2022

Regenerative Agriculture and Climate

FUNDERS FOR REGENERATIVE AGRICULTURE

CONTENTS

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OVERVIEW

Regenerative agriculture is a 'shovel ready' solution to climate change.

The escalating climate crisis requires rapid action on two critical fronts: (1) a steep reduction in greenhouse gas emissions; and (2) the removal of carbon dioxide from the air and its safe, long-term storage.[1] Regenerative agriculture can do both. Taking its cues from nature, regenerative agriculture creates the conditions *for* life above and below ground. Using photosynthesis and biology, it can restore and maintain the carbon cycle on land. Any amount of carbon dioxide (CO_2) absorbed by trees, plants, and soils and subsequently stored has been removed directly from the atmosphere and will help alleviate climate change.[2] It can also reduce methane, a potent greenhouse gas, from livestock production.[3] Regenerative agriculture's multiple co-benefits, including growing nutritious food, increasing soil health, and improving water, mineral, energy and nitrogen cycles, will play a significant role in adapting our food system to climate challenges.

Regenerative agriculture has ancient origins, drawing on centuries of Indigenous and traditional practices and knowledge worldwide. Diversifying farming systems, for example, is a common concept in regenerative agriculture, but the practice is not new. Indigenous people have been doing it for hundreds of years, a process called intercropping. In the Americas, the Iroquois and other Native peoples are known for planting the Three Sisters – corn, beans, and squash together. In this system, the corn stalks provide a natural support system for the beans to grow on, which in turn helps the corn by increasing the nitrogen in the soil. Simultaneously, the squash vines maintain soil moisture and prevent weeds from growing. Indigenous people also use agroforestry, which integrates trees and shrubs into crop and animal systems, as well as silvopasture techniques, which place grazing animals among trees to improve soil fertility and to foster healthy wildlife populations.

Photo by Skylar Zilka on Unsplash.com

However, since 1850 these practices, working in harmony with nature, have been largely replaced in developed countries by industrial agriculture, creating a legacy of pollution, degraded land, wildlife habitat destruction, and climate change. In industrial agriculture, the vast majority of farmers grow just a few crops each year in monocultures using synthetic chemicals, including herbicides and insecticides, that kill biology in the soil while also contributing to emissions from manufacturing and application. Furthermore, topsoil can become unstable with repeated plowing or as a result of unmanaged livestock grazing, resulting in a significant loss of stored carbon as plants wither and fields erode.[4] Globally, the conversion of intact land to monocrop agriculture is often accompanied by deforestation and land clearing. All of this has adverse effects on the essential services that nature provides, such as clean water, pollination of crops, pollution removal, and carbon sequestration.[5]

In contrast, regenerative agriculture works with nature, not against it. It utilizes biological and ecological principles found in nature, which has a long history of successfully growing things. Human societies all over the world have employed nature-based food production systems for millennia, characterized by plant and animal diversity, integration, and a respect for the regenerative power of the natural world, often referred to as agroecology. Regenerative agriculture is rooted in this ancient wisdom and in agroecology, and, in the past several decades, has aligned with the organic food movement, where decades of work has concluded that the "health of soil, plants, animals, and humans is one and indivisible."[6] To this, we can add 'the climate.'

Comparison of conventional and regenerative almond management in neighboring orchards in California.

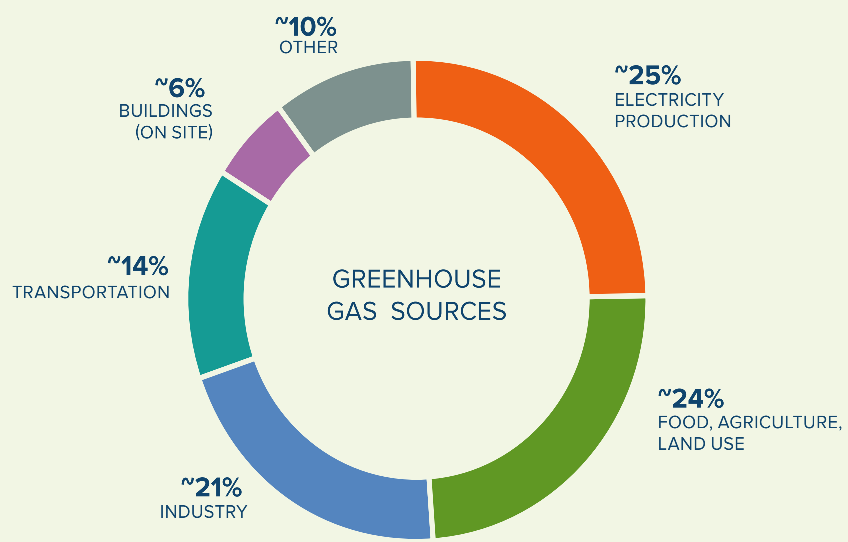
Photo by Christina Lind, Ecdysis Foundation

CLIMATE CHANGE AND AGRICULTURE

The word *climate* refers to the 30-year-average condition of a region's shorter-term weather: its seasonal temperatures, its precipitation and wind levels, its relative humidity.[7] This average allows us to recognize anomalies over time, such as a day that is hotter than any other; a winter that is drier than those that came before; storms that hit harder, more frequently, and in places outside their usual range.[8] This is *regional climate*. There is also *global climate*. Partly calculated by averaging regional weather differences, global climate is further determined by the amount of solar energy that reaches the Earth's surface after passing through clouds and gases in the atmosphere, including nitrogen, argon, and oxygen. Greenhouse gases (GHGs) – carbon dioxide, methane, nitrous oxide, and others – trap solar radiation. As the amount of GHGs increases as a result of human activity, the greater their effect on global climate.

According to the IPCC, the food, agriculture, and land use sector generates nearly one-quarter of all greenhouses gas emissions produced globally each year and is thus a major contributor to climate change. When emissions rise, we get increased climate instability. That instability causes more heat and aridity, more storms and flooding, more erratic weather such as the dangerously frigid temperatures that swept across Texas in February of 2021, as well as drought, desertification, and extreme wildfires such as those that burned well over four million acres in California in August of 2020. And these events lead to crop loss and failure, yield gaps, more pests and plant diseases, and a broadly unstable food system. Industrial agriculture's response to these challenges has been to double down with more chemical inputs, more tilling of more land to plant more monoculture crops and increasing the number of livestock in confined animal feeding operations (CAFOs). These practices rebound on themselves, generating more GHGs, that exacerbate climate and food system instability and lock us into a never-ending, always-worsening cycle of loss.[9,10,11,12]

Primary Sources of Greenhouse Gas Emissions



Greenhouse gas emissions come from a variety of sectors, including electricity, food, agriculture and land use (FALU), industry, transportation, buildings, and other. It is important to note that food, agriculture, and land use is nearly tied with electricity as a leading contributor to climate change.

Citation: Project Drawdown: *Farming Our Way Out of Climate Crisis*, Dec 2020.

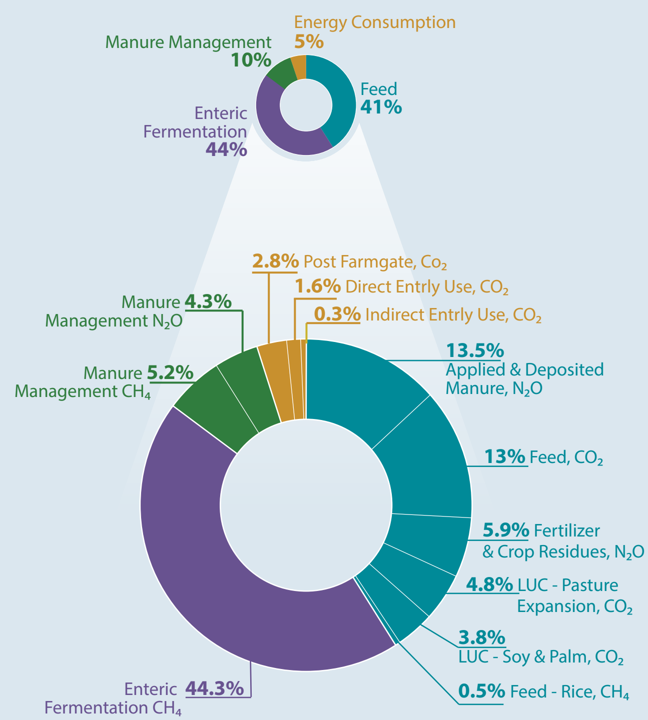
The U.S. Environmental Protection Agency estimates that land use and forestry account for approximately 11% of total GHG emissions in the U.S.[13] This sector's positive and negative greenhouse gas contributions offer insight into the practices here that are most impactful. Land is generally considered to be a net sink of carbon. However, when forests or grasslands are damaged, degraded, cleared, or converted to croplands and residential use, GHGs are emitted. Land conversion of forests is problematic because forests have a high potential to sequester GHGs.[14] Tropical deforestation in the Global South is responsible for three billion tons of global CO_2 emissions, an estimated 10% of the overall total.[15] Another study of deforestation in the Amazon found that it significantly increased the impacts of climate change, including higher land surface temperatures and reduced rainfall. [16]

INDUSTRIAL AGRICULTURE PRACTICES THAT DIRECTLY CONTRIBUTE TO CLIMATE CHANGE

Industrial Soil Management: Agriculture's primary contribution to GHG emissions is soil management. According to the EPA, 5.2% of total U.S. GHG emissions are associated with this practice.[17] Implicated in this figure are industrial agriculture practices such as the regular use of soil tilling, which disrupts soil, releasing unfixed carbon and nitrogen and leaving soil bare and exposed between crop seasons.

Extensive Fossil Fuel and Chemical Use: The over-use of fossil fuel-based inputs such as pesticides, synthetic fertilizers, and other chemicals is not just a destructive practice in its own right, it causes emissions at multiple points: fuel extraction, manufacturing, and application. Nearly 200 million metric tons of synthetic fertilizers are used in agriculture every year, up from 46 million metric tons in 1965.[18] The use of fossil fuels, chemicals, pesticides and drugs in industrial agriculture is the subject of another FORA brief.

Livestock: The UN Food & Agriculture Organization (FAO) has estimated all direct and indirect emissions from industrial livestock (cattle, buffalo, goats, sheep, pigs, and poultry) at 7.1 gigatons of CO_2 equivalent per year, or 14.5% of all anthropogenic emissions. Of this total, beef contributes 41% and dairy 20%. **Emissions from the industrial production, processing, and transport of feed account for about 45% of sector emissions.** The fertilization of feed crops and intensive-excessive deposition of urea and manure on pastures generate substantial amounts of nitrous oxide (N_2O), a potent greenhouse gas. Enteric fermentation (belches) by livestock is the second largest source of emissions, contributing about 40% to total emissions. Cattle emit most of the enteric methane (77%), followed by buffalo (13%) and small ruminants (10%). **Methane and N_2O emissions from manure storage and processing represent about 10% of total emissions.**



Food and Agriculture Organization of the United Nations, *Global Livestock Environmental Assessment Model 2.0*, July 2018.

Grasslands are efficient in capturing and storing carbon dioxide and other greenhouse gases. After forests, they have the second largest land-based potential to sequester atmospheric carbon in soil. However, poorly managed grazing and its attendant soil erosion is a growing concern. Grazing covers more than 25% of the global land surface and has a larger geographic extent than any other form of land use, representing a 600% increase over the past three hundred years.[19 20] Globally, as much as 49% of total grasslands have been degraded to some extent.[21] On former grasslands that have been converted to cropland, such as the Midwest, the application of nitrogen fertilizers to grow corn and soy for CAFOs produces greenhouse gases.

Regenerative agriculture and livestock production can restore degraded land, reduce greenhouse gas emissions, and store carbon while producing nutritious food.[22] It does so by increasing soil organic matter and biology in tandem with enhanced natural cycling of carbon, nitrogen, phosphorus, and water, all of which boost beneficial insects, soil microbes, and fungi. Recent studies suggest that high plant diversity may be the key to greatly increased carbon capture and storage rates on degraded and abandoned agricultural lands.[23] A key practice is progressive livestock management, especially on grasslands. Regenerative ranching mimics the "graze-and-go" behavior of native herbivores using domesticated livestock. Methods include planned grazing, mob grazing, adaptive high-stock-density grazing, and adaptive multi-paddock grazing. These methods can build topsoil quickly, especially if they are implemented in conjunction with other regenerative agricultural practices (see below).[24] These methods also counter a large portion of the greenhouse gas emissions generated by industrial agriculture. For example, manure from livestock doesn't need to be stored or "managed" in regenerative systems if it is deposited on grazing lands (via the animals themselves) or composted and applied to farms or fields. In both scenarios, incorporating manure into the soil will help increase soil organic matter, improving carbon sequestration. Synthetic fertilizers are not required to boost soil fertility or crop yield – it happens naturally!


Photo by Alicia Arcidiacono taken at Paicines Ranch, CA

CLIMATE CHANGE THREATENS ALL LIFE

Climate stability and integrity are directly correlated to the healthy functioning of our planet and people. The rapid acceleration of climate change is associated with increased frequency of weather extremes, including floods, fires, and resulting erosion. The cumulative effects of climate-related disasters at local levels affect the livelihoods of marginalized and low-income communities and the ability of these communities to prepare for and respond to future disasters.[25] Most at risk are people living in poor communities and developing nations that have limited ability to adapt to a changing climate. Wealthy countries are not exempt from climatic impacts. They are also suffering the effects of intensifying storms and heat events, even if potentially better financially equipped to cope with them.

By degrading our natural resource bases and disrupting our natural carbon, nitrogen, and nutrient cycles, climate change increases environmental stressors on human beings and social systems. Depending on their vulnerability, the socioeconomic stress increases as a result of water and food insecurity, health problems, migration, economic degradation, weakening institutions, diminishing economic growth and erosion of whole societies. The interplay between these factors may create a vicious cycle inducing social instability and insecurity.

Climatic change also has deleterious effects on human health, including a rise in foodborne infections and cardiopulmonary illnesses such as asthma.[26] In 2010, there were 600 million cases of foodborne illness, with 420,000 of those cases leading to death, according to WHO.[27] Climate change is certain to exacerbate these numbers, as increases in rainfall, temperature, and extreme events lead to a variety of scenarios in which pathogens can proliferate. For example, increased heat might lead to more animals being raised indoors, where there is increased risk of exposure to zoonotic diseases. Flooding of croplands can lead to the spread of pathogens into the food chain. Increased heat may also lead to higher demand for irrigated water as a drinking source, raising the potential for disease outbreaks if the water is contaminated.

Excess GHGs in the atmosphere are causing a rise in global temperatures, putting the global carbon, nitrogen, and nutrient cycles out of equilibrium. As a result, over the last 150 years, levels of soil carbon and nitrogen — as well as levels of many soil nutrients and minerals — have been in decline. This has led to a severe nutrient depletion in our soils then onward to our food and to us.[28] In addition, excess CO_2 in the atmosphere has been linked to a decline in the nutritional value of certain foods, making crops grow faster but with fewer macronutrients. Researchers estimate that this reduction in nutrient density and quality will leave millions of people in the most vulnerable regions of the world susceptible to significant zinc, iron, and protein deficiencies by 2050.[29] [30]

MISCONCEPTIONS

"Soil carbon sequestration is variable and difficult to compare so there's no way, at this time, to measure its overall relevance or importance." While it's true that all land does not sequester carbon equally – varying based on land type and regionality – this should not be used to dismiss regenerative agriculture's drawdown potential. Multiple controlled paired studies of farms in the same region illustrate the benefit of regenerative versus conventional systems to soil health and carbon sinking. However, no one "fix" is a silver bullet to climate change. Rather, regenerative agriculture is one tool among many necessary for mitigation and building a resilient, livable future.

"All livestock/cows are bad for the climate and a sustainable future requires that we not raise animals or eat meat." While enteric fermentation does contribute significant methane to our atmosphere, this needs to be considered in perspective. Studies show that well-managed livestock on pasture-based systems can increase fertility, biodiversity, soil health, nutrient cycling, and fertilization - all of which contribute to increased carbon sequestration. In this way, regenerative production can help offset methane emissions from livestock. Meat is also a culturally relevant food for many low-resource communities, providing much needed calories, protein, and micronutrients, like iron, that are more readily absorbed when they're sourced from beef over plants—as well as offering enjoyment and comfort.

"Livestock require too much land, taking away from cropland that is needed to increase food production for a growing population." Removing cattle doesn't mean that more land will be available for crop production. More than 60% of global land and 40% of land in the contiguous U.S. is too rocky, steep, and/or arid to support cultivated agriculture, but it is well suited and ecologically appropriate for grazing animals. This otherwise inarable land allows for cattle to convert cellulose from grasses and plants into high-quality protein for human consumption. A study on grassfed beef production demonstrated that, through regenerative practices, we can increase the productivity of grazing lands by 30% and, subsequently, grass finish every head of beef cattle in the U.S.[31] This is backed up by a recent study, that showed that moving the entire U.S. grain-fed beef production system to a grass-finished system is possible without displacing food production and, even under conservative soil carbon change estimates, results in reduced carbon footprints, while improving soil health, water quality, and biodiversity. Additionally, converting land to intensive crop production often leads to environmental degradation. Industrial livestock, including the industrial feedcrop monoculture this system requires, is currenlty taking up a lot of land that is managed poorly and, thus, degrading land. Instead, by switching from industrial to regenerative agricultural practices and principles, we can move toward managed grazing that regenerates land with biology and biodiversity. The complexity of the land use question, including a deeper understanding of how regenerative agriculture requires ongoing management and learning in order to steward land well, is the subject of another FORA brief.

Photo by Jenni Harris, White Oak Pastures, GA.

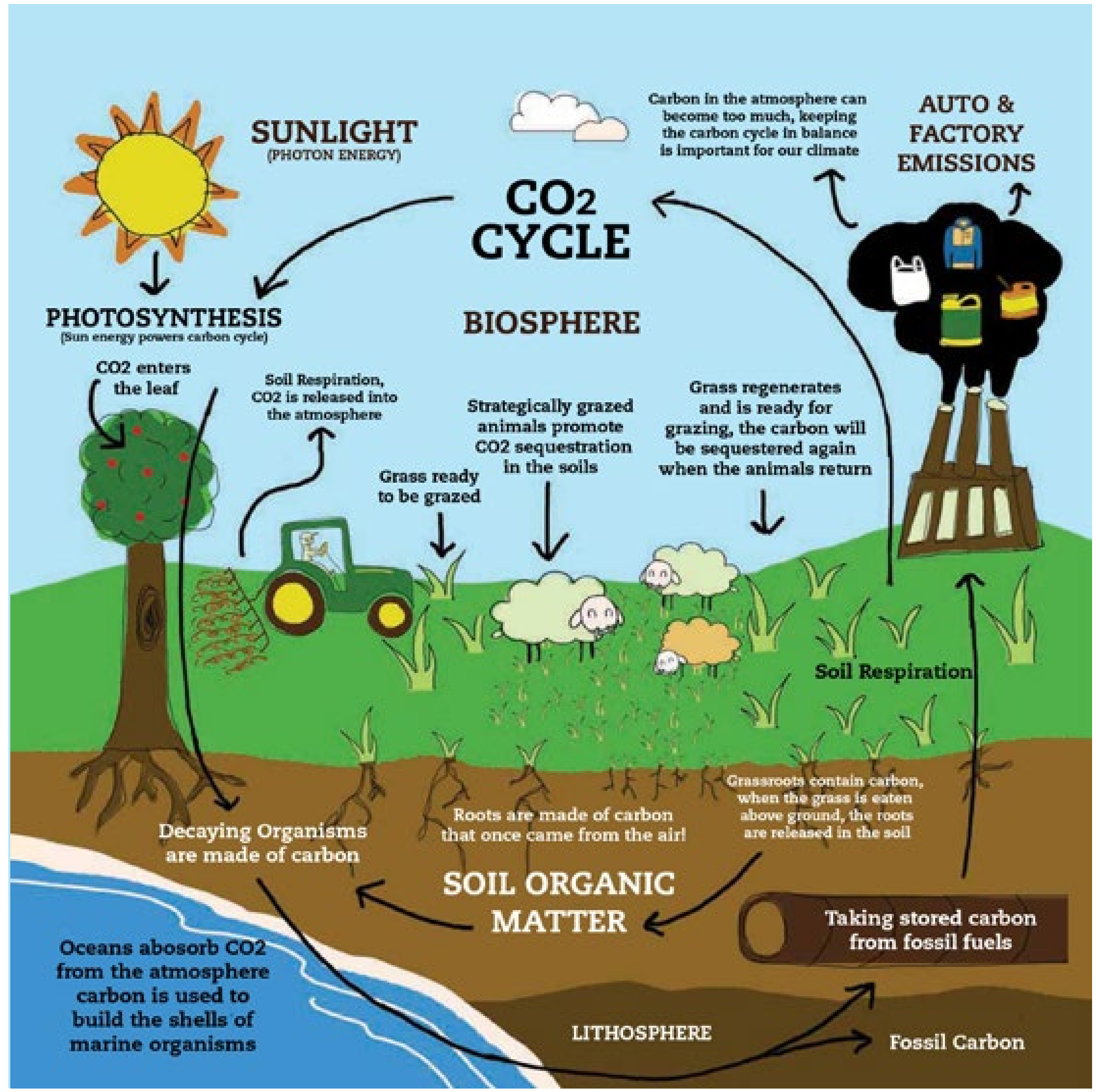
Industrial agricultural practices, especially monocropping and the use of chemicals, contribute to the reduction of biodiversity, which, in turn, accelerates climate change. For example, insects are an integral part of every terrestrial ecosystem, performing irreplaceable ecological services including natural checks on pests, assisting in the decomposition of leaves and wood, and the removal of dung. Their burrowing aerates the soil, allowing increased water and air infiltration. Insects pollinate three fourths of all flowering plants and are a food source for many species of birds and fish. However, insect populations are declining an alarming rate, sometimes called the "insect apocalypse." The reasons include habitat conversion, land degradation, deforestation, invasive species, widespread use of agricultural chemicals, loss of codependent species, and drought.[32] The decline of insects creates severe impacts ecologically and economically, including to biodiversity and food production.[33] These impacts, in turn, affect carbon and nitrogen cycles in the soil, hampering the sequestration of atmospheric carbon.

Deforestation of the Amazon Basin, for example, is transforming the region from a net carbon sink to a net carbon emitter.[34] Biodiversity is essential to a healthy, resilient planet. The interdependence of plant and animals (including us) is called the web of life. Traditionally, it has been protected by Indigenous people – who continue to do so in many parts of the world.[35] The breakdown of the web of life in other places and the loss of biodiversity that results spells serious trouble. In 2019, a landmark report from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) based on 15,000 scientific and governmental sources, concluded that one million species are threatened with extinction and that biodiversity is declining around the world at accelerating rates unprecedented in human history.[36] Climate change is making it worse. It disturbs natural habitats and species in many ways, including rising temperatures, altered rainfall patterns, and the effects of extreme weather events. These threats, in combination with activities such as deforestation, development and industrial agriculture, pose a significant threat to global biodiversity. We need thriving, biodiverse ecosystems (For more, see upcoming **Biodiversity** brief).


Photo by Alfribeiro on iStock Photos

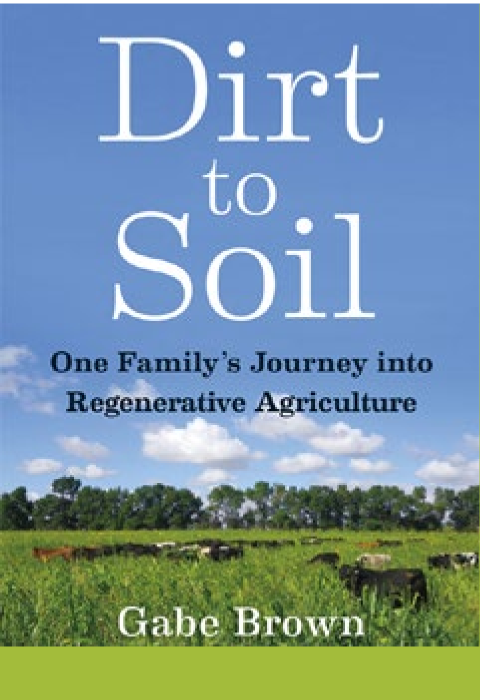
A SOLUTION: REGENERATIVE AGRICULTURE

Soil is one of earth's largest carbon sinks. A sink refers to the process by which a gas—in this case, carbon dioxide—is removed from the atmosphere and stored somewhere for a period of time. The largest carbon sink on the planet are the oceans. On land, the largest sink are young forests. Soils are close behind. The key to regenerative agriculture as a solution to climate change is the carbon cycle by which atmospheric CO_2 is transformed by photosynthesis into sugars that plants use to grow.[37] Some of the carbon makes its way into the soil via plant roots to be consumed by microbes in exchange for nutrients the plants need. Carbon and nitrogen are also cycled into soil from decomposing organic matter—compost, for instance—and transformed by microbes and insects into nutrients that can be taken up by terrestrial and aquatic organisms, comprising our entire food web. As organic matter builds up over time, new topsoil is formed. If undisturbed, carbon can remain stored in the soil for long periods of time.[38] A small increase in total soil carbon could significantly reduce the concentration of CO_2 in the atmosphere. Ultimately, the carbon that is locked up in biomass or soil organic matter is returned to the atmosphere through decomposition and microbial respiration.



Carbon Cycle Institute and Fibershed, *Carbon Farming Brochure*, 2014.

One of the most efficient contributions to climate mitigation comes from improving soil health, including restoring soil carbon storage on farmland and grasslands. Research shows that improved soil carbon represented 47% of the mitigation potential of agricultural lands when efforts were taken both to conserve current carbon stocks as well as restock those in depleted stores.[39] Cover cropping and "optimal intensity" grazing could provide 0.41 gigatons and 0.15 gigatons respectively of CO_2 emissions mitigation a year, contributing to food security and biodiversity conservation. This strategy is embraced by the United Nations and other nations in their climate action plans. One example is the *4p1000 Initiative*, a reference to increasing the amount of carbon in the soil by 0.4% annually, which could sequester a large amount of atmospheric CO_2 every year.[40] Restoring soil carbon has the potential to remove up to 1.54 gigatons of carbon a year.[41] (For more, see upcoming **Soil** brief)



Gabe Brown, an innovative farmer in North Dakota, transformed his family's conventionally-managed, eroded, depleted farm into a biologically rich, healthy, and productive operation by turning dirt into soil with regenerative agriculture. *Dirt* is chemistry: particles and minerals, including calcium, phosphorus, and potassium. In industrial agriculture, getting plants to grow in dirt means getting the chemistry right. *Soil* is biology: bacteria, fungi, protozoa, nematodes, earthworms, and other form of life. Gabe Brown got the biology right.[42] Here are Brown's Five Principles for creating topsoil:

1. **Limit Disturbance.** Limit mechanical, chemical, and physical disturbance of the soil. Tillage destroys soil structure. It is constantly tearing apart the "house" that nature builds to protect the living organisms in the soil that create natural soil fertility.
2. **Armor the Surface**. Keep the soil covered with plants. Bare soil is an anomaly; nature always works to cover the soil. Providing a natural "coat of armor" protects the soil from wind and water erosion while providing food and habitat for macro- and microorganisms.
3. **Increase Diversity**. Strive for diversity of both plant and animal species. Grasses, forbs, legumes, and shrubs all live and thrive in harmony with each other. Some have shallow roots, some deep, some fibrous, some tap. Each of them plays a role in maintaining soil health.
4. **Deepen Living Roots**. Maintain a living root in the soil as long as possible throughout the year. Living roots are feeding soil biology by providing its basic food source: carbon. This biology, in turn, fuels the nutrient cycle that feeds plants.
5. **Integrate animals**. Nature does not function without animals. Grazing stimulates plants to send more carbon into the soil, feeding the microbiology that drive ecosystem function and creating aboveground habitat for farm animals, pollinators, predator insects, and earthworms.

These goals cannot be achieved by one single regenerative practice; rather, they rely on embracing a diversity of practices that can be applied in regional contexts as they are feasible and suited to individual lands and growing systems. Regenerative agricultural practices that improve the carbon cycle include (but are not limited to):

- **Organic no-till** is a combination of chemical-free and no-tillage agriculture, often achieved with the use of cover crops.
- **Cover crops** keep the ground covered using a wide variety of plants in order to protect the soil and build organic matter.
- **Polycultures and food forests** traditionally employ two or more food types grown together, often utilizing trees in a multistory system.
- **Agroforestry** is the integration of trees and shrubs into crop and animal farming systems. It has been practiced around the world for centuries.
- **Silvopasture** is the integration of trees and grazing livestock on the same land, managed intensively for both forest products and forage.
- **Pasture cropping** is the intercropping of an annual crop within a perennial pasture and usually includes livestock grazing.
- **Perennial crops** are trees and vegetables that grow every year without seeding, including olives, asparagus, rhubarb, and globe artichokes.
- **Short-duration rotational grazing**, including holistic planned grazing, mob grazing, and adaptive multi-paddock grazing (AMP).
- **Integration of livestock into cropping** is the deliberate use of grazing animals as part of annual crop production.
- **Biochar** is a supercharged charcoal traditionally used as a method to boost the fertility of soils and capture water.
- **Multispecies grazing**, such as combining cattle and sheep into a single herd, can deliver multiple ecological and economic benefits.
- **Keyline and permaculture** use landforms and natural processes, such as water flow, as part of a design process for farming and regeneration.

REGENERATIVE AGRICULTURE NEEDS LIVESTOCK

The role of animals in regenerative agriculture is essential to building topsoil. Consider the symbiotic relationships between herds of bison and native plants that existed for millennia on the Great Plains of the United States. The vast herds traveled across the land in annual migrations, never lingering in one place for long. They took what they needed from the plant community and kept going, leaving behind natural fertilizer in the form of manure and urine. The disturbance caused by thousands of hooves to the soil surface facilitated seed-to-soil contact and created water-collecting divots. All of this made a significant contribution to soil formation and carbon stocks. The grass-grazer relationship is a natural one that can be found worldwide and is essential to restoring degraded lands.[43] Studies show that well-managed grazing boosts soil carbon stocks better and faster than crop systems that rely on synthetic inputs and no grazing at all.[44 45]

Regenerative ranchers and farmers mimic the behavior of wild herbivores by grouping their livestock into a herd and carefully controlling the timing, intensity, and frequency of the herd's impact on the land. Timing refers to how many days the herd spends in a specific paddock, often just a few days; intensity indicates the size of the herd for that period of time; frequency is the amount of time the paddock is rested before the herd returns. The idea was first proposed by biologist Allan Savory, who spent years observing the behavior of migrating wildlife in Africa. One name for this type of strategy is Adaptive Multi-Paddock (AMP) grazing. In a study that compared AMP plots to those grazed under conventional cattle management, a team of researchers concluded that AMP plots sequestered three tons (equal to one-sixth of an individual's annual greenhouse gas contribution) more carbon than plots that were continuously grazed.[46] Other research has shown that AMP grazing can be a carbon sink without expanding beef's footprint.[47] By some estimates, well-managed grazing systems could sequester up to 26 gigatons of carbon by 2050.[48]

Photo by Ната Рута on Unsplash

One of the significant co-benefits of increasing topsoil via regenerative agriculture is the production of healthy, nutrient-dense food, a useful prospect for a world trying to feed billions of people under the stress of climate change. Building topsoil quickly and producing healthy food is not a pipe dream – it is widely practiced around the world, particularly among Indigenous, traditional, and smallholder farm communities who have lived regeneratively for centuries. It is a practicality in industrialized societies, as regenerative agriculture, because it is based on the same biological components that create and maintain life on the planet: photosynthesis, carbon, plant roots, water, and microbes. By building topsoil naturally, we create the potential to put many hopeful, proactive solutions into operation, including the restoration of land health, intensified production of local food, expansion of watershed-based collaboratives, and the exploration of regenerative economic strategies.

Soil profile in virgin prairie in Kansas

Photo by Jim Richardson

ENDNOTES

1 James Hansen, Makiko Sato, Pushker Kharecha, et al, "Young People's Burden: Requirement of Negative CO_2 Emissions," *Earth System Dynamics*, 8 (3), 2017, https://doi.org/10.5194/esd-8-577-2017

2 W. Amelung, D. Bossio, W. de Vries, et al, "Towards a Global-scale Soil Climate Mitigation Strategy," *Nature Communications*, 11 (5427), 2020, https://doi.org/10.1038/s41467-020-18887-7

3 W. R. Teague, S. Apfelbaum, R. Lal, et al, "The Role of Ruminants in Reducing Agriculture's Carbon Footprint in North America," *Journal of Soil and Water Conservation* 71, (2), 2016 https://doi.org/10.2489/jswc.71.2.156

4 Evan A. Thaler, Isaac J. Larsen, and Qian Yu, "The Extent of Soil Loss Across the US Corn Belt." *Proceedings of the National Academy of Sciences* 118 (8), 2021, https://doi.org/10.1073/pnas.1922375118

5 UN Food & Agriculture Organization, "Ecosystem Services and Biodiversity," https://www.fao.org/ecosystem-services-biodiversity/en/

6 Albert Howard. An Agricultural Testament (1940); UK; Benediction Classics, 2010.

7 Climateurope. "What is climate? What is climate change?" *Climateurope*, n.d. Retrieved May 26, 2021 from https://www.climateurope.eu/what-is-climate-and-climate-change/

8 National Centers for Environmental Information. "What's the Difference Between Weather and Climate?" *National Oceanic and Atmospheric Administration*, March 23, 2018. Retrieved May 26, 2021 from https://www.ncei.noaa.gov/news/weather-vs-climate

9 Eric Roy, Courtney Hammond Wagner, and Meredith Niles, "Hot Spots of Opportunity for Improved Cropland Nitrogen Management Across the United States." *Environmental Research Letters*, 16 (3), February 16, 2021, https://iopscience.iop.org/article/10.1088/1748-9326/abd662

10 Emanuele Lugato, Pete Smith, Pasquale Borrelli, et al, "Soil Erosion is Unlikely to Drive a Future Carbon Sink in Europe." *Science Advances*, 4 (11), 2018, DOI: 10.1126/sciadv.aau3523

11 Gowri Koneswaran and Danielle Nierenberg, "Global Farm Animal Production and Global Warming: Impacting and Mitigating Climate Change," *Environmental Health Perspectives*, 116 (5), 2008, doi: 10.1289/ehp.11034

12 S. Park, P. Croteau, K.A. Boering, et al, "Trends and Seasonal Cycles in the Isotopic Composition of Nitrous Oxide Since 1940." *Nature Geoscience*, 5, 2012, https://doi.org/10.1038/ngeo1421

13 U.S. Environmental Protection Agency, "Sources of Greenhouse Gas Emissions." *United States Environmental Protection Agency*, Greenhouse Gas Emissions, n.d. Retrieved May 26, 2021, from https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions#land-use-and-forestry

14 Polly C. Buotte, Beverly E. Law, William J. Ripple, and Logan T. Berner, "Carbon Sequestration and Biodiversity Co-benefits of Preserving Forests in the Western USA," *Ecological Applications*, 30 (2), 2019, DOI:10.1002/eap.2039

15 Union of Concerned Scientists, "Measuring the Role of Deforestation in Global Warming." *Union of Concerned Scientists*, December 9, 2013, https://www.ucsusa.org/resources/measuring-role-deforestation-global-warming

16 Eduardo Maeda, Temesgen Abera, Mika Siljander, et al, "Large-scale Commodity Agriculture Exacerbates the Climatic Impacts of Amazonian Deforestation." *Proceeding of National Academy of Sciences*, 118 (7), 2021, https://doi.org/10.1073/pnas.2023787118

17 U.S. Environmental Protection Agency, "Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2019." *United States Environmental Protection Agency*, 2021. Retrieved May 26, 2021, from https://www.epa.gov/sites/production/files/2021-02/documents/us-ghg-inventory-2021-main-text.pdf

18 Global Consumption of Agricultural Fertilizer by Nutrient from 1965 to 2019, *Statista* web site, https://www.statista.com/statistics/438967/fertilizer-consumption-globally-by-nutrient/

19 Asner, Gregory P. et al. "Grazing systems, ecosystem responses, and global change." *Annual Review of Environment and Resources*, Vol. 26:261-299, November 21, 2004. Retrieved May 26, 2021, from https://www.annualreviews.org/doi/abs/10.1146/annurev.energy.29.062403.102142

20 Gregory Asner, Andrew Elmore, Lydia Olander, et al. "Grazing Systems, Ecosystem Responses, and Global Change." *Annual Review of Environment and Resources*, 29, 2004. Retrieved May 26, 2021, https://doi.org/10.1146/annurev.energy.29.062403.102142

21 Richard Bardgett, James Bullock, Sandra Lovell, et al, "Combatting Global Grassland Degradation," *Nature Reviews Earth & Environment*, 2, 2021, https://doi.org/10.1038/s43017-021-00207-2

22 Rattan Lal, "Regenerative Agriculture for Food and Climate," *Journal of Soil and Water Conservation*, 75 (5), 2020, DOI: https://doi.org/10.2489/jswc.2020.0620A

23 Yi Yang, David Tilman, George Furey, and Clarence Lehman, "Soil Carbon Sequestration Accelerated by Restoration of Grassland Diversity," *Nature Communications*, 10 (718), 2019, https://doi.org/10.1038/s41467-019-08636-w

24 Gabe Brown. *One Family's Journey Into Regenerative Agriculture*. White River Junction, VT: Chelsea Green Press, 2018.

25 IPCC, Climate Change and Land, Special Report, 2019 https://www.ipcc.ch/srccl/

26 "Climate Change and Asthma." *Harvard T.H. Chan School of Public Heath*, Center for Climate, Health, and the Global Environment, Harvard University, Retrieved May 26, 2021, from https://www.hsph.harvard.edu/c-change/subtopics/climate-change-and-asthma/

27 I.R. Lake and G. C. Barker, "Climate Change, Foodborne Pathogens and Illness in Higher-Income Countries." *Current Environmental Health Reports*, 5 (1), 2018, doi: 10.1007/s40572-018-0189-9

28 Elena Suglia, "Vanishing Nutrients," *Scientific American* web site, December 10, 2018, https://blogs.scientificamerican.com/observations/vanishing-nutrients/

29 Chunwu Zhu, Kazuhiko Kobayashi, Irakli Loladze, et al, "Carbon Dioxide (CO_2) Levels This Century Will Alter the Protein, Micronutrients, and Vitamin Content of Rice Grains with Potential Health Consequences for the Poorest Rice-dependent Countries," *Science Advances*, 4 (5), DOI: 10.1126/sciadv.aaq1012

30 Matthew Smith and Samuel Myers, "Impact of Anthropogenic CO_2 Emissions on Global Human Nutrition," *Nature Climate Change*, 8, 2018, https://doi.org/10.1038/s41558-018-0253-3

31 "Back to Grass: the Market Potential for U.S. Grassfed Beef," *Stone Barns Center for Food & Agriculture*, 2017, https://www.stonebarnscenter.org/wp-content/uploads/2017/10/Grassfed_Full_v2.pdf

32 Matthew L. Forister, Emma M. Pelton, and Scott H. Black, "Declines in Insect Abundance and Diversity: We Know Enough to Act Now," *Conservation Science and Practice*, June 22, 2019, https://doi.org/10.1111/csp2.80

33 John E. Losey and Mace Vaughan, "The Economic Value of Ecological Services Provided by Insects," *BioScience* 56 (4), 2006, https://doi.org/10.1641/0006-3568(2006)56[311:TEVOES]2.0.CO;2

34 Luciana V. Gatti, Luana S. Basso, John B. Miller, et al, "Amazonia as a Carbon Source Linked to Deforestation and Climate Change," *Nature*, 595, 2021, https://doi.org/10.1038/s41586-021-03629-6

35 Benji Jones. "Indigenous People Are the World's Biggest Conservationists, But They Rarely Get Credit For It," *Vox* web site, June 11, 2021, https://www.vox.com/22518592/indigenous-people-conserve-nature-icca

36 "*UN Report: Nature's Dangerous Decline Unprecedented," United Nations Sustainable Goals* web site, https://www.un.org/sustainabledevelopment/blog/2019/05/nature-decline-unprecedented-report/

37 Christine Jones, "Liquid Carbon Pathway," *Australian Farm Journal*, 338 (3), 2008, https://www.amazingcarbon.com/PDF/JONES-LiquidCarbonPathway(July08).pdf

38 Douglas Kell, "Large-scale Sequestration of Atmospheric Carbon Via Plant Roots in Natural and Agricultural Ecosystems: Why and How," *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* 367 (1595), 2012, doi: 10.1098/rstb.2011.0244

39 D. A. Bossio, S.C. Cook-Patton, P.W. Ellis, et al, "The Role of Soil Carbon in Natural Climate Solutions," *Nature Sustainability*, 3, 2020, https://doi.org/10.1038/s41893-020-0491-z

40 Cornelia Rumpel, Farshad Amiraslani, Lydie-Stella Koutike, et al, "Put More Carbon in Soils to Meet Paris Climate Pledges," *Nature*, December 3, 2018, https://www.nature.com/articles/d41586-018-07587-4

41 W. Amelung, D. Bossio, W. de Vries, et al. "Towards a Global-scale Soil Climate Mitigation Strategy," *Nature Communications*, 11, 2020, https://doi.org/10.1038/s41467-020-18887-7

42 Gabe Brown. Ibid.

43 Douglas A. Frank, Samuel J. MacNaughton, and Benjamin F. Tracy, "The Ecology of the Earth's Grazing Ecosystems," *BioScience* 48 (7), 1998, https://doi.org/10.2307/1313313

44 Wenquing Chen, Ding Huang, Nan Liu, et al, "Improved Grazing Management May Increase Soil Carbon Sequestration in Temperate Steppe," *Scientific Reports*, 5, 2015, https://doi.org/10.1038/srep10892

45 W. R Teague, S.L. Dowhower, S.A. Barker, et al, "Grazing Management Impacts on Vegetation, Soil Biota and Soil Chemical, Physical and Hydrological Properties in Tall Grass Prairie," *Agriculture, Ecosystems, and Environment*, 141 (3-4), 2011, https://doi.org/10.1016/j.agee.2011.03.009

46 Richard Teague, et al, "The Role of Ruminants in Reducing Agriculture's Carbon Footprint in North America," *Journal of Soil and Water Conservation* 71, no. 2 (2016), 156, http://www.jswconline.org/content/71/2/156.abstract.

47 Paige Stanley, Jason Rowntree, David Beede, et al, "Impacts of Soil Carbon Sequestration on Life Cycle Greenhouse Gas Emissions in Midwestern USA Beef Finishing Systems," *Agricultural Systems*, 162, https://doi.org/10.1016/j.agsy.2018.02.003

48 "Managed Grazing." *Project Drawdown* web site, https://www.drawdown.org/solutions/managed-grazing

CONTACT:

FORA Staff
staff@forainitiative.org

forainitiative.org