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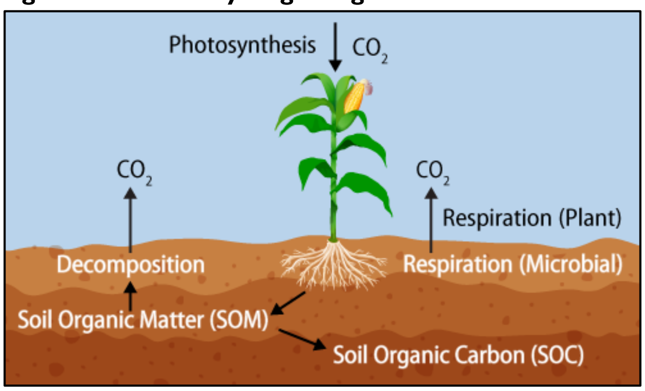
Agricultural Soils and Climate Change Mitigation

Policymakers, scientists, farmers, and other stakeholders have debated the potential of agricultural soils to sequester (store) carbon and help mitigate future climate change. This discussion includes various approaches to agriculture—referred to as *carbon farming*, *regenerative agriculture*, farming for *soil health*, and farming for *soil carbon sequestration*—and their potential to increase agriculture's role as a greenhouse gas (GHG) sink and reduce its role as a GHG source. *GHG sinks* remove and store GHGs from the atmosphere, and *GHG sources* emit (release) them.

Figure 1. Carbon Cycling in Agricultural Soils



Source: Figure created by CRS.

Agriculture: A GHG Source and Sink

According to the Environmental Protection Agency (EPA), the agriculture sector is a net emitter of GHGs; agricultural practices, including crop and livestock operations, currently emit more GHGs than they remove. The EPA's annual *Inventory of U.S. Greenhouse Gas Emissions and Sinks* reports estimates of anthropogenic GHG emissions and sinks in the United States, using internationally standardized sectors. On the source side, the agriculture sector's GHG emissions—primarily methane and nitrous oxide—include those from livestock and soil management. The 2020 *Inventory* shows that in 2018, the agriculture sector contributed about 10% of total U.S. GHG emissions.

The *Inventory* reports estimates of net emissions (emissions minus removals) from the Land Use, Land-Use Change, and Forestry sector (LULUCF)—primarily carbon dioxide (CO_2) emissions and carbon storage. LULUCF includes net emissions for forestlands, agricultural croplands, grasslands, and other land types. Data from 2018 and prior years indicate that U.S. croplands are a net GHG source and grasslands are a net sink. Land-use change, rather than land use, largely shapes these patterns—the conversion of other land-use types to croplands (net emissions) and to grasslands (net removals).

Agricultural Practices That Store Carbon

Soils store carbon in two basic forms: organic (derived from living material, such as plant roots) and inorganic (derived from nonliving material, such as minerals). Soil organic carbon (SOC) measures the carbon in soil organic matter (SOM), which consists largely of soil microbes (i.e., bacteria and fungi), and decaying and decayed plant and animal material. In addition to its role sequestering carbon, SOM is important to soil health and agricultural productivity. Photosynthesis, decomposition, and respiration are the major factors in determining SOC levels (**Figure 1**). Photosynthesis fixes atmospheric CO_2 into plant material, which can lead to increased SOC. Decomposition of SOM releases CO_2 into the atmosphere and leaves a small amount of carbon in the soil. Respiration of plants and microbes releases CO_2 into the atmosphere as a by-product of using organic materials for energy and growth; this process returns to the atmosphere some of the carbon fixed through photosynthesis.

Agricultural practices have generally increased net GHG emissions, but certain practices can reduce GHG emissions in the atmosphere and increase net carbon storage in soils. Such practices generally reduce soil exposure to air and increase plant root growth. These practices include no-till or reduced-till land management and use of cover crops, compost, and manure. The combination of multiple practices may further increase carbon storage in soils. The adoption of carbon-sequestering practices depends on factors that include requirements for equipment and labor and vary widely in the United States (**Table 1**).

Table 1. Selected Carbon-Sequestering Management Practices in Use in U.S. Croplands (2017)

Management Practice	Acres (millions)	% of Total Cropland
No-Till (includes Rotational Till)	105	27%
Reduced-Till	98	25%
Cover Crops	15	4%

Source: USDA, *2017 Census of Agriculture (COA)*, 2019, Table 47.

Note: Total U.S. cropland = 396 million acres (*COA*, Table 1).

Scientific Debate

The carbon sequestration potential of agricultural soils has been an active research area for decades. Some scientists are optimistic and others advise caution when considering agriculture's potential to measurably mitigate global GHG emissions.

The utility and effectiveness of mitigating GHG emissions via agriculture depends in part on the

- carbon-storage potential of agricultural soils,
- carbon-storing potential of agricultural practices, and
- carbon storage over time.

Carbon-storage potential of agricultural soils. Recent estimates suggest that over the past 12,000 years, human land use has resulted in a cumulative global loss of about 116 gigatons (GT) of SOC. Some researchers assert that today's soils have the *technical* potential to achieve the amount of SOC that they held prior to these losses, and that today's soils have the *attainable* potential to store some proportion of the lost amount. Scientists' estimates of the attainable potential vary considerably.

Differences between the technical and attainable potentials derive from many factors, including socioeconomic and policy constraints. As examples, farmers who rent rather than own their land may not have long-term economic incentives to implement soil management changes; farmers may not have the equipment needed to adopt new management practices; or existing agricultural policies may incentivize management decisions that align with goals other than carbon sequestration (e.g., maximizing production or reducing labor and other inputs).

Carbon-storing potential of agricultural practices. A 2019 report by the National Academies of Sciences, Engineering, and Medicine reviewed a variety of technologies aimed at reducing and eliminating GHG emissions and evaluated agricultural carbon sequestration as among the most cost-effective. It estimated that agricultural practices could sequester up to 0.25 GT of CO_2 (0.07 GT of carbon) per year in the United States—equivalent to about 4% of total U.S. emissions from all sectors in 2018—for a cost of less than $20 per ton of CO_2. The report's estimate for agricultural carbon sequestration assumes full adoption of soil conservation practices.

Carbon storage over time. Ongoing questions include how long sequestered carbon remains in the soil and how long management practices designed to store carbon continue to sequester carbon. Research shows that some practices store carbon only while they are in use. For example, carbon accumulated through no-till management is released when the field is tilled again. Research suggests that no-till management may increase net soil carbon sequestration for an estimated 20 years before plateauing and declining to near-zero in later decades.

Selected Initiatives and Policy Proposals

Existing and proposed approaches in the U.S. private and public sectors, and internationally, may encourage climate change mitigation in agriculture. Some cite climate change mitigation as a goal, while others identify increased economic opportunities for the agriculture sector. Selected current examples are discussed below.

Private sector. A number of private and nonprofit entities are attempting to use markets to create business incentives to reduce net CO_2 emissions in agriculture. For example, Indigo Ag, a U.S.-based private company, launched its Terraton Initiative in 2019. The initiative aims to remove 1 trillion tons of CO_2 (~272 GT of carbon) from the atmosphere by bringing 12 billion acres of global farmland under *regenerative agriculture* practices (e.g., no-till, reduced synthetic fertilizers, and incorporating livestock into croplands). The initiative includes a domestic *carbon market* focused solely on agriculture. Carbon markets enable entities to buy or sell *credits* or *offsets* for GHG emissions reductions. Carbon markets may pay farmers for the reduced emissions resulting from the use of specific management practices or measures of soil carbon over time.

Public sector. Some legislation introduced in the 116th Congress would support farmers that implement carbon-sequestering practices. For example, the Growing Climate Solutions Act of 2020 (S. 3894/H.R. 7393) would create a U.S. Department of Agriculture (USDA) program to certify third parties as GHG technical assistance providers and verifiers of carbon sequestration protocols. Such a program might facilitate farmer and forest owner participation in carbon markets but would not create them.

The Agriculture Resilience Act (H.R. 5861) would promote voluntary, incentive-based conservation measures. Among proposed actions, the bill would amend the USDA Environmental Quality Incentives Program (EQIP, 16 U.S.C. §3839aa et seq.) to add reducing GHGs and sequestering carbon to existing program considerations.

State-level initiatives also provide public sector opportunities to encourage GHG mitigation through agricultural soils. California's mandatory emissions trading system and the Regional Greenhouse Gas Initiative both allow agricultural offsets, though not for soil carbon.

International. Most observers argue that addressing climate change will involve some degree of internationally coordinated efforts. Specific to soil carbon, France launched the 4 per 1000 Initiative in 2015, with the premise that increasing the carbon in global agricultural soils by four parts per thousand (~3.5 GT) per year would mitigate the annual increase of atmospheric CO_2 due to human activity. The initiative invites its stakeholders (e.g., national governments, private companies) to declare or implement practical actions related to soil carbon storage. Some nonfederal U.S. entities (e.g., private companies, foundations) are members, but the U.S. government is not.

Policy Challenges

Many initiatives to increase soil carbon sequestration through agriculture are predicated on accurately quantifying SOC. Scientists recognize this as a technical challenge, as such quantification needs to be extrapolated from remote sensing data or discrete sampling over space and time. Improving measurement accuracy may need additional research, innovation, investment, and technical assistance.

If carbon-storing agricultural practices cost more than alternative practices (e.g., in terms of labor, equipment, productivity, or sale price), farmers are unlikely to adopt them absent requirements or incentives. Various incentives, such as those provided through carbon markets, may change the economic calculus.

Lack of awareness among agricultural producers of carbon-storing agricultural practices—what they are, what costs and benefits they may provide, and how to implement them—may also impede adoption. USDA programs, such as the USDA Climate Hubs, cooperative extension, and Natural Resource Conservation Service technical assistance programs, may play a role in increasing awareness of these practices, as may other state and private efforts.

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