CHOICES

AAEA Agricultural & Applied Economics Association

Volume 38. Quarter 4

Agricultural Soils and the Quest for Net Zero Emissions

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JEL Classifications: Q54
Keywords: Climate mitigation, Mitigation appraisal, Soil carbon sequestration

Introduction

Climate change impacts how we live, work, and grow food/fiber. It affects agriculture directly by altering productivity and indirectly through efforts on adaptation (which reduces damages without changing the extent of climate change) and mitigation (which reduces drivers of climate change like greenhouse gas emissions and thus alters the future extent of climate change). This paper will cover mitigation, primarily considering prospects for storing (sequestering) carbon in agricultural soils. In treating this possibility, we will cover 1) reasons why this topic is of current interest, 2) the physical characteristics of sequestering carbon, and 3) what influences the value of sequestered carbon, along with comments throughout on implications for policy design.

Why Consider Soil Carbon Sequestration

Every year, the earth goes through a cycle of vegetation growth, during which it absorbs carbon dioxide from the atmosphere, then later vegetative decomposition, releasing carbon back into the atmosphere. This results in a large carbon flux between the atmosphere and the Earth's ecosystem. Concurrently, substantial carbon infiltrates into the soil through roots and decomposing material. A broad estimate of carbon sequestered in soils places its mass at about three times the amount of carbon resident in the atmosphere (Kayler, Janowiak, and Swanston, 2017). Additionally, the amount of carbon sequestered in soil has fallen, with estimates indicating historically that soils have been a source of 10%–20% of total anthropogenic contributions to the atmosphere (Sanderman, Hengl, and Fiske, 2017). In the face of this, the basic idea of soil carbon sequestration (SCS) mitigation is that we can modify the annual ecosystem/atmosphere exchange so that more carbon is retained using the current, underused soil storage potential.

Society may wish to increase SCS for a number of reasons. McCarl, Murray, and Antle (2002) list seven reasons for its pursuit. In this article, we update and augment the reasons to be reflective of today's context.

1) Greenhouse Gas Forcing and Climate Change. Climate change is increasingly being discussed as a disruptive force, with many indicating it is changing the environment in which we live and affecting actions and agricultural productivity (Intergovernmental Panel on Climate Change, 2014; Intergovernmental Panel on Climate Change et al., 2022; U.S. Global Change Research Program, 2018). Greenhouse gas (GHG) control is a means of addressing climate change. The concept of the United States hitting net zero emissions by 2050 has appeared in government documents, including from the White House (2021). There are also provisions for funding agricultural net emissions reductions like SCS in the Inflation Reduction Act of 2022 (117th Congress, 2022)

2) Compliance with International Agreements. The U.S. government is a party to the Paris Agreement, and the associated Nationally Determined Contribution document (United States of America, 2021) states an economy-wide target of reducing net GHG emissions by 50%–52% below 2005 levels in 2030. Strategies are also proposed in the document, including ones related to agriculture and SCS. More specifically,

> "Agriculture and lands: America's vast lands provide opportunities to both reduce emissions, and sequester more carbon dioxide. The United States will support scaling of climate smart agricultural practices (including, for example, cover crops), reforestation, rotational grazing, and nutrient management practices" (The United States of America Nationally Determined Contribution).

3) International Attitudes toward U.S. Emission Levels. Globally, the United States has the second highest level of total GHG emissions and is among the highest on a per capita basis (Ritchie, Roser, and Rosado, 2020). Internationally, the United States is viewed as having excess emissions, and movements toward lower net emissions would help alleviate that perception.

4) Domestic Pollution Related Policy. The Clean Air Act is a key part of U.S. air pollution policy. An EPA endangerment finding placed GHG control underneath that act (U.S. Environmental Protection Agency, 2021), although not much control activity has happened. Duffy et al. (2019) review the situation and argue that the basis for action is growing. Also, the Inflation Reduction Act of 2022 strengthens the case, amending the Clean Air Act to include GHGs as air pollutants, including carbon dioxide, hydrofluorocarbons, methane, nitrous oxide, perfluorocarbons, and sulfur hexafluoride (117th Congress, 2022).

5) Industry Planning in the Face of Uncertainty. Policy statements about the United States moving toward net zero emissions raise future cost risk for industries in which production is highly correlated with GHG emissions. This has led some industries, like electrical power generators, to explore ways of reducing emissions. SCS has been one strategy that has been investigated.

6) Need for Cheap Emission Offsets. Concerns have been expressed about how expensive it would be to reduce emissions, and there is undoubtedly a need for inexpensive options. Studies advocate agricultural actions, including SCS, as low-cost ways of reducing emissions (Murray et al., 2005).

7) Linkage to Other Goals for Agriculture and Environmental Impacts. SCS has implications not only for net GHG emissions but also for erosion rates, water quality, soil organic matter, yields, and farm income. Several U.S. programs have supported farm conservation activities with the goals of improving both the environment and income. Under the Inflation Reduction Act, the U.S. Department of Agriculture Natural Resources Conservation Service (2023) indicates that an additional $19.5 billion will support conservation programs that yield climate-change mitigation benefits, providing more producers with conservation assistance.

8) Development of Another Market for Farm Products. Agricultural markets are often such that increases in production lead to substantial decreases in price, mainly due to inelastic demand. Maintaining farm income has long been a concern of farm policy and has often involved supply control to raise prices. The potential volume of emissions in a comprehensive carbon market would be quite large, with the potential agricultural market share being small. Thus, SCS amounts would face much more elastic demand with little influence on the carbon price. In that case, increases in farm carbon production would lead to higher farm incomes, as when agricultural-based ethanol production entered the liquid fuels market.

Physical Characteristics of SCS

The amount of SCS in a location is influenced by numerous forces, including climate, vegetation, topography, soil type, management history, and disturbance. These forces create local, regional, and temporal heterogeneity in SCS. SCS can be enhanced through many practices, such as the use of cover crops, less intensive tillage, land use changes, afforestation, soil amendments, use of perennials, and incidence of deep-rooted crops, among other options (Paustian et al., 2016). These practices affect SCS by modifying the relative rates of carbon addition versus destruction in the soil (Paustian, Collins, and Paul, 1997).

SCS can not only be increased but also be depleted. In particular, if practices are altered, such that the carbon is exposed to oxygen by increased soil disturbance, or if the soil conditions are changed (becoming more arid, erosion increases, or increasing soil microbial activity because of increased temperature), then the amount of soil carbon will be reduced. In fact, this can occur quite rapidly (Olson, 2013). Practices, once begun, need to be continued to maintain the carbon SCS volume.

Additionally, it is important to note that soil carbon accumulation does not continue forever. Instead, as soil carbon is added to a particular amount of soil, this also increases soil carbon destruction, mainly through microbial activity. Under many practices, the soil carbon stock reaches an equilibrium generally in 10–15 years for practices such as less intensive tillage use (West and Post, 2002). Thus, the amounts sequestered decrease over time as equilibrium is approached (West and Six, 2007; West and Post, 2002)

Finally, it is worth mentioning that the effect of different management practices on SCS amount depends on soil conditions and climate, with a consequent regional variation in practice effects. Hutchinson, Campbell, and Desjardins (2007) provide evidence on the heterogeneity of the impact of SCS, as does the review in Ogle et al. (2023).

Issues Regarding the Value of SCS Enhancements

Many issues have been raised regarding the desirability of adopting particular practices to reduce net GHG emissions. Across the spectrum, several of these have led to the exclusion of strategies like SCS enhancement from implemented policies. Here we discuss issues that have been raised repeatedly.

Permanence

For many years, there have been concerns over the permanence of the carbon sequestered by SCS practices relative to other mitigation alternatives. For example, capturing and burning methane is a permanent removal from the atmosphere as the methane is eliminated and cannot come back. But sequestering carbon in soils and vegetation places it in potentially temporary storage, as the carbon may be released by reversals of practices such as intensifying tillage. Coupled with the fact that practices can be reversed, SCS may not be permanent. Several studies have argued that SCS should not be used as part of the strategy for addressing GHGs or that its price be discounted (as reviewed in Murray, Sohngen and Ross, 2007; and Kim, McCarl and Murray, 2008; Thamo and Pannell, 2016).

Additionally, soil carbon generally reaches a new equilibrium after a relatively short period (10–15 years for tillage and longer for land use change) in reaction to changing disturbance regimes (West and Six, 2007). Thus, policy needs to consider what to do for payments as the net carbon sequestration amounts diminish. In such a case, if payments are discontinued, producers could be incentivized to discontinue practices, possibly releasing the carbon previously sequestered. The latter issue led to suggestions for long-term contracts such as 100 years and for paying maintenance costs to maintain SCS stocks even after increases have halted (Kim et al., 2008; Thamo and Pannell, 2016). These impermanence features diminish the value of the soil carbon due to its potential future release and/or need for maintenance payments. Longer-term commitments also reduce the desirability of farmer participation (as they limit future options) and raise transaction costs (as there would be a need to monitor whether the practice were continued on a piece of property for several generations).

In policy design, consideration needs to be given to: 1) the length of the contract, 2) the consequences for anyone who reverses practices, and 3) the encouragement of practices that store carbon in more permanent forms, such as deeper in the soil and/or in forms that resist degradation, like biochar. Additionally, it may be desirable to target practices that reduce soil disturbance, such as moving croplands into grass or afforestation. Finally, policy design could formally recognize the impermanency of SCS using discounted prices or limited duration carbon leasing (Kim et al., 2008). For example, a lease might mandate sequestration for 20 years, giving time to develop emission reductions from other sources, as discussed in McCarl and Sands (2007).

Uncertainty

The uncertainty of SCS amounts under alternative practices is important for several reasons. First, the regional heterogeneity of SCS amounts and responses to practices imposes a burden: Region-specific information on the amount of carbon sequestered must be developed. Second, the spatial pervasiveness of carbon in the soil means that it can never be measured, only estimated, and is thus subject to error. Third, Kim and McCarl (2009) find that in models, variability in soil carbon increments are highly correlated (over 90%) with variability in crop yields, which we know to be highly variable over time and space. This means that carbon uptake rates will also be highly variable over time and space. Kim and McCarl (2009) propose addressing uncertainty in policy design by forming spatially diverse, multiyear portfolios to reduce variability.

Additionality

One concern that has been raised for years is the desire for additionality when funding mitigation actions. Namely, there is a desire arising from the efficiency of spending funds that people be paid for a practice that improves carbon sequestration only if they would not have used that practice in the absence of payment. This raises issues regarding “good actors,” those that have already been using a practice before a policy is implemented. For example, under strict additionality in the case of no-till, only new individuals who previously had not been using no-till would be eligible for payments. However, there is debate over whether we should reward farmers already using the practices for the SCS they have accumulated. Obviously, paying for existing practices increases the program cost, but it would reduce the likelihood that some farmers might reverse practices to become eligible for the payment, thus losing SCS. Several treatments have addressed the issue (Weinberg and Claassen, 2006; Murray, Sohngen, and Ross, 2007; Smith et al., 2007). Policy approaches could include 1) targeting only those with a new practice change for full payment, 2) paying a maintenance cost or a graduated fee for existing practices depending on when the practice has begun, or 3) paying the full fee for existing practices motivated by protecting the stock or reducing transactions cost.

Leakage

One phenomenon that can arise in association with climate-smart agricultural practices involves emissions leakage. Leakage occurs when actions in one region reduce the amount of product moving into the marketplace, causing higher prices and leading to production and GHG emission increases elsewhere. Some climate-smart agricultural practices can reduce production and thus stimulate such leakage. For example, evidence shows that the use of cover crops slightly reduces the yield of conventional crops (Deines et al., 2023). In turn, following the line of leakage arguments presented in Murray, McCarl, and Lee (2004), increases in the use of cover crops that reduce production would lead to an increase in crop prices, which in turn would stimulate additional production, emissions, and land use changes elsewhere (as discussed in the indirect land use dialogue related to biofuels; see Searchinger et al., 2008; Hertel and Tyner, 2013).

Addressing emission leakage in the policy context is difficult. But the policy could possibly be designed not to incentivize anything that reduces conventional production or include some form of discount when leakage occurs. Examples of leakage estimation and a price discounting approach can be found in Murray, McCarl, and Lee (2004); Gan and McCarl (2007); and Kim, Peralta, and McCarl (2014).

Accounting for the Full Spectrum of Greenhouse Gases

Only focusing on CO_2 reduction by SCS can stimulate additional emissions of other GHGs, which offsets the SCS CO_2 reduction effects. Namely, some SCS-enhancing possibilities involve the usage of emission causing inputs, and these may positively and/or negatively impact the net GHG emission effect of the SCS activities. For example, using cover crops may require the use of additional nitrogen fertilizer to maintain crop yields or may involve directly using nitrogen-fixing legumes as cover crops. Such outcomes can increase emissions of nitrous oxide, a gas that has about 300 times the effect on retained heat as does carbon dioxide. Again, policy approaches could prohibit anything that adds emissions in other categories and/or require a complete lifecycle GHG accounting across the practice. For example, see the discussion in Schlesinger (2000) relative to nitrogen fertilization, the lifecycle example in McCarl et al. (2009) regarding biochar, and the analysis in Gleason et al. (2009) on trade-offs between SCS and increased methane emissions.

Transactions Costs

Last, another policy design consideration that merits discussion is transaction costs. Programs that distribute money for SCS payments require intermediaries for program administration; consequently, programs will cost more than the sum of payments made to farmers. When farmers pay for crop insurance, for example, about 30% of their payments are retained by the local agent and 70% goes to the overall insurance company. A similar proportion of transaction cost is expected in the case of SCS. Alston and Hurd (1990) estimate that the transaction costs of administering the farm program ranged from $0.25 to $0.50 for each $1.00 distributed. McCann and Easter (2000) find transaction costs to be 38% of total expenses or over 50% of direct payments. Further, if one uses an average carbon sequestration rate of somewhere around 1 metric ton per acre, then producing 1 million tons of SCS would require the involvement of around 2,250 average-sized (445 acres) U.S. farms and a lot more for smaller operations such as exist in developing countries. This implies that the cost of administering the program may be as much as 50% above the amount of money that finds its way to producers and has implications for the cost of achieving SCS offsets. Thus, in establishing policy, substantial attention needs to be paid to controlling transaction costs so they do not become excessive.

Concluding Comments

As the United States strives to reduce its net GHG contributions to climate change, agricultural soil carbon sequestration is one strategy identified as a way of making progress. In encouraging soil carbon sequestration, there are some critical considerations involved with policy design, including 1) how much sequestered carbon will be stored, 2) how long it will last, 3) uncertainty regarding the amount of carbon sequestered; 4) how much it will cost; 5) how to maintain existing stocks; 6) effects of practices on the full suite ofGHGs; and 7) the potential added cost of administering the program. In this article, we outlined some of these issues and possible policy ways to address them, but clearly more work and careful policy design choices are needed.

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Acknowledgments: The materials are based upon work partially supported by the National Science Foundation under Grant Addressing Decision Support for Water Stressed FEW Nexus Decisions (1739977), and USDA NIFA under Grants the Impact of Climate Change, Carbon Markets and Climate Smart Agriculture and Forestry Practices on U.S. Agricultural Sector and Market (2023-67023-39814) and Sustainable Agricultural Intensification and Enhancement Through the Utilization of Regenerative Agricultural Management Practices (2021-68012-35897).

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