Agriculture and Global Change: Environmental benefits of Soil Carbon Sequestration

by

D.C. Reicosky

[1]Reicosky, D.C. Soil Scientist, USDA-Agricultural Research Service, North Central Soil Conservation Research Lab, 803 Iowa Avenue, Morris, MN USA 56267; 320-589-3411 ext. 144, Fax: 320-589-3787; E-mail: reicosky@morris.ars.usda.gov

Key Words: CO_2 emissions, sustainability, soil carbon, soil organic matter, carbon credits

Introduction

The amount of carbon dioxide (CO_2) in the atmosphere has increased by 30% over the past 150 years. Many scientists believe there is a direct relationship between increased levels of greenhouse gasses, especially CO_2 in the atmosphere and rising global temperatures. One proposed method to reduce atmospheric CO_2 buildup is to increase the global storage of carbon (C) in agricultural soils. Additional benefits to this solution are the potential for simultaneous enhancement in agricultural production and ecosystem services for enhanced environmental quality. Much of the land-based C in agricultural ecosystems is in the form of soil C, which is the fundamental building block of soil organic matter. Consequently soil C is a primary determinant of many soil chemical, physical, and biological properties including nutrient availability, soil structure, and water holding capacity, all of which directly influence all ecosystem services, productivity and land quality. Soil C sequestration through conservation agriculture may be one of the most economical ways to reduce C emissions to buy time to help society develop cleaner fuels and produce in harmony with nature. Society needs to look at agriculture as part of the solution to the increasing concern of global climate change.

Agriculture has contributed some to environmental degradation and contamination from sedimentation and the greenhouse effect with tillage-induced carbon dioxide (CO_2) losses. Improved tillage management techniques have shown that scientific agriculture can also be a solution to these environmental issues in general and specifically to mitigating the greenhouse effect (Lal et. al., 1998). Improved agricultural practices such as direct seeding or conservation tillage have the potential to sequester more carbon (C) in the soil than farming emits through land use and fossil fuel combustion. In this way, agriculture can store more soil carbon and help society by off setting industrial CO_2 emissions. Thus, a combination of the economic benefits of enhanced soil management through reduced labor requirements, time savings, reduced machinery and fuel savings with direct seeding, combined with numerous environmental benefits has universal appeal. Indirect measures of social benefits as society enjoys a higher quality of life from environmental quality enhancement will be difficult to quantify. However, conservation agriculture, working in harmony with nature using direct seeding techniques that increase soil C, can be of benefit to society and can be viewed as both "feeding and greening the world" for global sustainability.

Fossil fuels are the life-blood of our industrial economy and our way of life. High levels of fossil fuel combustion have transformed fossil C from coal and oil into atmospheric CO_2. Industries have benefited from the availability of fossil fuels and have helped provide a standard of living in the U.S. that is second to none. However, as we learn more about our earth systems and possible global warming, the health and environmental costs of fossil fuels are threatening. International strategies aimed at reducing CO_2 in the atmosphere include soil C sequestration, tree planting, and ocean sequestration of C. Other technological strategies to reduce C inputs include developing energy efficient fuels, and efforts to develop and implement non-C energy sources, such as hydrogen fuel cells. All of these efforts combined can reduce CO_2 concentrations in the atmosphere and help to alleviate global warming.

Soil carbon management in conservation agriculture

Agricultural crop residues and their proper management can also play a big role in helping society cope with increased greenhouse gas emissions from the burning of fossil fuels. Croplands have the potential to offset a very significant portion of greenhouse gas emissions, but questions about crop residue decomposition research need to be addressed. As illustrated in Fig. 1, properly managed biological carbon cycling through conservation agriculture can improve soil productivity and crop production by maintaining or increasing soil C levels. Two significant advantages of surface residue management are increased C near the soil surface and enhanced nutrient cycling and retention. Greater microbial biomass and activity near the soil surface acts as a reservoir for nutrients needed in crop production and increases structural stability for increased infiltration. In addition to the altered nutrient distribution within the soil profile, changes also occur in the chemical and physical properties of the soil. All of this points to the value of C that starts with crop biomass input. Under today's economic standards, soil C is priceless for all the social and environmental benefits provided. While agriculture's contribution to these global change issues will likely be for the short-term (25 to 50 years), it will help society buy time to develop new technologies and cleaner burning fuels.

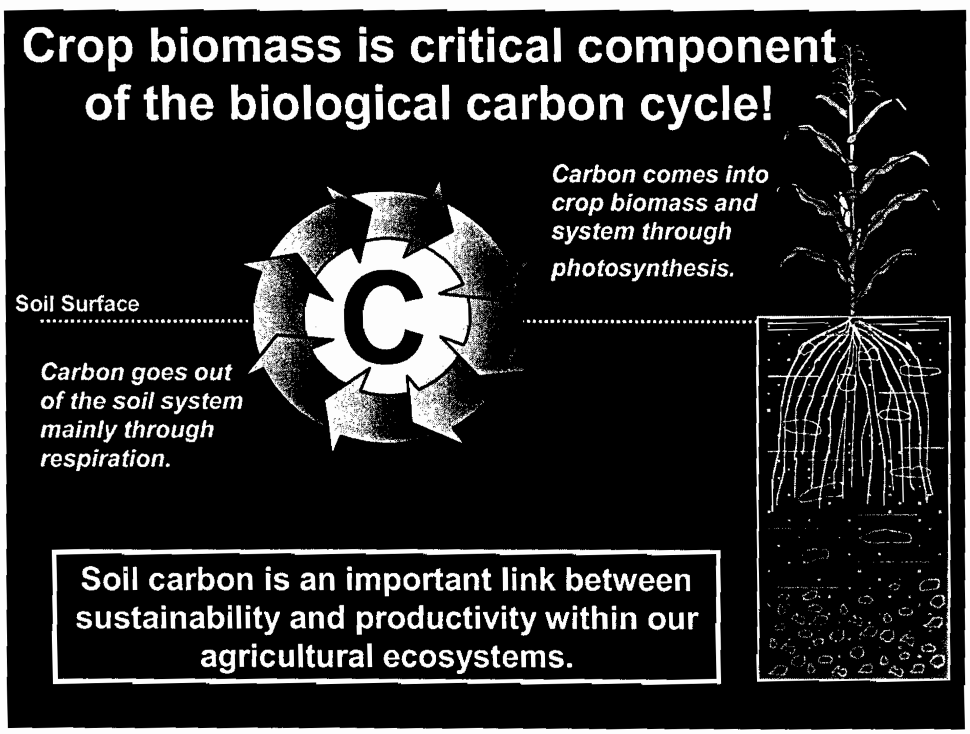

Figure 1. Carbon cycling in agricultural production systems.

Soil C management is the focus of current and future international negotiations and treaties related to global climate change. To manage terrestrial C inventories and fluxes effectively, it is important for agriculture to find a more efficient way to measure and utilize soil C to find more efficient ways of offsetting greenhouse gas emissions from industry. In this way, agriculture can increase soil C storage to temporarily help offset the greenhouse gas emissions from industry until cleaner burning fuels are developed. Industrial manufacturing is a big player in the "fossil C" cycle, however it is a small player in the "biological C" cycle. Agriculture is a big player in the biological C cycle and relatively small player in the fossil C cycle as illustrated in Fig.2. These differences between agriculture and industry provide an opportunity to join forces to address the increasing greenhouse gas emissions for all society's benefit. Carbon dioxide in the atmosphere from burning can be extracted by plant into a more manageable form for sequestration. A dynamic part of soil C cycling is directly related to the "biological C" cycle that is differentiated from the "fossil carbon" cycle. Agriculture and forestry, which manages much of the "biological C" cycle can help offset CO_2 emissions from the "fossil C" cycle that result in production and environmental benefits.

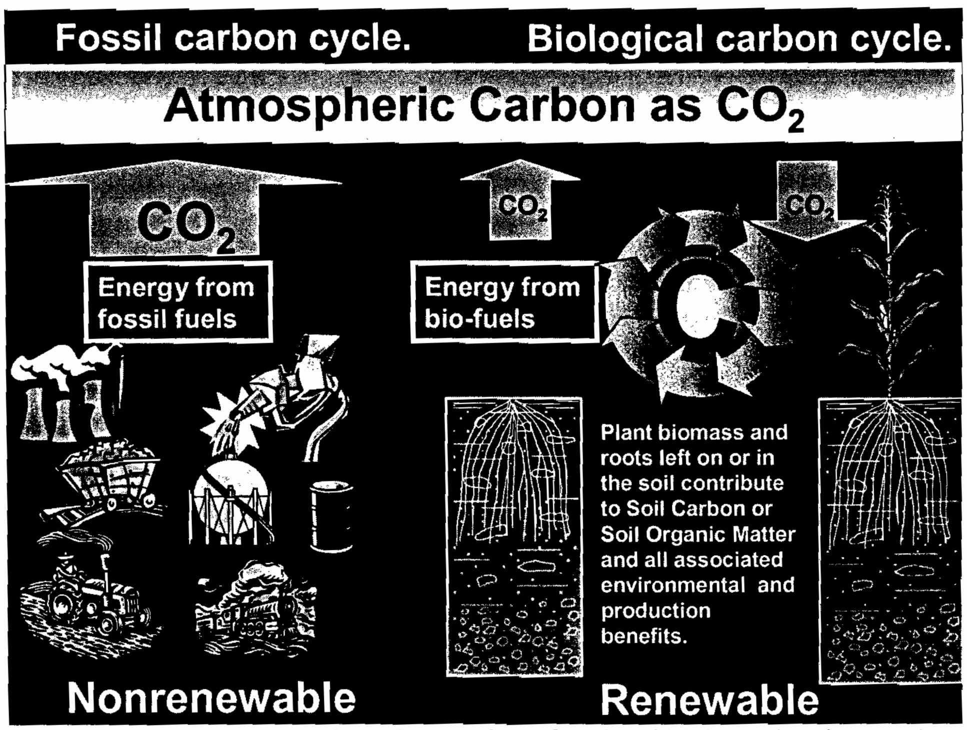

Figure 2. Comparison of CO_2 emissions from fossil and biological carbon cycles.

Fossil C sequestration entails the capture and engineered storage of C content of fossil fuels prior to its release to the atmosphere. Biological C sequestration entails removal of C from the atmosphere by plants. Fossil fuels (fossil C) are very old geologically, as much as 2 million years. Biofuels (bio-C) are very young geologically and can very from <1 to 10 years in age and as a result can be effectively managed for improved C cycling. One example of biological C cycling is the agricultural production of biomass for fuel to supplement fossil fuels. The major strength of biofuels is the potential to reduce net CO_2 emissions to the atmosphere. Enhanced C management in conservation agriculture, may make it possible to take CO_2 released from the fossil C cycle and transfer it to the biological C cycle to enhance food, fiber and bio-fuel production as well as for C sequestration for enhancing environmental quality. The social benefits in this scenario require agriculture and industry to work hand-in-hand to research and address increased CO_2 emissions.

Environmental benefits of soil C sequestration

The key role of agriculture is efficient management of the biological C cycle. The main benefit of conservation agriculture or direct seeding is the immediate impact on soil organic matter and soil C interactions (Reicosky, 2001). Soil organic matter is so valuable for what it does in the soil it can be referred to as "black gold" because of its vital role in physical, chemical and biological properties and processes within the soil system. Agricultural policies are needed to encourage farmers to improve soil quality by storing C that also will lead to enhanced air quality, water quality and increased productivity as well as mitigating the greenhouse effect. Soil C is one of our most valuable resources and may serve as a "second crop" if global C trading systems becomes a reality. While technical discussions related to C trading are continuing, there are several other secondary benefits of soil C impacting environmental quality that should be considered. In agricultural production systems, many decisions are made based on farmer experience and economic considerations. However, the recent emphasis on environmental concerns from using fossil fuels requires a balance between economic and environmental factors that have caused soil organic matter management decisions to rise to a high-level priority.

True soil conservation is C management with emphasis on C sequestration. By properly managing the C in our agricultural ecosystems, we can have less erosion, less pollution, clean water, fresh air, healthy soil, natural fertility, higher productivity, C credits, beautiful landscapes, and sustainability. Dynamic soil quality encompasses those properties that can change over relatively short time periods (e.g. soil organic matter, labile soil organic matter fractions, soil structure components, and macro porosity) in response to human use and management and that are strongly influenced by agronomic practices. The main contribution of conservation agricultural management techniques, which are successful in providing a net C sink in soils, includes no till (direct seeding) that minimizes or eliminates manipulation of the soil for crop production. It also includes the practice of conservation or mulch tillage, which leaves most crop residues on the soil surface. These procedures generally protect the soil, increase infiltration, reduce soil erosion, improve water use efficiency, and increase C concentrations in the topsoil. Conservation tillage can also reduce the amount of fossil fuel consumed in intensive tillage and by other farm operations and thus decrease the rate of CO_2 buildup in the atmosphere. Cover crops, such as clover for nitrogen accumulation and small grains, capture CO_2 through photosynthesis for soil protection and improvement between periods of regular crop production. Cover crops improve C sequestration by enhancing soil structure, adding nitrogen to the soil, and adding organic matter to the soil. Diverse crop rotation is a sequence of several different crops grown in regularly recurring succession on the same area of land. The more diverse crop rotations provide long-term stability in crop production systems by minimizing pest and disease problems. Diverse rotations mimic the diversity of natural ecosystems more closely than intensive mono-cropping practices. Varying the type of crops grown can increase the quality and level of soil C. However, effectiveness of crop rotation depends on the type of crops grown, rotation duration, intensity of tillage, soil type and climate conditions.

Soil C is so important that it can be compared to the central hub of a wheel as shown in Fig. 3. The wheel represents a circle, which is a symbol of strength, unity and progress. The "spokes" of this wagon wheel represent incremental links to soil C that lead to the environmental improvement that supports total soil resource sustainability. Many spokes make a stronger wheel. Each of the secondary benefits that emanate from soil C contributes to environmental enhancement through improved soil C management. Thus, farmers who use conservation agriculture or direct seeding techniques are helping to maintain environmental quality for all of society. Quality food production and economic and environmentally-friendly management practices that are socially acceptable will lead to sustainable production and be mutually beneficial to farmers and all of society. Enhanced soil C management is a win-win strategy (Lal et al., 1998). Agriculture wins with improved food and fiber production systems and sustainability. Society wins because of the enhanced environmental quality.

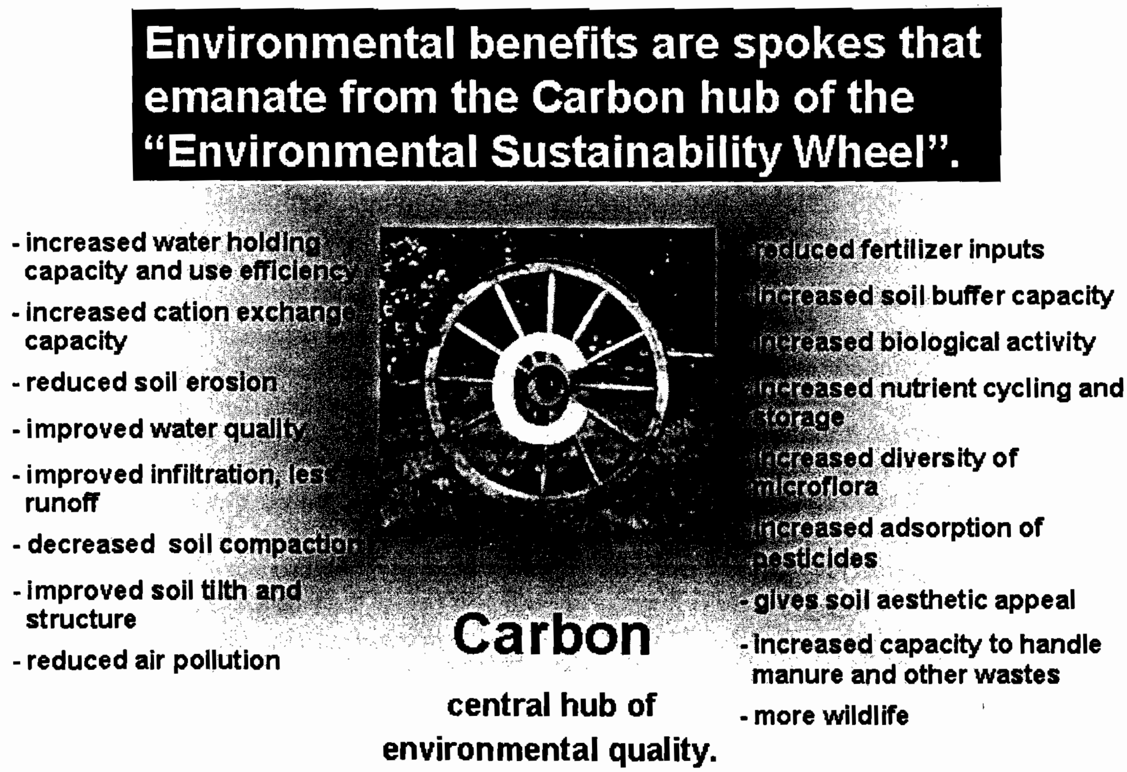

Figure 3. Environmental sustainability wheel with benefits emanating from the soil carbon hub.

Increased soil organic matter is known to increase the water holding capacity along with increasing infiltration so that it has a tremendous effect on soil water management. Soils relatively high in C, particularly with crop residues on the soil surface, are very effective in increasing soil organic matter and reducing soil erosion loss. Under these situations, the crop residue acts as tiny dams that slow down the water runoff from the field allowing the water more time to soak into the soil. Worm channels, macropores and plant root holes left intact increase infiltration. Soil organic matter contributes to soil particle aggregation that makes it easier for the water to move through the soil and enables the plants to use less energy to establish to root systems. Intensive tillage breaks up soil aggregates and results in a dense soil making it more difficult for the plants to get nutrients and water required for their growth and production. Reducing or eliminating runoff that carries sediment from fields to rivers and streams will enhance environmental quality. It is important, therefore, that C loss from the soil system through historical land use of farming practices be restored to its natural potential using direct seeding and conservation tillage methods for sustainable production.

A secondary benefit of less tillage and increasing soil C is reduced air pollution. Carbon dioxide is the final decomposition product of soil organic matter and is released to the atmosphere. Research has shown that intensive tillage, particularly the moldboard plow, releases large amounts of CO_2 as a result of physical release and enhanced biological oxidation (Reicosky et al., 1995). With conservation tillage, crop residues are left more naturally on the surface to protect the soil and control the conversion of plant C to more stable organic matter and humus. Intensive tillage releases soil C to the atmosphere as CO_2 where it can combine with other gases to contribute to the greenhouse effect.

Ecosystem services provided by soil C

Understanding the role of soil C and biodiversity in agricultural ecosystems has highlighted the value and importance of a range of processes that maintain and fulfill human needs. These basic needs are called "ecosystem services" that are the basis of our economic and social system. Ecosystem services are the processes by which the environment produces resources that we often take for granted. An ecosystem is a community of animals and plants interacting with one another and with their physical environment. Ecosystems include physical, chemical and biological components such as soils, water, and nutrients that support the biological organisms living within them. People are part of these ecosystems. Agricultural ecosystem services include production of food, fiber and biofuels, provisions of clean air and water, natural fertilization, nutrient cycling in soils, mitigation of climate, pollination, genetic resources, recreational, cultural and social benefits and many other fundamental life support services required for our existence. These ecosystem services will be enhanced by increasing the amount of soil C stored. Our agricultural ecosystems help moderate weather extremes and their impacts, mitigate natural droughts and floods, protect stream and river channels and coastal shores from erosion, control agricultural pests, maintained biodiversity, generate and preserve soils and renew their fertility, detoxify and decompose wastes, contribute to climate stability, purify the water and air, regulate disease carrying organisms, to name a few. Conservation agriculture through its impact on soil C is the best way to enhance ecosystem services. Recent analyses have estimated national and global economic benefits from ecosystem services of soil formation, nitrogen fixation, organic matter decomposition, pest bio-control, pollination and many others. Intensive agricultural management practices cause damage or loss of ecosystem services, in the form of changes in nutrient cycling, primary productivity, species diversity, species dominance, and population fluctuation in exchange for economic productivity (Smith et al., 2000). Soil C sequestration plays a critical role in the harmony of our ecosystems providing these services.

Eco-efficient farming is economically competitive and environmentally friendly that maintains sustainable production. This requires a certain level of environmental consciousness and a normal part of doing business in modern agriculture. We must reduce pollution and use our resources in line with the earth's carrying capacity for sustainable production of food and fiber. The responsibility lies on the shoulders of the farmer to maintain a delicate balance between the economic implications of farming practices and the environmental consequences of using the wrong practices. This responsibility entails producing food and fiber to meet the increasing population while maintaining the environment for a high quality of life. The social value of an agricultural community is not just in food and fiber production, but producing in harmony with nature for better quality soil, water, air and biological diversity where improved C cycling is fundamental to offsetting greenhouse gas emissions.

Carbon sequestration policies and perspectives

The increase in greenhouse gas concentrations in the atmosphere is a global problem that requires a global solution (Kimble et al., 2002; Lal, 2002). Concern about negative effects of climate warming resulting from increased levels of greenhouse gases in the atmosphere has led nations to establish goals and policies for reductions of these emissions. Initial targets for reductions are stated in the Kyoto protocol to the United Nations framework convention on climate change, which allows trading credits that represent verified emission reductions and removal of greenhouse gases from the atmosphere (United Nations framework convention on climate change secretariat, 1997). The emissions trading may make it possible to achieve reductions in net greenhouse gas emissions for far less cost than without trading (Dudek et al., 1997). Storing C in soils using conservation agriculture techniques can help offset greenhouse gas emissions while providing numerous environmental benefits (Lal et al., 1998; Lal, 2002). Storing C in forests may also provide environmental benefits resulting from increased numbers of mature trees contributing to C sequestration (Row et al., 1996).

As interest in soil C sequestration grows and C trading markets are developed, it is important that appropriate policies be developed that will prevent the exploitation of soil organic C and at the same time replace the lost C and establish its value (Walsh, 2002). Policies are needed that will encourage the sequestration of C for all environmental benefits that will evolve (Kimble et al., 2002). Making C a commodity necessitates determining its market value with rational criteria. Both farmers and society will benefit from sequestering C. Enhanced soil quality benefits farmers, but farmers and society in general benefit from erosion control, reduced siltation of reservoirs and waterways, improved air and water quality, and biodegradation of pollutants and chemicals. Farmers need to be compensated for the societal benefits of C sequestration and the mechanisms that develop will allow for C trading and maintaining property rights. One important criterion in developing the system is the measurement and verification of the C options for sequestration that must be developed and the importance of making policymakers aware of these procedures and the technical difficulties. The use of the C credit market mechanisms is intended to help meet the challenge of climate change and future C constraints that enable sustainable development and at the lowest social cost. Carbon credit accounting systems must be transparent, consistent, comparable, complete, accurate, and verifiable (IPCC, 2000). Other attributes for a successful system include global participation and market liquidity, linking of different trading schemes, low transaction costs, and rewards for early actions to voluntarily reduce emissions before regulatory mandates are put in place. Characterizing the relationships between soil C and water quality, air quality and all the other environmental benefits should be an easy sell to get social acceptance of this type of agriculture. The largest impediment is the educational processes directed at the policymakers and food consuming public that require further enhancement. In the evolution toward a global economy and as concerns over global environmental impacts increase, CO_2 emissions management will become a factor in the planning and operations of industrial and government entities all over the world, creating challenges and opportunities for those who are able to recognize and capitalize on them. Care should be taken in the design of these policies to ensure their success and to avoid unintended adverse economic and environmental consequences to provide maximum social benefit.

Summary

Agriculture and industry must keep the communication lines open to address global concerns related to CO_2 emissions. While we in agriculture learn more about soil C storage and its central role in environmental benefits, all society must understand the secondary environmental benefits of conservation agriculture (no-till) and what they mean to sustainable production agriculture. Understanding these environmental benefits and getting the conservation practices implemented on the land will hasten the development of harmony between man and nature while increasing production of food and fiber and offsetting industrial greenhouse emissions. Increasing soil C storage can increase infiltration, increase fertility, decrease wind and water erosion, minimize compaction, enhance water quality, decrease soil C emissions, impede pesticide movement and generally enhance environmental quality. Increased levels of greenhouse gases in the atmosphere require nations to establish international and national goals and policies for reductions. Accepting the challenges of maintaining food security by incorporating soil C storage in conservation planning demonstrates concern for our global resources and our willingness to work in harmony with nature. This concern presents a positive role for conservation agriculture that will have a major impact on global sustainability and our future quality of life.

References:

Dudek, D.J., J. Goffman and S.M. Wade. Emissions trading in nonattainment areas: Potential, requirements, and existing programs. In Kosobud, R.F. and J.M. Zimmermann (ed.) *Market-based Approaches to Environmental Policy: Regulatory Innovations to the Fore.* Van Nostrand Reinhold, New York pp. 151-185. 1997.

IPCC. *Land use, Land-Use Change, and Forestry,* Special report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K. 377 pp. 2000.

Kimble J. M., R. Lal and R.R. Follett. Agricultural practices and policy options for carbon sequestration: What we know and where we need to go. In Kimble, J.M., R. Lal and R.R. Follett (ed.). *Agricultural Practices and Policies for Carbon Sequestration in Soil.* Lewis publishers. CRC Press. Boca Raton, FL. pp. 495-501. 2002.

Lal, R. Why carbon sequestration in agricultural soils? In Kimble, J.M., R. Lal and R.R. Follett (ed.). *Agricultural Practices and Policies for Carbon Sequestration in Soil.* Lewis Publishers. CRC Press. Boca Raton, FL. pp. 21-30. 2002.

Lal, R., Kimble, J.M., Follet, R.F. and Cole, V. *Potential of U.S. Cropland for Carbon Sequestration and Greenhouse Effect Mitigation.* USDA-NRCS Washington, D.C. Ann Arbor Press, Chelsea, MI. 128 pp. 1998.

Reicosky, D.C. Conservation agriculture: Global environmental benefits of soil carbon management. pp. 3-12. In Garcia-Torres, L., J. Benites, and A. Martinez-Vilela (ed.) *Conservation agriculture: A worldwide challenge.* XUL, Cordoba, Spain. 2001.

Reicosky, D.C. Strip tillage methods: Impact on soil and air quality. p. 56-60. In Mulvey (ed.) Environmental benefits of soil management. *Proceedings of the ASSSI National Soils Conf., Brisbane, Australia.* 1998.

Reicosky, D.C. and M.J. Lindstrom. Fall tillage method: effect on short-term carbon dioxide flux from soil. *Agronomy Journal* 85:1237-1243. 1993.

Row, C., R.N. Sampson, and D. Hair. Environmental and land-use changes from increasing forest area and timber growth. In Sampson, R.N. and D. Hair (eds), *Forest and Global Change,* Vol. 2: *Forest Management Opportunities for Mitigating Carbon Emissions,* American Forests, Washington, D.C. 1996.

Smith, O.H., G.W. Petersen, and B.A Needelman. Environmental indicators of agroecosystems. *Advances in Agronomy* 69:75-97. 2000.

United Nations Framework Convention on Climate Change. *Kyoto Protocol to the United Nations Framework Convention on Climate Change.* United Nations Framework Convention on Climate Change Secretariat. Bonn, Germany. 1997.

Walsh, M.J. Growing the Market: Recent developments in Agricultural Sector Carbon Trading. In Kimble, J.M., R. Lal and R.R. Follett (ed.). *Agricultural Practices and Policies for Carbon Sequestration in Soil.* Lewis Publishers. CRC Press. Boca Raton, FL. pp. 375-385. 2002.