Climate Central Solutions Brief: Capturing Carbon, the Soil Solution

Part of the Climate Solutions series

CLIMATE CENTRAL

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INTRODUCTION

The soil that we walk on every day may be an important tool for helping address the climate change crisis. Soils contain the largest stocks of carbon on land and they naturally remove carbon dioxide from the atmosphere. Soil is a living system, housing vast communities of microbes – including bacteria and fungi – and invertebrates that break down organic matter, releasing carbon and other nutrients into the soil pool. In some ecosystems, soils can store, or sequester, carbon for a long time. But the key: keeping soils healthy.

The soil solution calls for new farming and land management practices and intact natural ecosystems. Choices by farmers and policymakers will decide whether or not soils reach their full potential in sequestering carbon. When soils aren't healthy, they can be a source of carbon emissions instead of a sink. That means agriculture is a significant partner in combating climate change.

Box 1. CARBON SEQUESTRATION

Carbon sequestration is the process of removing carbon dioxide from the atmosphere and storing it so the heat-trapping gas doesn't cause the planet to warm. Plants capture carbon through photosynthesis and store it in plant biomass aboveground, in leaves, trunks and branches, as well as belowground in root systems. Soils sequester carbon through the activity of microbes that break down plant material, releasing carbon that is then stored in the earth.

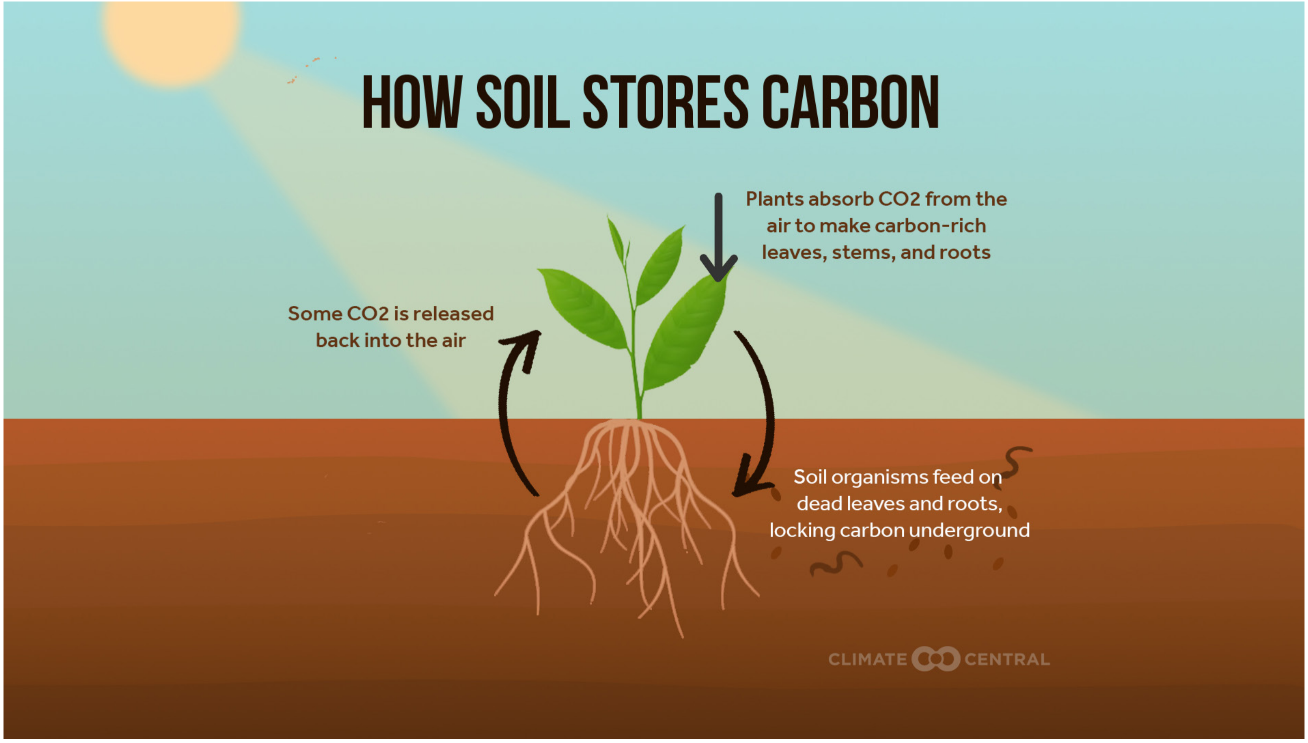
Soils capture significant amounts of carbon from the atmosphere each year, adding to the total stocks of carbon they already store in the ground. Some scientists estimate that agricultural soils have the potential globally to sequester about a billion tons of carbon each year. But estimates for soil carbon storage potential vary significantly, based on different models and assumptions.

Moreover, soils cannot take carbon out of the atmosphere as fast as humans are adding it today, so soil solutions must be coupled with substantial cuts in greenhouse gas emissions in order to reach global climate goals: "Holding the increase in the global average temperature to well below 2°C [3.6°F] above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C [2.7°F] above pre-industrial levels."

This brief explains how we can better maintain carbon in soil, and perhaps increase it in some circumstances. The brief has two parts: carbon in agriculture, including grazing lands, and carbon in natural ecosystems, such as forests, wetlands and grasslands.

HEALTHY AGRICULTURE SOIL

Keeping soils healthy and productive is of paramount importance. Climate change and poor land management practices both threaten our soil health. Conventional agricultural practices have accelerated soil erosion, causing widespread soil degradation in some of the country's most productive farming regions. A recent study showed that, in the Midwest U.S., more than 63 billion tons of soil were lost to farming practices in the last 150 years.



Croplands in the U.S. alone sit on vast stores of carbon, estimated at nearly 20 billion tons, second only to Russia. Climate-friendly agriculture practices work to sequester carbon, but to become widespread, they must also help farmers' bottom lines. Research suggests that certain agricultural practices can maintain or improve soil health and possibly increase carbon sequestration.

REGENERATIVE AGRICULTURE

Regenerative agriculture takes a holistic approach that works with nature and uses practices that restore soil and ecosystem health. It aims to improve soil health, and subsequently the capacity for soil carbon storage. But to be effective, these practices need to be tailored to the farm and its particular soils, making it challenging to implement at scale.

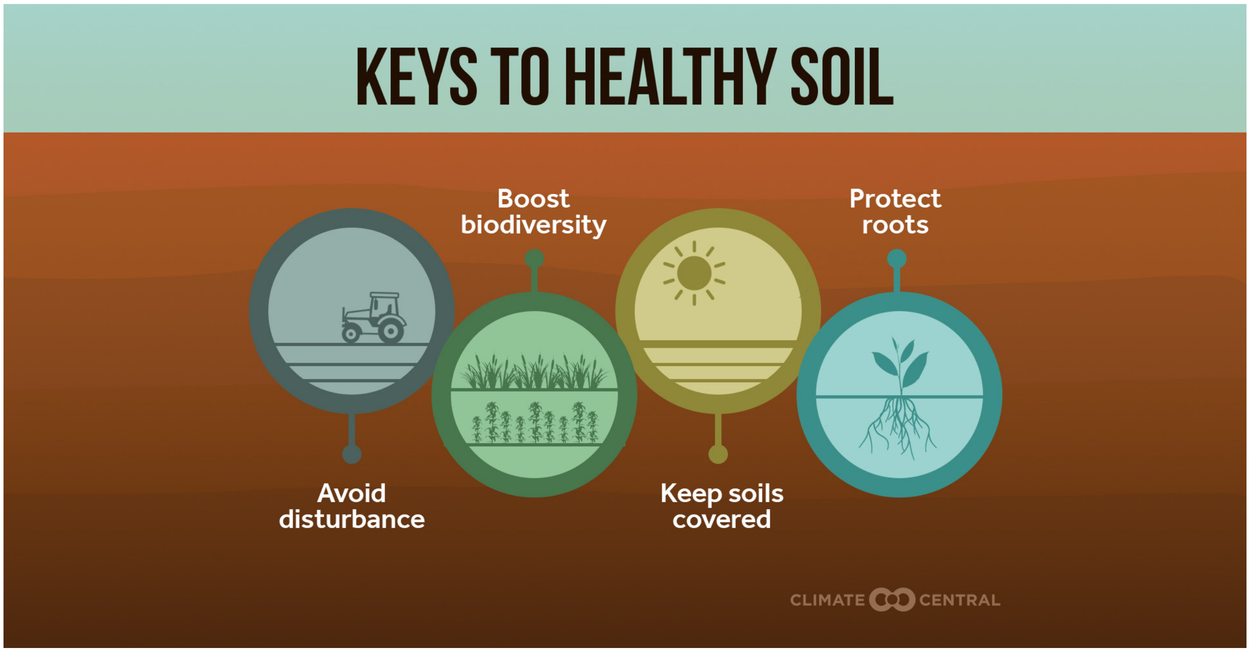
Minimize soil disturbance. Minimizing soil disturbance and erosion can support overall soil health. About half of the cropland in the U.S. currently uses no-till or another kind of reduced-tillage practice, according to the 2017 Census of Agriculture. Carbon benefits of no-till farming, however, may be less significant than previously thought.

Keep the soil covered. Planting cover crops in soil that would otherwise be bare after harvest helps stabilize the soil and prevent erosion. Roots retain water and improve overall soil health, so more carbon can be sequestered. Cover crops can be planted during a harvest or between rows of the primary crop. Currently, only 4 percent of croplands are managed with cover crops, according to the 2017 Census of Agriculture. Cover-cropping all U.S. cropland could sequester more than 165 million metric tons of carbon each year.

Box 2. PRECISION AGRICULTURE AND CLIMATE

Farmers are using data and information technology to improve soil health and reduce overall carbon emissions. Precision agriculture fine-tunes application of fertilizers, pesticides, tillage and irrigation water, helping farmers grow more with less. For example, satellite imagery and field mapping can optimize what crops need water and when. These practices reduce soil erosion, carbon emissions, and fertilizer use, as well as improving crop yields, and that enhances carbon sequestration.

Plant diverse crops. Planting perennials and a variety of crops can improve soil health. Since perennials do not need to be planted every year, they cause less soil disturbance. Also, their long root systems can grow to sequester more carbon. Indigenous farming practices, such as the "Three Sisters" technique of growing corn, legumes and squash together, help to maintain soil health by planting diverse crops alongside each other.



Integrate livestock. Managed grazing, also known as rotational or prescribed grazing, mimics the way large animals naturally move across the landscape by moving livestock between pastures. It prevents overgrazing so soil doesn't go bare, allowing grass to keep roots in the soil, improving water infiltration and preventing soil erosion and nutrient runoff. That promotes carbon sequestration.

Increase organic inputs and nutrients. Ensuring appropriate nutrient balance is also crucial, particularly in nutrient-deficient soils. Natural inputs, including composted food waste, plant material, or manure can benefit soil and increase carbon storage.

Mix farmland with nature. Conservation buffers can be a great way to use farmland that is hard to grow on, such as adjacent to streams or on steep slopes. Buffers protect habitat and store carbon while mitigating flooding and protecting water quality.

Case Study: GOOD NEWS FOR THE CORN BELT

Recent research shows adaptive strategies increase crop yields and resist loss of soil carbon. A study by researchers at Colorado State and Columbia universities looked at how

Box 3. THE BENEFITS OF ELECTRIFICATION IN FARMING

The benefit of carbon sequestered by farmers is reduced, to some extent, by emissions from their use of fossil fuels. With only 24 percent of modern farms' energy coming from electricity, a huge potential remains to reduce emissions by transitioning to greater use of electricity. In most regions of the country, the emissions produced by generating electricity are lower than those generated by the direct use of fossil fuels to perform the same task on the farm. One study suggests that electrification could decrease the carbon footprint of farming by up to 70 percent, depending on the kind of farm and whether the electricity is produced from carbon-free sources.

different management strategies affected soil carbon under future climate change scenarios on corn and soybean farms in the U.S Corn Belt: Iowa, Illinois, Indiana, Kansas, Michigan, Minnesota, Missouri, North Dakota, Nebraska, Ohio, South Dakota, and Wisconsin. Soil carbon stocks increased in northern states, while they were slightly reduced due to higher rates of plant breakdown elsewhere. However, all areas fared better under adaptive strategies compared to conventional agriculture practices.

CARBON IN NATURAL ECOSYSTEMS

Forest, grassland, and wetland ecosystems can sequester carbon to help mitigate climate change. In 2021, the Intergovernmental Panel on Climate Change identified protection of these natural ecosystems as a critical component in countering fossil fuel emissions and thus avoiding a catastrophic rise in temperatures and extreme weather events. Here, we discuss land management solutions to capture carbon.

FORESTS

Forests receive the most attention for sequestering carbon in their biomass and the soils beneath them. Roughly 30 percent of the U.S. is forested. In 2021, U.S. forests stored over 61 billion tons of carbon, with over half that found in forest soils. In fact, the boreal forests – northern forests that freeze up to eight months of the year, also called taiga – store more carbon in their soils than they do aboveground. However, between 2001 and 2021 the U.S. lost 16 percent of its tree cover due to deforestation. Most of these losses occurred in Alaska, followed by Georgia, Alabama, and California.

Reforestation can increase the carbon in the soil, but it can take a long time for forest soils to build up depleted carbon stores. Some forests can store more carbon than others. The amount of carbon that can be stored in forest soils depends on local factors, such as soil type and vegetation. Soils with more organic material store more carbon, as do soils where freezing for part of the year slows decomposition.

Forest management can support carbon sequestration by maintaining cover, reducing erosion, and growing more trees. Increasing the diversity of trees and plant species within a forest can discourage rapid decomposition that would speed carbon losses from the soil. In some cases, even clearcutting can sequester more carbon, by introducing fast-growing younger trees. Minimizing soil disturbance during timber harvests can support forest health and increase carbon sequestration. Controlling invasive species is also important, as they can change the makeup of soil microbes and stop forest regeneration, decreasing a forest's ability to capture carbon.

Box 4. Partnering with Indigenous communities

Indigenous peoples manage vast amounts of carbon in forests, wetlands and grasslands on traditional lands worldwide. Indigenous management styles have evolved over a long period of time and are deeply rooted in relationships with nature. Conservationists are increasingly seeing traditional ecological knowledge as an important tool to manage nature in a way that will make land more resilient to climate change impacts. Conservation easements, land transfers or opportunities for co-management can help restore lands, bringing back their potential to store carbon.

- In central California, a land trust recently transferred over 1,000 acres of redwood forest and prairie to the Esselen tribe.
- Near Yellowstone National Park, tribes are co-managing bison that graze on U.S. Forest Service land.
- In southern coastal Oregon, the Coquille Tribe acquired 3,200 acres of their ancestral forestland.

WETLANDS

Wetlands store vast amounts of carbon in their soil, holding upwards of 30 percent of the world's soil carbon, despite consisting of a small fraction of the land surface. Peatlands, which comprise half of the world's wetlands, are a critical carbon sink, because vegetation that grows in them doesn't fully break down, forming peat, which is very rich in carbon.

Wetlands in the contiguous U.S. contain a stock of nearly 13 billion tons of carbon, much of this in deeper soil layers. But their future is very much at risk from habitat destruction, polluted runoff, invasive species, and water level changes, all factors that reduce their potential to store carbon. For coastal wetlands, some of the most substantial losses occur in Louisiana, with one third of the country's coastal wetlands, followed by North Carolina and Texas. Preserving wetlands is an important climate change mitigation strategy as well, because degraded wetlands become a huge source of emissions, if their age-old store of carbon is released.

The North American Wetlands Conservation Act has conserved over 30 million acres of wetlands across the U.S. since 1989. Today, voluntary restoration also plays a large role in securing wetlands as carbon stores, since 75 percent of wetlands are owned by private citizens. Major wetlands controversies remain for the local, state, and federal governments. For instance, a heavy mineral mine could threaten the Okefenokee Swamp in southeastern Georgia, the largest blackwater swamp in North America, with a tremendous store of carbon in its spongy peat soils. In addition, the U.S. Supreme Court is considering Sackett v. Environmental Protection Agency, a case that could reduce the EPA's ability to protect wetlands under the Clean Water Act. A decision is expected in 2023.

Learn more: In 2022, Climate Central published a study and report detailing the risks to coastal wetlands across the country.

GRASSLANDS

Grasslands are home to rich stores of carbon, mostly underground in soil organic matter and in the deep root systems of native grasses. With climate change bringing droughts, extreme rainfall and wildfires, grasslands will be increasingly valuable, perhaps becoming more reliable as carbon sinks than forests.

Despite this, North American grasslands are one of our most threatened ecosystems. Grasslands tend to be open and flat, making them vulnerable to human development for agriculture and urban expansion. It's estimated that less than 40 percent of North American grasslands remain, and, in the U.S., only 4 percent of native tallgrass prairie. Each year during the past decade, at least two million acres of grasslands across the United States and Canadian Great Plains were plowed and converted to agricultural uses.

Tilling grassland for agriculture can release carbon to the atmosphere, which can take decades and even centuries for plants to recover in the soil, if it does at all. Conservation and restoration of these lands is critical. But 85 percent of grasslands are privately owned, so policy-makers need voluntary programs to encourage conservation. The USDA Conservation Reserve Program pays farmers to restore habitat, such as native grasslands, on parts of their land that are fallow or unused. The North American Grasslands Conservation Act, pending in Congress, would also protect and restore grasslands through grants and support to rural economies.

Learn more: A recent review paper outlines strategies and perspectives on restoring grasslands.

LIMITATIONS OF CARBON STORAGE IN SOILS

The potential of soil carbon sequestration has not yet been fully determined, and is a matter of ongoing investigation within the climate science community. We still lack rigorous, long-term measurements of carbon in soils, and methods of measurement have not been standardized. Although global agricultural soils have the potential to store significant amounts of carbon, there are complicating factors.

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As other analysts note, “many practices that sequester soil carbon at the field level involve taking crops out of production” at particular locations. As global food demand continues to grow with increases in world population, reducing production in one location likely means expanding it elsewhere to make up the difference, driving deforestation and grassland conversion that in turn releases carbon to the atmosphere. In other words, assessing the overall carbon benefit of particular agricultural practices at scale is more complex than might initially be apparent.

Climate change may even be making it harder for soils to sequester carbon, because warming may cause plant material and organic matter to break down more rapidly, leading to carbon losses from soil, as is already seen in warming Arctic permafrost.

In addition, there are economic and social barriers to implementing healthy soil practices, which can only be overcome with additional research, education and public policy. Carbon credits could be an important tool for encouraging sequestration in soils, but as yet broadly accepted standards do not exist for measuring and reporting credits, and more rigorous rules and models are needed to make sure that carbon credits are legitimate, representing carbon that is actually stored long-term.

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