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TECO: Carbon Monoxide Consumption by Forest and Agroecosystem Soils

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Project Participants

Senior Personnel

Name: King, Gary
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Nanba, Kenji
Worked for more than 160 Hours: Yes
Contribution to Project:
Visiting investigator from Japan

Post-doc

Name: Milligan, Peter
Worked for more than 160 Hours: Yes
Contribution to Project:

Graduate Student

Undergraduate Student

Research Experience for Undergraduates

Name: Garey, Meredith
Worked for more than 160 Hours: Yes
Contribution to Project:
Outstanding student; completed an Honors thesis at Mt. Holyoke in part using work from summer.

Years of schooling completed: Junior
Home Institution: Other than Research Site
Home Institution if Other: Mt. Holyoke College
Home Institution Highest Degree Granted(in fields supported by NSF): Bachelor's Degree
Fiscal year(s) REU Participant supported: 1999
REU Funding: REU supplement

Name: Crosby, Heidi
Worked for more than 160 Hours: Yes
Contribution to Project:
Outstanding student; started Honors thesis at UMaine based on REU support.

Years of schooling completed: Sophomore
Home Institution: Same as Research Site
Home Institution if Other:
Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree
Fiscal year(s) REU Participant supported: 2000

REU Funding: REU supplement

Name: Rollins, Jarod

Worked for more than 160 Hours: Yes

Contribution to Project:

Years of schooling completed: Sophomore

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 1999

REU Funding: REU supplement

Organizational Partners

Other Collaborators or Contacts

Support in the field was provided by Drs. K. Ingram and G. Gascho of the University of Georgia Agricultural Expt. Stations in Griffin and Tifton, GA, respectively.

Activities and Findings

Research and Education Activities:

Research activities consisted of extensive field observations of carbon monoxide fluxes in forests and agroecosystems at 3 field primary field sites in Maine and Georgia. These observations were supplemented by extensive lab assays of specific dynamics and controls of CO fluxes and the microbiology of CO transformations.

Educational activities consisted of the training of a Masters student and 3 NSF REU students.

Findings:

Seasonal analyses of in situ CO fluxes from forested and agricultural soils in Maine and Georgia, and more limited comparisons in Hawai'i indicated that agricultural land use consistently enhanced CO consumption. Soils at an agricultural site in Maine consumed approximately 1.9 g CO m-2 yr-1while uptake in a nearby mixed forest was about 70% lower, 0.6 g CO m-2 yr-1. A similar trend was observed for sites in Georgia, where annual uptake by agricultural sites was approximately 1.0 g CO m-2 while net emission (about -0.5 g CO m-2) was observed for neighboring pine stands. Net CO fluxes in Maine and Georgia were generally aseasonal. Accordingly, seasonal changes in temperature and water content played variable but often minimal roles as determinants of net fluxes and gross CO uptake and production. However, comparisons among sites suggested that soil organic matter contents were an important control of the magnitude of CO fluxes. In particular net CO consumption for a given soil type increased with decreasing organic matter content associated with forest to agriculture transitions in land use. Although interactions among soil organic matter and the various microbiological, physical and chemical parameters in soils are complex, changes in organic matter at the sites described here appear to affect net CO fluxes primarily by reducing the relative significance of abiological CO production.

CO, one of the most important trace gases, regulates tropospheric methane, hydroxyl radical and ozone. Of the estimated global CO flux, 10-25% may be consumed by soils annually. Depth profiles of 14CO oxidation and CO concentration indicate that this activity occurs primarily in surface soils and that photooxidation of soil organic matter does not necessarily contribute significantly to CO fluxes. Kinetic analyses reveal an apparent Km of about 18 nM (17 ppm) and a Vmax of 6.9 Ámol gfw-1 h-1; the apparent Km is similar to that for atmospheric methane consumption but the Vmax is > 100x higher. Atmospheric CO oxidation responds sensitively to soil water regimes with decreasing water content in initially saturated soils resulting in increased uptake with an optimum at 30-60%. However, extended drying leads to decreased uptake and net CO production. Rewetting can restore CO uptake, albeit with a pronounced hysteresis. Responses to changing temperature indicate an optimum for net uptake between 20-25 oC, with a transition to net production above 30 oC. Responses to methyl fluoride and acetylene indicate that populations other than ammonia oxidizers and methanotrophs must be involved in forest soils. The response to acetylene is notable, since strong initial inhibition is reversed after 12 h incubation; in contrast, methyl fluoride has no inhibitory effect. Ammonium does not inhibit CO uptake; nitrite inhibition is initially substantial, but reversible over time. Nitrite inhibition appears to occur through indirect effects based on abiological formation of NO.

Carboxydotrophic activity in forest soils was enriched by incubation in a flow through system with elevated headspace CO concentrations (40 ppm-400 ppm). CO uptake increased substantially over time, while the apparent Km (appKm) for uptake remained similar to that of unenriched soils (<10 ppm-20 ppm). Carboxydotrophic activity was transferred to and further enriched in sterile sand and forest soil. The appKm for secondary and tertiary enrichments remained similar to values for unenriched soils. CO uptake by enriched soil and freshly collected forest soil was inhibited at headspace CO concentrations > about 1%. A novel isolate obtained from the enrichments was inhibited similarly. However, in contrast to extant carboxydotrophs this isolate consumed CO with an appKm of about 15 ppm, a value comparable to that of fresh soils. Phylogenetic analysis based on approximately 1200 bp of 16S rRNA gene sequence suggested that the isolate is an a-proteobacterium most closely related to the genera Pseudaminobacter, Aminobacter, and Chelatobacter (96%-97% sequence identity).

Rates of macroalgal carbon monoxide (CO) production were compared among 5 taxa representing three major phylogenetic groups (Phaeophyta, Chlorophyta, Rhodophyta). CO production varied substantially from a minimum of about 20 ng CO gdw-1 h-1 for Fucus vesiculosus to > 4000 ng CO gdw-1 h-1 for Laminaria saccharina. None of the macroalga examined contained significantly elevated CO concentrations within their pneumatocysts (float bladders), so the variability among taxa reflects other intrinsic properties. An in vitro evaluation of Ascophyllum nodosum indicated that CO production varied as a function of temperature, desiccation and illumination. CO production increased strongly for live fronds over an ecologically relevant range (5 oC-23 oC), but decreased at 45 oC. For non-living desiccated wrack, CO production increased consistently from 5 oC-47 oC. Short-term desiccation of living algae decreased CO production substantially, but long-term changes in water content appeared not to markedly alter CO production relative to fresh material. Illumination strongly increased CO production relative to dark incubations, with similar responses for living and non-living material. CO oxidation (presumably bacterial) was observed for most living algae during incubations with exogenous CO at concentrations of 100 ppm, suggesting that a microbe-algal association might limit in part CO fluxes. Extrapolation of CO production rates indicates that macroalgae likely contribute only a minor fraction (< 1%) to global marine CO emissions to the atmosphere (about 10 Tg yr-1).

Training and Development:

The Masters and REU students all participated in basic field research and learned the associated methodology. In addition, all had opportunities to learn how to sample terrestrial systems, establish lab experimental systems and manipulate microbes relevant to the processes being addressed.

Outreach Activities:

I taught science to a group of 7th graders for about 7 months, 1 day a week.

Journal Publications

King, G.M., "Characteristics and significance of atmospheric carbon monoxide consumption by soils.", Chemosphere: Global Change Sci., p. 53-63, vol. 1, (1999). Published

King, G.M., "Attributes of atmospheric carbon monoxide oxidation in Maine forest soils.", Appl. Environ. Microbiol., p. 5257, vol. 65, (1999). Published

Nanba, K. and King, G.M., "Response of atmospheric methane consumptionby Maine forest soils to exogenous aluminum salts.", Appl. Environ. Microbiol., p. 3674, vol. 66, (2000). Published

King, G.M. , "Impacts of land use on atmospheric carbon monoxide consumption by soils.", Glob. Biogeochem. Cyc., p. 1161, vol. 14, (2000). Published

Milligan, P. and King, G.M. , "Carbon monoxide production is not enhanced by nitrogenase activity.", FEMS Microbiol. Ecol., p. 157, vol. 34, (2000). Published

Benstead, J. and King, G.M., "The effect of acidification on atmospheric methane uptake by a Maine forest soil. ", FEMS Microbiol. Ecol., p. 207, vol. 34, (2001). Published

Hardy, K. and King, G.M., "Enrichment of high affinity CO oxidizers in Maine forest soil.", Appl. Environ. Microbiol., p. 3671, vol. 67, (2001). Published

King, G.M., "Aspects of carbon monoxide production and consumption by marine macroalgae.", Mar. Ecol. Prog. Ser., p. 69, vol. 224, (2001). Published

Books or Other One-time Publications

Web/Internet Site

Other Specific Products

Contributions

Contributions within Discipline:

The results have shown that agroecosystems enhance atmospheric CO consumption by soils, a process that can ameliorate in part anthropogenic changes in the troposphere. In addition, the study has resulted in the first isolation of a microbe with kinetic characterisitics for CO uptake similar to those of the soil from which it came.

Other elements of the work have furthered our understanding of atmospheric methane consumption by soils and the role of marine macroalgae in global CO dynamics.

Contributions to Other Disciplines:

Contributions to Human Resource Development:

The project has helped train 1 graduate student and 3 undergraduate students in addition to providing further training for a postdoc and for a visiting scientist from Japan.

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

Categories for which nothing is reported:

Organizational Partners

Any Book

Any Web/Internet Site

Any Product

Contributions: To Any Other Disciplines

Contributions: To Any Resources for Research and Education

Contributions: To Any Beyond Science and Engineering