Kansas State University

Soil Organic Carbon and the Global Carbon Cycle

Department of Agronomy **MF-2548** **Carbon Series**

Carbon is the fundamental building block of all life. Carbon is present in the atmosphere, in plant and animal life, in nonliving organic matter, in fossil fuels, in rocks, and dissolved in oceans. Movement of carbon molecules from one form to another is known as the carbon cycle (Figure 1). Plants acquire carbon from the atmosphere through photosynthesis. Using carbon dioxide (CO_2) from the atmosphere and energy from sunlight, plants convert CO_2 to organic carbon as they produce stems, leaves, and roots. The cycle of life and death of plants results in accumulation of decomposing plant tissue, both aboveground and belowground (plant roots), and produces a significant amount of soil organic carbon.

Soil Organic Carbon

Soils vary in the amount of soil organic carbon[1] they contain, ranging from less than 1 percent in many sandy soils to greater than 20 percent in soils found in wetlands or bogs. Kansas soils had a native soil organic carbon content ranging from 1 to 4 percent. Most Kansas cultivated soils now have soil organic carbon levels of 0.5 to 2 percent.

In Kansas, native prairie grasses, such as big bluestem (*Angdropogon gerardii* Vitman) and Indiangrass (*Sorghastrum nutans* (L.) Nash), helped develop deep soils. Roots of these and other grass species are fibrous, and can grow to great depths, producing a majority of their annual biomass belowground. Consequently, the significant organic carbon level in soils that developed under native grasses occurs to a depth of several feet. The dark black color associated with rich, fertile soil is largely a measure of its organic carbon content. As a soil's organic carbon content drops, the soil's color lightens and reflects its mineral content. Thus the red soils of southeastern Kansas and northeastern Oklahoma are indications of higher iron concentration and lower soil carbon levels.

Soils that form under forests tend to accumulate high levels of soil organic carbon near the surface and have lower carbon levels in the subsoil. This layering of soil, is primarily due to the accumulation of leaf litter and decaying wood from limbs and trees that accumulate at the soil surface. But soil layering is also a function of higher annual rainfall and the accelerated weathering process that enriches the subsoil with clay.

Atmospheric Carbon

Scientists using ice core data, combined with long-term monitoring of CO_2 in the atmosphere, have verified tremendous fluctuations in atmospheric CO_2 over the past 200,000 years. Looking at the past 1,000 years, atmospheric CO_2 levels have increased significantly (Figure 2). The current level (2000 A.D.) of CO_2, approximately 369 ppm, is now higher than at any time in the past 1,000 years. More importantly, this unprec-

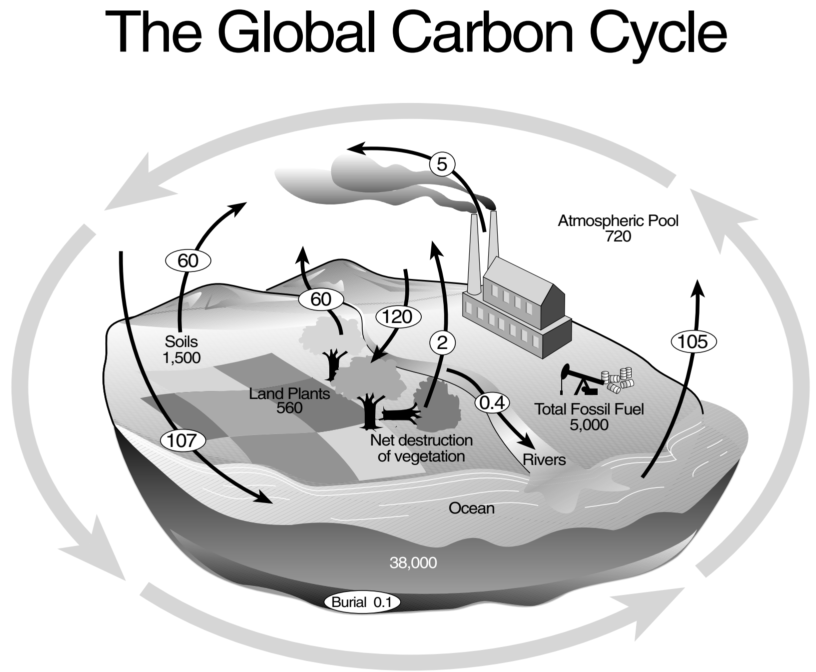

Figure 1. *The present-day global carbon cycle. All pools are expressed in units of gigatons of carbon, and rates are gigatons of carbon per year. (from: Schlesinger, 1991)*

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[1] *Note: The chemical formula for soil organic matter is very complex, but consists primarily of organic carbon, nitrogen, and hydrogen. To convert soil organic matter (%OM) as reported in most soil tests to just soil organic carbon, divide percent organic matter by 1.7.*

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edented rate of increase has accelerated so quickly that the ecosystem may be unable to adapt.

This rise in CO_2 corresponds with the use of fossil fuel, land clearing, and land use change as seen here in the Great Plains and around the world. The most significant factor that explains rising atmospheric CO_2 levels is fossil fuel use. At the current use rate of 5 Gt carbon per year, (Gt stands for a gigaton, which equals 2.2 trillion pounds), the total reserves of fossil fuel will likely be exhausted during the next 300 to 400 years.

As the fossil fuel inventory is expended, carbon that has been out of the cycle for millions of years is moved directly to the atmosphere. Atmospheric carbon will eventually cycle back into organic carbon, or into the oceans and reach a new equilibrium, but the process may take thousands of years to occur.

In the short-term, this "new" carbon will remain in the atmosphere as CO_2. Current atmospheric models predict that the complete expenditure of the fossil fuel reserves will drive peak concentrations of atmospheric CO_2 to levels near 1,200 ppm. Some scientists believe even higher concentrations will occur. This increased level of CO_2 has led some scientists to believe that the average global temperatures may begin to increase. In the popular press this is referred to as global warming. The so-called greenhouse gases, CO_2, methane (CH_4), and nitrous oxide (N_2O) that exist in the atmosphere, help retain heat that normally radiates away from the earth's surface. With greater concentrations of these gases, heat may not be able to escape, resulting in increased global temperatures. Changes in global temperatures so far are slight and show no definite trend, but changes in atmospheric CO_2 levels are well documented and are accepted by most scientists.

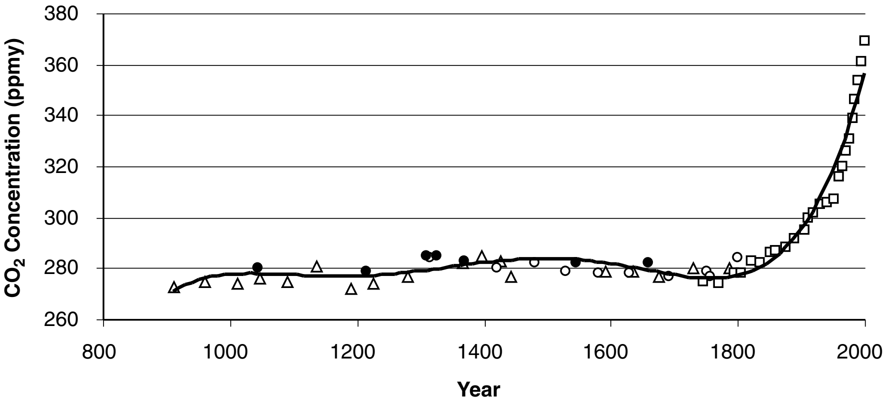

Figure 2. *Changes in atmospheric carbon dioxide levels. (Note: This graph shows* CO_2 *levels from ice core data from Greenland, and Antarctica (various symbols represent different sampling sites) + monitoring at Mauna Loa, through ~2000. (Adapted from IPCC, 1995, and from CDIAC, U.S. Department of Energy, 2002)*

Managing Carbon

What can be done to slow or reverse the increase in CO_2? Thinking in terms of sources, where CO_2 is produced, and sinks, where CO_2 is removed, an obvious solution is to reduce input of the source, by reducing fossil fuel use. This would limit the input of CO_2 to the atmosphere. Eventually, cleaner and more efficient energy sources will be required, but the current economics of fossil fuel limits the adoption and development of alternative energy sources. In the interim, as we develop alternative energy technologies, increasing the use of sinks may help stabilize atmospheric CO_2 levels.

An inventory of the world's carbon reservoirs (Figure 1) illustrates that carbon storage in the deep oceans is the major reservoir, but changes to this pool can take millions of years. In addition, our ability to manipulate that pool is limited. The next biggest pool is soil organic carbon. Soil organic carbon constitutes more than twice as much stored carbon as that of the earth's vegetation (plants, trees, crops, and grasses). One way to help stabilize atmospheric CO_2 would be to adopt practices worldwide that increase soil carbon levels.

How much carbon can be stored in a given Kansas soil? It's a simple question, but there is no simple answer. Storage potential for the soil is a function of the soil's current organic carbon level, atmospheric CO_2 concentration, and soil-management practices. For many Kansas soils, significant topsoil losses due to erosion, and frequent tillage operations have reduced carbon levels to less than half of their native values. With proper management, soil organic carbon of most soils can be increased.

Losses of soil carbon over the first half of the 20th century were partly recovered in the second half as soil conservation practices improved and cropping systems intensified (Figure 3). Proper fertility practices and improved hybrids and cultivars have also played a role in building soil organic carbon levels. Higher yields and greater cropping intensities increase the amount of biomass returned to the soil, providing a larger input that can become soil organic carbon. The right-hand side of Figure 3 shows future projections of soil organic carbon levels assuming 1990 tillage and cropping practices.

Soils that are managed with no-tillage and intensified cropping systems could increase soil carbon at the rate of 0.1 percent per year. Currently in Kansas 10 percent of the 21 million acres of cropland is under no-tillage management and should be sequestering an additional 21,000 tons carbon per year. Increased adoption of no-tillage and intensified cropping systems would sequester more carbon.

Worldwide, the potential to use soil as a carbon sink does exist, but remains a short-term solution. After some period of time, likely 30 to 50 years, a new soil organic carbon equilibrium level will be reached, where further gains in carbon storage will be difficult to achieve. The long-term solution to stabilizing atmospheric CO_2 levels will involve reducing our dependence on fossil fuel for energy.

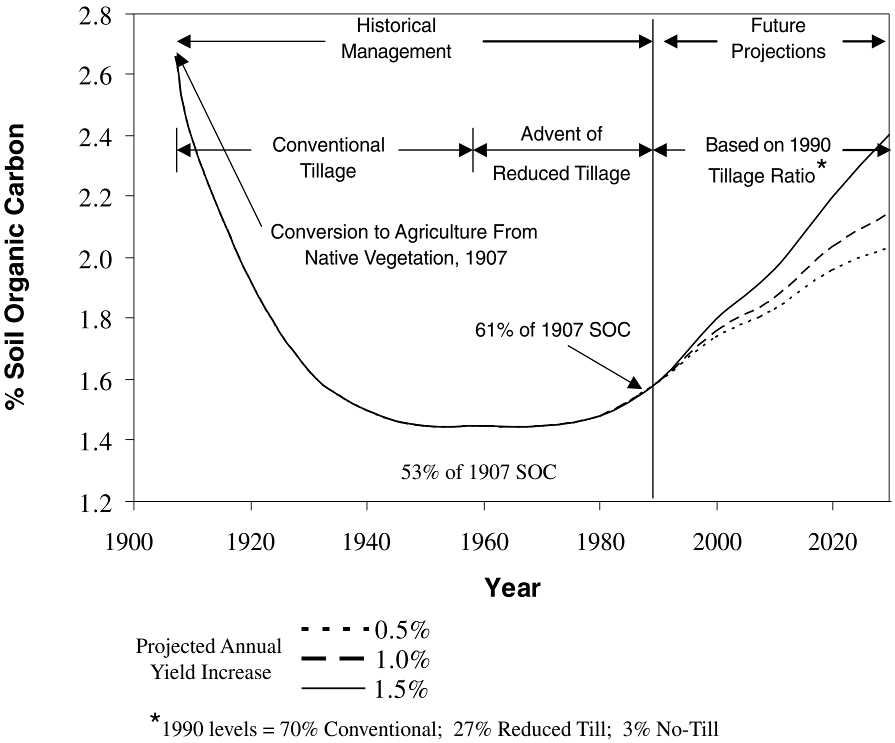

Figure 3. *Measured and predicted changes in soil organic carbon content of a prairie soil throughout the period of cultivation. (from: Donnigan et al., 1998)*

Summary

Carbon is the building block of plant life and a major constituent of soil organic matter. Carbon dioxide is the gaseous form of carbon and is a greenhouse gas. Since the beginning of the industrial revolution, CO_2 levels have risen at a rate of approximately 1.5 percent per year. The continued rise of atmospheric CO_2 concentration could lead to global warming. Fixation of CO_2 by plants into soil organic carbon is one possible mechanism for reducing the rise of CO_2 concentration in the atmosphere. A long-term reduction in atmospheric CO_2 levels will require a reduction of fossil fuel use and development of alternative energy sources.

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