# Can Farmers Reverse Climate Change Through Carbon Farming?

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## Key Points

- As part of a broad-based climate change initiative, the Biden administration has proposed subsidizing farmers to plant cover crops to sequester carbon in the soil, an approach widely described as "carbon farming."
- However, it is expensive to measure the amount of carbon trapped in soil, implying carbon farming programs are likely to be inefficient, and carbon sequestered in response to such incentives is likely to be rereleased if conventional farming practices are reintroduced.
- At present, remedies for these concerns are few, and adopting carbon farming is costly for farmers, suggesting government resources may be more wisely used for other approaches to reducing greenhouse gas emissions from the agricultural sector.

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Soils play an important role in our changing climate, yet they are often overlooked in favor of more well-known factors such as fossil fuels. However, the prospect of government payments to farmers for climate-friendly soil management has brought soils to the fore. In his April 2021 address to a joint session of Congress, President Joe Biden promoted a plan for farmers to plant "cover crops, so they can reduce carbon dioxide in the air and get paid for doing it"[1]—an approach widely described as promoting "carbon farming."

In this report, I argue that such policies are unlikely to significantly affect the rate of climate change.

## How and Why Is the Climate Changing?

Greenhouse gases (GHGs) in the Earth's atmosphere help keep the planet warm enough for life to flourish. They act like a blanket, letting heat from the sun through to Earth and then preventing that heat from escaping into space. The more GHG in the atmosphere, the warmer the planet.

The average global temperature in January through October 2021 was 0.84°C higher than the 20th-century average over the same months. Scientists estimate that because of further emissions of GHGs, temperatures will rise another 0.3°C to 3.5°C over the next century, depending on the extent of GHG emission mitigation activities.[2]

The most prominent GHG is carbon dioxide ($CO_2$), but others include methane (including emissions from livestock), nitrous oxide (largely from nitrogen fertilizer), and water vapor (clouds). However, the focus here is on carbon emissions, which have been estimated to be responsible for 80 percent of global warming since 1850,[3] and whether the Biden administration's proposal for paying farmers to plant cover crops will affect such emissions.

Carbon is absorbed from the atmosphere by living plants and passed along to animals that eat those plants. When these organisms die and decay, their carbon is either trapped underground or mixed with oxygen and emitted as $CO_2$. Clearing forests releases carbon from trees; tillage releases carbon from soils. Decaying organisms that were trapped underground millions of years ago formed fossil fuels such as oil, coal, and natural gas. Using these fossil fuels releases the sequestered carbon back into the atmosphere in the form of $CO_2$.

Humans have increased the amount of carbon in the atmosphere by almost 50 percent, from 588 gigatonnes[4] (GT) at the beginning of the Industrial Revolution to 873 GT at the end of 2019 (Figure 1). These are quantities of carbon rather than $CO_2$; when mixed with oxygen, every 12 tons of carbon becomes 44 tons of $CO_2$.

The two human-generated carbon emissions sources are fossil fuels and land-use change. Since the beginning of the Industrial Revolution, these sources have emitted 685 GT of carbon into the atmosphere, which is more than the total amount of carbon in the atmosphere in 1750. About two-thirds of these emissions were from burning fossil fuels and the remainder from land-use change. Earth's oceans and lands have absorbed 58 percent of the new carbon, so the net increase is 285 GT.

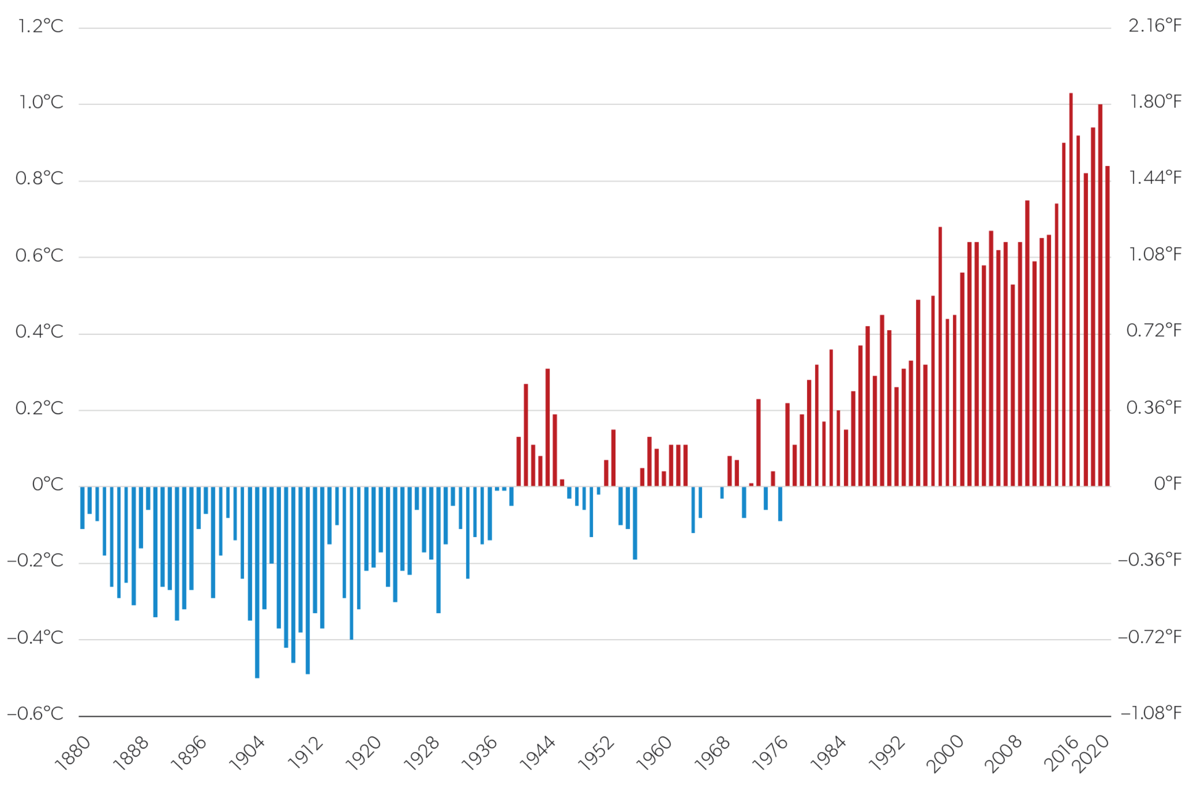
Most land-use change emissions are from loss of biomass rather than soils. It is estimated that 116 GT of carbon has been lost from soils due to agriculture, of which 70 GT occurred before 1750.[5] Restoring these 116 GT to soils would offset a substantial proportion of fossil fuel emissions since 1750. This theoretical possibility explains why carbon farming is so alluring.

## The Carbon Cycle

Understanding the role of soils in climate change and evaluating the associated policy options require a perspective on the quantities of carbon in the earth and its atmosphere and the exchange between them—that is, the carbon cycle, which is illustrated in Figure 3.

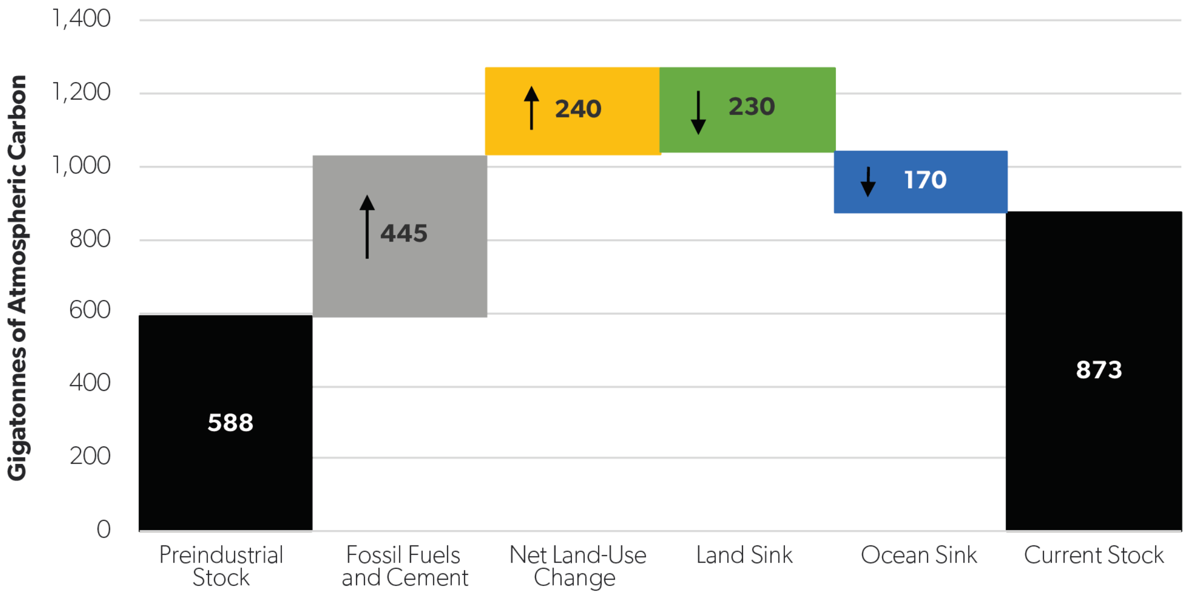
The amount of carbon in the atmosphere currently is about double the amount in all the trees and plants in the world. There is substantially

**Figure 1. Global Temperature Anomalies**



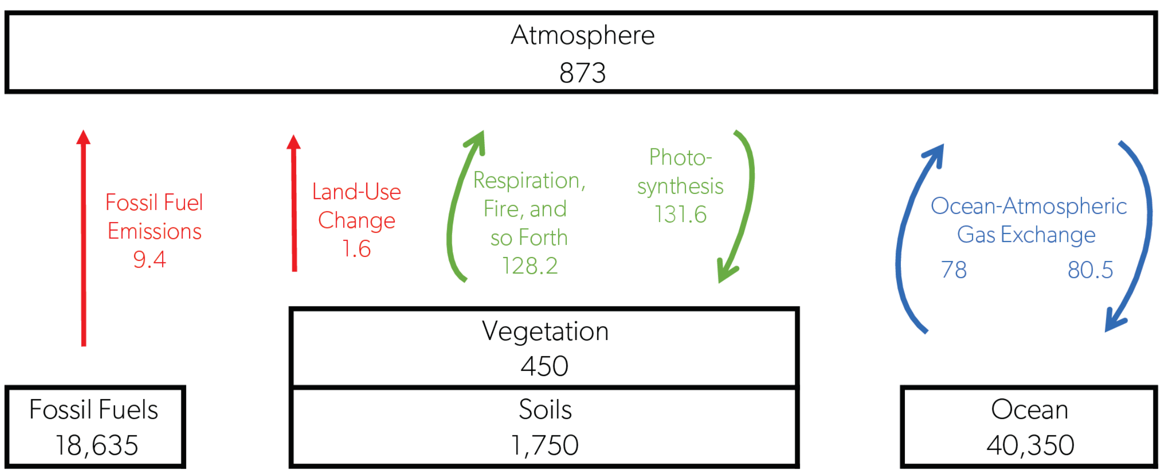

Source: National Centers for Environmental Information, "Climate at a Glance," https://www.ncdc.noaa.gov/cag/global/time-series/globe/land_ocean/ytd/10/1880-2021.

**Figure 2. Changes in Atmospheric Carbon Since 1750**




Source: Intergovernmental Panel on Climate Change, *Climate Change 2021: The Physical Science Basis*, August 7, 2021, Table 5.1, https://www.ipcc.ch/report/ar6/wg1/.

**Figure 3. The Carbon Cycle**




Note: Black numbers represent total stock of carbon in gigatonnes. Colored numbers represent average annual flows in 2010–19 in gigatonnes. The number for "Respiration, Fire, and so Forth" is set equal to photosynthesis in Figure 5.12 minus terrestrial sink in Table 5.1. For the numbers of "Ocean-Atmospheric Gas Exchange," 78 is flows from ocean to atmosphere in Figure 5.12, and 80.5 equals 78 + 2.5, where 2.5 is the net ocean sink in Table 5.1. Ocean stocks of carbon are the sum of surface ocean, marine biota, dissolved organic carbon, intermediate and deep sea, and ocean floor sediment in Figure 5.12. Fossil fuel resources are as listed in notes to Figure 5.12. Permafrost is not shown.

Source: Intergovernmental Panel on Climate Change, *Climate Change 2021: The Physical Science Basis*, August 7, 2021, Table 5.1 and Figure 5.12, https://www.ipcc.ch/report/ar6/wg1/.

more carbon in soil than in vegetation, 1,750 GT versus 450 GT. Carbon from these two sources is released when land is converted to agriculture (e.g., when forests are burned and soil is stirred up, bringing carbon to the surface, where it can mix with oxygen and be emitted into the atmosphere). Globally, these land-use change emissions averaged 1.6 GT per year over the past decade.

Plants take in about 130 GT of carbon per year through photosynthesis. They return almost all that carbon to the atmosphere, approximately half from aerobic respiration (through mixing with oxygen) and half from respiration of soil microbes as they decompose plant matter. This means plants can recycle all the carbon in the atmosphere every seven years. Globally, plants absorb slightly more carbon through photosynthesis than they send back to the atmosphere, which means land is a net carbon sink, as shown in Figure 2. This is because the increasing atmospheric concentration of $CO_2$ in recent decades has increased the rate of photosynthesis, a phenomenon known as $CO_2$ fertilization.

In the past decade, land has been a net sink of 3.4 GT per year.[6] The goal of carbon farming is to increase the net sink by encouraging more photosynthesis and lower emissions from soils. Crops absorb about 17 GT of carbon per year through photosynthesis, which is 13 percent of the total for all plants.[7] Assuming half this carbon is respired by the crop, we are left with about 8.5 GT of carbon in crops annually, most of which is lost to harvest or soil microbe respiration.

## Do Modern Farmers Emit or Sequester Carbon in Their Crops?

When land is first converted to pasture or cropland, large amounts of carbon are typically emitted by burning and tillage. After this, the carbon in the soils and plants cycles constantly. As a crop grows, it absorbs $CO_2$ through photosynthesis and emits $CO_2$ through respiration. After harvest, microbes decompose the crop residue and emit $CO_2$. The harvested crop may be eaten by animals that breathe out some of the carbon that was in the plant, or microbes may decompose the animal after it dies and emit $CO_2$.

If a farmer grows a crop every year, he or she is mostly cycling carbon. The farmer could be sequestering carbon on net (e.g., if the roots of the crop are left to decay into the soil). A farmer also could be emitting carbon on net (e.g., if repeated tillage brings carbon to the surface, where microbes feed on it and respire $CO_2$).

One measure of whether a farmer is emitting or sequestering on net is whether the quantity of carbon in the soil is increasing or decreasing. A theoretically efficient policy would pay farmers an amount equal to the social cost of carbon for each ton they sequestered, and it would tax them for each ton they lost. This policy would be too expensive to implement. The standard means of measuring soil carbon rely on chemical analysis performed by scientists in a lab. These methods require a soil core sample to be drawn from the field. They are time-consuming and expensive.

Because measuring soil carbon is expensive, proposed programs focus on incentivizing farmers to adopt easily observed practices that are thought to increase soil carbon. This approach reduces a program's administrative cost but also reduces its impact because practices may have different effects in different environments.

## On-Farm Practices to Increase Carbon Sequestration

The four most commonly proposed practices are as follows.

**Cover Crops.** This involves planting grasses or legumes on cropland that would otherwise be bare (e.g., between trees in an almond orchard or over the winter between crops). Cover crops can fix carbon into the soil and reduce erosion, which is a source of soil carbon loss.

**Minimum Tillage.** Tillage brings carbon to the surface, where microbes decompose it and emit $CO_2$. Without tillage, the carbon stays buried.

**Plant Growth.** Plant matter stores carbon, so increasing the volume of plant matter increases carbon storage. If residual plant matter remains in the field after harvest, then it can decompose and be trapped in the soil. Plants with high root mass are most effective.

**Cropland Conversion.** Converting from crops to pasture, especially deep-rooted perennial pasture, or to trees works similarly to cover crops by fixing carbon into the soil and reducing erosion.

## Challenges to Subsidizing Carbon Farming

I highlight three challenges.

**Permanence.** Sequestering carbon in the soil one year and then tilling the soil and releasing it the next year has little effect on the climate. Thus, policies are needed to incentivize long-term sequestration. This is difficult because farmers would be unwilling and unable to commit to farm a certain way for decades into the future. An alternative would be to subsidize farmers while they use the practice and tax them (or require them to return their subsidies) if they deviate from the practice.

**Additionality.** Carbon farming achieves climate change mitigation only if it reduces atmospheric carbon relative to what it otherwise would have been. If a farmer receives a payment for planting cover crops on a field that would have been planted to cover crops anyway, then the payment has not affected the amount of carbon in the atmosphere. If a government wishes to pay farmers for doing something they would do anyway, then it should do so, but not under the guise of climate change mitigation.

**Measurement.** Soil carbon dynamics are complicated. The amount of carbon stored and released varies widely depending on temperature, precipitation, what crop is planted, and numerous other factors. Measuring changes in soil carbon accurately is costly. Moreover, the efficacy of on-farm practices in increasing soil carbon is a subject of vigorous debate among scientists. For example, David Powlson et al. find that no-till agriculture barely affects soil carbon.[8]

## Conclusion

Governments and private companies around the world are working on programs that attempt to address these three challenges. Australia's Emissions Reduction Fund created an auction by which industry leaders offer bids for emissions reductions. Approved actions included sustainable intensification, stubble retention, conversion to pasture, nutrient management, soil acidity management, new irrigation, and pasture renovation. Farmers must agree to do the actions for 100- or 25-year periods, after which they are free to change their practices, and they must certify that the projects are not "business as usual" to preserve additionality. However, take-up of the program has fallen far short of expectations.

Several private companies have created their own exchanges specializing in carbon sequestration in agricultural soils. For example, Nori and Indigo Ag require farmers to perform the practice for a minimum of 10 years to address permanence concerns, and they hold a percentage of the credits in escrow to insure the farmer against the risk of having to make repayments if they switch practices and lose soil carbon before the 10-year period is finished. They use a third-party verification program to monitor, report, and verify the carbon sequestered, and they require some soil sampling to supplement their soil sampling models and remote-sensing data. For both programs, farmers must verify that they are not already performing these practices. Nori charges fees of 15 percent of the credit price, and Indigo Ag takes 25 percent to cover administrative costs. Indigo Ag currently has three million acres in its program, according to its website. These measures go some way to addressing the three challenges, although 10 years is a short period on a climate change scale.

At present, it is difficult to see how programs that simply pay farmers for using particular practices would overcome these challenges. Programs that pay out based on measured changes in soil carbon face the same challenges and the high cost of monitoring soil carbon. In theory, soils could store enough carbon to offset a significant proportion of fossil fuel emissions, but technical and economic challenges make this approach impractical.[9]

## About the Author

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## Notes

1. White House, "Remarks by President Biden in Address to Joint Session of Congress," press release, April 28, 2021, https://www.whitehouse.gov/briefing-room/speeches-remarks/2021/04/29/remarks-by-president-biden-in-address-to-a-joint-session-of-congress/.

2. Intergovernmental Panel on Climate Change, *Climate Change 2021: The Physical Science Basis*, August 7, 2021, https://www.ipcc.ch/report/ar6/wg1/.

3. Intergovernmental Panel on Climate Change, *Climate Change 2021*, Figure 5.16.

4. A gigatonne is defined as one billion metric tons.

5. Jonathan Sanderman, Tomislav Hengl, and Gregory J. Fiske, "Soil Carbon Debt of 12,000 Years of Human Land Use," *Proceedings of the National Academy of Sciences of the United States of America* 114, no. 36 (February 2017): 9575–80, https://doi.org/10.1073/pnas.1706103114.

6. Intergovernmental Panel on Climate Change, *Climate Change 2021*, Table 5.1.

7. Luis Guanter et al., "Global and Time-Resolved Monitoring of Crop Photosynthesis with Chlorophyll Fluorescence," *Proceedings of the National Academy of Sciences of the United States of America* 111, no. 14 (April 2014): E1327–33, https://doi.org/10.1073/pnas.1320008111.

8. David S. Powlson et al., "Limited Potential of No-Till Agriculture for Climate Change Mitigation," *Nature Climate Change* 4 (2014): 678–83, https://www.nature.com/articles/nclimate2292.

9. For more background on carbon farming, see Tas Thamos et al., "Private Incentives for Sustainable Agriculture: Soil Carbon Sequestration" (working paper, University of Western Australia, Agricultural and Resource Economics, Crawley, Western Australia, 2004).