Research Challenges for Carbon Sequestration in Terrestrial Ecosystems

Roger C. Dahlman
U.S. Department of Energy
Office of Science, Biological and Environmental Research
19901 Germantown Road, MS-F-240
Germantown, MD 20874-1290

301/903-4951 (ph)
301/903-8519 (fx)
roger.dahlman@science.doe.gov

Gary K. Jacobs
Environmental Sciences Division
Oak Ridge National Laboratory[1]
P.O. Box 2008
Building 1505, MS-6035
Oak Ridge, TN 37831

865/576-0567 (ph)
865/574-7287 (fx)
jacobsgk@ornl.gov

Abstract

Carbon sequestration is a growing research topic that addresses one important aspect of an overall strategy for carbon management to help mitigate the increasing emissions of CO_2 into the atmosphere. There are estimates that terrestrial ecosystems could sequester significant quantities of carbon over the next 50 years. The impact of this sequestration could help buy time for other technologies to come on-line by delaying the need for more dramatic decreases in global emissions. There is increasing interest in scientific advances that can be used to further enhance this potential sequestration of carbon in soils. This paper summarizes current research that is addressing some of the major uncertainties in the carbon cycle and introduces new research that is being initiated specifically related to carbon sequestration in terrestrial ecosystems.

Keywords: Carbon sequestration, carbon cycle, climate change, AmeriFlux, ecosystem research, soil carbon

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Introduction

Currently, emissions of CO_2 are increasing globally and are projected to double over the next century.[1] This excess CO_2 enters the global carbon cycle where part remains in the atmosphere, part is taken up by oceans and the terrestrial biosphere. But significant uncertainty still surrounds the quantitative description of the natural carbon cycle. A major challenge of the greenhouse gas and climate change issue is to understand what happens to the excess CO_2 generated from the burning of fossil fuels. In particular, the rate and magnitude by which excess carbon is assimilated into terrestrial and oceanic sinks will determine the balance that remains in the atmosphere. While research in this challenging area continues, there are new efforts to begin research that might help mitigate increasing CO_2 emissions through special efforts to sequester CO_2.

Carbon sequestration in terrestrial ecosystems can be defined as the net removal of CO_2 from the atmosphere into long-lived pools of carbon. The pools can be living, aboveground biomass (e.g., trees), wood products with a long, useful life created from biomass (e.g., lumber), living biomass in soils (e.g., roots and microorganisms), or recalcitrant organic and inorganic carbon in soils and deeper subsurface environments. It is important to emphasize that increasing photosynthetic carbon fixation alone is not enough. This carbon must be fixed into long-lived pools. Otherwise, one may be simply altering the size of fluxes in the carbon cycle, not increasing carbon sequestration.

The DOE Roadmap for Carbon Sequestration

The U. S. Department of Energy (DOE) has recently completed a report that details the state of science related to carbon sequestration.[2] The report also lays out future research topics that will be necessary in achieving increases in carbon sequestration. There are four main objectives that must be addressed for terrestrial ecosystems: (1) assessing ecosystem dynamics, (2) increasing below-ground carbon stocks, (3) increasing the rate of growth, standing stocks of carbon, and utilization of above-ground biomass, and (4) optimizing land use for carbon sequestration. It is important to remember that while many processes occur at the molecular level (i.e., photosynthesis, formation and protection of soil organic matter, etc), management practices to enhance carbon sequestration will be implemented at the landscape scale. At this scale ecosystems are the key functional units for estimating productivity and carbon sequestration, and for assessing potentially deleterious impacts associated with efforts to increase carbon in ecosystems.

The DOE report goes on to detail examples of specific research areas that are ripe for innovations that will advance our scientific underpinnings for enhanced sequestration. The other key component of research is on developing improved measurement and monitoring systems. It will be important to be able to determine what sequestration methods are working, and current measurement techniques are lacking in sensitivity and spatial resolution. The Offices of Science and Fossil Energy of the U.S. Department of Energy are implementing research opportunities identified by the state of the science report.

Current Research in DOE

While the DOE Office of Science/Biological and Environmental Research (OBER) is embarking on a new research program focused on carbon sequestration in terrestrial ecosystems, current research efforts in OBER have been addressing the natural carbon cycle and potential impacts to ecosystems from global change for some time.

The Terrestrial Carbon Program (TCP) performs research that provides the scientific underpinnings for predicting future concentrations of CO_2 in the atmosphere. The research, which focuses on natural systems that regulate the abundance of CO_2 in the atmosphere, emphasizes (i) understanding the processes controlling exchange rate of CO_2 between atmosphere and terrestrial biosphere; (ii) developing process-based models of atmosphere-terrestrial carbon exchange; (iii) evaluating source-sink mechanisms for atmospheric CO_2; and (iv) improving reliability of global carbon models for predicting future atmospheric concentrations of CO_2. Three particularly key parts of the TCP are:

- Mechanistic terrestrial carbon models for evaluating the role of the biosphere in atmospheric CO_2 changes, and the influence of climate and other feedbacks on the biogeochemical cycle of carbon.

- AmeriFlux network of CO_2 measurements for estimating carbon cycling by terrestrial ecosystems.

- Free Air CO_2 Enrichments (FACE) experiments that evaluate the responses of terrestrial plants and ecosystems to increased concentrations of atmospheric CO_2.

AmeriFlux involves the measurement of net CO_2 exchange of representative ecosystems across United States and North America. For the present network of 35 sites, net annual CO_2 exchange is measured by eddy covariance methods producing annual estimates of net carbon gain or loss by ecosystems such as forests, grasslands and croplands. In addition to flux measurements, biological/ecological data are collected on processes such as photosynthesis, respiration, primary productivity and growth rates and the turnover of different ecosystem carbon pools. Together with flux measurements these data provide unique estimates of net ecosystem production (NEP); positive values of NEP mean the system is storing carbon and negative values indicate net loss of carbon. Initial results show that forest ecosystems are gaining carbon at the rate of 2 to 6 tons of carbon per hectare per year. This network of flux measurements, and related ecosystem and micrometeorological data collectively provide vital ground surface information about carbon sequestration. The data also help interpret other observations of atmospheric CO_2 and space-based information about ground surface processes. Research products of AmeriFlux contribute significantly to the understanding of the role of the terrestrial biosphere in the global carbon cycle, to uniquely quantify carbon sequestration by the terrestrial biosphere, and to provide vital data for evaluating the hypothesis that N. America is a significant terrestrial carbon sink.

The Program for Ecosystem Research (PER) includes both experimental and modeling research related to both the direct and indirect effects of climatic and atmospheric changes on ecosystem components and processes. Research emphasizes the detection and quantification of adjustments to global atmospheric and climatic changes (e.g., temperature, moisture, ozone, CO_2) and the mechanisms that control the observed adjustment processes. Ecosystem responses that are studied include (1) ecological adjustments such as changes in the organized hierarchy of ecosystem processes, structure, and diversity; and (2) biological adjustments at the organism level that are manifested at the ecosystem level, including homeostatic (physiological, biochemical) and genetic responses.

New Research Directions

DOE formed a new center in 1999 to focus on research related to enhancing carbon sequestration in terrestrial ecosystems. A consortium of institutions (see next section) will perform research to help determine how to increase the amount of carbon entering into "pools" that are stabilized in soil and protected against decomposition. The center will also research ways to measure, monitor and verify sequestration so that it may be appropriately accounted for in national inventories of greenhouse gas emissions.

In addition to the Centers approach, there is a solicitation for research from the scientific community involving investigator-initiated ideas and innovative research for enhancing carbon sequestration of terrestrial ecosystems. New ideas and concepts will be selected from the competition that can be expected to promote significantly increased capture and storage of carbon by terrestrial ecosystems.

The DOE Center for Research to Enhance Carbon Sequestration in Terrestrial Ecosystems (CSiTE)

The newly formed research center is known as CSiTE – Carbon Sequestration in Terrestrial Ecosystems. CSiTE performs fundamental research that supports methods that will lead to enhanced carbon sequestration in terrestrial ecosystems as one component of a carbon management strategy. The goal of CSiTE is to discover and characterize links between critical pathways and mechanisms for creating larger, longer-lasting carbon pools in terrestrial ecosystems. Research is designed to establish the scientific basis for enhancing carbon capture and long-term sequestration in terrestrial ecosystems by developing (1) scientific understanding of carbon capture and sequestration mechanisms in terrestrial ecosystems across multiple scales from the molecular to the landscape, (2) conceptual and simulation models for extrapolation of process understanding across spatial and temporal scales, (3) estimates of national carbon sequestration potential, and (4) assessments of environmental impacts and economic implications of carbon sequestration.

Summary

Carbon sequestration is an important part of an overall carbon management strategy to help reduce and/or mitigate global CO_2 emissions. Research into how to enhance sequestration in terrestrial ecosystems could lead to significant beneficial practices that could be implemented during the next 20-50 years. These practices could help "buy time" for other methods of sequestration and energy technologies to come on-line. At the same time, it is essential to continue to emphasize understanding the carbon cycle which drives future global change scenarios and also can impact the efficacy of sequestration options in natural systems.

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