

Figure 3. Mean monthly nitrate concentrations from soil warming plots at 15 and 50 cm depth.

Carbon Dioxide Flux

Carbon dioxide flux showed the strongest correlation to soil temperature of the three gases analyzed (Fig. 4). The relationship was stronger in 1993 ($r^2 = 0.41, p \leq 0.05$) than in 1994 ($r^2 = 0.23, p \leq 0.05$). The relationship was linear and weaker than a similar soil warming study at Harvard Forest (Peterjohn et al., 1993) where the relationship was exponential and explained 72 percent of the variability. Methane and nitrous oxide fluxes failed to show any significant relationship to soil temperature.

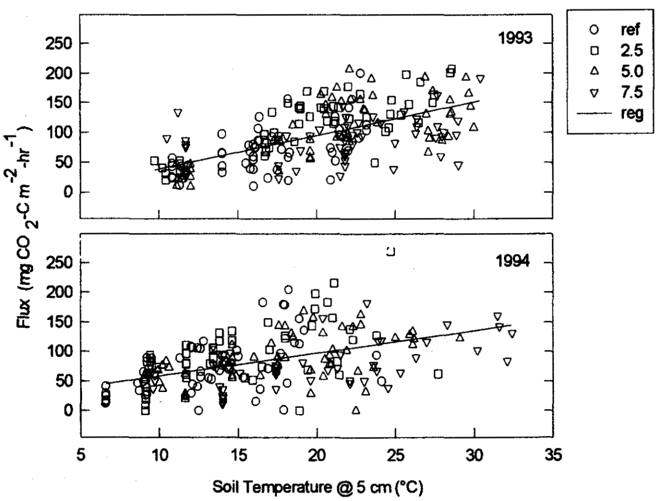

Figure 4. Carbon Dioxide flux verses soil temperature at 5 cm depth.

Decomposition

One-way ANOVA showed that percent mass remaining in maple versus American beech litter bags was statistically significantly lower both one (p = 0.005, n = 48) and two (p = 0.0003, n = 93) years after heat treatments began (Fig. 5), which would be expected since the latter has higher lignin content (Melillo et al. 1982) and thus is more resistant to decay. Maple did not exhibit any statistically significant differences between treatments in either year one or year two. In comparison, percent mass remaining after one year for American beech litter bags in the two highest heat treatments was statistically lower (p = 0.001, n = 24) than the reference and 2.5°C plots. After two years *in situ*, mass remaining was significantly lower in the 7.5°C plot than both the reference and 2.5°C plots (p = 0.0001, n = 48). These results suggest that elevated soil temperatures increased the decomposition rate for American beech litter.

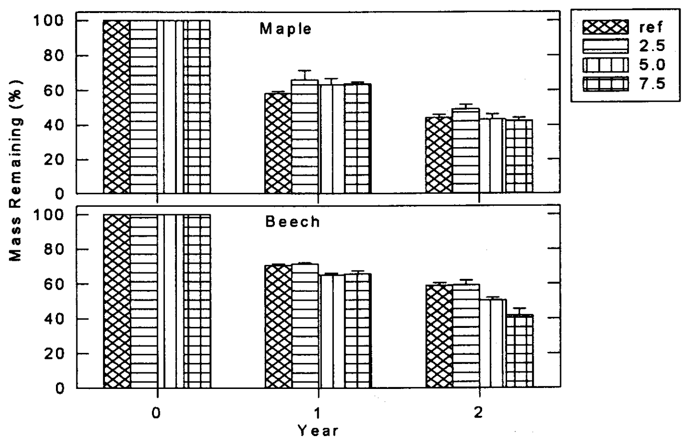

Figure 5. Percent mass remaining in litter bags since time of installation (year = 0), (vertical lines are S.E.).

Seed Germination

Cumulative germination of planted eastern hemlock seeds failed to display a pattern of stimulation with increasing plot temperatures (Fig. 6) and was low in all plots. The reference plot had the highest germination rates for the entire study period. White pine seeds germinated faster with increasing temperatures in heated plots. The results of this experiment are consistent with the growth requirements of both species. Eastern hemlock is adapted to cool, moist conditions; white pine is more drought tolerant (Burns and Hondala 1990). Hemlock germination was more influenced by soil moisture than soil temperature. In comparison, white pine germination was strongly affected by soil temperature differences among the experimental plots.

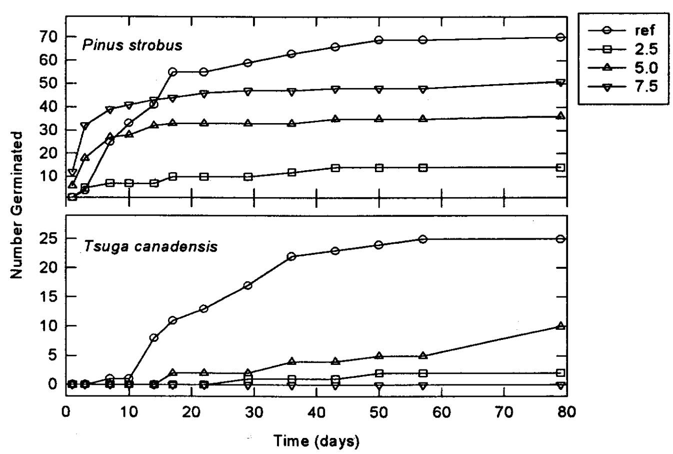

Figure 6. Cumulative germination of tree seeds planted in soil warming plots.

CONCLUSIONS

Experimental manipulation of soil temperature is feasible and can be maintained throughout an entire field season. Experimentally heating a northern hardwood forest soil showed that elevated temperature can influence solute chemistry. Of the trace gases analyzed (CO_2, CH_4 and N_2O), carbon dioxide exhibited the strongest correlation to soil temperature. Elevated soil temperature showed differential effects on litter decomposition and seed germination. These results will be further evaluated using various biogeochemical simulation models.

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LITERATURE CITED

Burns, R.M. and B.H. Honkala, tech. coords. 1990. Silvics of North America: 1. Conifers. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, D.C. vol. 1, 675p.

David, M.B., M.J. Mitchell and J.P. Nakas. 1982. Organic and inorganic sulfur constituents of a forest soil and the irrelationship to microbial activity. Soil Sci. Soc. Am. J. 46:847-852.

Dustin, C.D. 1986. Effects of acidic deposition on sugar maple seedling development. M.S. Thesis. State Universityof New York, College of Environmental Science and Forestry, Syracuse, NY , USA.

Graham, R.L., M.G. Turner and V.H. Dale. 1990. How increasing CO_2 and climate change affect forests: At many spatial and temporal scales, there will be forest responses that will be affected by human activities. Bioscience 40: 575-587.

Hornbeck, J.W., C.W. Martin, R.S. Pierce, F.H. Bormann, G.E. Likens and J.S. Eaton. 1986. Clearcutting northern hardwoods: effects on hydrologic and nutrient ion budgets. Forest Sci. 32:667-686.

Houghton, J.T., G.T. Jenkins and J.J. Ephraums. (eds.). 1990. Climate Change: The IPCC Scientific Assessment. Cambridge University Press, Cambridge.

Houghton, J.T. and G.M. Woodwell. 1989. Global climate change. Scientific American 260:36-44.

Likens, G.E., F.H. Bormann, N.M. Johnson, W.D. Fisher and R.S. Pierce. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook Watershed-Ecosystem. Ecol. Monogr. 40:23-47.

McHale, P.J. and M.J. Mitchell. 1995. Disturbance effects on soil solution chemistry due to heating cable installation. Biol. Fert. Soils (In press).

Melillo, J.M., J.D. Aber and J.F. Muratore. 1982. Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. Ecology 63:621-626.

Mollitor, A.V. and D.J. Raynal. 1982. Acid precipitation and ionic input in Adirondack forest soils. Soil Sci. Soc. Am. J. 46:137-141.

Peterjohn, W.T., J.M. Melillo, F.P. Bowles and P.A. Steudler. 1993. Soil warming and trace gas fluxes: experimental design and preliminary flux results. Oecologia 93:18-24.

Richey, D.G. 1994. Nitrous oxide and methane flux between forest soils and the atmosphere and the effects of ammonium sulfate fertilization. M.S. Thesis. Syracuse University, Syracuse, NY USA.

Shepard, J.P. M.J.Mitchell, T.J. Scott, Y.M. Zhang and D.J. Raynal. 1989. Measurement of wet and dry deposition in a northern hardwood forest. Water, Air and Soil Pollution 48:225-238.

Somers, R.C. 1986. Soil classification, genesis, morphology, and variability of soils found within the central Adirondack region of New York. Ph.D. Dissertation. State University of New York, College of Environmental Science and Forestry, Syracuse, NY USA.

Standard Methods: For the Examination of Water and Wastewater, 18th ed. 1992. Greenberg A.E., L.S. Clesceri and A.D. Eaton, Eds. American Public Health Association, Washington, D.C.

Vitousek, P.M., J.R. Gosz, C.C. Grier, J.M. Melillo, W.A. Reiners and R.L. Todd. 1979. Nitrate losses from disturbed ecosystems. Science 204:469-474.