Terrestrial Carbon Sequestration Potential

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Introduction

Fossil fuel and land use change have increased the atmospheric content of CO_2 and other greenhouse gases that may be impacting climatic change. Enhanced terrestrial uptake of CO_2 during this century has been suggested as a way to reclaim the 150 or more gigatons of carbon (Gt C) lost to the atmosphere from vegetation and soil as a consequence of land use change, thus effectively "buying time" for development and implementation of long term technical solutions, such as C-free fuels (1). However, the true potential for C sequestration is unknown because of inadequate understanding of biogeochemical, microbial and plant processes responsible for ecosystem storage, particularly as they influence storage in soils, which account for two-thirds of global terrestrial organic C stocks. Technical issues associated with measurement, leakage and longevity need resolution. This presentation considers current understanding of ecosystem potential and innovative technology and addresses key scientific issues related to enhancing C sequestration potential through ecosystem management.

Ecosystem Sequestration Potential

Land use options for enhanced C sequestration at the landscape and regional scales include protection and selective management of native ecosystems, and use of appropriate and advanced management practices in manipulated ecosystems. Table 1 includes estimates of sequestration potential for major ecosystems. Sustained, long-term annual sequestration of more than 5 Gt C is speculative, of course, given that terrestrial systems today sequester only about half this amount, with the exact amount being uncertain (1).

Ecosystem	Primary Method to Increase CS*	Potential CS (GtC/y)
Agricultural lands	Management (H)	0.85 – 0.90
Biomass crop lands	Manipulation (H)	0.5 - 0.8
Grasslands	Management (M)	0.5
Rangelands	Management (M)	1.2
Forests	Management (M)	1 - 2
Wetlands	Restoration and maintenance (M)	0.1 – 0.2
Urban forest and grass lands	Creation and maintenance (M)	< 0.1
Deserts & Degraded lands	Manipulation (H)	0.8 – 1.3
Sediments and aquatic systems	Protection (L)	0.6 – 1.5
Tundra and taiga	Protection (L)	0.1 – 0.3
TOTAL		**~ 5.5 – 8.7**

Table I. Sustained Terrestrial C Sequestration Potential.
*The primary C sequestration method is rated with High (H), Medium (M), and Low (L) levels of sustained management intensity required over the long term. Global potential C sequestration (CS) rates were estimated that might be sustained over a period of up to 50 years (2).

Sequestration Potential In Managed Ecosystems

Enhancing terrestrial C sequestration with proven management practices includes converting marginal land to productive grassland or forest, increasing productivity on crop and forest land with residue management, reduced C loss with modified tillage practices, the efficient use of fertilizer, pesticide, and water, and other technologies. It is difficult to estimate global C sequestration enhancement potential because of inadequate baseline inventories. However, an analysis of the U.S. potential for soil C sequestration can be made (Table 2). Based on such information, conclusions regarding C sequestration potential of managed systems should be applicable wherever in the world local land use and economic conditions are known.

Table 2. Annual U.S. potential for C sequestration from managed forests, arable lands and pastures (2).

	Average C sequestration	
	Low estimate	High estimate
	--- Pg C / year ----	
Forestry		
Converting marginal crop/pasture to forest	0.033	0.119
Increasing timber growth on timber land	0.138	0.190
Growing short-rotation woody crops for energy	0.091	0.180
Increasing tree numbers/canopy cover in urban areas	0.011	0.034
Planting trees in shelter belts	0.003	0.006
Subtotal	0.276	0.529
Arable land		
Cropland conversion to CRP (excluding agroforestry)	0.006	0.014
Soil restoration (eroded land, mine land, salt affected soil)	0.011	0.025
Conservation tillage/residue management	0.035	0.107
Better cropping systems (fertilizer, cover crops, manure)	0.024	0.063
Subtotal	0.075	0.208
Total managed forests, arable land, pastures	0.351	0.737

Enhanced C sequestration in managed lands aims to increase the productivity of crop and forestland. In agriculture, adoption of conservation tillage practices is a viable mechanism that also reduces erosion, increases soil aggregation, and lessens loss of SOM to microbial oxidation (3). The C sequestration potential of the combined practices of no-till, mulch, and ridge tillage was estimated to be 14.1 x 10^6 MT (0.014 Gt) C/yr, with associated savings in fossil fuel equivalent to 1.6 x 10^6 MT C/yr. In addition, managing crop residues from these systems may sequester another 22.5 x 10^6 MT C/yr. As of 1997, 37% of all U.S. cropland was under some form of conservation tillage (3).

The U.S. Forest Service has estimated that 85 Mha of forested land has the potential to increase production through regeneration and stocking control. For an economic constraint of 4% annual return on investment, much of this area could sequester 0.138 Gt C/yr under appropriate management. If all timberlands were managed for C sequestration, the potential might increase to 0.19 Gt C/yr. Another strategy for sequestrating C is the conversion or reallocation of agricultural land to woody crops. Wright et al. (4) estimated that between 14-and-28 Mha of cropland are suitable for woody biomass species with a sequestration potential of between 0.09 to 0.18 Gt C/yr.

Worldwide, temperate grasslands may also be significant. To enhance production and sequestration, it is necessary to manage these lands more closely, with one option being N fertilization. However, grasslands have an inherent capacity to emit N_2O, a strong greenhouse gas. Thus, a comprehensive accounting that includes all greenhouse gas emissions and the C cost of fertilizer production and application is needed to evaluate net sequestration benefits.

Degraded lands also represent some potential for C sequestration. Worldwide, there are approximately 1965 x 10^6 ha of degraded soils;

4% from physical degradation, 56% from water erosion, 28% from wind erosion, and 12% from chemical degradation. With proper management this represents a potential to sequester between 0.81 and 1.03 Gt C/yr. (5).

New Technology for Terrestrial Carbon Sequestration

Science and technology that might drive enhanced terrestrial C sequestration includes (a) technology for soil, crop and forest management, (b) exploitation of underutilized land resources and existing biodiversity, (c) plant biotechnology, (d) microbial biotechnology, and (e) innovative chemical technology. Included is precision agriculture applied to food crops and forestry; i.e., sensor technology, aerial and satellite imaging "just in time" irrigation, fertilization, and other, yet-to-be identified innovations.

Science Needs

There are many fundamental knowledge gaps in our understanding of terrestrial C sequestration needed to identify, develop and implement new sequestration technology. Research efforts to improve basic understanding can be addressed in the context of a primary set of overarching questions in need of resolution:

- How can we best reduce the large uncertainties in global terrestrial C inventories?
- Are native ecosystem C sequestration capacities equivalent to their maximum carrying capacities?
- Is historic storage capacity of terrestrial systems equivalent to maximum inherent capacity?
- What will be the effects of climate change?
- How can ancillary benefits and risks of enhanced C sequestration be adequately quantified?
- What is the potential for plant and microbial biology in the post-genome era to impact C sequestration?

Summary

Storage of C in soils and plants has the potential to offset CO_2 emissions to the atmosphere in the coming decades while new "clean" energy production and CO_2 sequestration technologies are developed and deployed. Because they are economically important, have a rich history of directed research and can be most easily managed, forests and croplands are best suited for application of existing and new technology to enhance terrestrial C sequestration in the near term. Nonetheless, estimates of the potential for enhanced C storage, even in the United States, vary more than two-fold. In addition to proven management approaches, new management, chemical, and biological technology have the potential to impact C storage. What is needed is basic research to improve our fundamental understanding of natural phenomena controlling soil C sequestration and basic and applied research and development to bring new management and technology to the challenge.

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