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Carbon Sequestration

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Rising carbon dioxide (CO2) levels in the atmosphere are causing growing concerns about the possibility of global warming in the future. A major source of these emissions – 5.5 gigatons – is the burning of fossil fuels. In contrast, the earth's ecosystem currently sequesters only about 1.2 gigatons of carbon, through photosynthesis, in trees and plants and as soil organic matter below the ground (Figure 1). Significantly larger quantities of carbon could be sequestered in soils and forests, but the available land is not being effectively used for this purpose. Changes in land use to sequester more carbon can be a relatively low-cost approach to address climate change at least in the near term. Such changes also would create other co-benefits such as reduced soil erosion, higher soil productivity, and improved soil and water quality and wildlife habitat.

Carbon sequestration defined

Carbon sequestration here refers to removal of carbon dioxide from the atmosphere and its long-term storage in forests and perennial grasses in the form of plant biomass and in soils as soil organic matter. Photosynthesis is the method by which atmospheric carbon dioxide is absorbed by forests and plants. Some of this carbon is then accumulated in the soil, in an organic form, by plant roots and plant litter.

This paper discusses the potential for carbon sequestration, some strategies for enhancing sequestration in soils and forests and the factors that affect the magnitude of carbon sequestration that can be

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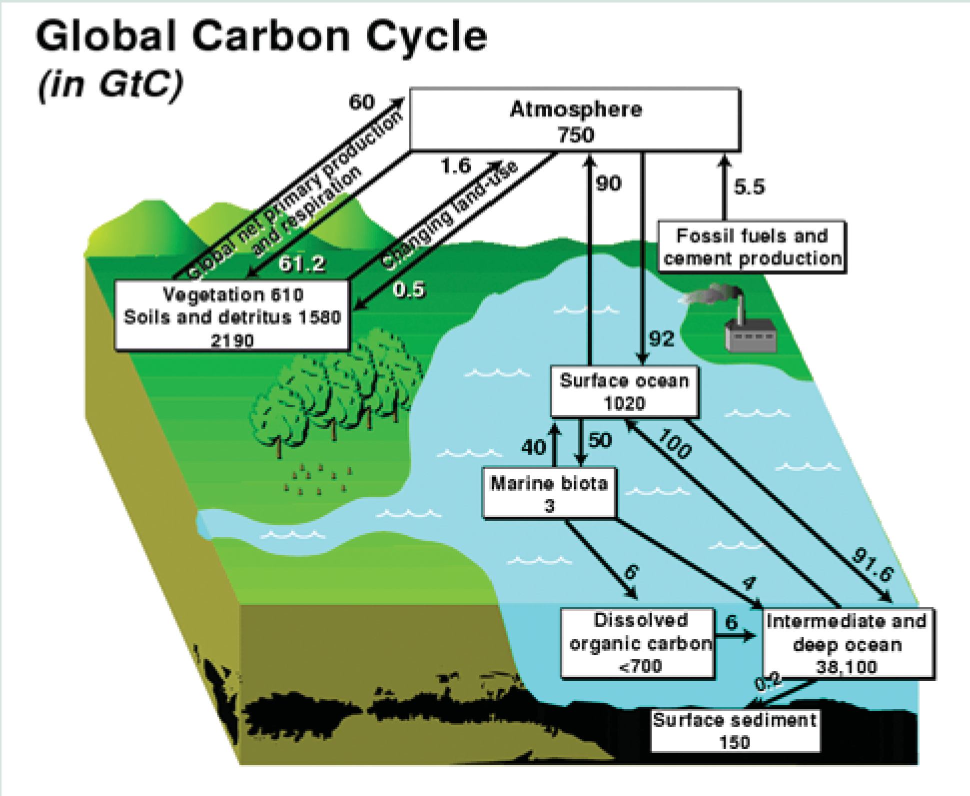
achieved with these practices. The costs of sequestration determine the economic potential for sequestration and have implications for the payments that need to be provided to landowners to create incentives for adopting sequestration friendly practices. The paper concludes with a discussion of the type of policies needed to enhance carbon sequestration and issues that arise in their implementation.



Source: Wilfred M. Post (Oak Ridge National Laboratory)

Several strategies are available for increasing carbon sequestration in soils and forests. These include:

a) Changing management practices on cropland such as less intensive tillage, changes in crop rotation, conversion of land to pasture and restoration of degraded soils.

b) Afforestation of agricultural land.

c) Modifications in forestry management practices, including lengthening of forest rotation cycles and agroforestry by growing short rotation plantations.

How much Carbon can be Sequestered?

Soil can potentially sequester up to ten times the amount of carbon currently being sequestered. The current level of CO_2 sequestration in cropland is estimated at 55 million metric tons per year. Through changes in management practices on cropland alone between 300 and 500 million tons of CO_2 could be sequestered per year over a two-three decade period (Paustian et al., 2001). This is

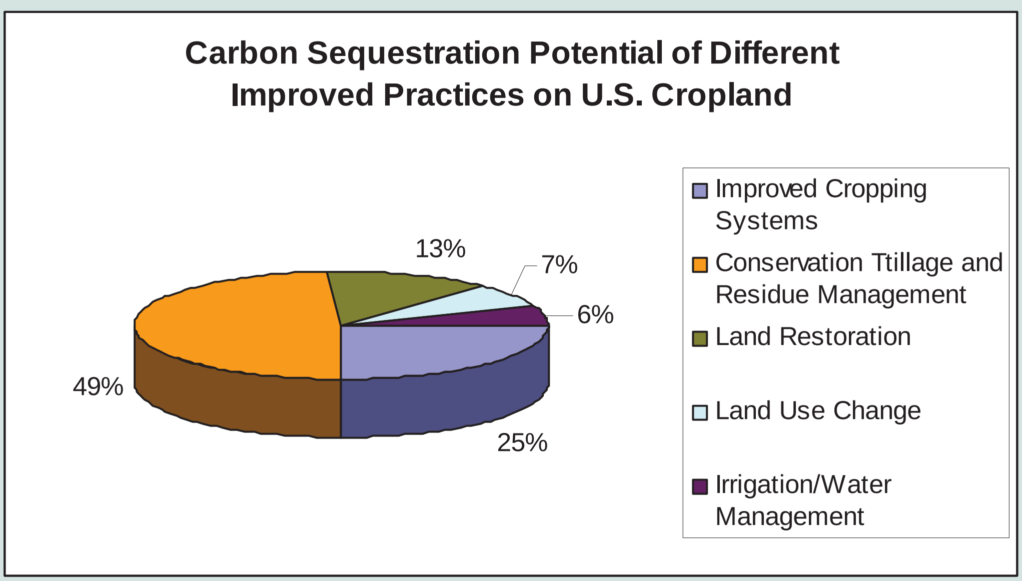
Conventional tillage does not sequester any carbon in the soil and releases previously sequestered carbon.

Conservation tillage allows the soil to accumulate organic matter and carbon.

equivalent to 4% to 7% of the US emissions of greenhouse gases in 2005 (USEPA, 2007) or the amount of CO2 emitted annually by 25 to 45 million cars (Murray, 2004).

Changes in forestry practices can also sequester large additional quantities of CO2. Afforestation can store as much as 5-10 tons of CO2 per acre per year over a timber rotation (20-50 years in the U.S). With the amount of land available for conversion from agriculture to forests, hundreds of millions of tons of additional CO2 could be sequestered annually. Since carbon can be stored in harvested wood products for several decades, forests can provide for long-term sequestration.

Changing land use and management practices to sequester carbon is not without costs; thus the economic potential for carbon sequestration is less clear. Land owners and farmers typically face a cost associated with switching from their current (most profitable) practices to others that may involve lower returns



Source: Feng et al. (2000)

to land. This creates a need for policy interventions to provide financial incentives for them to adopt such practices. The design and implementation of these interventions is complicated by the biophysical features of carbon sequestration.

Factors Affecting Carbon Sequestration

Land has a finite capacity to sequester carbon. This capacity depends on the land use/management practice, the quality of the soil and the biophysical conditions of the site. Soil carbon sequestration occurs rapidly during the first few years after a land use/practice is changed to a sequestration-friendly use/practice; the rate of soil absorption of carbon decreases over time until the soil carbon stock reaches its maximum capacity (or an equilibrium level) in about 20 to 30 years. If the sequestration-friendly land use/practice is maintained indefinitely, the soil carbon stock will remain at this equilibrium level. However, a reversion back to traditional land management practices such as conventional tillage in place of reduced tillage will lead to a release of soil carbon. The dynamic process of soil carbon accumulation is asymmetric, in that the rate of soil carbon accumulation is slower than the rate at which carbon is released. The rate of soil carbon sequestration is also spatially variable and depends on the amount of carbon already present in the soil. The latter tends to vary with land use history, soil type and depth, climatic conditions and the specific sequestration-friendly land uses or practices followed.

Baselines: The climate change mitigation benefits from carbon sequestration arise from the additional sequestration achieved by changing land use or management practices beyond the level that would have been achieved in its absence. To determine how much additional carbon can be sequestered on a piece of land, a baseline needs to be established. This represents the amount of carbon sequestration that would occur if existing land use or management practices had continued.

Permanence: Carbon stocks do not increase indefinitely and after a few decades the soil is saturated with carbon and there is no further accumulation. Moreover, the climate benefits of carbon sequestration only last if the practices which led to the accumulation of carbon in soils and forests are maintained indefinitely. Abandonment or temporary interruption of stock-enhancing practices, for example, switching from conservation tillage to conventional tillage, would result in rapid release of stored carbon. The possibly temporary nature and finite holding capacity of the soil and the difficulties in determining how much additional carbon can be sequestered on a piece of land have been at the heart of the international debate over the inclusion of carbon sequestration as an allowable mitigation strategy under the Kyoto Protocol.

Measurement and Monitoring: A key feature of soil carbon sequestration is that it cannot be observed and the amount of carbon sequestered for a given practice may be uncertain because it depends on weather and other stochastic variables. The nonpoint source characteristic of soil carbon sequestration and the considerable differences in soil quality make it costly to measure, monitor and verify the soil carbon sequestration achieved by change in land use or management practices. Methods to measure soil carbon include direct on-site measurements of soil carbon or biomass and indirect remote sensing techniques. Due to the high cost of using these methods, average values for sequestration based on the land use or management practice adopted are typically used to estimate sequestration levels.

Costs of Sequestration

Agricultural producers operate in competitive markets and can be expected to be using practices that will generate the highest return or profit per unit of land. These practices are likely to have been selected without considering their sequestration potential in the absence of any markets and policy incentives that provide a monetary value to carbon sequestration. While in some cases the most profitable practice might also be a sequestration friendly practice, typically a switch to sequestration friendly practices lowers returns to (or profits from) land due to higher production costs, lower or more variable yields or lower quality products. The profits foregone by switching to a sequestration friendly practice are referred to as the opportunity cost of sequestration. These costs can differ considerably across locations due to differences in production practices, soil quality, yields, and sequestration potential of alternative land uses. These costs are also likely to differ with the amount of sequestration desired; greater sequestration typically requires incurring higher costs of sequestration per unit. Studies show that the costs of sequestration increase fairly steeply as the amount of sequestration desired per year increases. This is because sequestration-friendly practices are initially more likely to be adopted on lands where foregone profits due to conversion to those practices are low and the potential for sequestration is high. Additional sequestration would require adopting such practices on land where the potential for additional sequestration is low and where conventional practices are much more profitable, raising the opportunity costs of sequestration. Studies for Montana and Iowa (Antle and McCarl, 2002) indicate that 0.5 metric tons of carbon can be sequestered on cropland per year at a cost of $20 per ton in Montana and $80 per ton in Iowa, suggesting that the opportunity cost of carbon sequestration is lower in Montana. However, opportunity costs rise more rapidly in Montana than in Iowa as available cropland becomes a limiting factor. Estimates by McCarl and Schneider (2001) indicate that at prices lower than $50 per ton of C, cropland offers greater potential to sequester soil carbon than even forests. However, costs of soil carbon sequestration rise much more steeply than those due to afforestation. Afforestation can also achieve much higher quantities of sequestration than cropland because it captures a higher amount of carbon both in the soil and in the biomass.

Designing Policies for Carbon Sequestration

The above cost estimates suggest a need for conservation programs to compensate agricultural landowners for their foregone profits due to a switch to sequestration-friendly practices. There are two ways in which these incentive payments could be made. First, farmers could be given a fixed payment per acre of land for switching from a practice with low annual rates of sequestration to a practice with high annual rates of sequestration. Such a scheme would be similar to that used by existing conservation programs such as the Conservation Reserve Program that provide area-based payments to landowners who retire cropland and adopt conservation practices. The second approach would be to pay farmers a fixed amount per ton of carbon sequestered by switching to a sequestration-friendly practice. Given the spatial and temporal variability in the amount of sequestration per acre of land associated with switching to a sequestration-friendly practice, such a scheme would imply that payments per acre of land would vary over space and time. We next discuss the implications of these two approaches and the biophysical process of carbon sequestration for the effectiveness of policies for sequestration.

First, given the non-point nature of soil carbon sequestration, area-based payments are likely to have lower transactions costs than per ton payment schemes. The per acre payment scheme requires monitoring to ensure that specified practices are being implemented by landowners, while the per ton payment scheme requires establishing the baseline carbon stock at each site, the soil carbon sequestration rates for each type of land use/practice, and the monitoring of carbon accumulation. Given a non-linear path of carbon accumulation, a per ton payment scheme requires knowledge of the duration a practice has been employed, the baseline carbon level and time-varying rates of annual sequestration. These sequestration rates would need to be determined either using field measurements or biophysical models that are calibrated to local conditions resulting in higher implementation costs.

Second, the two policies can have very different opportunity costs of sequestration per ton of carbon. According to one estimate, the cost of sequestering one ton of carbon could be four times higher under a per acre payment scheme than a per ton payment scheme (Antle and McCarl, 2002). This is because the latter is targeted more precisely to create incentives for land with high sequestration rates and low opportunity costs to switch to sequestration friendly practices. Further, payment schemes that assume a fixed rate per acre run the risk of overestimating the amount of carbon accumulation if they extrapolate this annual average rate of soil carbon accumulation over periods which are too long and if they ignore the baseline stocks and saturation limits of the soil.

Third, the temporary nature of the sequestration process implies that contracts signed by farmers to switch practices to sequester carbon might be violated in the future resulting in a release of accumulated carbon. Changes in crop prices or input prices or pest problems may induce a farmer to break the contract. Variable length contracts that pay farmers a discounted rate depending on the duration of time carbon is sequestered; or pay as you go schemes that reward/tax farmers for sequestering/releasing carbon may be needed to provide economically efficient solutions to the non-permanent nature of soil carbon sequestration (Feng et al., 2001).

Fourth, payment schemes to reward carbon sequestration will require monitoring and enforcement of contracts and mechanisms to establish a baseline level of carbon. They also require consideration of the possibility that adoption of sequestration friendly practices in one area might be accompanied by reversion to conventional practices in other areas leading to “leakage” of carbon emissions and no net gain in climate change mitigation.

Last, payment schemes need to address the issue of who is eligible for payments under a conservation program to sequester soil carbon. Some farmers may have adopted sequestration friendly practices such as conservation tillage even prior to the conservation program payments. Programs that pay only the new adopters of conservation tillage would create perverse incentives for such farmers to switch to conventional tillage, release the accumulated carbon and then join the conservation program. Conservation programs may, therefore, need to reward farmers for good practices adopted historically, which will make these programs very costly for taxpayers.

Carbon as a Marketable Commodity

Soil carbon can become an income-providing commodity through another route -- private markets for carbon that might develop if mandatory caps for carbon abatement are imposed on other sectors of the economy. According to one estimate, farmers in Iowa and Montana could sequester 9 million tons of carbon a year, which is about 1.5% of the US commitment under the Kyoto Protocol, by changing their practices to conservation tillage in Iowa and continuous cropping instead of crop/fallow rotations in Montana (Antle and McCarl, 2002). Soil carbon sequestration payments at $20 per ton of carbon could lead to a revenue of $100 million per year for Iowa farmers and $9 million per year for Montana grain producers. Markets for carbon are emerging as energy companies are approaching producers to generate carbon offsets. The Chicago Climate exchange (CCX) has set up guidelines for trading carbon credits generated by landowners on cropland and forests at the prevailing market price of carbon. CCX provides a credit of 0.14 tons of carbon per acre of land switched to conservation tillage, 0.2 tons of carbon per acre for planting grasses and 1 ton per acre for planting trees. Similar types of schemes have been initiated by the Illinois Environmental Protection Agency (Illinois Climate and Conservation Initiative) and by the Iowa Farm Bureau to provide carbon credits to landowners. These schemes do not consider land use in the past and thus baseline stocks of carbon present in the soil, the spatial and temporal variability in sequestration rates per acre of land, or the impermanence of the sequestration; no requirements for maintaining these land use practices beyond the typical 4 to 5 year time period of the contract are imposed.

The current price of carbon in the US has been relatively low, ranging between $2 per ton and $4 per ton in 2007, compared to that in the European Union which is several times higher. Current climate policies have emphasized voluntary actions and goals rather than mandates to reduce carbon emissions. Carbon prices are likely to be low in this situation and agriculture and forestry would then have a small role to play in climate change mitigation. However, a number of regions in the US are now establishing regional greenhouse gas reduction targets. This could lead to more rapid development of carbon markets and demand for low cost sequestration activities by agriculture to provide offsets for higher cost emissions abatement by other sectors of the economy.

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