SOLUTION SERIES

FOUNDATION FOR CLIMATE RESTORATION

SOIL CARBON PRACTICES

JUNE 2022

AUTHORS: DELANEY PUES, ERICA DODDS
COPYEDITOR: LAURE KOHNE

ACKNOWLEDGMENTS: This paper was made possible thanks in huge part to the careful review of Chris Tolles (Co-Founder and CEO, Use Yardstick), Roozbeh Ravansari (CEO, X-Centric Sciences Inc.), and Lewis Epstein (Special Advisor, Foundation for Climate Restoration).

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OVERVIEW

The Foundation for Climate Restoration is committed to restoring a climate that supports the long-term survival of humanity and our natural world. To this end, the Foundation's explicit goal is to reduce atmospheric carbon dioxide (CO_2) to preindustrial levels of 300 parts per million (ppm) by 2050.

This is the third installment of the Foundation's Solution Series, which examines a diverse portfolio of natural and technological approaches that can remove CO_2 from our atmosphere and return us to safe, preindustrial levels of carbon.

In this paper, we explore Soil Carbon Sequestration and Regenerative Agriculture, explored collectively as *soil carbon practices*, through a climate restoration lens. This paper focuses mainly on the United States context for these practices, but most of the following applications can be generalized to a broader international context. We also discuss the ability of these methods to achieve durable, scalable, financeable, and equitable outcomes and then provide ways for readers to advocate for their safe and thoughtful implementation.

INTRODUCTION

There's no strict rule book, but the holistic principles behind the dynamic system of regenerative agriculture are meant to restore soil and ecosystem health, address inequality, and leave our land, water, and climate in better shape for future generations.

—The Natural Resources Defense Council[1]

Excessive carbon dioxide in the atmosphere is a major contributor to climate change. While most of that atmospheric CO_2 has been released into the air by burning fossil fuels, some of it is released from soil through natural processes like respiration of soil microorganisms, as well as through human intervention.

The atmosphere contains only one third as much carbon as our global soils, which hold 25,000 gigatons (Gt) of CO_2.[2] In the United States, the 915 million acres of farmland soils constitute the second largest natural carbon sink after oceans.[3] However, this is offset by the significant environmental footprint of modern global agriculture, which contributes as much as 37% of global greenhouse gas (GHG) emissions when accounting for land use, transport, packaging, retail, and waste.[4] Crops and farms around the globe occupy one third of usable land and are a key driver of deforestation in biodiverse tropical regions.[5]

Modern agricultural practices, including the use of synthetic pesticides, artificial fertilizers, fossil fuels, and the production of excess waste,[6] have caused the loss of around 140–150 Gt of carbon from soils. This loss of carbon from soils through intensive production systems has contributed to ecosystem degradation and greenhouse gas emissions.[7] If carbon loss is not stopped, levels of CO_2 will increase in the atmosphere, soils will be unable to retain nutrients or water, and biodiversity will be dramatically reduced.[8]

In addition to causing environmental destruction, modern agriculture has historically placed an unequal burden on smallholder farmers and Black, Indigenous, Latinx, Asian American, and other vulnerable groups through the theft of indigenous land, the forced enslavement of Africans, and the exploitation of immigrant labor.[9] Scaling regenerative farming requires reckoning with the discriminatory history of agriculture and dismantling unjust labor practices and policies that have prevented many farmers of color from building wealth through land ownership.[10]

By sequestering CO_2 into soils, farmers have an opportunity to turn emissions that can otherwise cause extreme weather into carbon-rich soil that is more resilient to droughts, heatwaves, and floods. Soil carbon sequestration also reduces input costs, creates new revenue streams, and revives ancestral methods of growing food that have been suppressed by the industrial food system.[11] Soil carbon sequestration and regenerative agricultural practices thus have the capacity to repair both our soils and our communities and to shift us from an extractive to a reciprocal relationship with the planet. The potential ecological, social, and economic benefits of soil carbon sequestration make it an important component of climate restoration's portfolio of solutions.

HOW SOIL CARBON SEQUESTRATION AND REGENERATIVE AGRICULTURE WORK

Soil carbon sequestration is a natural process where CO_2 is captured by plants via photosynthesis and then stored as carbon in the plant's leaves, stems, and roots.[12] These carbon reserves are secreted from plant roots, known as exudates, where they feed the microbial community living in the soil. Worms ingest a combination of organic materials (plant residue) and inorganic materials (soil), which are then excreted as soil "casts" through their guts. These microaggregates bind together to form stronger soil aggregates that protect surface plant material from decomposition. This carbon continues to move deeper into the soil, increasing stability through a continuous cycle of microbial consumption and transformation of plant-derived carbon.

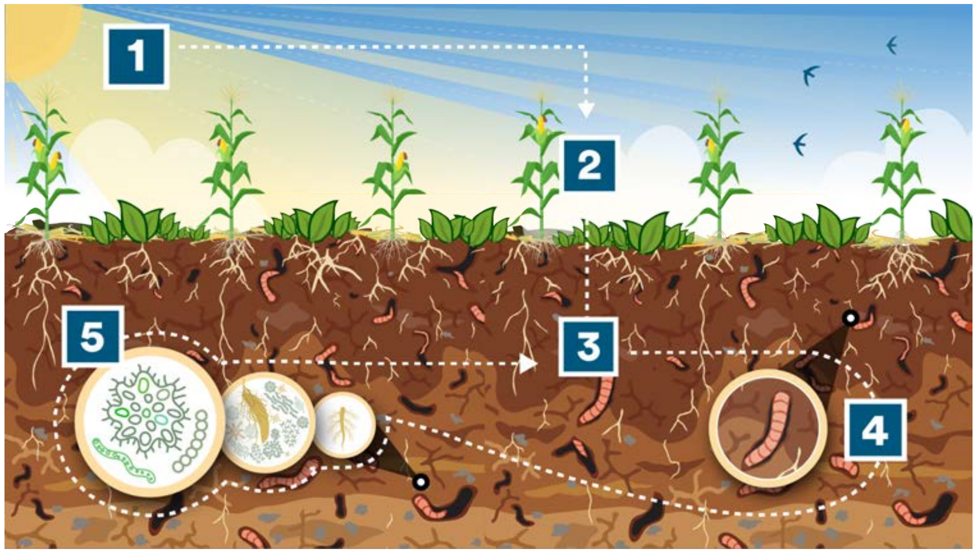

Image: https://www.indigoag.com/blog/how-does-soil-carbon-sequestration-work

However, massive industrial monocultures,[13] like those used to grow one third of US produce in the Central Valley of California, threaten the habitat needed to store carbon in the soil.[14] Plant diversity aboveground directly corresponds to microbial diversity aboveground and below ground, fostering soil health and supporting the processes that sequester carbon.[15] Modern industrial farmers often leave fields bare during the off-season, turn the soil by tilling it before planting, and grow monocultures. These practices contribute to the release of carbon from soils, reducing their resilience and productivity and requiring more inputs to maintain crop yields.

Some **regenerative agriculture** definitions focus on processes, some on outcomes, and others on both. In all cases, regenerative agriculture is intended to restore carbon—and therefore health—to soils. Regenerative agriculture *processes* include integrating crops and animals, using no-till agriculture, stopping or reducing the use of synthetic fertilizers and pesticides, and planting cover crops. (See Appendix I for a complete list of practices and descriptions.) Regenerative *outcomes* include enhancing carbon sequestration, improving soil health, increasing biodiversity, improving water resources, and increasing the social and economic wellbeing of communities.[16]

Regenerative agriculture can also be seen as an approach to land management that asks us to look at food production not as a linear supply chain, but as a network of entities that grow, enhance, exchange, distribute, and consume goods and services.[17] For regenerative agriculture to be fully realized, the entire web of agriculture must be repaired so that interconnected parts, including people, can function as a whole.[18,19]

As described above, modern agricultural practices disrupt the natural soil processes that store CO_2, effectively speeding up, instead of slowing down, global warming and climate change.[20] Regenerative practices, in contrast, support healthier plant species and biodiversity, which take more CO_2 out of the atmosphere and return it to the soil.

BENEFITS AND BARRIERS TO ADOPTION

ECONOMIC BENEFITS

Farmers and ranchers who adopt regenerative agriculture and soil carbon sequestration techniques could experience reduced costs and increased revenue from their farms.[21] Healthy, carbon-rich soil requires less irrigation and less fertilizer, meaning lower input costs for farmers. These groups can also receive financing from federal government programs or the emerging soil carbon markets, which can help them cover costs of changing or adopting regenerative practices.[22] However, in order to be most effective in achieving climate restoration goals, these markets need to account for the costs and emissions associated with agricultural production, in addition to improving monitoring, reporting, and verification (MRV), to ensure accurate accounting of the net negative carbon emissions overall.[23]

ECOLOGICAL BENEFITS

High-carbon soils have a more stable structure, which can support more consistent crop yields and improve water infiltration, retention, and quality.[24] When farmers don't plow up their dirt and disturb the soil, a method called no-till farming, the result is well-structured soil.[25] Well-structured soil is more resilient to extreme weather events like droughts and floods because it can both hold more water, which is helpful when there is little precipitation, and allow more water to drain through it without washing away the soil, which is important in the event of floods.

Additionally, planting cover crops—the practice of growing additional, often non-commercial plant species alongside cash crops or in between seasons to cover soil through the winter—can reduce the need for fertilizer, improve soil moisture and fertility, limit water pollution, and improve biodiversity.[26] Grazing ruminants, like cows, can help control weeds and clear cover crops while fertilizing and improving the soil.[27]

These practices, among others,[28] have been shown to improve microbial, pollinator, and plant diversity within farms and crops and to decrease the need for pesticides and insecticides in agriculture. Reducing chemical inputs and runoff benefits the entire watershed ecosystem and more specifically, prevents harmful algal blooms.

BARRIERS TO ADOPTION

As farmers and ranchers, especially historically underserved producers,[29] adopt these practices, they face a number of barriers including cost of change, operation planning, and uncertainty around agricultural productivity.[30] In order to scale soil carbon practices, these barriers need to be more fully explored via social science research. Studies should focus on the cost of implementation, financial outcomes, potential yield increases, and the transformative benefits of transitioning to an entirely regenerative system.[31]

[29] Historically underserved producers include BIPOC farmers, small and mid-size farmers, and beginning farmers.

SOIL CARBON SEQUESTRATION AND REGENERATIVE AGRICULTURE AS CLIMATE RESTORATION SOLUTIONS

[32] To be durable, a solution must keep the captured CO_2 out of circulation for at least a century.

[40] To be scalable, a solution must be able to be scaled within a decade to remove and store at least 10 Gt of CO_2 per year.

[47] To be financeable, the solution must have funding that is already available or easily mobilized.

DURABILITY[32]

The durability of soil carbon storage depends on the storage method. On the high end, soils can store carbon for hundreds of thousands of years, and on the low end, reversals and the release of captured carbon can be immediate if practices are not maintained.[33]

Soils store carbon through one of two forms: biotic and abiotic. Through the abiotic route, carbonate minerals form over the course of thousands of years as rock breaks down into soil.[34] These carbonates can store the trapped carbon for hundreds of thousands of years. There are currently initiatives that support the production of these carbonates and more permanent carbon sequestration,[35] but, given this significant time horizon, the biotic route is a more effective climate restoration method.

Through the biotic route, plants use photosynthesis to draw carbon from the air and form carbon compounds. Plants use some of this carbon to grow, and the rest is sent through the roots where it feeds soil organisms. Long-term conservation practices that factor in soil conditions, land use, and climate change[36] are critical in maintaining these carbon stocks[37] because disruption of natural soil processes may release the stored carbon back into the atmosphere. In light of this, additional research into the MRV of soil carbon levels over time is needed.[38] The federal government has been working to advance MRV approaches with the Natural Resources Conservation Services Rapid Carbon Assessment and the Department of Energy's Advanced Research Projects Agency-Energy's SMARTFARM. However, an overarching vision and greater coordination will be needed to scale MRV for soil carbon sequestration.[39]

SCALABILITY[40]

Global estimates of the maximum scale of soil carbon sequestration range from 1 to 22 Gt[41] annually by 2050.[42,43] Some studies suggest that sequestration potential is maxed out over time.[44] These estimates depend on how widespread practices are adopted, which practices are utilized, and if the risks from land use change and extreme weather, among others, are reduced. Currently, about 12 million hectares of land are being used for regenerative agriculture, but this number could increase to 320 million hectares by 2050.[45] However, scientists have also concluded that sequestering significant quantities of CO_2 in soils will take hundreds of years.[46] Consequently, regenerative agriculture and soil carbon sequestration fall short of climate restoration's scalability requirement and will need to be deployed alongside other solutions to remove 10 Gt of carbon dioxide per year.

FINANCEABILITY[47]

The cost of soil carbon sequestration depends on physical conditions (i.e., soils, climate, topography, etc.) and socio-economic conditions[48] and can range from \$45 to \$100/tCO_2.[49] Agricultural soils in the United States alone have the capacity to sequester up to 10% of domestic GHG emissions annually for as little as \$10 per ton.[50] Non-soil disrupting methods, like no-till farming, can save time and preserve yields while reducing costs, giving it an economic edge over conventional farming. Despite these benefits, this solution still faces operational, scientific, and technical challenges that will need to be addressed with additional research in order to be implemented at scale.[51]

The barriers to adoption are largely deployment and maintenance costs. They include the additional cost of seed for cover crops, the necessity of fencing for Adaptive Multi-Paddock grazing,[52] and the increased risk of failure due to ineligibility for federal crop insurance, among others.[53] In order to overcome these barriers to adoption, significant financial assistance to farmers is needed,[54] but the requisite federal programs are currently underfunded. At the state level, California and Montana offer incentive programs through grants to farmers and ranchers.[55] The private sector and startups also provide an opportunity for farmers to receive payment through voluntary carbon market credits to offset emissions and insetting, which has evolved as a way for companies to address their supply chain footprint.[56] Models suggest that regenerative agriculture, once established and scaled, could provide $2–3.5 trillion savings in lifetime operational costs.[57]

EQUITY

PROCEDURAL JUSTICE

Soil carbon sequestration has long been used by generations of BIPOC communities. For example, the concepts of compost and cover crops originated from the Asian continent, where these soil-building strategies have been used for thousands of years.[59] Additionally, Asian farmers provided the foundations of the organic movement by utilizing a zero-waste, closed-loop farming system that pulled and stored atmospheric carbon through living mulches.[60]

Before Europeans came to America, Indigenous people harvested food with the grazing of the buffalo as a guide,[61] and they have a keen understanding of the ecological importance of elk, deer, and bison in supporting regenerative outcomes.[62] Similarly, immigrants from Central and South America have a profound understanding of polycultures[63] which have demonstrated improved biodiversity and ecosystem functions to support soil carbon sequestration.[64]

In the interest of procedural justice, members of these communities should be actively engaged in the decision-making processes and policy design required to scale soil carbon sequestration and regenerative agriculture. Incentive programs and other means of funding should remove financial barriers to their active participation in these practices and support the economic health of their regenerative projects.

DISTRIBUTIVE JUSTICE

Modern agriculture practices, policies, and institutions predominantly benefit the largest and best-resourced farms and disproportionately burden small-scale farmers, BIPOC farmers, and individuals in the Global South who face the greatest food insecurity.[65] To ensure an equitable distribution of the benefits from soil carbon projects, these disenfranchised groups should be the first to benefit from improved crop yields and more sustainable food sources,[66] job creation and job training,[67] safer working conditions,[68] and land ownership,[69] among others.

[58] To be equitable, a solution must provide a fair distribution of benefits and burdens to all, regardless of income, race, and other characteristics.

[60] According to Healing Grounds: Climate, Justice, and the Deep Roots of Regenerative Farming, these practices are notably absent from the US system because, when the US was developing its own agricultural practices, Asian farmers were excluded from policymaking.

[76] Rematriation, an Indigenous tradition, refers to returning to the land of your ancestors while also returning to an ancestral way of life that carries reverence for Mother Nature.

Malcolm X says that land is the basis of all revolution, freedom, justice, and equality. So when we talk about reparations, we really have to center land.
—Leah Penniman[71]

REPARATIVE JUSTICE

Even though communities of color make up 40% of the US population, they account for more than 60% of the current agricultural laborer population and own only 2% of agricultural land.[72] This disparity, a result of American colonialism,[73] enslavement, and systemic racism,[74] has led to the erasure of regenerative agricultural practices from today's agriculture industry.[75]

To repair these harms and revive the use of regenerative practices, impacted communities should be given long-term, secure access to land through reclamation and rematriation[76] and through policies like The Justice for Black Farmers Act,[77] which provides up to 160 acres to both current and aspiring Black farmers.[78] Food justice initiatives, like fighting for land access, saving and sharing seeds, adopting agroecological farming techniques,[79] expanding food access, defending workers rights, ensuring equal opportunity, and championing food education,[80] can also address past harms by transforming systems of oppression and prioritizing healing through equitable access to resources and opportunities.[81]

The most sustainable food systems...are liberated ones.
—Liz Carlisle[82]

[79] Agroecology is the science of keeping plants, animals, humans, and the environment in balance. Agroecological farming aims to sustain food production and address food insecurity while also restoring ecosystems.

TRANSFORMATIVE JUSTICE

Agriculture as it is practiced today not only complicates carbon storage but also problematizes our food system: agricultural food production is associated with 23-42% of global GHG emissions, but we still struggle with widespread food insecurity and malnutrition.[83] To further transformative justice, we must find ways to meet our food needs with alternative, localized, and communal methods that optimize carbon storage while achieving racial justice goals.[84] This can be achieved with targeted education and research and a robust set of incentives that encourage food sovereignty[85] at the local level. In this way, implementing soil carbon practices in alignment with regenerative principles can improve environmental and public health[86] by building both food security and climate-change resilience.[87]

HOW TO SCALE SOIL CARBON SEQUESTRATION AND REGENERATIVE AGRICULTURE

RESEARCH AND DEVELOPMENT OPPORTUNITIES

In the United States, soil carbon research is woefully underfunded.[88] In order to transform agricultural practices for small-scale and large-scale producers alike, additional economic and social science research is needed. Grants to agricultural communities and agriculture-focused colleges and universities can be helpful in this respect. Additionally, an interagency research program, like a Soil Carbon Moonshot,[89] could offer a standardized, affordable, and accessible MRV system to maximize benefits to farmers and the climate.[90]

POLICY OPPORTUNITIES

In the past few years, we have gained a better understanding of the role agriculture plays in mitigating climate change,[91] and as a result, soil carbon and regenerative practices have taken center stage in climate action. In the United States, for example, policy references "climate-smart agriculture,"[92,93] and the 2021 American Rescue Plan includes $5 billion for farmers of color and $1 billion to help underrepresented farmers secure land, technical assistance, and legal support.[94]

[85] Food sovereignty is a food system in which the people who produce, distribute, and consume food also control the mechanisms and policies of food production and distribution. This stands in contrast to the present corporate food regime, in which corporations and market institutions control the global food system.

[89] 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.

[92] Climate-smart agriculture (CSA) is an approach that seeks to transform agri-food systems with green and climate-resilient practices. CSA has three main objectives: to sustainably increase agricultural productivity and incomes; to adapt and build resilience to climate change; and to reduce and/or remove greenhouse gas emissions whenever possible.

However, we still need more sophisticated agroecological policies that standardize land use, cropping system type, soil fertility management, disease and pest control, soil testing and evaluation, and biological status for regenerative projects.[95] To support soil carbon sequestration and regenerative agriculture, government policy should:

- Subsidize infrastructure to scale soil carbon storage
- Expand programs to non-owner operators[96]
- Adjust existing incentives to account for the speed of soil carbon accrual in agricultural soils
- Adapt the Federal Crop Insurance Program[97] to address climate impacts
- Simplify access to incentives[98]
- Improve financing mechanisms to fully fund soil health programs
- Create new, more durable market incentives to encourage adoption of regenerative practices.[99]

The Biden administration has recently proposed the "Growing Climate Solutions Act of 2021," which incentivizes farmers to enter a market in which they are paid for storing carbon in soil.[100] There are other bills in Congress that encourage soil carbon sequestration such as H.R. 4134, the Sustainable Agriculture Research Act;[101] H.R. 4133, the Study on Improving Lands Act;[102] H.R. 4051, S. 2284, Climate Action Rebate Act of 2019;[103] and H.R. 4051, S. 2452, Climate Stewardship Act of 2019.[104]

CONCLUSION

Soil carbon sequestration provides a range of benefits to soil health and food production while fostering carbon removal. Additionally, this method has the potential to support BIPOC and Indigenous communities that have implemented the methods needed to maximize soil carbon sequestration for generations. These substantial benefits to food security, safety, and historically marginalized communities come with relatively few costs and should be implemented without delay.

Policy that not only mandates explicit levels of soil carbon sequestration but also supports those transitioning to these practices is absolutely necessary. Additionally, the participation of BIPOC and Indigenous communities in regenerative agriculture can be facilitated through job creation, monetary compensation, and local initiatives that address environmental racism. Ultimately, soil carbon sequestration has significant potential to remove carbon from the atmosphere and provide food security, health, and safety co-benefits. Thoughtful policies and adequate funding can help us accelerate this important restorative practice.

[96] Landowners and non-owner operators require different incentive structures to implement practices.

[98] Creating a format that allows applications to be eligible for multiple programs and that requires less time and expertise can provide producers with the information they need to transition.

APPENDIX 1

REGENERATIVE AGRICULTURE PRACTICE	DEFINITION
NO-TILL FARMING	Plant crops without tilling the soil.
CONSERVATION TILLAGE[106]	Minimize soil disturbance.
PERENNIALIZATION[107]	Develop and grow perennial crops, which reduce the need to till.
COVER CROPPING[108]	Grow crops during the off-season to maintain plant cover and reduce erosion.
DOUBLE CROPPING	Grow an additional crop during the growing season.
CROP ROTATION[109]	Rotate the crop(s) between growing seasons.
MANAGED GRAZING[110]	Rotate grazing of livestock between pastures to stimulate plant regrowth and add manure to the soil.
COMPOST APPLICATION[111]	Add compost to a field or pasture.
MANURING[112]	Fertilize soil using animal manure.
BIOCHAR APPLICATION[113]	Use biochar, charcoal produced from plant matter, to enrich soil.
SILVOPASTURE[114]	Integrate trees and pasture into a single system for raising livestock.
FOREST FARMING OR AGROFORESTRY[115]	Incorporate the cultivation and conservation of trees into agriculture.
WINDBREAKS[116]	Plant trees and shrubs in linear formations to slow the wind, which creates a more beneficial condition for soils, crops, livestock, wildlife, and people.
ALLEY CROPPING[117]	Cultivate food, forage, or specialty crops between rows of trees.
RIPARIAN FOREST BUFFERS[118]	Plant trees, shrubs, and/or other perennial plants adjacent to a stream, lake, or wetland to provide conservation benefits.

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FOUNDATION FOR CLIMATE RESTORATION

952 S SPRINGER RD
LOS ALTOS, CA 94024

info@f4cr.org
foundationforclimaterestoration.org