Soil Carbon Moonshot

Grounding Carbon Storage in Science

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Carbon180

ABOUT CARBON180

Carbon180 is a climate NGO with a vision to remove legacy carbon emissions from the atmosphere and create a livable climate in which current and future generations can thrive. Based in Washington, DC, we design and champion equitable, science-based policies that bring carbon removal solutions to gigaton scale.

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Section One

Executive Summary

Investments from the US federal government have shaped the notion of modern farming known across the country. For decades, the agriculture sector benefited from robust public research and investment that once established the US as a global leader and helped the sector navigate economic downturns, global competition, and rapid population growth.

Since the early 2000s, however, public investments in agricultural research have stagnated; meanwhile, the sector faces its greatest challenge yet as extreme weather intensifies existing economic challenges.

American farmers and ranchers are now working on the frontlines of climate change, at once managing huge swaths of land, feeding the country, stewarding our natural resources, and retooling their long-standing practices to build resilience and remain competitive. More than ever, they need support to make informed changes on their land to curb and adapt to climate change and ensure their businesses thrive.

Soil carbon sequestration can be a solution that radically transforms the agriculture sector's relationship to climate change. Experts estimate that globally, soils could store up to 5 billion metric tons of carbon dioxide (CO_2) per year — an amount equal to 13% of global annual greenhouse gas emissions.[1] If we draw down ambient CO_2 and stow it in the soil of our agriculture system, we can turn the very emissions causing drought, yield instability, and labor impacts into a source of economic and environmental benefit. Healthy, carbon-rich soils build resilience to extreme weather and contribute to increased productivity — and across the 915 million acres of US farmland, soil can play an important role as a climate solution.

Despite the potential, there is virtually zero dedicated funding for soil carbon research today and related efforts across the federal government are fragmented. While soil carbon is gaining momentum with policymakers, private companies, and farmers alike, many knowledge gaps remain, and reaching scale will require

1. Paustian, K., Larson, E., Kent, J., Marx, E., & Swan, A. (2019). Soil C Sequestration as a Biological Negative Emission Strategy. *Frontiers in Climate*, 1. https://www.frontiersin.org/articles/10.3389/fclim.2019.00008/full

strategic investments in research. What remains most acutely unknown is the measurement and verification of carbon stored in our soils from acre to acre. For one, few rigorous soil carbon protocols exist, making it difficult to reliably ensure that carbon stays sequestered over long periods of time.[2] Today, farmers are asked to take physical samples from their land and mail them to a lab for carbon analysis — an arduous process, especially for small- and medium-sized farms and those that lack access to additional capital. Existing protocols, to fill in a complete picture of an operation's soil storage potential, often rely on models informed by insufficient source data to predict soil carbon. Measurement aside, soil carbon research to date has neglected to explore the economics and real-world implementation challenges that farmers face and has stopped short of developing best practices for the diversity of regions and operation types that makeup US agriculture, including specialty crop, dryland, livestock, and small-scale operations.[3] If we can advance our understanding of soil carbon — with practices embraced by farmers, tools that accurately measure climate benefits, and incentives grounded in science — the US will be positioned to develop and deploy the next generation of climate solutions for the agriculture sector.

To meet this challenge and scale soil carbon in a science-driven way, we need an ambitious, interdisciplinary, coordinated interagency research program: a Soil Carbon Moonshot (SCM). Only a moonshot program can marshall the necessary resources from across the federal government to pursue ground-breaking research and speed up innovation where solutions may not yet be profitable or scalable. The Soil Carbon Moonshot provides a North Star for agencies, ensuring that efforts are coordinated across the federal government and fill core research gaps to equip policymakers, farmers, and technical assistance providers with the findings necessary to scale soil carbon practices. Moonshot research programs can also be more expansive, investing in emerging technologies and practices that are so far unexplored but could unlock new benefits.

Critically, the Soil Carbon Moonshot offers a path forward for standardized, affordable, and easy-to-use monitoring, reporting, and verification (MRV) of soil carbon to ensure that farmers can maximize and be rewarded for soil carbon storage and that agriculture's climate benefits are tangible. A successful research

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2. Zelikova, J., Chay, F., Freeman, J., & Cullenward, D. (2021). A buyer's guide to soil carbon offsets. CarbonPlan. https://carbonplan.org/research/soil-protocols-explainer

3. Zelikova, J., Amador, G., Suarez, V., Kosar, U., & Burns, E. (2020). *Leading With Soil: Scaling Soil Carbon Storage in Agriculture*. Carbon180 Reports. https://static1.squarespace.com/static/5b9362d89d5abb8c51d474f8/t/5eaa30d12c3a767e64c3845b/1588211922979/LeadingWithSoil_Final+Text.pdf

program will also recognize farmers and ranchers are on the frontlines of this work and need assistance in overcoming the socioeconomic and cultural barriers to the widespread adoption of soil carbon practices — an element of this moonshot program that is particularly salient for small-scale and Black, Indigenous, and people of color (BIPOC) producers. Ultimately, the goal is to encourage wide-scale adoption of regionally-appropriate soil carbon practices, position farmers and ranchers to be rewarded for soil carbon storage, and catalyze agriculture's climate-mitigating potential.

To realize this vision, the Soil Carbon Moonshot proposes an interagency, coordinated $2.3 billion investment, centered at the United States Department of Agriculture (USDA), over five years, and across five key categories: (1) fundamental research, (2) MRV, (3) data collection and management, (4) adoption of soil carbon practices, and (5) soil carbon demonstration trials. A program like this can drive a powerful transformation for USDA's approach to climate mitigation.

A research moonshot for soil carbon is both critical and timely given the increasing interest and action in soil carbon sequestration, including voluntary carbon market programs, net-zero climate pledges, unprecedented bipartisan action on climate-smart agriculture, and new programs to support climate-smart agriculture and forestry projects. Outside of the government, environmental nonprofits, commodity groups, and global food businesses have also emphasized the need for improved science around agriculture as a climate solution. Paying for soil carbon storage — whether through carbon markets or dedicated policy incentives — is critical for actualizing soil carbon storage, but foundational science is an urgent prerequisite that deserves further Congressional and administrative attention and investment.

At scale, soil carbon storage is both an economic and environmental answer to the pressures facing our farming system. We need to strategically, robustly, consistently, and specifically invest in soil carbon research before these practices can be scaled acre by acre. A robust and coordinated soil carbon research program reestablishes US leadership in public agriculture R&D and positions our farming system to address our generation's most pressing, complex societal and environmental challenges. The Soil Carbon Moonshot spells out a holistic and multifaceted roadmap to ground soil carbon storage in science, serving the patchwork of farmland across the country, the farmers and ranchers who steward our natural resources, and the soil itself.

Key investment areas for soil carbon

High-level Recommendations

CATEGORIES	RECOMMENDATIONS	FUNDING INCREASE OVER 5 YEARS*
Leadership and Coordination	1. Establish an interagency committee to develop a strategy and action plan to advance soil carbon research, education, and technical assistance initiatives across the federal government.	N/A
	2. Establish a dedicated official to lead coordination of soil carbon research efforts within USDA and across other federal agencies.	N/A
Fundamental Research	3. Invest in soil carbon dynamics research across programs and agencies.	Climate Hubs (+$25 million) SARE (+$10 million) LTAR (+$25 million) GEO (+$25 million) BER (+$25 million) **Total: $110 million**
	4. Develop advanced cultivars that can enhance carbon uptake and retention.	AFRI (+$100 million) ARS (+$125 million) **Total: $225 million**
	5. Develop, test, and deploy region-specific best practices for increased soil carbon.	Climate Hubs (+$28 million) SARE (+$10 million) LGU (+$30 million) NAC (+$20 million) **Total: $88 million**
	6. Expand support for underexplored soil amendments to forge the next generation of agricultural climate solutions.	ARS (+$250 million) **Total: $250 million**
		TOTAL $673M

* Funding levels adapted from the National Academies of Sciences Negative Emissions Technologies and Reliable Sequestration: A research agenda, Energy Futures Initiatives Clearing the Air report, reviews of existing and analogous program funding, as well as conversations with experts.

High-level Recommendations

CATEGORIES	RECOMMENDATIONS	FUNDING INCREASE OVER 5 YEARS*
Monitoring, Reporting, and Verification	7. Audit existing and develop new soil sampling protocols to support data collection efforts.	Climate Hubs (+$6 million) LTAR (+$25 million) **Total: $31 million**
	8. Improve and develop new measurement tools to generate robust soil carbon quantification.	LTAR (+$100 million) AFRI (+$100 million) FFAR (+$100 million) Climate Hubs (+$20 million) SARE (+$25 million) **Total: $345 million**
	9. Advance modeling and predictive tool development to reduce the cost and expand the number of acres with soil carbon MRV.	ARS (+$45 million) NIFA (+$20 million) GEO (+$25 million) ESD (+$25 million) **Total: $115 million**
	10. Assess and verify the effectiveness of soil carbon measurement tools in real-world agricultural contexts.	CTA (+$25 million) **Total: $25 million**
	11. Create decision support tools to empower farmers and ranchers to implement the best soil carbon practices for their unique operations.	NRCS (+$50 million) **Total: $50 million**
		TOTAL $566M
Data Collection and Management	12. Launch a national soil carbon monitoring network to map existing soil carbon stocks, uncover the areas with the greatest potential gains, and link agricultural management practices to carbon outcomes.	SCMN (new) (+$300 million) RaCA ($75 million) LTAR (+$200 million) Climate Hubs (+$25 million) **Total: $600 million**
		TOTAL $600M

* Funding levels adapted from the National Academies of Sciences Negative Emissions Technologies and Reliable Sequestration: A research agenda, Energy Futures Initiatives Clearing the Air report, reviews of existing and analogous program funding, as well as conversations with experts.

High-level Recommendations

CATEGORIES	RECOMMENDATIONS	FUNDING INCREASE OVER 5 YEARS*
Adoption of Soil Carbon Practices	**13.** Investigate the costs and benefits of soil carbon practice adoption to better incentivize wide-scale adoption and maximize soil carbon storage.	ERS (+50 million) **Total: $50 million**
	14. Identify barriers to adoption of soil carbon practices to create the necessary conditions to scale soil carbon storage.	NASS (+$3 million) NRCS (+$3 million) **Total: $6 million**
		TOTAL $56M
Demonstration Trials	**15.** Establish an extensive network of real-world demonstration trials to test and de-risk soil carbon practices across the diversity of US agriculture.	CIG (+$320 million) SARE (+$60 million) **Total: $380 million**
		TOTAL $380M

* Funding levels adapted from the National Academies of Sciences Negative Emissions Technologies and Reliable Sequestration: A research agenda, Energy Futures Initiatives Clearing the Air report, reviews of existing and analogous program funding, as well as conversations with experts.

Section Two

Introduction

The $136 billion US agricultural system has a long history of public research leadership.[4] Decades of US innovation, technology investment, and science dedicated to high crop yields and productivity have directly shaped modern farming.[5] However, public agricultural research has since dropped off, leaving mounting social and environmental pressures — from economic downturns, to increasing global competition, to feeding a growing population — unaddressed.

American farmers now face their most difficult challenge yet, as extreme weather intensifies pest pressures, suppresses yields, and threatens their livelihoods. The modern farming system — the one the US built — is yet to be calibrated for climate change.

Farmers and ranchers work on the frontlines of climate change, at once managing huge swaths of land, feeding the country, stewarding our natural resources, and retooling their long-standing practices to build resilience and remain competitive. More than ever, they need support to make informed changes on their land to curb and adapt to climate change and ensure their businesses thrive. This starts with a renewed federal investment in research.

4. US Department of Agriculture. (2018). USDA ERS - Ag and Food Sectors and the Economy. USDA. https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/ag-and-food-sectors-and-the-economy/

5. Clancy, M., Fuglie, K., & Heisey, P. (2016). U.S. Agricultural R&D in an Era of Falling Public Funding. *Amber Waves*. USDA ERS. https://www.ers.usda.gov/amber-waves/2016/november/us-agricultural-r-d-in-an-era-of-falling-public-funding/

6. European Environment Agency. (2019). Soil, Land and Climate Change. https://www.eea.europa.eu/signals/signals-2019-content-list/articles/soil-land-and-climate-change

The US can reaffirm its leadership in agriculture research and help realize soil carbon's potential as a climate solution by launching a coordinated interagency moonshot research program led by the United States Department of Agriculture (USDA). A Soil Carbon Moonshot (SCM) can completely reimagine what we know — and don't know—about soil carbon across the country.

At 915 million acres, soil on American farmland is part of the second largest natural carbon sink after our oceans.[6] By drawing down ambient CO_2 into soil, US farmers can turn the very emissions causing record drought, heatwaves, and floods into an asset. In this way, soil carbon represents more than a climate solution: Carbon-rich soil is more resilient to extreme weather, reduces input costs, and creates new revenue streams. For stretches of US farmland, healthy soil is the foundation for a resilient farming system that can better adapt to a changing climate.

Today, there is virtually zero dedicated funding for soil carbon research, and related efforts across the federal government are fragmented. This report lays out 15 recommendations for building a comprehensive research program that can realize the full potential of soil carbon storage and radically transform the agriculture sector's relationship to climate change — from USDA programs to farmers themselves. As we move to incentivize these practices acre by acre, we must first deepen our understanding of how to measure soil carbon on US farms' diverse landscapes and craft science-based policies that equip our farmers and ranchers to meet pressing environmental and economic challenges.

The Soil Carbon Moonshot spells out a major transformation for the agriculture sector that has so far gone unarticulated and underfunded at the federal level: A farmer-driven research agenda steered by a powerful coalition of policymakers, farmers and ranchers, and innovators to catalyze agricultural climate solutions at scale. Together, recommendations in this report seek to advance the next generation of agricultural climate solutions and support farmers in making the best operational decisions for their land, bottom lines, and the climate.

Lay of the Land

The Soil Carbon Opportunity

Today, agriculture contributes approximately 10% of greenhouse gas (GHG) emissions in the United States.[7] The climate imperative requires us to reduce emissions in the agriculture sector and draw down legacy carbon dioxide (CO_2) into our soils, which would both reduce future impacts of climate change and unwind existing climate threats. To harness that potential, we'll need to fundamentally change US land management practices to replenish the soil carbon stocks that have been severely depleted over the past few hundred years.[8] In addition to mitigating climate change, farmers and ranchers who implement practices that increase soil carbon can reap economic and ecological benefits. Increasing soil carbon leads to improved soil structure, which can stabilize yields, build operational resilience as weather extremes become more prevalent, reduce input costs, and improve water infiltration, retention, and quality.[9]

7. US EPA. (2019). Sources of Greenhouse Gas Emissions. US EPA. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions#agriculture

8. National Academy of Sciences. (2018). *Negative Emissions Technologies and Reliable Requestration: A Research Agenda.* The National Academies Press.

9. Milne, E., Banwart, S. A., Noellemeyer, E., et al. (2015). Soil carbon, multiple benefits. *Environmental Development, 13*, 33–38. https://doi.org/10.1016/j.envdev.2014.11.005

GLOSSARY

Soil carbon stocks
The total quantity of carbon currently stored in a "pool"— in this case the soil. Soil carbon stocks can be quantified across scales, ranging from a field to global scales.

How does soil carbon storage work?

ADDING SOIL AMENDMENTS:

Incorporating compost, mulch, or biochar into soil to increase its organic carbon levels and ensure that crops receive key nutrients.

ROTATIONAL/ IMPROVED GRAZING:

Continuously moving animals to help aerate the soil and distribute manure prevents overgrazing, and increases the amount of carbon stored.

REDUCING EROSION:

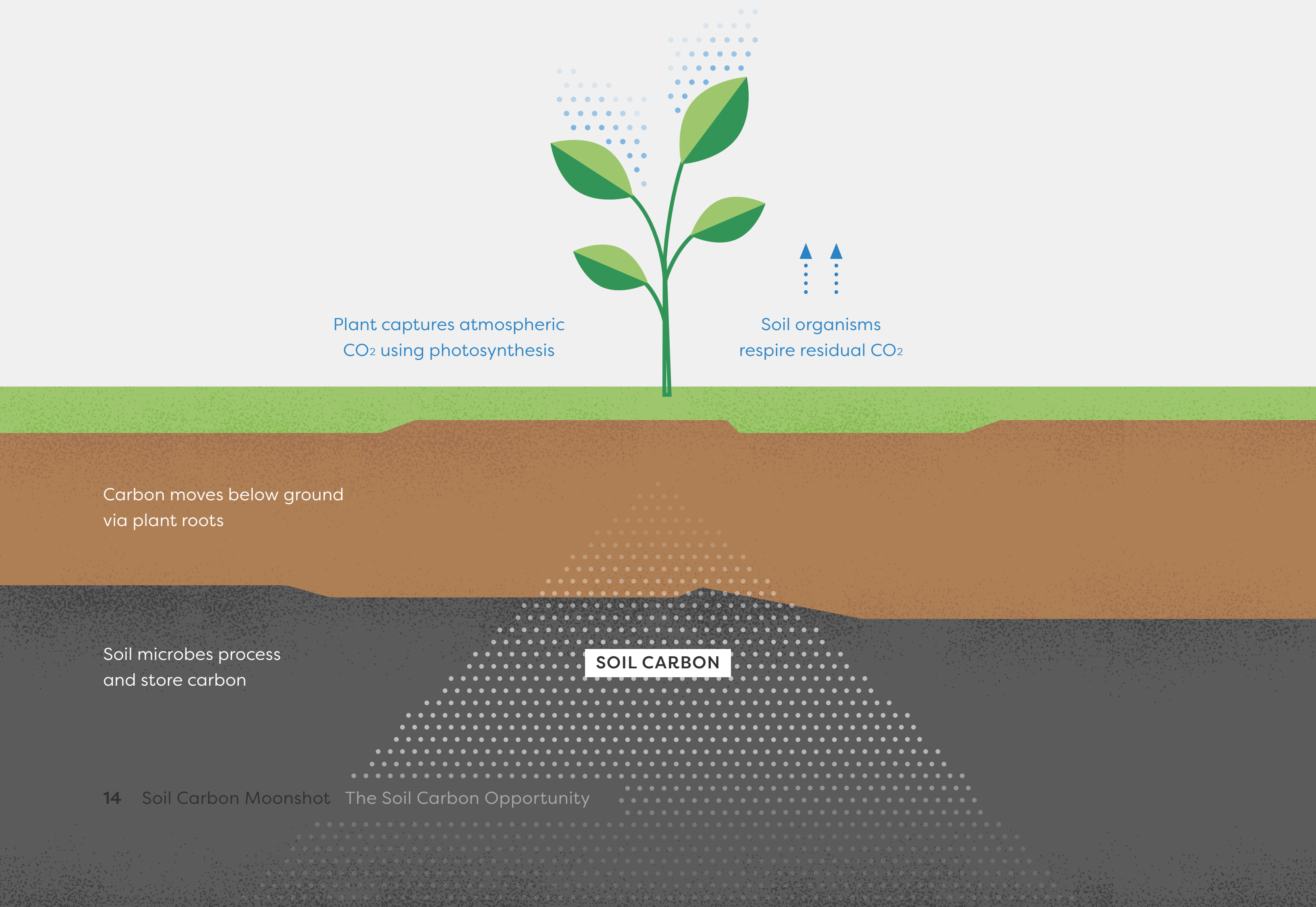
The addition of windbreaks, trees or shrubs planted at the edge of fields, slows wind, maintains the ground covered, and minimizes soil disturbance, fostering greater carbon storage.

INCREASING CROP DIVERSITY:

Bringing in different species, companion, or cover crops to support carbon cycling, nitrogen fixation, and favorable habitats for microbes and beneficial insects. Increased plant diversity leads to accelerated carbon storage rates.

AGROFORESTRY:

Planting trees in cropland or pasture to increase the above-ground carbon stock of farms.



Growing Political Momentum on Soil Carbon

Over the past few years, there has been an uptick in interest and action in soil carbon sequestration from the public and private sector alike — from voluntary carbon market programs to net-zero climate pledges to unprecedented bipartisan action on climate-smart agriculture. Dozens of bills have been introduced with ideas on how agriculture can contribute to climate change mitigation. S.1251/H.R.2820, the Growing Climate Solutions Act, S.1337/H.R.2803, the Agriculture Resilience Act, and S.1072/H.R.2534, the Climate Stewardship Act, are of significant importance. Each of these bills offers a vision for how to engage agricultural producers in stopping climate change. The Growing Climate Solutions Act aims to streamline and reduce barriers to entry for farmers, ranchers, and foresters looking to access voluntary carbon offset markets that will finance climate-friendly practices and monetize their carbon storage. Whereas the Agriculture Resilience Act and the Climate Stewardship Act suggest increasing investments in existing federal conservation, research, rural development, and forestry programs to advance climate change mitigation and adaptation more generally.[10, 11] These three bills share the common goal of widespread adoption of climate-smart agricultural practices, although the financing mechanism proposed to achieve this goal differs fundamentally.

LEARN MORE

For more information on recent soil carbon policies, try Carbon180's policy tracker: www.carbon180.org/policy-tracker

The Biden administration has also taken steps on soil carbon sequestration, with the US Department of Agriculture's (USDA) late 2021 announcement of the forthcoming Climate-Smart Agriculture and Forestry Partnership Program.[12] Other budding efforts are focused on addressing one of the major gaps in the soil carbon research space: how to measure and verify soil carbon gains. USDA invested $10 million in Climate Change Mitigation Assessment Initiative projects to survey, sample, and measure soil carbon on Conservation Reserve Program (CRP) acres to quantify climate outcomes.[13]

10. S.1337. Agriculture Resilience Act, 2021. (2021). https://www.congress.gov/bill/117th-congress/senate-bill/1337/text?r=3&s=1

11. S.1072. Climate Stewardship Act, 2021. (2021). https://www.congress.gov/bill/117th-congress/senate-bill/1072/text

12. USDA. (2021). USDA Announces $3 Billion Investment in Agriculture, Animal Health, and Nutrition; Unveils New Climate Partnership Initiative, Requests Public Input. USDA Newsroom. https://www.usda.gov/media/press-releases/2021/09/29/usda-announces-3-billion-investment-agriculture-animal-health-and

13. USDA. (2021). USDA launches first phase of Soil Carbon Monitoring Efforts Through Conservation Reserve Program initiative. USDA Newsroom. https://www.fsa.usda.gov/news-room/news-releases/2021/usda-launches-first-phase-of-soil-carbon-monitoring-efforts-through-conservation-reserve-program-initiative

GLOSSARY

Voluntary carbon market
A marketplace that enables emitters to purchase carbon credits generated by entities removing or reducing emissions in other sectors with the goal of offsetting their greenhouse gas emissions.

Climate adaptation
Reducing our vulnerability to current and expected climate impacts.

Climate mitigation
Avoiding and reducing emissions as well as removing legacy carbon emissions to prevent the worst impacts of climate change.

Additionally, H.R. 5376, the Build Back Better Act, which passed in the House, included more than $28 billion in climate and agriculture investments spread across conservation, research, data collection, and technical assistance programs, with more than $2 billion specifically to support agricultural research, education, and extension as it relates to climate change.[14] While these additional investments are much needed, this funding is still in limbo, and the nature of the reconciliation process does not allow for much direction to be given to federal agencies in the utilization of these funds.

Outside of the government, many organizations — from environmental nonprofits to commodity groups to global food businesses — have also emphasized the need for improved science around agriculture as a climate solution, particularly when it comes to monitoring, reporting, and verifying (MRV) soil carbon outcomes. The National Academies of Sciences outlined a research agenda for negative emissions technologies, including steps to enhance soil carbon storage;[15] the Bipartisan Policy Center released a report that includes recommendations to increase support for innovation around the science of natural climate solutions;[16] and the Food and Agriculture Climate Alliance developed recommendations to engage farmers and ranchers in deploying climate solutions that include investing in MRV.[17]

There is growing support for agriculture as a climate solution, but we need to learn more about soil carbon. Given the urgency of the climate crisis and the nature of soil carbon, we need to strategically, robustly, consistently, and specifically invest in research in this area. Without significant strategic investments in science, other efforts around soil carbon will fall short of what's needed to support America's farmers and ranchers at a time when they are facing both market instability and severe climate impacts. Incentives for climate-smart practices are critical for actualizing soil carbon storage, but foundational science is an urgent prerequisite that deserves further Congressional and administrative attention and investment.

> *Incentives for climate-smart practices are critical for actualizing soil carbon storage, but foundational science is an urgent prerequisite that deserves further Congressional and administrative attention and investment.*

14. H.R. 5376. Build Back Better Act, 2021. (2021). https://www.congress.gov/bill/117th-congress/house-bill/5376/text

15. National Academy of Sciences. (2018). *Negative Emissions Technologies and Reliable Requestration: A Research Agenda.* The National Academies Press.

16. Bipartisan Policy Center. (2022). *Federal Policies to Advance Natural Climate Solutions: Recommendations From the BPC Farm and Forest Carbon Solutions Task Force.* Bipartisan Policy Center. https://bipartisanpolicy.org/download/?file=/wp-content/uploads/2022/02/BPC_Farm-and-Forest_RV10_Final.pdf

17. Food and Agriculture Climate Alliance. (2021). *Food and Agriculture Climate Alliance Joint Policy Recommendations.* Food and Agriculture Climate Alliance. https://agclimatealliance.com/files/2020/11/faca_recommendations.pdf

GLOSSARY

Technical assistance programs
Provide technical expertise, information, and tools to farmers, ranchers, and other eligible entities that inform on-farm operational decisions and often support specific goals like conservation of natural resources and climate change mitigation.

THE CONSERVATION-SOIL CARBON CONNECTION

USDA has a long history of supporting farmers and ranchers in adopting conservation practices through core farm bill programs such as the Environmental Quality Incentives Program (EQIP), CRP, and the Conservation Stewardship Program (CSP). The purpose of these programs is to address concerns with natural resources and secure environmental benefits. Many of the conservation practices supported by these programs can improve soil health and potentially increase soil organic matter and soil organic carbon. More research is needed to specifically understand the carbon benefits of these practices across the diversity of US agricultural operations, particularly in the Western United States and in ranching, dryland, and specialty crop systems. These practices also offer many co-benefits, both ecological and economic, and help farmers build resilience into their operations.

Measuring and Incentivizing Soil Carbon

Interest in agriculture as a climate solution has surged, and questions have arisen around how to best incentivize farmers and ranchers to adopt soil carbon practices at large scales. The private sector has a stake in soil, too. Companies are looking for ways to meet net zero goals but often find that existing emissions reductions pathways are too expensive or nascent. To compensate for their emissions, companies can pay for cheaper emissions reductions or carbon removal in another geography or sector to offset their own emissions. This creates a one-to-one relationship — 1 ton of CO_2 is "allowed" to be emitted in one place, while 1 ton of CO_2 is reduced or removed elsewhere. Most offset purchases to date finance emissions reduction or avoidance projects, such as paying an entity to avoid deforestation or replacing hydrofluorocarbons in refrigerant systems.[18] Carbon offset markets have sprung up to enable the exchange between offset purchasers and those reducing or removing emissions from other sectors, as well as to provide some amount of oversight on offset quality.

18. Irfan, U. (2020). Can you really negate your carbon emissions? carbon offsets, explained. Vox. https://www.vox.com/2020/2/27/20994118/carbon-offset-climate-change-net-zero-neutral-emissions

GLOSSARY

Soil organic matter
The portion of soil that consists of living and dead plant or animal tissue in various stages of decomposition. It provides essential nutrients for plants and soil microbes, aids in water infiltration and retention, and holds reserves of nutrients.

Soil organic carbon
The carbon stored in soil organic matter, which plays a crucial role in soil and ecosystem services.

However, a number of critiques have been raised by environmental justice groups and climate advocates about the quality and implications of voluntary offset markets.[19, 20] Many recent analyses of offset markets have shown pervasive issues around permanence, additionality, and leakage.[21] Furthermore, offset purchasers in many cases are incentivized to purchase cheap, low-quality offsets that produce little real-world impact and give fossil fuel companies license to continue to operate and harm communities on the frontlines of poverty and pollution.

For nature-based offsets in particular, permanence is a notable concern. Carbon naturally cycles through ecosystems over time, and climate impacts and land management changes may cause reversals of carbon stored in our farmland, rangelands, and forests. Despite long-standing studies of the impacts of conservation practices on the environment and national assessments of soil carbon stocks, the commercial measurement of soil carbon storage at the field level is relatively new. Protocols are scarce and many lack robust measurement, making it difficult to reliably quantify and verify the amount of carbon stored from acre to acre and ensure that carbon stays sequestered over long periods of time.[22]

19. Lejano, R. P., Kan, W. S., & Chau, C. C. (2020). The Hidden Disequities of Carbon Trading: Carbon Emissions, Air Toxics, and Environmental Justice. *Frontiers*. https://www.frontiersin.org/articles/10.3389/fenvs.2020.593014/full

20. Vanderwarker, A. (n.d.). Environmental Justice Issues in California's Cap and Trade System. California Environmental Justice Alliance. https://caleja.org/wp-content/uploads/2017/04/EJissuesinCAcapandtrade.pdf

21. Zelikova, J. (2020). In search of carbon removal offsets. Carbon180. https://carbon180.medium.com/in-search-of-carbon-removal-offsets-42abf71b3ccc

22. Zelikova, J., Chay, F., Freeman, J., & Cullenward, D. (2021). A buyer's guide to soil carbon offsets. CarbonPlan. https://carbonplan.org/research/soil-protocols-explainer

GLOSSARY

Nature-based offsets
Offset credits generated through land management activities that avoid, reduce, or remove emissions, including protection, management and restoration of forests or wetlands

Permanence
The duration of carbon storage in a reservoir or stock. Many carbon offsets require 100-year permanence for credible offsets, but this poses a challenge for biological systems that naturally cycle carbon and are prone to reversals from climate impacts.

Additionality
Climate mitigation activities that would not have occurred without an intervention, most often a carbon credit. For example, a farmer chooses to adopt a soil carbon practice solely because of the incentive and would not have adopted this practice otherwise.

Leakage
Emissions that occur outside of the project area as a result of activities undertaken to mitigate or offset greenhouse gas emissions within the project area — meaning that emissions aren't really reduced but are instead "moved."

Accurately measuring soil carbon today requires physical sampling, which is arduous and costly for farmers and ranchers to implement across their entire operations, especially for small- and medium-sized farms and those that lack access to additional capital. To work around physical sampling, existing protocols often rely on models informed by insufficient source data to predict soil carbon, which calls into question the integrity of the carbon credits currently being generated.[23] Despite these gaps, interest in crediting agricultural soil carbon in voluntary carbon markets has increased.[24]

However, offset markets are not the only way to finance wide-scale adoption of climate-smart practices. Federal conservation programs have been used for decades to share the cost of implementing practices that enhance environmental outcomes, many of which increase soil carbon storage. These programs do not pay for the amount of carbon being stored in a given acre; they help farmers and ranchers cover the costs of changing or adopting practices. Other federal conservation programs provide rental payments to farmers and ranchers for taking environmentally sensitive land out of production, recognizing that producers should be compensated for foregone income and the environmental benefits that accrue from not working these susceptible lands. These policy incentives have strong alignment with practices that increase soil carbon but are not focused explicitly on climate benefits. Carbon-specific policy incentives do not yet exist but could include creating a label for climate-smart agricultural commodities to provide premium prices to farmers, utilizing federal procurement to purchase climate-smart agricultural commodities or direct carbon storage, and/or providing low-interest loans to farmers and ranchers adopting climate-smart practices.

An important precondition to paying for soil carbon storage — whether through offset markets or dedicated policy incentives — is investing in comprehensive research to better understand the connection between land management practices and soil carbon storage. Advancing our understanding of soil carbon will enable us to develop the next generation of soil carbon practices that are supported by farmers on the ground, produce tools that accurately measure soil carbon over long time periods, and determine science-based incentives. Until we can accurately measure soil carbon storage, incentives that pay for soil carbon specifically are premature.

23. de Gruijter, J. J., McBratney, A. B., Minasny, B., et al. (2018). Farm-Scale Soil Carbon Auditing. *Pedometrics*, 693–720. https://doi.org/10.1007/978-3-319-63439-5_23

24. Johnson, N., & Kempe, Y. (2021). The US is about to go all-in on paying farmers and foresters to Trap Carbon. Grist. https://grist.org/agriculture/us-carbon-removal-capture-offset-forests-farms-trees-soil/

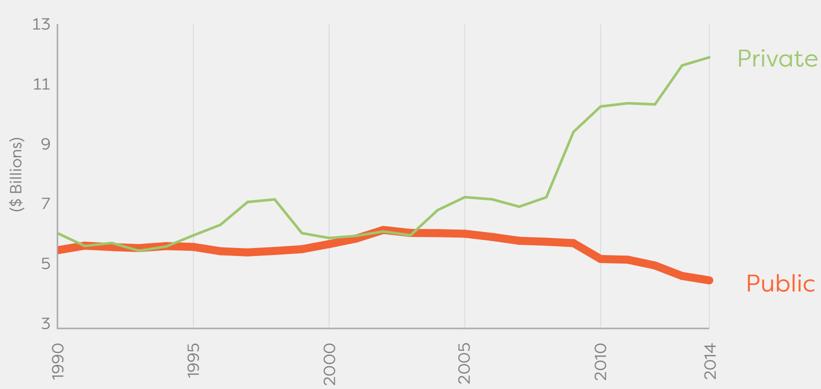
Section Three

Gaps in Existing Research

Current State of Soil Carbon Research Within the US Federal Government

The US used to be the global leader in agriculture research, accounting for the greatest amount of agricultural science publications and patents and far outproducing China, Japan, and Western Europe.[25] Public investments in agricultural research in the US, however, have stagnated and decreased since the early 2000s,[26] outpaced significantly by private sector investment.[27] Even though research investment is a primary driver of productivity growth in agriculture, the US now spends less than half of the Chinese government's investment in agricultural research and also lags behind Western Europe and Pacific Rim countries.[28, 29] Within USDA's $150 billion budget, only 2% of the agency's funding is dedicated to research.[30] A major reinvestment in collaborative, public sector agricultural research is urgently needed for the sector to meet its next big challenge: climate change mitigation and adaptation. With farmers facing more frequent climate impacts such as droughts and floods and the urgency to mitigate climate change growing stronger, soil carbon research is needed to equip all farmers with the tools and resources they need to meet the challenge. Private sector research alone has shown that it cannot and will not fill this role, especially in a way that puts farmers, science, and equity first.

Public and private funding trends for agriculture research



NOTE:

Public and private columns are adjusted for inflation to reflect 2013 values (billion USD)

Source: Congressional Research Service using data from Economic Research Service (ERS)

25. Clancy, M., Fuglie, K., & Heisey, P. (2016). U.S. Agricultural R&D in an Era of Falling Public Funding. *Amber Waves*. USDA ERS. https://www.ers.usda.gov/amber-waves/2016/november/us-agricultural-r-d-in-an-era-of-falling-public-funding/

26. SoAR Foundation. (2020). *Retaking the Field, Volume 5: Innovation to Profit*. SoAR Foundation. https://supportagresearch.org/assets/pdf/retaking-the-field-5_innovation-to-profit_final.pdf

27. Jacobson, R., & Sanchez, D. L. (2019). Opportunities for Carbon Dioxide Removal Within the United States Department of Agriculture. *Frontiers, 1*. https://doi.org/10.3389/fclim.2019.00002

28. Clancy, M., Fuglie, K., & Heisey, P. (2016). U.S. Agricultural R&D in an Era of Falling Public Funding. *Amber Waves*. USDA ERS. https://www.ers.usda.gov/amber-waves/2016/november/us-agricultural-r-d-in-an-era-of-falling-public-funding

29. Heisey, P., & Fuglie, K. (2018). Agricultural Research in High-Income Countries Faces New Challenges as Public Funding Stalls. *Amber Waves*. USDA ERS. https://www.ers.usda.gov/amber-waves/2018/may/agricultural-research-in-high-income-countries-faces-new-challenges-as-public-funding-stalls/

30. SoAR Foundation. (2020). *Retaking the Field, Volume 5: Innovation to Profit*. SoAR Foundation. https://supportagresearch.org/assets/pdf/retaking-the-field-5_innovation-to-profit_final.pdf

Efforts around soil carbon research are taking place across the federal government, but they are fragmented and siloed, which slows the overall progress of our understanding of soil carbon storage and the speed at which solutions could be deployed. At USDA, for example, the Long Term Agroecological Research (LTAR) Network has conducted long-term studies on how soil carbon storage varies across test fields under different management practices, the Natural Resources Conservation Service (NRCS) has spearheaded an effort to quantify and map soil carbon stocks across the US, and the Climate Hubs have synthesized climate change research and developed tools to help farmers and ranchers understand the risks that climate change poses to their operations and how to adapt to climate stresses. These USDA efforts are happening in tandem but are not coordinated, diminishing their potential climate impact.

In addition to USDA, the Department of Energy (DOE), the Department of the Interior (DOI), the National Aeronautics and Space Administration (NASA), the Environmental Protection Agency (EPA), and the National Science Foundation (NSF) all have ongoing projects on various aspects of soil carbon research — from advancing our understanding of soil carbon dynamics to mapping soil carbon stocks across the country. Importantly, research is not coordinated across agencies, findings are not shared in a systematic manner, and oftentimes agencies approach soil carbon with differing goals. For example, DOE may view soil carbon through the

GLOSSARY

Long Term Agroecological Research (LTAR) Network
Eighteen research sites that coordinate research, collect, and manage long-term data, develop new management techniques and technologies, and pursue agricultural innovation partnerships.

Climate Hubs
Ten regional hubs, co-led by the USDA's ARS and the USFS, that develop and deliver science-based information and technology to natural resource and agricultural managers, enabling climate-informed decision-making and reduced agricultural risk.

Existing government efforts on soil carbon research

USDA
- Rapid Carbon Assessment
- CRP Climate Change Mitigation Assessment Initiative
- SARE Soil Carbon Demonstration Trials
- CIG On-Farm Soil Health Demonstration Trials
- Cooperative Extension and USDA Climate Hubs partnerships
- Partnerships for Climate-Smart Commodities
- COMET Farm and Planner tools
- DAYCENT and DNDC models
- Long-Term Agroecosystem Research
- NRCS National Resources Inventory

FFAR Soil Health Grants and OpTIS

DOE
- ARPA-E SMARTFARM Program
- ARPA-E ROOTS Program
- Carbon Negative Shot
- Office of Science Biological and Environmental Research

NSF
- National Ecological Observatory Network
- Long Term Ecological Research
- Division on Environmental Biology
- Soils DAta Harmonization database (SoDaH)

EPA
- Greenhouse Gas Inventory

DOI
- US Geological Survey

OSTP
- US Global Change Research Program

NOAA
- Global Monitoring Lab’s CarbonTracker

NASA
- US Climate Reference Network Harvest Program

lens of reducing bioenergy life cycle emissions, whereas EPA may focus on developing credible estimates for soil carbon fluxes to support its greenhouse gas inventory work.

A robust and coordinated soil carbon research program can help return the US to its leadership role in public agriculture R&D and position our farming system to address our generation's most pressing complex societal and environmental challenges. A program like this has the opportunity to be transformative and revolutionize how USDA manages climate mitigation, bringing together expertise from within the agency and across the federal government to develop multifaceted approaches and solutions for farmers and ranchers to increase soil carbon stocks on their land and build resilience.[31]

Core Research Gaps

There is no one-size-fits-all solution when it comes to agriculture and climate change, and a research agenda should reflect that. For one, research has primarily focused on management practices most applicable to large-scale commodity crop operations in the Midwest.[32] Additional research efforts are needed to better understand soil carbon dynamics and best practices across the diversity of regions and operation types that make up US agriculture, including specialty crop, dryland, livestock, and small-scale operations.

We also need to expand research on nascent soil carbon practices, such as biochar, compost, and advanced breeding, and their impacts on soil carbon sequestration and storage.[33] For example, biochar is recognized by university researchers across the US as a promising climate solution due to its potential to deliver durable carbon sequestration, improve yields and build resilience, but further research is needed to identify sustainable production and appropriate application methods.[34] Diversifying soil carbon research augments existing soil carbon practices and their co-benefits, providing greater flexibility to producers in their choices of practices to increase soil carbon storage and protect their bottom lines.

31. SoAR Foundation. (2020). *Retaking the Field, Volume 5: Innovation to Profit.* SoAR Foundation. https://supportagresearch.org/assets/pdf/retaking-the-field-5_innovation-to-profit_final.pdf

32. Zelikova, J., Amador, G., Suarez, V., Kosar, U., & Burns, E. (2020). *Leading With Soil: Scaling Soil Carbon Storage in Agriculture.* Carbon180 Reports. https://static1.squarespace.com/static/5b9362d89d5abb8c51d474f8/t/5eaa30d12c3a767e64c3845b/1588211922979/LeadingWithSoil_Final+Text.pdf

33. Amelung, W., Bossio, D., de Vries, W., et al. (2020). Towards a global-scale soil climate mitigation strategy. *Nature Communications, 11 (1)*, 5427. https://doi.org/10.1038/s41467-020-18887-7

34. Amonette, J.E., Archuleta, J.G., Fuchs, M.R., et al. (2021b). *Biomass to Biochar: Maximizing the Carbon Value.* Report by Center for Sustaining Agriculture and Natural Resources, Washington State University, Pullman WA. https://s3.us-west-2.amazonaws.com/wp2.cahnrs.wsu.edu/wp-content/uploads/sites/32/2022/01/Biomass2Biochar-Maximizing-the-Carbon-Value1.1.pdf

GLOSSARY

Biochar
A carbon-rich, charcoal-like substance produced by heating biomass (i.e., plant residue) under low-oxygen conditions — a process called pyrolysis. The application of biochar to soils is a nascent approach that could create significant and long-term carbon sequestration.

Advanced breeding
The process of creating better-performing crop species by identifying desirable traits within plants or animals and selectively cross-breeding for specific outcomes like drought tolerance. It is also known as selective breeding.

Beyond the question of regionally appropriate and novel practices, measurement is the biggest research gap affecting large-scale implementation, certification, and financing of soil carbon practices.[35] We can't manage what we can't measure when it comes to soil carbon — which is why MRV must be standardized, affordable, and easy to use to ensure that farmers can maximize and be rewarded for soil carbon storage and that agriculture's climate benefits are real.[36] Accurate measurement is also essential to enhancing data collection efforts and modeling tools. At large, being able to measure soil carbon precisely enables us to develop science-based carbon incentives, track and meet policy goals, and evaluate soil carbon gains.

While all of these technological advances and research efforts are needed to jumpstart large-scale sequestration efforts, farmers and ranchers are the frontlines of this work. As they consider transforming their operations and taking on new practices, we need to understand and address the production and financial risks that they face in adopting soil carbon practices. This economic and social science research is particularly key for small-scale and Black, Indigenous, and people of color (BIPOC) producers who face unique challenges and barriers to practice adoption.[37] In addition, demonstration trials can de-risk practice implementation for farmers and ranchers and increase community support.

The challenges facing the agriculture sector are complicated — first and foremost because they aren't uniform across regions or operations. Any research approach to climate mitigation will need to be holistic and multifaceted, in service of the patchwork of farmland across the country, the farmers and ranchers who steward our natural resources, and the soil itself.

35. Smith, P., Soussana, J., Angers, D., et al. (2019). How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal. *Global Change Biology, 26*(1), 219–241. https://doi.org/10.1111/gcb.14815

36. FAO. (2019). *Measuring and modelling soil carbon stocks and stock changes in livestock production systems: Guidelines for assessment (Version 1).* Livestock Environmental Assessment and Performance (LEAP) Partnership. https://www.fao.org/3/ca2934en/CA2934EN.pdf

37. Thompson, A., Coronel, E., & Young, K. (2021). *Environmental Outcomes from On-Farm Agricultural Production in the United States, Fourth Edition.* Field to Market. http://fieldtomarket.org/media/2021/12/Field-to-Market_2021-National-Indicators-Report_FINAL.pdf

GLOSSARY

Demonstration trials
Farms and ranches that research or demonstrate various agricultural techniques, particularly innovative or nascent practices. They are typically designed to show other farmers a new technology or production practice on operationally-relevant scales.

Section Four

The Soil Carbon Moonshot

We can radically transform the agriculture sector's relationship to climate change— from USDA down to smaller farms. At scale, soil carbon sequestration can be both an economic and environmental answer to the pressures facing the US farming system. To meet this challenge and scale soil carbon in a science-driven way, we propose the launch of an interdisciplinary, coordinated interagency effort: a Soil Carbon Moonshot (SCM). Only a moonshot program can marshall the necessary resources from across the federal government to pursue ambitious and ground-breaking research and speed up innovation where solutions may not yet be profitable or scalable. A research moonshot for soil carbon provides a northstar for agencies — ensuring that research efforts are coordinated across the federal government, and equipping policymakers, farmers, and technical assistance providers with the findings necessary to implement practices.

The Soil Carbon Moonshot proposed below fills core research gaps—strengthening our understanding of soil carbon dynamics, increasing the availability of accessible and cost-efficient tools to measure soil carbon, improving data collection and management to drive public and private sector innovation, and overcoming socioeconomic and cultural barriers to the widespread adoption of soil carbon practices. To realize this vision, we propose a coordinated $2.3 billion investment, centered at USDA, over five years, and across five key categories: (1) fundamental research, (2) MRV, (3) data collection and management, (4) adoption of soil carbon practices, and (5) soil carbon demonstration trials. Each of these research priorities requires strong leadership to guide these efforts and ensure coordination across agencies. The Soil Carbon Moonshot is the roadmap to catalyze agricultural research, translate research

LEADING WITH SOIL

This report's proposal for a research moonshot builds on Carbon180's work with local organizations and agricultural producers across the Rocky Mountain states beginning in 2017. The on-the-ground work informs our understanding of soil carbon practices and how they might vary across landscapes. Our key findings highlighted three core roadblocks in soil carbon practice adoption: education, science, and incentives. The Soil Carbon Moonshot (SCM) addresses the need for science and research, and begins to make headway on farmer and rancher education. More broadly, the research moonshot is meant to inform incentives — with a better understanding of soil carbon, we are better equipped to design effective, science-based incentives.

Key investment areas for soil carbon

findings from the lab to the field, and equip farmers with accurate and reliable information to make decisions on the best ways to store carbon on their land and reap economic benefits. While some of these aspects are currently incorporated and undertaken in siloed approaches within agency efforts, the Soil Carbon Moonshot provides a centralized legislative blueprint for scaling soil carbon sequestration across US agricultural lands.

Leadership and Coordination

The broad scope of research projects needed on soil carbon requires a whole-of-government approach involving numerous federal agencies. Leadership and coordination will be a critical component of the success of this interagency research effort, especially to ensure that findings are rapidly shared with policymakers, farmers and ranchers, field agents, and technical assistance providers. USDA is uniquely positioned to lead coordination of this interdisciplinary, interagency collaboration: The agency's expertise and mission are deeply aligned, and its ongoing efforts around food, agriculture, natural resources, rural development, and nutrition support this work. The department has thousands of connections to farmers and ranchers, extension agents, university researchers, technical service providers, and community-based organizations. USDA also has a long track record of supporting research, translating research findings to actionable steps in the field, delivering technical assistance, and incentivizing protection of natural resources through practice implementation. DOE, DOI, NASA, EPA, and NSF are conducting important work related to soil carbon and will be critical partners for USDA in this research moonshot.

The overarching goal for the interagency moonshot research program should be to centralize all soil carbon research in one publicly available repository to improve coordination and collaboration across the federal government, promote private sector investment and innovation, and increase transparency on this type of research to the public.

The overarching goal for the interagency moonshot research program should be to centralize all soil carbon research in one publicly available repository to improve coordination and collaboration across the federal government, promote private sector investment and innovation, and increase transparency on this type of research to the public. This repository can serve as a source of reliable, evidence-based information and guidance for farmers and ranchers interested in implementing soil carbon practices. It's also a beacon of information for university researchers and private sector innovators developing

SEE MORE

For more details on the kinds of information the central repository should contain, please refer to pages 44-48 of this report

the next generation of agricultural climate solutions, as well as community-based organizations or technical assistance providers advising farmers on practice implementation.

Recommendation 1: Establish an interagency committee to develop a strategy and action plan to advance soil carbon research, education, and technical assistance initiatives across the federal government.

USDA, alongside DOE, DOI, NASA, EPA, and NSF, should develop an interagency strategy and action plan to coordinate and advance soil carbon research, education, and technical assistance. The Office of Science and Technology Policy should play a central role in helping coordinate the interagency committee. At least two members of the White House Environmental Justice Advisory Council should be a part of the interagency committee to ensure environmental justice is embedded from the beginning and any outcomes center frontline communities. The action plan should include goals, key deliverables, details on interagency collaboration across projects, and expected outcomes, ensuring that environmental justice goals are met. This plan should be submitted to Congress 18 months after establishment of the moonshot research program. USDA should draw upon previously completed climate research plans, as well as its climate adaptation and resilience plans to inform the interagency strategy and action plan.[38] In addition, an initial baseline report on existing soil carbon research activities should be submitted to Congress with subsequent progress reports on the goals and key deliverables identified in the action plan submitted to Congress at one-, three-, and five-year increments.

In addition, the committee should create and oversee interagency working groups tasked with coordinating on cross-cutting priorities, including fundamental research, MRV, and data collection and management. Additionally, working groups should be tasked with engaging with community and producer groups, particularly those that work with historically underserved and disadvantaged farmers and ranchers, to ensure that research is rooted in strong engagement with stakeholders and on-the-ground perspectives. This engagement should be done before the completion of the action plan and throughout the research process. Finally, the working groups should also conduct annual budget reviews with assistance from the Office of Management and Budget to align budget requests across soil carbon research priorities.

38. USDA. (2021). *Action Plan for Climate Adaptation and Resilience.* https://www.sustainability.gov/pdfs/usda-2021-cap.pdf

GLOSSARY

Environmental justice
All people, regardless of race, color, national origin, or income, have the same degree of protection from environmental and health hazards. This also includes equal access to decision-making processes that result in having a healthy environment to live, learn, and work.

Recommendation 2: Establish a dedicated official to lead coordination of soil carbon research efforts within USDA and across other federal agencies.

A new position should be crafted under the Research, Education, and Economics mission area of USDA to serve as the coordinator of the moonshot research program. This position should lead a committee composed of representatives from each agency for all research, education, and technical assistance activities in the interagency action plan. The lead coordinator for soil carbon research can help reduce redundancies, evaluate effectiveness, and collaborate across agencies on land-based carbon removal research in both agriculture and forestry. The lead coordinator should also review and advise on all USDA soil carbon research budget proposals alongside the interagency working groups and oversee the evaluation of said projects. This position should work closely with the USDA Climate Change Program Office to ensure that research findings are translated to other related work.

ADMINISTRATIVE ACTION

USDA and other agencies should evaluate actions they can take administratively to advance soil carbon research immediately. For example, USDA should expand its existing memorandum of understanding with DOE's Office of Science Biological and Environmental Research (BER) to explicitly include carbon sequestration objectives within the scope of the current genomics research program.[39] USDA can continue to prioritize climate change mitigation and adaptation across programs by increasing incentive payments for climate-smart practices under existing conservation programs, funneling funds to improve soil carbon monitoring, and explicitly including soil carbon sequestration as a research priority in future notices of funding opportunities. Additionally, USDA should request that the Foundation for Food and Agriculture (FFAR) include carbon removal and soil carbon sequestration and storage in its program scope.

39. DOE-USDA. (n.d.). Plant Feedstock Genomics for Bioenergy. Genomic Science Program. DOE. https://genomicscience.energy.gov/research/DOEUSDA/

GLOSSARY

Biological and Environmental Research (BER) program
A program within the DOE that supports scientific research on complex biological, earth, and environmental systems. It explores the underlying biology of plants and microbes to reengineer them with the aim of advancing US energy and infrastructure security.

Foundation for Food and Agriculture Research (FFAR)
Established by Congress in the Agricultural Act of 2014 to build public-private partnerships that fund cutting-edge research and address the most pressing challenges in food and agriculture.

Research Investments

With leadership and coordination underscoring all research areas, SCM proposes investments to support (1) fundamental research, (2) MRV, (3) data collection and management, (4) adoption of soil carbon practices, and (5) soil carbon demonstration trials. This research moonshot can lead a holistic, farmer-driven research agenda where farmers and ranchers can not only mitigate climate change but also harness the myriad environmental benefits associated with soil carbon storage, including preventing soil erosion, improving water infiltration and retention, protecting water resources from pollution, and improving resilience to weather extremes.[40]

Fundamental Research

There is great potential for carbon storage in soils, but our understanding continues to be limited in a number of areas. Soil carbon dynamics and durability, for example, vary between specialty and row crop systems. Soil amendments such as biochar should be utilized in different quantities across different soil types. However, we need more precise information, since what works for a corn-soybean farmer in Iowa won't work for a rancher in Colorado. Research can identify which soil carbon practices work best in each region and for different operations. This research moonshot aims to fund and enable USDA to craft a menu of soil carbon practices that a specialty crop farmer in California, a row crop farmer in Illinois, and a livestock rancher in Nebraska can utilize. Ultimately, the goal is to encourage wide-scale adoption of soil carbon practices, position farmers and ranchers to be rewarded for soil carbon storage, and catalyze agriculture's climate-mitigating potential.

We also have an opportunity to advance research across the board, giving farmers and ranchers more options to build resilience to climate change. Particularly impactful research areas include crops bred to sequester more carbon in the soil and exploring novel and underemployed soil carbon practices that haven't been as heavily researched but could work better for small-scale, livestock, dryland, and specialty crop operations.

Research is critically needed in four key areas, most of which can be primarily housed within USDA's Agricultural Research Service (ARS) and National Institute of Food and Agriculture (NIFA): (1) soil carbon dynamics, (2) enhanced carbon uptake crops, (3) regional best practices for productivity and sequestration, and (4) soil amendments. This research should balance short-term and long-term research to encourage both innovation and deeper knowledge on soil carbon. Funding opportunities within SCM are distributed across agencies and programs to ensure

40. Hinge, G., Surampalli, R. Y., Goyal, M. K., et al. (2021). Soil carbon and its associate resilience using big data analytics: For food Security and environmental management. *Technological Forecasting and Social Change*, *169*, 120823. https://doi.org/10.1016/j.techfore.2021.120823

GLOSSARY

Soil carbon dynamics
How certain factors (i.e., temperature) affect the way soils cycle and store carbon.

Durability
In this context, the ability to maintain soil carbon storage over long periods of time.

Specialty crop system
A farming system that produces specialty crops, which include fruits, vegetables, tree nuts, and horticulture and nursery crops.

Row crop system
A farming system that typically produces annual crops planted in dense rows, such as corn, soy, wheat, rice, and cotton.

Enhanced carbon uptake crops
Crop varieties bred to store more carbon in the soil. Specific traits, like deeper and more extensive roots enable higher carbon storage.

Soil amendment
A material added to the soil to improve farm outcomes.

that a diverse set of researchers — within USDA, at Land Grant Universities (LGUs), nongovernmental organizations (NGOs), private companies, and research institutions — have access to funds and contribute to advances in soil carbon research.

Recommendation 3: Invest in soil carbon dynamics research across programs and agencies.

Investment over 5 years:	Programs:	
$110 million	Climate Hubs (+$25 million)	SARE (+$10 million)
	LTAR (+$25 million)	GEO (+$25 million)
	BER (+$25 million)	

Additional investments are necessary to better understand soil carbon dynamics and, in particular, the mechanisms of carbon input, transformation, and stabilization in soils.[41] Future research in this area should explore soil carbon chemistry, plant-microbe interactions, soil carbon dynamics across a depth profile, microbial soil carbon transformation and stabilization, and soil physical structure, among other topics.[42] Research can leverage and coordinate several existing initiatives within USDA, DOE, and NSF to advance this priority.

ARS supports longer-term research conducted by USDA researchers and includes LTAR, a network of research sites focused on sustainable intensification of agriculture. Given the nuance and variability of soil carbon, long-term coordinated research is essential to identify how soil carbon stocks fluctuate across time and various depths and how management practices, climate, soil type, and other factors impact soil carbon. Deeper understanding of soil carbon dynamics will be critical to design science-based policy incentives. **SCM proposes an additional $25 million investment over five years for the LTAR Network to advance soil carbon dynamics research.**

Sustainable Agriculture Research and Education (SARE) under NIFA, alongside USDA ARS, can also support projects dedicated to furthering our understanding of soil carbon dynamics. SARE has already supported hundreds of research projects that focus on carbon sequestration, soil carbon, and soil organic matter in addition to research focused on building resilience and evaluating management practices that affect soil carbon.[43] **SCM would dedicate an additional $10 million over five years to SARE to support soil carbon dynamics research.**

41. Dynarski, K. A., Bossio, D. A., & Scow, K. M. (2020). Dynamic Stability of Soil Carbon: Reassessing the "Permanence" of Soil Carbon Sequestration. *Frontiers.* https://doi.org/10.3389/fenvs.2020.514701

42. National Academy of Sciences. (2018). *Negative Emissions Technologies and Reliable Requestration: A Research Agenda.* The National Academies Press.

43. USDA SARE. (n.d.). SARE Grant Management System. SARE. https://projects.sare.org/search-projects/

GLOSSARY

Sustainable Agriculture Research and Education (SARE) program
A USDA program offering farmer-driven grassroots grants and education programs. Projects support research and education that bring new ideas to farms and ranches around the country based on the principles of sustainable agriculture.

USDA's Climate Hubs synthesize and repackage research findings to increase accessibility and usability for stakeholders so that they may better leverage these findings to make decisions, including those around developing tools and technologies. Five of the 10 Climate Hubs are co-located with LTAR sites across the country, enabling collaboration and coordination and speedy delivery of research findings to the field. By working alongside all LTAR Network sites and other research sites, the Climate Hubs will be able to expand research synthesis, tool development, and stakeholder engagement on soil carbon sequestration and climate change mitigation, in addition to the ongoing resilience and climate adaptation work already conducted by the hubs. **SCM would devote an additional $25 million over five years for the Climate Hubs to advance this work.**

Additional research in this area is being carried out by DOE's BER and NSF's Directorate for Geosciences (GEO). **Congress should invest an additional $25 million over five years in each of these programs to support further soil carbon dynamics research.**

Recommendation 4: Develop advanced cultivars that can enhance carbon uptake and retention.

Investment over 5 years:	Programs:
$225 million	AFRI (+$100 million) ARS (+$125 million)

Advanced cultivars, developed through selective breeding and genetic engineering, can grow deeper and more extensive roots that then increase the amount of carbon stored in soil.[44] Similarly, perennial crops grow larger roots and transfer more carbon to the soil, increasing carbon drawdown and storage rates. Many of these crops today are not yet commercial, and more varieties will need to be developed. Additional research is needed around the development of enhanced carbon uptake crops, as well as perennial varieties of the largest annual agricultural commodities, including corn, soybeans, wheat, etc.[45] Sixty percent of projects should utilize conventional selective breeding methods, and the remaining 40% should explore genetic modification techniques to enhance soil carbon sequestration traits.[46, 47]

44. Energy Futures Initiative. (2019). *Clearing the Air: A Federal RD&D Initiative and Management Plan for Carbon Dioxide Removal Technologies.* Energy Futures Initiative Reports. https://www.dropbox.com/s/x0880okedchb18p/EFI%20Clearing%20the%20Air%20Full%20Report.pdf?dl=0

45. Energy Futures Initiative. (2019). *Clearing the Air: A Federal RD&D Initiative and Management Plan for Carbon Dioxide Removal Technologies.* Energy Futures Initiative Reports. https://www.dropbox.com/s/x0880okedchb18p/EFI%20Clearing%20the%20Air%20Full%20Report.pdf?dl=0

46. Harnessing Plants Initiative. (n.d.). Salk Institute for Biological Studies. https://www.salk.edu/harnessing-plants-initiative/

47. Energy Futures Initiative. (2020). *From the Ground Up: Cutting-Edge Approaches for Land-Based Carbon Dioxide Removal.* Energy Futures Initiative Reports. https://static1.squarespace.com/static/58ec123cb3db2bd94e057628/t/6011a6f0e5315209523218f2/1611769596475/From+the+Ground+Up.pdf

GLOSSARY

Directorate for Geosciences (GEO)
A program within the NSF that supports research to advance the frontiers of knowledge and drive technological innovation, focused on processes that affect the global environment from the role of the atmosphere and oceans in climate to ocean acidification and more.

Advanced cultivars
Plants that have been bred or cultivated by humans with identified desirable traits.

This research should be done in coordination with existing research at DOE BER, NSF GEO, USDA NIFA, and ARS. **SCM proposes an additional $100 million investment over the next five years for NIFA's Agriculture and Food Research Initiative (AFRI) to support the development of enhanced carbon uptake crops.**

While NIFA can support more cutting-edge projects, ARS can advance long-term studies for deeper research. Through the lens of SCM, that means novel projects are buoyed and research is done over extensive timescales on everything from crops with increased ability to store carbon to the natural variation in carbon storage across existing crops. USDA should strive to engage farmers in this type of research as much as possible. For example, we can support public plant breeding research and enable farmers' access to high-quality, locally adapted seeds.[48] Farmer-driven research and public plant breeding provide farmers with more choice and control and give them viable alternatives to engineered seeds manufactured by private companies.[49] **SCM recommends an additional $125 million over five years for ARS to advance this work.[50]**

Recommendation 5: Develop, test, and deploy region-specific best practices for increased soil carbon.

Investment over 5 years:
$88 million

Programs:
Climate Hubs (+$28 million)
SARE (+$10 million)
LGU (+$30 million)
NAC (+$20 million)

A Midwest row crop farm may sequester large amounts of carbon using certain land management practices, but those same practices may not apply to a ranching system in the American West; soil carbon benefits are dependent on myriad factors including soil type, management practices, and geography.[51] SCM aims to create a region-specific baseline of soil carbon practices so all farming and ranching operation types and scales located across the vast variety of geographies in the country can benefit and contribute to soil carbon storage. First and foremost, we must develop and test region-specific best practices in cropland and rangeland management systems for increased soil carbon. Climate Hubs and SARE are uniquely positioned to lead in this work due to their regional structures and emphasis on delivery of regionally relevant information to producers. **SCM would dedicate an additional $28 million for Climate Hubs and $10 million for SARE over five years to support the development, testing, and deployment of region-specific soil carbon practices.**

48. NSAC. (n.d.). Building a better future for family farms by investing in 21st century seeds. National Sustainable Agriculture Coalition. https://sustainableagriculture.net/our-work/campaigns/fbcampaign/seed-breeding-and-research/

49. NSAC. (n.d.). Building a better future for family farms by investing in 21st century seeds. National Sustainable Agriculture Coalition. https://sustainableagriculture.net/our-work/campaigns/fbcampaign/seed-breeding-and-research/

50. NSAC. (n.d.). Building a better future for family farms by investing in 21st century seeds. National Sustainable Agriculture Coalition. https://sustainableagriculture.net/our-work/campaigns/fbcampaign/seed-breeding-and-research/

51. Zelikova, J., Amador, G., Suarez, V., Kosar, U., & Burns, E. (2020, May). *Leading With Soil: Scaling Soil Carbon Storage in Agriculture.* Carbon180 Reports. https://static1.squarespace.com/static/5b9362d89d5abb8c51d-474f8/t/5eaa30d12c3a767e-64c3845b/1588211922979/LeadingWithSoil_Final+Text.pdf

GLOSSARY

Agriculture and Food Research Initiative (AFRI)
A USDA competitive program that provides research, education, and extension grants to improve rural economies, increase food production, mitigate impacts of climate variability, and address water availability issues, among other priorities.

Furthermore, SCM proposes the creation of a competitive grant program focused on soil carbon at 1890 and 1994 LGUs, Tribal colleges and universities (TCUs), and Hispanic-Serving Agricultural Colleges and Universities (HACUs). **SCM would direct an additional $30 million over five years to 1890 and 1994 LGUs, TCUs, and HACUs to deliver education, the latest scientific research, and technical assistance to underrepresented and historically underserved agricultural communities, supporting equitable distribution of research benefits.** It is vital to ensure that all farmers, particularly those who have historically lacked access to federal programs, can benefit from and contribute to increases in soil carbon stocks. At a larger level, this grant program within SCM aims to level the playing field both in terms of the institutions conducting and translating research and those served by research dollars.

To carry out this new program, USDA should establish six regional Climate Centers and provide $1 million annually to each center to provide competitive grants within each region with the goal of addressing soil carbon sequestration and storage challenges particular to that region's soils, operation types, and climates. Eligible applicants must represent a consortium of 1890 and 1994 LGUs from within each of the Climate Center regions. This program could be modeled after the USGS National and Regional Climate Adaptation Science Centers[52] and NIFA's Sun Grant Program.[53]

SCM also emphasizes research on climate-smart practices for underresearched farming systems that may particularly benefit specialty crop and small-scale operations, including agroforestry practices. **SCM recommends an additional $20 million over five years to the National Agroforestry Center (NAC) to address some of these existing gaps and expand the list of climate-smart practices.** NAC's Technology Transfer and Applications team should promote region-specific agroforestry practices through workshops, training, and other events across the country.[54]

52. USGS. (n.d.). Climate Adaptation Science Centers. USGS. https://www.usgs.gov/programs/climate-adaptation-science-centers

53. USDA NIFA. (n.d.). Sun Grant Program. NIFA. https://nifa.usda.gov/funding-opportunity/sun-grant-program

54. USDA. (n.d). National Agroforestry Center. USDA. https://www.fs.usda.gov/nac/about/index.php

GLOSSARY

1890 Land Grant Universities
Land grant institutions that are historically Black universities. Established under the Second Morrill Act of 1890 to strengthen research, extension, and teaching in the food and agricultural sciences by building institutional capacity.

1994 Land Grant Universities
Land grant institutions that are Native American tribally-controlled colleges and universities. Established under an Act of Congress in 1994 to foster higher education programs involving teaching, community outreach, and research.

Agroforestry
Incorporates the cultivation and conservation of trees and shrubs into crop and animal farming systems to increase above groundcarbon stocks.

National Agroforestry Center (NAC)
The USDA sole unit dedicated to accelerating the adoption of agroforestry. The center leads, catalyzes, coordinates, and conducts research and science-based outreach.

Recommendation 6: Expand support for underexplored soil amendments to forge the next generation of agricultural climate solutions.

Investment over 5 years:
$250 million

Programs:
ARS (+$250 million)

Applying organic amendments, including compost, manure, and biochar, to a farming system can increase soil carbon stocks and improve overall soil quality, particularly in areas with degraded soils.[55] However, suggested amendment mixtures and rates of application will vary by soil type and condition, location, and type of operation. Organic amendments can also help reduce fertilizer needs since they conserve the carbon already in the system and recycle nutrients.[56] Further research is needed to determine the potential of organic amendment applications for improving soil health, enhancing soil carbon sequestration, and bolstering climate change mitigation.[57] Specifically, those amendments have different impacts on soil carbon, crop productivity, water and nutrient retention, albedo, and soil residence time through field studies — all critical information to understand before implementation.

Research should also include life cycle assessments of these soil amendments, including how they are produced and what emissions they create in the process, ensuring sustainability and net climate benefits. In addition, this program area should include research on nonorganic soil amendments with the potential to store carbon, including the application of reactive alkaline minerals to agricultural soils. **SCM would funnel an additional $250 million over five years to ARS to conduct long-term coordinated research on soil amendments to address existing knowledge gaps related to the production and use of these amendments as climate mitigation practices.**

Monitoring, Reporting, and Verification (MRV)

When it comes to soil carbon, measurement is synonymous with management — without it, carbon sequestration is underutilized at best or, at worst, climate benefits are misrepresented. Accurately quantifying soil carbon gains involves a process known as monitoring, reporting, and verification, or MRV. Current methods to measure soil carbon stocks at the farm level — the "M" in MRV — require physical

55. Alvarenga, P., Carneiro, J. P., Fangueiro, D., et al. (2020). Managing organic amendments in agroecosystems to enhance soil carbon storage and mitigate climate change. *Climate Change and Soil Interactions, 89*–141. https://doi.org/10.1016/b978-0-12-818032-7.00005-9

56. NSAC. (2019). *Agriculture and Climate Change: Policy Imperatives and Opportunities to Help Producers Meet the Challenge.* National Sustainable Agriculture Coalition. https://sustainableagriculture.net/wp-content/uploads/2019/11/NSAC-Climate-Change-Policy-Position_paper-112019_WEB.pdf

57 Silver, W., Vergara, S., Mayer, A., & Brown, E. (2018). *Carbon Sequestration and Greenhouse Gas Mitigation Potential of Composting and Soil Amendments on California's Rangelands.* California's Fourth Climate Change Assessment, California Natural Resources Agency. https://www.energy.ca.gov/sites/default/files/2019-11/Agriculture_CCCA4-CNRA-2018-002_ADA.pdf

GLOSSARY

Soil amendment
A material added to the soil to improve farm outcomes — often improving the soil's physical properties or providing nutrients for plants.

Albedo
The ability of surfaces to reflect light. In connection to climate change, low albedo (i.e., dark) surfaces absorb more energy and increase warming.

Lifecycle assessments
Analysis that accounts for the total greenhouse gas impact of a product or process, from production to use or disposal.

sampling by land managers and are therefore time-consuming, expensive, and not feasible to scale to every acre.[58]

58. Oldfield, E.E., Eagle, A.J., Rubin, R.L., et al. (2021). *Agricultural soil carbon credits: Making sense of protocols for carbon sequestration and net greenhouse gas removals.* Environmental Defense Fund. http://edf.org/sites/default/files/content/agricultural-soil-carbon-credits-protocolsynthesis.pdf

MRV BREAKDOWN

Monitoring, reporting, and verification is a process or system used to assess and monitor the impacts of climate mitigation activities. In the context of soil carbon, each step involves the following:

- **Monitoring:** Measurement or estimation of soil carbon sequestration and other GHG fluxes based on physical measurements or other information (e.g., models) over time. This step is sometimes referred to as measurement or measuring, though those terms most often refer to the collection of data at a single point in time.
- **Reporting:** Standardizing and sharing data with stakeholders. This may vary from national governments to publicly accessible platforms to offset verifiers.
- **Verification:** Quality control done by an independent party to ensure data are complete, consistent, and accurate.

Improvements are necessary across all components of MRV, but currently the largest gap is related to simplifying and scaling measurement technology.

Today, farmers must go through an arduous process to complete soil carbon MRV. When a farmer decides to adopt climate-smart practices and track soil carbon outcomes through MRV, they must draw boundaries for which acres they want to include and select a soil sampling protocol. This soil sampling protocol then helps them determine how and where to take physical soil samples called soil cores. Based on their operations and selected protocol, farmers will need to make decisions about how many soil samples to take, in what pattern across the field, and at what depth. These choices are critical — they affect the statistical credibility of these samples andt will allow the farmer to estimate the soil carbon content of the entire farm based on the extrapolation of these samples. Farmers then execute the sampling, taking at least eight soil cores for each sampling depth. Farmers then bag and mail the soil samples to a lab, where soil organic carbon is assessed using the dry combustion method. Farmers pay fees for the samples to be analyzed and often have to wait weeks for results. This entire process results in baseline estimates of a farmer's soil carbon content and needs to be repeated every year to monitor soil carbon changes and ensure durability of carbon storage.

This onerous process has hindered wide-scale MRV and created a perverse incentive to rely on incomplete models to project soil carbon storage. A recent assessment of existing soil carbon offset protocols showed that the most rigorous of these protocols are even more difficult for farmers to implement, and credit prices are too low to overcome the high transaction costs, in turn failing to encourage a transition to high carbon storage practices.[59] Improved measurement technology, in connection with improved data collection and management (see recommendations on page 44) can help unravel some of those pain points, but additional research is a necessary first step.

Advancing MRV requires a multi-pronged approach

1

Protocols tell us how to implement measurement tools and standardize the way we measure soil carbon, leading to greater accuracy.

2

Soil carbon measurements are used to calibrate models. New tools enable more high-quality data collection, leading to greater model accuracy at smaller scales.

Protocols

Tell us how to sample soils at the field level

↓ 1

Measurement tools

Measure soil carbon and, combined with robust protocols, estimate soil carbon at the farm level

2 ↓ ↑ 3

Models

Predict soil carbon storage at the landscape level

3

Improved models draw clearer connections between practice adoption and carbon storage, reducing overall reliance on direct MRV.

59. Zelikova, J., Chay, F., Freeman, J., & Cullenward, D. (2021). A buyer's guide to soil carbon offsets. CarbonPlan. https://carbonplan.org/research/soil-protocols-explainer

GLOSSARY

Dry combustion
A method utilized to calculate soil organic carbon in a soil sample. The soil sample is burned at a high temperature in an atmosphere of pure oxygen to measure the total carbon content of the sample.

Spectroscopy
An interaction between a substance and the natural absorption and radiation of light. Soil spectroscopy uses measurements of this absorption and radiation to infer soil structure and attributes, including soil carbon content.

Without major advances in soil sampling protocols, measurement tools, and predictive models, we are at risk of overcounting carbon removals and stifling the scale at which these practices can be meaningfully deployed. Overestimating removals would be detrimental to society from a climate perspective, but especially harmful for disadvantaged communities who are not only impacted most by a warming climate but are also living on the frontlines of polluting industries further enabled by ineffective offset markets. High-quality MRV is central to any just and effective climate strategy.

THE CASE FOR ADVANCING MRV

Advancing MRV approaches and technology would improve the integrity of agricultural carbon credits currently being generated for voluntary carbon markets. Outside of carbon markets, there are many reasons to advance MRV, including equipping farmers with information to better manage their soil health or factoring soil carbon into the life cycle carbon impacts of land management decisions. USDA and DOE have both made investments in the sector for these alternative reasons. For more than 100 years, USDA's NRCS has led and managed the Soil Survey to characterize soil types and carbon content of soil across the US, annually completing thousands of samples over tens of millions of acres.[60] In 2010, the NRCS' Rapid Carbon Assessment (RaCA) launched and provided 144,833 samples of soil profiles using spectroscopy and bulk density methods.[61] More recently, DOE's Advanced Research Projects Agency–Energy (ARPA–E) launched SMARTFARM to commercialize technologies that can measure GHG fluxes at the field level.[62] Collectively, these efforts represent a strong starting point, but an overarching vision, coordination, and resources will be necessary to realize MRV at scale.

60. USDA NRCS. (n.d). Web Soil Survey. USDA NRCS. https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

61. USDA NRCS. (n.d.). Rapid Carbon Assessment. USDA NRCS. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054164

62. ARPA-E. (2019). ARPA-E Announces $20 Million in Funding to Develop Feedstock Monitoring and Carbon Storage Technology. APRA-E Press Releases. https://arpa-e.energy.gov/news-and-media/press-releases/arpa-e-announces-20-million-funding-develop-feedstock-monitoring-and

GLOSSARY

Soil survey
A series of surveys conducted by the NRCS that collect soil data and information. They provide access to the largest natural resource information system in the world and contain soil maps and online data for more than 95% of US counties.

Rapid Carbon Assessment (RaCA)
A project conducted by the NRCS in 2010 to quantify US soil carbon at a single point in time. The project aimed to develop statistically reliable quantitative estimates of soil carbon stocks and provide data to support modeling efforts.

Advanced Research Projects Agency — Energy (ARPA-E)
A DOE program that advances high-potential, high-impact energy technologies that are too early for private sector investment. Awards provide funding, technical assistance, and market readiness to energy researchers.

SMARTFARM program
A DOE ARPA-E program focused on driving innovation around the quantification of bioenergy feedstock emissions from agriculture.

Recommendation 7: Audit existing and develop new soil sampling protocols to support data collection efforts.

Investment over 5 years:	**Programs:**
$31 million	Climate Hubs (+$6 million) LTAR (+$25 million)

Today, physical samples of soil are still required to achieve accurate soil carbon measurements. But taking physical soil samples is arduous, especially over time and spatial scales needed to monitor soil carbon fluctuations. If we're to scale soil carbon, long-term measurements are crucial to showing changes in soil carbon stocks over time, since soil carbon accrues slowly and nonlinearly.[63] Soil carbon measurements are influenced by many variables, including when samples are taken, the number of samples taken, and their depth and pattern across the field, and yet, there is no consistent protocol that exists today on how to sample soil for carbon.[64] The data gathered from direct soil samples have a ripple effect across soil carbon MRV, from sampling to predictive models, and inform our understanding of soil carbon stocks across the country. They are critical for both on-farm decision-making and determining carbon-focused incentives. The data gathered from direct soil samples need to be standardized to support high-quality soil carbon modeling and mapping. Currently, efforts such as the Open Soil Spectral Library are working to coordinate and organize existing datasets, but additional coordination and standardization are needed to ensure samples and data are collected using universal standards and processes.[65]

USDA's LTAR Network measurement working group should be tasked with auditing existing soil sampling protocols (within the federal government, at other research institutions, and in the private sector) and developing best practices for future sampling across USDA and other agencies. Furthermore, USDA grant recipients focused on short-term and long-term soil carbon data collection efforts should be required to utilize the protocols developed by the LTAR Network. As the LTAR Network sites and USDA grant recipients gather data, these soil sampling protocols can ensure data accuracy and standardization, enable long-term analysis, and feed into the development of new MRV technologies and core modeling tools, including the Daily Century (DayCent) model, COMET-Farm, and COMET-Planner, to improve predictions of soil carbon fluxes. From there, USDA can make these soil sampling protocols public through USDA Climate Hubs, lowering barriers to entry and encouraging self-reported soil carbon sequestration activities.[66] These data entries would need to be spot-checked, but they could contribute to the data pool and bolster models.[67] The upshot of greater participation from farmers and ranchers is not only more data, but also the increased buy-in and understanding from those same farmers and ranchers who can help scale soil carbon sequestration. **To support these activities, the LTAR**

63. Smith, P., et al. (2019). *How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal.* Wiley Online Library. https://onlinelibrary.wiley.com/doi/10.1111/gcb.14815

64. Smith, P., et al. (2019). *How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal.* Wiley Online Library. https://onlinelibrary.wiley.com/doi/10.1111/gcb.14815

65. Open Soil Spectral Library (OSSL) Explorer. (n.d.). Soil Spectroscopy for Global Good. https://explorer.soilspectroscopy.org/

66. Smith, P., et al. (2019). *How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal.* Wiley Online Library. https://onlinelibrary.wiley.com/doi/10.1111/gcb.14815

67. Smith, P., et al. (2019). *How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal.* Wiley Online Library. https://onlinelibrary.wiley.com/doi/10.1111/gcb.14815

GLOSSARY

Long Term Agroecological Research (LTAR) Network
Eighteen research sites that coordinate research, collect, and manage long-term data, develop new management techniques and technologies, and pursue agricultural innovation partnerships.

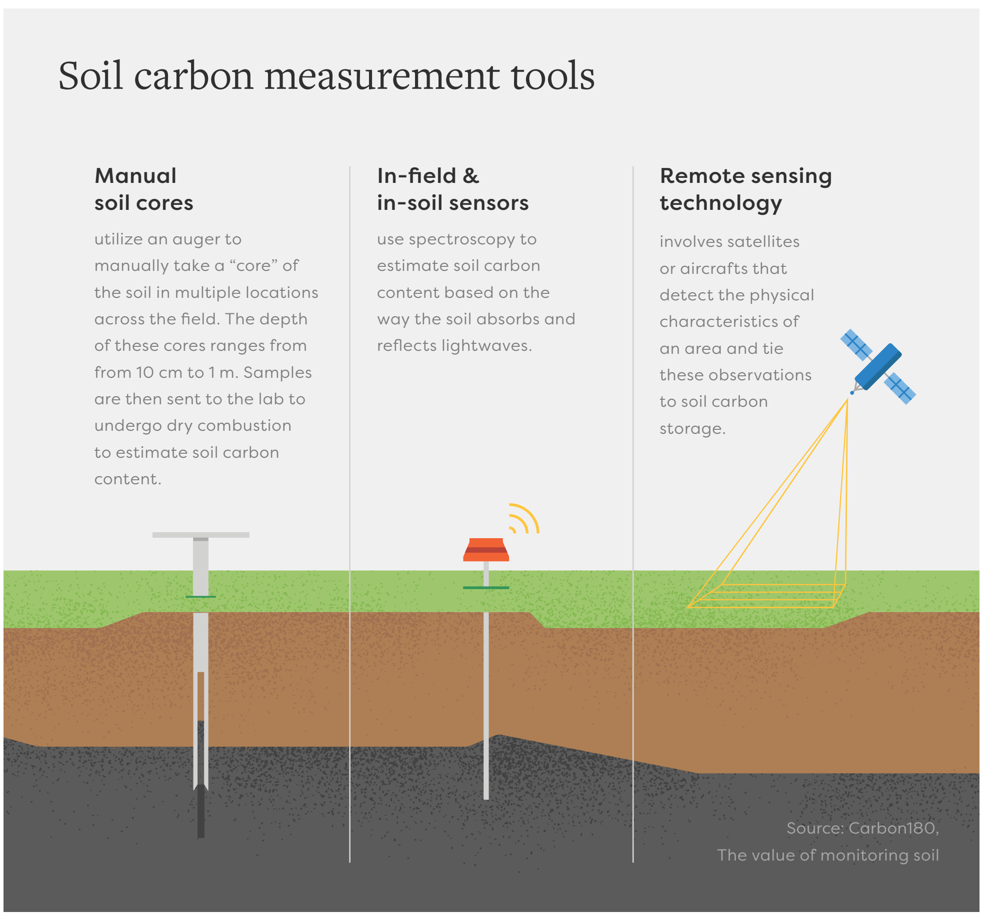
Network should receive $25 million over five years to audit and develop new soil sampling protocols, and the Climate Hubs should receive $6 million over five years to make publicly available resources on soil sampling.

Recommendation 8: Improve and develop new measurement tools to generate robust soil carbon quantification.

Investment over 5 years:
$345 million

Programs:
LTAR (+$100 million)
FFAR (+$100 million)
SARE (+$25 million)
AFRI (+$100 million)
Climate Hubs (+$20 million)

In addition to reviewing and developing soil sampling protocols, USDA should develop new and improved measurement tools, technologies, and techniques that make it easier and less costly for producers to implement soil carbon MRV. Soil carbon MRV tools should aim to account for full greenhouse gas fluxes, considering



GLOSSARY

Dry combustion
A method utilized to calculate soil organic carbon in a soil sample. The soil sample is burned at a high temperature in an atmosphere of pure oxygen to measure the total carbon content of the sample.

Spectroscopy
An interaction between a substance and the natural absorption and radiation of light. Soil spectroscopy uses measurements of this absorption and radiation to infer soil structure and attributes, including soil carbon content.

Remote sensing
A process of detecting the physical characteristics of an area, typically using satellites. Researchers are working to tie physical observations from satellites to soil carbon storage.

Field stratification
A process of dividing land to create a statistically significant plan for soil sampling.

SEE MORE

For more recommendations on data sharing and management, please see page 44.

agricultural sources of carbon dioxide, nitrous oxide, and methane. These tools can range from direct measurement tools (including in-field and in-soil hardware or sensors and remote sensing) to tools that can inform field stratification and sampling to data analysis tools that can track and synthesize data from multiple soil samples over time. Moving forward, USDA can focus research on improving the link between traditional soil carbon MRV, which relies on physical soil cores and combustion, with newer tools that take on- and in-the-ground measurements and remote sensing tools. These advancements are critical to reducing the cost and expanding the number of acres implementing soil carbon MRV.

The SCM proposes the following to support soil carbon measurement tool development:

- **The LTAR Network should receive $100 million for this work and partner with LGUs, Minority-Serving Institutions, TCUs, and NGOs to develop new measurement tools over five years.**
- **NIFA's AFRI should receive $100 million to further support LGUs, universities, research institutions, private companies, and NGOs in developing soil carbon measurement tools and supporting scaling and commercialization of new tools and technologies over five years.**
- **FFAR should receive $100 million over five years to develop, evaluate, and vet tools and find novel ways to use these tools within supply chains.**
- **The Climate Hubs should receive $20 million over five years to summarize advancements and translate relevant information to farmers and ranchers.**
- **SARE should receive $25 million over five years to support MRV tool development projects and compile and share research findings with the LTAR Network.** This funding is especially important to making MRV insights accessible to farmers and ranchers as SARE is the only farmer-led research program within USDA. SARE additionally should play an advisory role to the LTAR Network, with SARE regional directors compiling and sharing all projects with an emphasis on soil sampling protocols and soil carbon measurement tools with the LTAR Network.

Recommendation 9: Advance modeling and predictive tool development to reduce the cost and expand the number of acres with soil carbon MRV.

Investment over 5 years:
$115 million

Programs:
ARS (+$45 million)
NIFA (+$20 million)
GEO (+$25 million)
ESD (+$25 million)

As it stands, models and predictive tools for soil carbon storage aren't precise enough to support accurate carbon-based incentive payments. A major problem in modeling is high-quality, standardized data, and in the case of soil carbon, we don't have data to support modeling along specific conditions such as climate, management practices, or soil type. That's true of existing models such as the DayCent model, the COMET-Farm and COMET-Planner tools (which are based on DayCent outputs), and the DNDC model.[68] If we can rethink how we gather soil carbon data, we can remove a major roadblock to quality modeling of soil carbon and pave a path to scale carbon storage. Investments in MRV tools and data collection must happen simultaneously, since predictive models are dependent on source data. As more source data are gathered, models need to be continuously updated and refined. For example, USDA can work with and continue to support Colorado State University on the refinement of the COMET-Farm and COMET-Planner tools, as well as the University of New Hampshire on the DNDC model.

SCM recommends that Congress increase funding over the next five years by $45 million to ARS, $20 million to NIFA to support maintenance and improvements of the DayCent and DNDC models, and $25 million each to NSF's GEO and NASA's Earth Sciences Division (ESD) to support improved soil carbon modeling and predictive tool development.

Recommendation 10: Assess and verify the effectiveness of soil carbon measurement tools in real-world agricultural contexts.

Investment over 5 years:	**Programs:**
$25 million	CTA (+$25 million)

It's essential that soil carbon MRV tools are accessible and easy to use for farmers and ranchers. As a rule in effective agricultural policy, producers should be at the forefront of decision-making regarding management practices, including those that impact soil carbon. Tools should be designed to empower them to make decisions for their operations or we risk stalling adoption of soil carbon practices and reducing agriculture's contribution to climate mitigation. Furthermore, as new MRV tools are rolled out, field testing will continue to be critical to ground-truth soil carbon stock changes, particularly across diverse agricultural contexts. NRCS Conservation Technical Assistance (CTA) can support the assessment of on-the-ground tools.

Specifically, technical assistance providers have the benefit of working in real-world agricultural contexts. They are able to work with a variety of farmers to assess tools

68. Gilhespy, S. L., Anthony, S., Cardenas, L., et al. (2014). First 20 years of DNDC (DeNitrification DeComposition): Model evolution. *Ecological Modelling*, 292, 51–62. https://doi.org/10.1016/j.ecolmodel.2014.09.004

GLOSSARY

Earth Sciences Division (ESD)
A NASA program focused on missions to increase our knowledge about the planet's interconnected systems. ESD maps the myriad connections between Earth's vital processes and ongoing natural and human-caused climate change.

Conservation Technical Assistance (CTA)
A NRCS program that provides technical assistance to individuals and groups of decision-makers, communities, conservation districts, state and local governments, tribes, and other federal agencies, to help them voluntarily conserve, maintain, and improve natural resources.

along more diverse lines including region, operation type, soil type, and scale. In coordination with LGUs, NRCS should develop and regularly update a list of approved sampling and MRV technologies that meet the minimum precision and accuracy thresholds dictated by USDA in the standard soil carbon MRV protocol outlined in Recommendation 7.

SCM proposes that NRCS receive $25 million of additional technical assistance funding over five years to assess the effectiveness of MRV tools in real agricultural contexts. Forty percent of this funding should be set aside to serve BIPOC farmers and ranchers, in line with the Biden administration's Justice40 Initiative.[69] BIPOC producers have historically faced racial discrimination from USDA officials and policies, inhibiting access to USDA programs,[70] so it is critical to funnel resources directly to underserved farmers and ranchers, especially when it comes to climate change mitigation. Continuing to provide more resources to the largest and best-resourced farms will likely intensify consolidation in the agriculture sector and make it more difficult for small-scale and BIPOC farmers to remain in business.[71]

Recommendation 11: Create decision support tools to empower farmers and ranchers to implement the best soil carbon practices for their unique operations.

Investment over 5 years:	Programs:
$50 million	NRCS (+$50 million)

As we improve measurement tools and public data collection and management, farmers and ranchers need to directly benefit too — specifically using data to make the best operational decisions for their land, bottom lines, and the climate. NRCS should enter into cooperative agreements with LGUs, the Cooperative Extension System, NGOs, and private companies to support the development of decision support tools to improve yield, reduce risk, and increase soil carbon storage. A rancher in Colorado, for example, should be able to specify their location, current practices, the size of their ranch, the animals they raise, and the crops they grow into a tool that could then provide a menu of options of soil carbon practices tailored to maximize soil carbon storage given their particular operation and goals. Similar tools have been developed for other operational decisions such as water quality impacts[72] and life cycle GHG impacts of organic practices.[73]

NRCS should receive an additional $50 million over five years to enter into agreements that translate research findings, leverage soil carbon data efforts, and test various decision support tools with farmers and ranchers on the ground. NRCS and its partners should also work closely with the Climate Hubs, a central repository for soil carbon research. SCM proposes that 40% of this funding be

69. Young, S., Mallory, B., & McCarthy, G. (2021). The Path to Achieving Justice40. Briefing Room; The White House. https://www.whitehouse.gov/omb/briefing-room/2021/07/20/the-path-to-achieving-justice40/

70. Browning, P., et al. (1982). *The Decline of Black Farming in America.* Educational Resources Information Center; US Department of Education. https://files.eric.ed.gov/fulltext/ED222604.pdf

71. NSAC. (2021). *Climate Solutions for Farmers: Invest in Proven Conservation Programs, Not Carbon Markets.* National Sustainable Agriculture Coalition. https://sustainableagriculture.net/wp-content/uploads/2021/06/Climate-Solutions-for-Farmers_-Invest-in-Proven-Conservation-Programs-Not-Carbon-Markets-1.pdf

72. Gustafson, D. & Kok, H. (2019). N-Gage: Development of a Validation Tool to Support Local-Scale Water Quality Trading Programs in the Mississippi River Basin. 11th National Monitoring Conference. Conservation Technology Information Center. https://acwi.gov/monitoring/conference/2019/presentations/L6_Kok_Secure.pdf

73. The Organic Farming Footprint. (n.d.). The Center For Sustaining Agriculture and Natural Resources at Washington State University. https://ofoot.cafltar.org/

targeted to historically underserved producers to ensure that benefits of soil carbon storage flow to those on the frontlines and that these tools work for all types of farmers in terms of scale, operation type, geography, and demographics. Doing so will help limit biases in the development of decision support tools and ensure that the next generation of climate-smart agricultural solutions can serve everyone.

Data Collection & Management

Data are an important tool for farmers and ranchers as they make land management decisions, providing them with insights about which practices increase soil carbon, conserve natural resources, reduce risk, and improve yields. Beyond the producer, policymakers require the data to design appropriate and evidence-based carbon incentives. This type of data is also needed to improve models and develop more advanced remote sensing and measurement tools, helping us better predict and track soil carbon outcomes. The success of all of these efforts is contingent on the development of well-managed and consistently updated open-access data.

Though data are critical to drive innovation across the soil carbon space, there is currently a lack of standardized high-quality data on soil carbon that have been collected across long timespans, geographies, and uniform soil depths. Soil carbon data collection efforts have taken place across agencies in the past — including USDA, NASA, NSF, DOI, and EPA — but due to lack of consistent standards and, in some cases, stable funding and dedicated staff, the data have not been managed appropriately for continuity. Federal soil carbon data are also stored in multiple data warehouses and in different or difficult-to-access formats, creating redundancies and stifling advances by researchers and innovators lacking access to clean and accessible data. Meanwhile, data collection needs to be drastically ramped up in scale (especially in regions with fewer existing research sites) and frequency to understand where the greatest carbon gains can be made and maximize the potential of soil carbon sequestration.

As the largest collector, manager, and user of agricultural data, USDA is in an ideal position to lead soil carbon data collection and management efforts. The department has deep expertise and a long track record of collecting and managing many different datasets to ensure quality and confidentiality and allow for analysis of long-term trends. Existing initiatives within the Risk Management Agency, the Farm Service Agency, National Agricultural Statistics Service Information (NASS), and NRCS already collect management, yield, and climate data, yet this information is underutilized. This represents a major opportunity for USDA to step in as a centralizing force and reaffirm leadership in agricultural research.

DATA COLLECTION AND PRIVACY

Any data collection program developed to monitor soil carbon should have the same privacy protection provisions as other agricultural inventory, monitoring, and census programs operated by NASS. Congress should support this by giving private agricultural landowners participating in soil carbon data collection efforts the same legal protections already enjoyed by farmers and ranchers participating in other USDA programs. Additionally, we recommend that soil carbon data collection efforts implement measures to further protect farmer and rancher information, such as the 'fuzzing' and 'swapping' techniques undertaken by the US Forest Service (USFS) for the Forest Inventory and Analysis.[74] This can help meet the dual goals of maintaining the data's functional value while protecting farmer and rancher privacy.

Moving forward, USDA should perform a review of existing soil carbon data and data management processes, implement a narrow data rescue effort, apply rigorous common guidelines for data collection, and launch new efforts directly tied to improving our understanding of soil carbon storage — all with the broader goal of capturing relevant trends and informing soil carbon measurement tools and predictive modeling.

Recommendation 12: Launch a national soil carbon monitoring network to map existing soil carbon stocks, uncover the areas with the greatest potential gains, and link agricultural management practices to carbon outcomes.

Investment over 5 years:
$600 million

Programs:
SCMN (new) (+$300 million)
RaCA ($75 million)
LTAR (+$200 million)
Climate Hubs (+$25 million)

Congress should direct USDA to create a Soil Carbon Monitoring Network (SCMN) that is akin to the USFS Forest Inventory and Analysis and housed within the NRCS Soil Science Division. The goal of SCMN will be to provide a critical, up-to-date resource to producers, policymakers, investors, innovators, and the public on soil carbon stocks — both present and prospective — across the US and their connection

74. USFS. (2020). Spatial Data Services: Privacy Policy History and Implementation. Forest Inventory and Analysis National Program. USFS. https://www.fia.fs.fed.us/tools-data/spatial/Policy/index.php

GLOSSARY

Forest Inventory and Analysis (FIA)
A USFS program that collects, analyzes, and reports information on the status and trends of forests in the US. Its mission is to make and keep up-to-date a comprehensive inventory and analysis of the present and prospective conditions of the forest and rangelands of the US.

to different agricultural management practices. **SCM recommends that Congress provide $200 million over five years for the establishment of SCMN.**

Planning and Development: Upon its inception, SCMN should establish an advisory board, led by USDA, with representatives from across the federal government (including NSF, NASA, DOI, EPA, and DOE) to support the design and development of this initiative. Within USDA, there should be representation on the committee from the Climate Hubs, LTAR Network, National Resources Inventory (NRI), and NRCS Soil Survey program. This board should work with SCMN leadership to establish a strategic plan that outlines outcomes for the network and establishes data collection standards to meet those outcomes.

OUR DATA COLLECTION RECOMMENDATIONS

We recommend that the network, at a minimum, track land management information, soil properties, climate data, yield information, all GHG fluxes, bulk density, and soil organic carbon across a number of dimensions, including space, time, and depth. This information can be used as the basis to develop and benchmark models. All of this data should be captured using standardized practices and reporting to enable data consolidation and analysis.

Based on this information, SCMN should perform a selective and intentional data rescue effort across the federal government, drawing from the LTAR Network and other federal entities such as NASA, DOI, USDA, EPA, and DOE. In particular, SCMN should aim to integrate existing, aligned data from the LTAR Network, NSF National Ecological Observatory Network, NSF Long Term Ecological Research (LTER) Network, USDA NRI, USDA Soil Survey program, and USDA RaCA into a single public data platform. This data should be simplified, standardized, and cleaned before being published. The SCMN advisory board should decide which research sites across these federal entities are most aligned with the goals of SCMN and make a decision about how to best integrate and consolidate data collection efforts moving forward.

Activities: SCMN should act as the central node for all soil carbon data collection and management across the federal government. SCMN should be responsible for:

- **Annual surveys:** SCMN should complete an annual survey akin to RaCA, which was initiated in 2010 to develop estimates of amounts and distribution of carbon stocks for US soils under various land covers and agricultural management. The effort also aimed to provide data to support modeling of changes in soil carbon resulting from land-use changes, agricultural

GLOSSARY

National Resources Inventory (NRI)
A NRCS program that collects and produces scientific information on the status, condition, and trends of land, soil, water, and related resources on US non-federal lands in support of efforts to protect, restore, and enhance the country's lands and waters.

National Ecological Observatory Network (NEON)
A NSF program that monitors US ecosystems by collecting long-term, open-access ecological data.

Long Term Ecological Research (LTER) Network
A NSF network composed of 28 research sites across diverse ecosystems that are tasked with conducting studies on ecological processes over extended temporal and spatial scales.

management, conservation practice implementation, and climate change. RaCA was meant to provide a reliable inventory and map of soil carbon stocks across the US. However, the lack of continuity has limited the value and impact that RaCA could provide. There is neither dedicated funding for RaCA, nor an established cadence for doing the assessment, nor a common guideline for the depth of soil samples. **SCM proposes to authorize RaCA under SCMN and provide stable and continuous funding at $15 million per year for the assessment to be conducted annually, with soil samples taken at 1 meter in depth across the board.**

- **Soil carbon monitoring sites:** SCMN will be responsible for establishing a network of research sites that represent the geographic and operational diversity of US farms and ranches, with the goal of assessing the impact of various management practices on soil carbon stocks. These sites will be additional to the LTAR Network sites and focus most heavily where there are geographic or operational gaps in the LTAR Network. SCMN will coordinate closely with the LTAR Network to collect, share, and centralize soil carbon data. **To support this work, SCM recommends that Congress increase funding for the LTAR Network by $200 million over five years to establish additional long-term soil carbon research projects, hire a dedicated data management team to coordinate data efforts across all LTAR sites, and establish new monitoring sites as needed.**
- **Data collection and management:** SCMN will be responsible for collecting, centralizing, and managing data from across USDA, including long-term research from the LTAR Network, short-term research from SARE, and Conservation Innovation Grants' (CIG) Soil Carbon Demonstration Trials (see recommendation 16). In order to incentivize the continued collection of robust, high-quality data, USDA should require their grantees and university partners to share relevant data on soil carbon that can be added to the SCMN repository. It should also be responsible for setting best practices and standards on data submission and ensuring that there are systems in place for data consolidation, editing, and validation, as well as making sure there is the necessary data management infrastructure. SCMN should make this data easily accessible within and outside of the federal government while protecting data privacy.
- **Analysis and insights:** SCMN will be responsible for summarizing data into high-level insights needed by users of this database, providing details on how the data was collected, explaining what kinds of analysis and insights can be drawn from this data, and outlining options for others to share soil carbon data with SCMN.

GLOSSARY

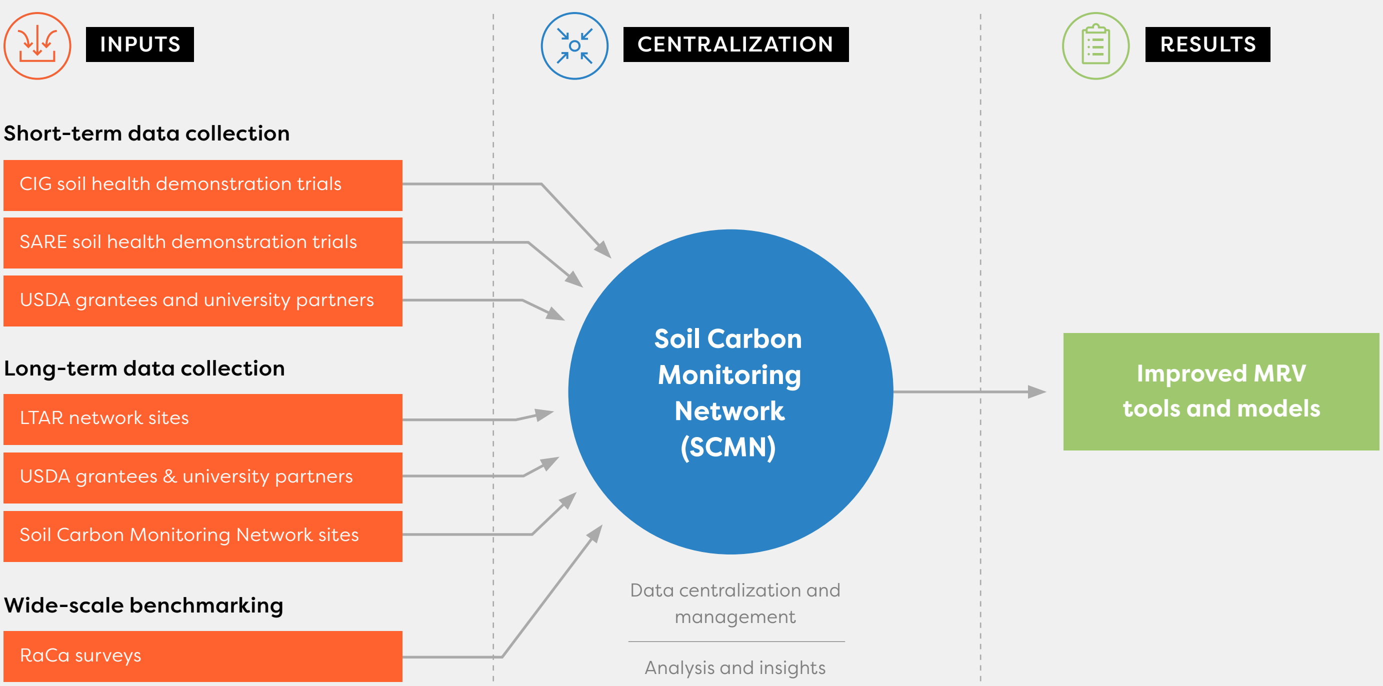
Conservation Innovation Grants (CIG)
A NRCS competitive grant program that supports the development of new tools, approaches, practices, and technologies to further natural resource conservation on private lands. Award recipients work to address water quality, air quality, soil health, and wildlife habitat challenges, all while improving agricultural operations.

- **Translation and communications:** The Climate Hubs should regularly share key findings with farmers and ranchers and develop decision support tools with the data collected by SCMN. As the Climate Hubs interact with producers, they can work to incorporate feedback into decision support tools, helping feed on-the-ground information to SCMN. **SCM recommends an increase for the Climate Hubs funding to $25 million over five years to support the translation of SCMN findings into actionable insights for farmers and ranchers.**

AUTHORIZING THE CLIMATE HUBS AND LTAR NETWORK

USDA's Climate Hubs and LTAR Network have provided and will continue to provide invaluable contributions to soil carbon data collection and translation efforts. However, neither of these initiatives are authorized in statute, jeopardizing their stability and hindering our collective understanding of soil carbon potential. We recommend that both the Climate Hubs and LTAR Network be authorized to provide continuity and long-term funding to these efforts.

The Soil Carbon Monitoring Network



Adoption of Soil Carbon Practices

Farmers and ranchers face uncertainty about which practices to implement and how to best implement them to maximize soil carbon storage. Farmers operate on slim margins, leaving very little room to take on additional risk. As weather extremes become more prevalent, those margins are becoming even slimmer. As farmers consider changing practices to build resilience to climate impacts and trap more carbon in their soil, they face specific roadblocks around the cost of changing practices, operation planning, and uncertainties in the impact to their agricultural productivity. Historically underserved producers, including BIPOC farmers, small and mid-size farms, and beginning farmers face even more uncertainties.

We need to create the necessary conditions to support adoption of soil carbon practices at scale, which starts with identifying and addressing these roadblocks. Investing and advancing hard sciences is not enough to scale soil carbon. We must support social science research to illuminate barriers to practice changes, empower farmers and ranchers to make informed decisions for their bottom lines, and pave the way for better policy design. This work should focus on answering key economic questions about the cost of implementation, financial outcomes, potential yield increases, and on-farm and on-ranch benefits from implementation of soil carbon practices. Ultimately, this research can promote sustained change in agricultural systems.[75]

75. Thompson, A., Coronel, E., &; Young, K. (2021). *Environmental Outcomes from On-Farm Agricultural Production in the United States, Fourth Edition.* Field to Market. http://fieldtomarket.org/media/2021/12/Field-to-Market_2021-National-Indicators-Report_FINAL.pdf

Recommendation 13: Investigate the costs and benefits of soil carbon practice adoption to better incentivize wide-scale adoption and maximize soil carbon storage.

Investment over 5 years:
$50 million

Programs:
ERS (+$50 million)

The costs and benefits of soil carbon practice adoption still aren't clear to farmers or ranchers, which hinders wide-scale adoption. Taking on new practices always means increased risk for a farmer, and that risk is even higher when the benefit will not be immediately reaped. This is the case with many soil carbon practices: They can require significant upfront investment, but it often takes a few years for producers to see benefits like higher yields, improved soil health, enhanced resilience, and reduced input costs. It's important for farmers to have transparency around the potential costs and benefits of changing practices to reduce risk and make informed decisions for their operations. This economic information will also be critical to ensure that policy incentives are designed most effectively to support farmers.

In this research, special emphasis should be given to farms and ranches operated by BIPOC and historically underserved farmers and ranchers to understand how the costs and benefits of practice adoption might differ from those operations managed by more established and white farmers. This is a critical piece of socioeconomic research that needs to be addressed to avoid the continued and inequitable distribution of climate funds and benefits to the best-resourced and most established farms.

This research should support cost-benefit analysis not only for farmers and ranchers as individuals but also for their communities. While individual farmers and ranchers will be the ones making management decisions on their lands, the collective effect of these decisions impacts their local communities.

To address these research gaps, SCM proposes $50 million in funding over five years for the Economic Research Service (ERS) to quantify the cost of practice adoption and the on-farm and community benefits of soil carbon practices. ERS should undertake this research in collaboration with LGUs and other universities. This research should be applied broadly, looking at varying operation types, scales, and geographies, as well as traditional and alternative agricultural production systems.

Recommendation 14: Identify barriers to adoption of soil carbon practices to create the necessary conditions to scale soil carbon storage.

Investment over 5 years:	Programs:
$6 million	NASS (+$3 million) NRCS (+$3 million)

Though there's been an uptick in interest in soil carbon and soil health practices in general, the cultural inertia of existing, predominantly conventional agricultural practices is still strong. Since management decisions can be slow and shaped by broader social and economic dynamics, it is critical to understand producers' motivations and the factors that influence their decision-making.[76] While the economic profitability of farm management and its influence on practice adoption has been extensively studied, research into other factors that influence the valuation of natural resources such as soil remains underexplored.[77]

Building upon the ongoing Conservation Practice Adaptation and Motivations Survey undertaken by NASS and NRCS, **SCM proposes $3 million each over five years to NRCS and NASS to identify barriers to the adoption and scale of carbon-storing agricultural practices.** This research should explicitly include identifying barriers unique to BIPOC, young, veteran, and beginning farmers to support equitable policy design.

76. Wilmer, H., Augustine, D. J., Derner, J. D., et al. (2018). Diverse Management Strategies Produce Similar Ecological Outcomes on Ranches in Western Great Plains: Social-Ecological Assessment. *Rangeland Ecology & Management, 71 (5)*, 626–636. https://doi.org/10.1016/j.rama.2017.08.001

77. Friedrichsen, C. N., Hagen-Zakarison, S., Wulfhorst, J. D., & Friesen, M. L. (2021). Soil health and well-being: Redefining soil health based upon a plurality of values. *Soil Security, 2*, 100004. https://doi.org/10.1016/j.soisec.2021.100004

GLOSSARY

Economic Research Service (ERS)
A USDA program that anticipates trends and emerging issues in agriculture, food, the environment, and rural communities and conducts high-quality, objective economic research to inform and enhance decision-making.

This research area should also include an analysis of federal conservation program effectiveness in incentivizing soil carbon storage, especially when combined with other state and federal incentives and programs, including commodity programs and crop insurance.

Demonstration Trials

Producers often don't have the on-the-ground — agronomic, labor, management, and economic — proof needed to make them feel more comfortable taking on the additional risk of changing practices. In addition, farmers and ranchers often look to and learn from neighbors, which often means that they are unlikely to shift practices without the demonstrated support of their community.[78] These cultural barriers are difficult to address but critical to consider to ensure that changes in agricultural practices endure. Facilitating peer-to-peer learning and mentorship can address both the operational and cultural barriers to adoption and help soil carbon practices take hold.[79] Demonstration projects can help promote practice adoption by reducing operational and economic risks, build confidence in regionally appropriate soil carbon practices, and empower farmers to make evidence-based decisions.

Recommendation 15: Establish an extensive network of real-world demonstration trials to test and de-risk soil carbon practices across the diversity of US agriculture.

Investment over 5 years:	Programs:
$380 million	CIG (+$320 million) SARE (+$60 million)

Getting buy-in from farmers requires de-risking the implementation of new or innovative agricultural practices, including demonstrating how different agricultural practices affect soil carbon storage in different contexts. An extensive network of soil carbon demonstration trials can play that role. Demonstration trials can also provide critical data to improve the accuracy of MRV tools and models that predict soil carbon storage based on practice change and ultimately inform carbon-based incentive payments.

78. Wilmer, H., Augustine, D.J., Derner, J.D., et al. (2018). Diverse Management Strategies Produce Similar Ecological Outcomes on Ranches in Western Great Plains: Social-Ecological Assessment. *Rangeland Ecology & Management 71 (5)*, 626-636.

79. Zelikova, J., Amador, G., Suarez, V., Kosar, U., & Burns, E. (2020). *Leading With Soil: Scaling Soil Carbon Storage in Agriculture.* Carbon180 Reports. https://static1.squarespace.com/static/5b9362d89d5abb8c51d474f8/t/5eaa30d12c3a767e64c3845b/1588211922979/LeadingWithSoil_Final+Text.pdf

GLOSSARY

Demonstration trials
Farms and ranches that research or demonstrate various agricultural techniques, particularly innovative or nascent practices. They are typically designed to show other farmers a new technology or production practice on operationally-relevant scales.

SCM proposes $320 million over five years to expand On-Farm Trials under the CIG to enable the development of an ambitious network of soil carbon demonstration trials. Sixty percent of this funding should be set aside for the Soil Health Demonstration (SHD) component of On-Farm Trials. In addition, half of all SHD funding should be dedicated to projects focused on soil carbon as the foremost purpose. This carve-out is critical to ensuring that trials are focused on the rigorous measurement of climate and carbon benefits in connection with practice implementation rather than more general soil health metrics. A recent review of SHD awards indicates strong emphasis on soil health but not nearly enough projects dedicated to soil carbon specifically.

These demonstration projects should aim to fill knowledge gaps around carbon storage for specific agricultural practices — especially grazing and soil amendments — and geographies. Additionally, the duration of these grants should be extended to a minimum of five years, and the current set-aside for historically underserved producers should be ramped up from 10% to 40% over the next five years, in alignment with the Justice40 Initiative.

SARE is also actively engaged in funding on-farm soil carbon demonstrations and research through its grant programs with direct involvement of small groups of farmers. SARE also has a track record of being more accessible and equitable to historically underserved farmers and ranchers. **To build upon these efforts, Congress should invest an additional $60 million over five years in SARE to expand on-farm soil carbon demonstrations.**

Through the soil carbon demonstration trials, funded through CIG SHD trials and SARE, grantees could organize and host field days and workshops that help connect farmers and ranchers who are interested in soil carbon and create a community of practice that is rooted in local agricultural realities. Local events and workshops provide opportunities for producers to engage with technical assistance providers and scientists, easing the transition to soil carbon practices. The recipients of soil carbon demonstration trial awards should be required to follow the soil sampling protocols and data collection guidelines developed by the LTAR Network, and the soil carbon data collected from these trials should be shared with the LTAR Network to enhance data collection efforts. Demonstration projects provide the "seeing is believing" piece that helps farmers gain comfort with new practices.[80]

80. Gosnell, H., Gill, N., & Voyer, M. (2019). Transformational adaptation on the farm: Processes of change and persistence in transitions to "climate-smart" regenerative agriculture. *Global Environmental Change 59*, 101965.

GLOSSARY

On-Farm Trials
Part of the CIG program that supports widespread adoption of innovative approaches, practices, and systems on working lands. Projects led by the NRCS and partners implement on-the-ground conservation activities and evaluate their impact in real agricultural contexts.

Soil Health Demonstration (SHD)
A new part of On-Farm Trials under the CIG program that was authorized in the 2018 Farm Bill. SHD focuses on the implementation of conservation practices and systems that improve soil health. Award recipients must follow consistent soil health assessment protocols to evaluate the impacts of practice and system implementation.

Section Five

Conclusion

Scaling soil carbon storage in agricultural systems will require multiple levers, including education, science, and carbon-based incentives.[81] The Soil Carbon Moonshot proposes a massive and critically timed investment in science, with many recommendations for advancing soil carbon research and education to ensure research findings are rapidly translated into action in the field.

81. Zelikova, J., Amador, G., Suarez, V., Kosar, U., & Burns, E. (2020). *Leading With Soil: Scaling Soil Carbon Storage in Agriculture*. Carbon180 Reports. https://static1.squarespace.com/static/5b9362d89d5abb8c51d-474f8/t/5eaa30d12c3a767e-64c3845b/1588211922979/LeadingWithSoil_Final+Text.pdf

Additional federal investments in research, education, and technical assistance are needed to enhance our understanding of which soil carbon practices work best across different geographies and scales, to improve monitoring, reporting, and verification of soil carbon storage, and to forge the path for new agricultural climate solutions.

Most importantly, we must engage farmers at every step and in every aspect of the research we conduct. Even the greatest advancements in soil science will not make a meaningful difference if producers are not at the forefront and engaged from the beginning. Shifting agricultural practices toward soil carbon has many economic and ecological benefits beyond carbon sequestration and is truly a win-win solution for farmers and climate. USDA can lead a coordinated interagency Soil Carbon Moonshot program to unlock agriculture's climate-mitigating potential, fill existing research gaps, and equip farmers with the knowledge and tools they need to store 5 billion metric tons of CO_2 in their soils.

Section Six

Appendix

APPENDIX 1

Funding by Research Area

The recommended funding levels below (in millions) are adapted from the National Academies of Sciences *Negative Emissions Technologies and Reliable Sequestration: A research agenda,* Energy Futures Initiatives *Clearing the Air* report, reviews of existing and analogous program funding, as well as conversations with experts.

RESEARCH AREA	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	TOTAL
Fundamental Research	$104M	$114M	$145M	$155M	$155M	$673M
MRV	$110M	$111M	$111M	$114M	$120M	$566M
Data Collection and Management	$120M	$120M	$120M	$120M	$120M	$600M
Adoption of Soil Carbon Pratices	$12M	$11M	$11M	$11M	$11M	$56M
Soil Carbon Demonstration Trials	$37M	$62M	$77M	$92M	$112M	$380M
Total	**$383M**	**$418M**	**$464M**	**$492M**	**$518M**	**$2,275M**

APPENDIX 2

Funding by Agency & Program

The recommended funding levels below (in millions) are adapted from the National Academies of Sciences *Negative Emissions Technologies and Reliable Sequestration: A research agenda,* Energy Futures Initiatives *Clearing the Air* report, reviews of existing and analogous program funding, as well as conversations with experts.

AGENCY	PROGRAM	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	TOTAL
USDA	LTAR Network	$70M	$70M	$70M	$70M	$70M	$350M
	Climate Hubs	$17M	$18M	$19M	$22M	$28M	$104M
	SARE	$21M	$21M	$21M	$21M	$21M	$105M
	SCMN (New)	$60M	$60M	$60M	$60M	$60M	$300M
	AFRI	$25M	$30M	$45M	$50M	$50M	$200M
	ARS	$69M	$74M	$89M	$94M	$94M	$420M
	LGU	$6M	$6M	$6M	$6M	$6M	$30M
	NAC	$4M	$4M	$4M	$4M	$4M	$20M
	CTA	$5M	$5M	$5M	$5M	$5M	$25M
	NRCS	$11M	$10.5M	$10.5M	$10.5M	$10.5M	$53M
	RaCA	$15M	$15M	$15M	$15M	$15M	$75M
	ERS	$10M	$10M	$10M	$10M	$10M	$50M
	NASS	$1M	$0.5M	$0.5M	$0.5M	$0.5M	$3M
	NIFA	$4M	$4M	$4M	$4M	$4M	$20M
	CIG On-Farm Trials	$25M	$50M	$65M	$80M	$100M	$320M
	FFAR	$20M	$20M	$20M	$20M	$20M	$100M
DOE	BER	$5M	$5M	$5M	$5M	$5M	$25M
NSF	GEO	$10M	$10M	$10M	$10M	$10M	$50M
NASA	ESD	$5M	$5M	$5M	$5M	$5M	$25M

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