Global Development Policy Center
Economics in Context Initiative

Agriculture and Climate: Economics and Policy Issues

By Anne-Marie Codur, Jonathan M. Harris and Kayleigh Fay

An ECI Teaching Module on Social and Environmental Issues in Economics

Global Development Policy Center
Boston University
53 Bay State Road
Boston, MA 02155
bu.edu/gdp

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Economics in Context Initiative
Global Development Policy Center
Boston University
53 Bay State Road Boston, MA 02215
http://www.bu.edu/eci/

Email: eci@bu.edu

NOTE – terms denoted in bold face are defined in the KEY TERMS AND CONCEPTS section at the end of the module.

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1. INTRODUCTION: THE ROLE OF AGRICULTURE IN GLOBAL CLIMATE CHANGE

The urgency of addressing climate change has been widely acknowledged by scientists and policymakers. According to the Intergovernmental Panel on Climate Change (IPCC), "Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in carbon dioxide (CO_2) and other greenhouse gas emissions occur in the coming decades"[1].

Exceeding 1.5°C would significantly increase projected and potentially catastrophic outcomes including: "increases in the frequency and intensity of hot extremes, marine heatwaves, and heavy precipitation, agricultural and ecological droughts in some regions, and proportion of intense tropical cyclones, as well as reductions in Arctic sea ice, snow cover and permafrost. . . Changes in several climatic impact-drivers would be more widespread at 2°C compared to 1.5°C global warming and even more widespread and/or pronounced for higher warming levels."

Addressing climate change means not only drastically decreasing human-created global emissions, but also promoting "natural climate solutions" that increase the potential of ecosystems to store carbon. This module discusses the role of agricultural ecosystems both in emitting greenhouse gases and in storing carbon, while a companion module[2] presents findings on forests and wetlands. Together, they examine strategies that could reshape these sectors to combat climate change, and what challenges such a transition might pose.

Terrestrial and ocean ecosystems have maintained a rough carbon balance for millennia, but this has been altered by emissions from human activities. Figure 1 depicts the global carbon budget, expressed in gigatons (or billions of tons, Gt) of carbon (see Box 1 on measurement of emissions in carbon or in CO_2).

Each year, human industrial and fossil fuel emissions, as well as land use changes such as deforestation, release more than 10 Gt of carbon into the atmosphere. Some of these emissions are absorbed by planetary "sinks".

"Land sink" refers to terrestrial ecosystems, which absorb about 3.1Gt of carbon. Microbial respiration, decomposition and plant respiration release approximately 120 Gt of carbon into the atmosphere each year while plants remove approximately 123 Gt from the atmosphere through photosynthesis, which is stored in plant biomass and the soil – so that there is a net terrestrial uptake of about 3Gt of carbon that is stored each year in ecosystems.

Oceans absorb an additional 2.6 Gt of carbon. The role of oceans as a carbon sink has buffered climate change, but has also caused their acidification, which poses grave threats to marine ecosystems.

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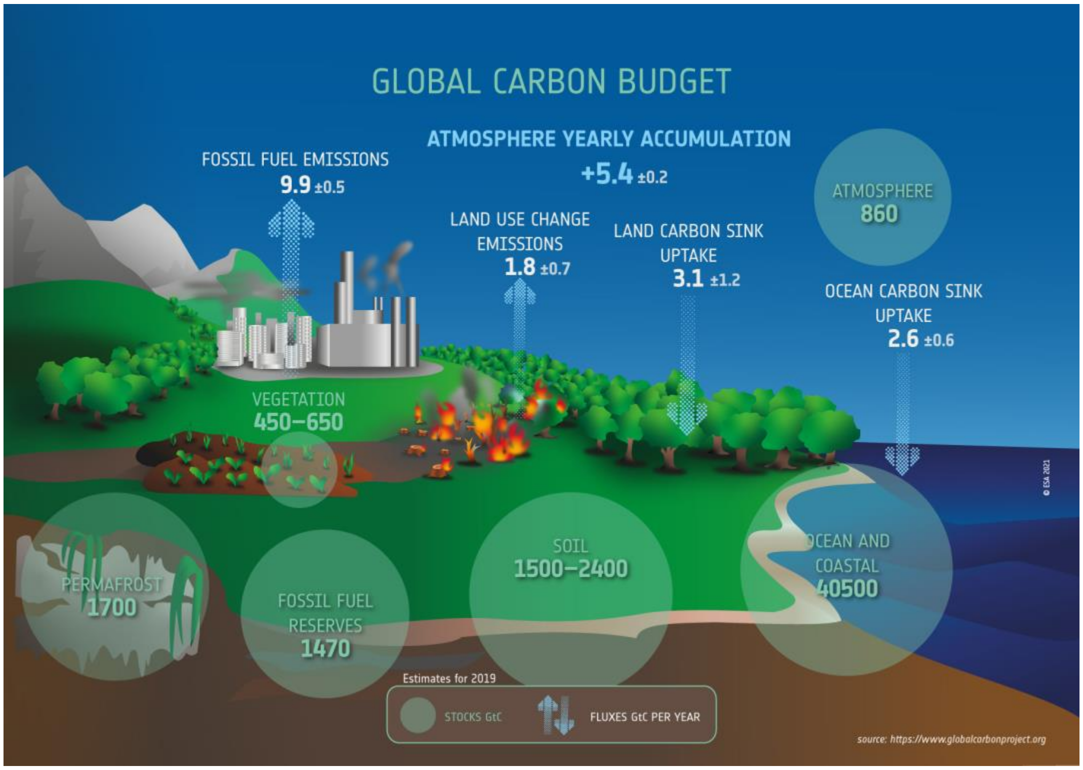
[1] IPCC, 2021.

[2] Codur, Harris, and Birjandi Feriz, 2022.

Greenhouse gases emissions have far exceeded the earth's capacity to store carbon in forests, oceans and living and dead biomass. Since total emissions exceed the sink capacity, there is an annual net increase in atmospheric carbon of about 5.4 Gt per year.

Figure 1. *Global Carbon Budget (Gigatons of carbon per year), 2019*



Source: European Spatial Agency, The Global Carbon Budget, 2019.
https://www.esa.int/ESA_Multimedia/Images/2021/11/Global_carbon_budget

The solution to the problem lies in reducing human-created carbon emissions while at the same time significantly increasing carbon absorption capacity. Most climate policy discussions focus on reducing emissions. A growing body of scientific research, however, shows the potential of terrestrial ecosystems including forests, mangroves, wetlands, croplands, grasslands, as well as currently degraded or barren lands, to become more potent carbon sinks that draw down excess CO_2 from the atmosphere and help to reverse climate change.

There is increasing evidence that ambitious goals to mitigate climate change, such as those set forth by the Intergovernmental Panel on Climate Change[3] cannot be met without a substantial contribution from increased absorption of CO_2 by forests, wetlands, and soils.

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[3] IPCC, *Global Warming of 1.5°C*, https://ipcc.ch/report/sr15/

BOX 1: MEASURING GREENHOUSE GAS EMISSIONS

Greenhouse gases (GHGs) include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), as well as industrially produced gases such as hydrofluorocarbons, among others. Carbon dioxide is the most prevalent GHG. In order to aggregate all GHG emissions, scientists often convert each GHG to its equivalent in emissions of CO_2. The heat trapping potentials of CH_4 and N_2O (i.e. their contribution to global warming) are much higher than that of CO_2, although their atmospheric lifetimes are shorter. One ton of methane has a global warming potential of 25 tons of CO_2, and so is equivalent to 25 tons of CO_2 in terms of its climate change impact. One ton of nitrous oxide is equivalent to 298 tons of CO_2.

Once all GHG emissions are converted into tons of CO_2 equivalent, the total emissions can be presented in two ways: either in tons of CO_2, or in tons of carbon. A molecule of CO_2 includes one atom of carbon plus two atoms of oxygen. The atomic weight of carbon is 12, and the atomic weight of oxygen is 16, therefore the weight of the CO_2 molecule is 44. The ratio of the weight of the CO_2 molecule to the weight of the carbon atom is 44/12 = 3.66, hence the measure of a quantity of CO_2 must be divided by 3.66 to obtain the measure of the same quantity in carbon. For instance, in 2021, total global emissions of greenhouse gases reached 36.4 gigatons of CO_2, which is the same as to say 36.4/3.66 = 9.93 gigatons of Carbon. Figure 1 presents the global carbon budget in gigatons of carbon.

2. UNDERSTANDING SOILS AND THEIR CARBON SINK CAPACITY

Below our feet, a repository of approximately 2,000 Gt C is stored in the world's soils. Soil plays a crucial role in the global **carbon cycle**. There is more carbon stored in soil than in plants and the atmosphere combined. But there is also significant potential for further carbon storage in soil, which could have a major effect in reducing net emissions of carbon to the atmosphere.

Soil is the basis of all terrestrial life. It is a matrix of inorganic mineral soil, air, water, and organic material. Minerals such as calcite, dolomite, and gypsum contain carbon and account for approximately 40% of carbon stored in soils. The remaining carbon is stored in organic matter, which includes roots, soil microbes, and decaying material from plants and animals.

Figure 2 illustrates the complex nature of soil ecosystems. Most carbon storage occurs in the A horizon, also called the topsoil. Topsoil is a mixture of sand, silt, clay and decayed or decaying organic matter, called humus. Humus is vital for plant growth and moisture retention. It is what gives carbon rich soils their dark color.[4]

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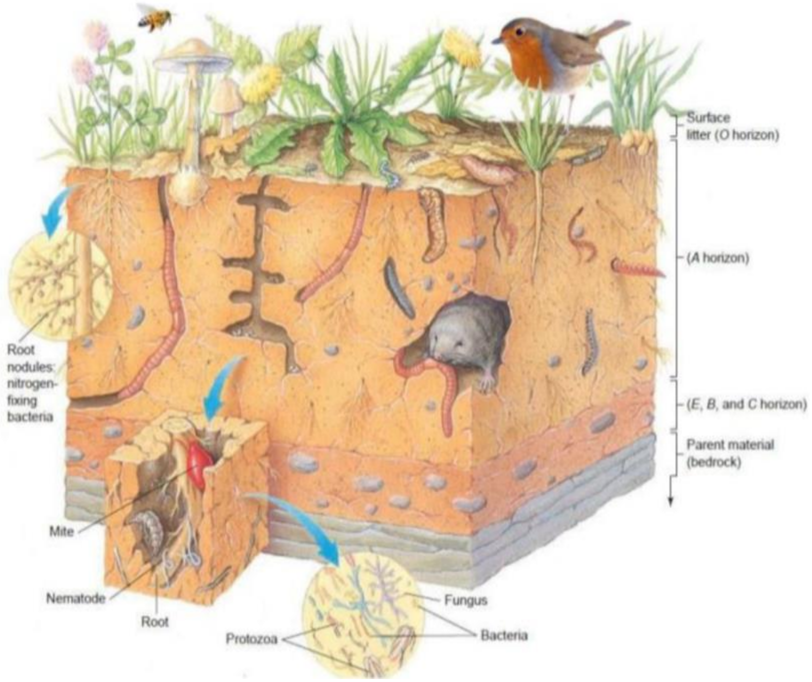
[4] Ontl and Schulte, 2012.

Figure 2. *Soil as a Thriving Ecosystem*



Source: [*http://geography.name/wp-content/uploads/2016/08/343477.jpg*](http://geography.name/wp-content/uploads/2016/08/343477.jpg)

Various processes within the soil are responsible for the storage, movement, and release of carbon, especially photosynthesis, respiration, and decomposition. Most of the organic soil carbon is stored in root systems and specialized fungi (mycorrhizae) that interact with the roots. The symbiotic relationship between roots and mycorrhizae has been referred to as the "wood wide web". Carbon is incorporated into plant biomass as plants grow via photosynthesis. Plants transfer some carbon from roots to mycorrhizae. Carbon is also stored in humus and plant matter that has not yet decayed.[5]

Carbon release occurs through microbial respiration as microscopic organisms in the soil decompose organic matter. Some soil carbon is retained through the formation of humus, which takes a long time to decompose. Plant matter in the surface liter layer of soil quickly decomposes and releases stored carbon. Other soil carbon loss occurs naturally through leaching of dissolved carbon into groundwater and erosion. Some levels of carbon loss are normal; however, these processes have been exacerbated through human activity, especially agricultural practices. The majority of soil carbon is stored in the topsoil. Seemingly small disturbances, like converting grassland to a field of row crops, can therefore have large impacts on the storage capacity and health of soil.[6]

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[5] Corning, Sadeghpour, Ketterings and Czymmek, 2016.

[6] Ibid.

2.1 Soil Ecosystems and their Carbon Storage Capacity

The function of soil and its carbon storage capacity vary widely across ecosystems. Temperature and precipitation are important determinants of carbon storage capacity because they affect plant growth and decomposition rates. Texture (proportion of sand, clay, etc.) and erosion levels also affect soil carbon storage capacity. Examples of soil ecosystems are described below.

Cropland

The NRCS (Natural Resource Conservation Service) defines croplands as "areas used for the production of adapted crops for harvest." Croplands may be cultivated or non-cultivated. Cultivated croplands may be used to grow row crops or close-grown crops.[7] Non-cultivated cropland includes permanent hay land and horticultural cropland, such as orchards, where the soil is not routinely disturbed. Cultivated cropland soils are often net contributors to carbon emissions due to erosion and the use of chemicals that decrease soil **biodiversity**.[8]

Range and Pasture

Range and pasture lands encompass a diverse collection of ecosystems. They are characterized by herbaceous plants (including most grasses) and shrubs and provide forage for both domestic livestock and wildlife. Range and pasture provide essential ecosystem services, including clean water and wildlife habitat. Their grassland vegetation and soils are an enormous reservoir for organic carbon.[9]

Forest Soils

Soils are the foundation of forest ecosystems. Forest soils regulate nutrient uptake, decomposition, and water availability, and provide trees with anchorage, water and nutrients. In turn, forest vegetation secures soil, preventing erosion, and contributes to soil creation as plant materials decompose. Deforestation and forest degradation pose imminent threats to global carbon storage in forest biomass and soils.[10]

Wetlands

Wetlands are areas where water covers the soil or is present either at or near the surface of the soil all year or for varying periods of time during the year.[11] Anaerobic conditions in wetland soils slow decomposition, leading to the accumulation of organic matter. As a result, wetlands accumulate large carbon stores, making them an important sink for atmospheric carbon dioxide.[12] The ecological value of wetlands is further discussed in Box 2.

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[7] Row crops are crops that can be planted in rows wide enough to allow them to be tilled or otherwise cultivated by agricultural machinery. Close-grown crops are crops that are generally "drill-seeded" (inserted into the soil) or "broadcast" (randomly scattered), such as wheat, oats, rice, barley, and flax.

[8] USDA, April 1, 2019.

[9] USDA, 2010.

[10] Achat, Fortin, Landmann, Ringeval and Augusto, 2015.

[11] EPA, 2018c.

[12] Nahlik and Fennessy, 2016.

BOX 2: THE IMPORTANCE OF WETLANDS IN CLIMATE CHANGE MITIGATION

Wetlands are some of the most diverse and productive ecosystems on Earth. Wetlands are extremely efficient at storing atmospheric carbon in plant biomass and in soils. Though they cover only 5-8% of the Earth's land surface, wetland soils hold 20-30% of organic soil carbon. They also protect against the effects of climate change. Wetlands store water from intense storms to prevent flooding, protect coasts from hurricanes, and can even increase in height as sea level rises to protect inland areas.[13] Despite these benefits, however, large scale efforts to "drain the swamp" have caused the loss of an estimated 54-57% of global wetlands.

Drainage for agricultural or development purposes and damage due to pollution are the leading causes of wetland loss (EPA, 2001). Draining wetlands causes rapid oxidation and release of organic soil carbon. Even if drained wetlands are restored, it can take decades to millennia for them to become net carbon sinks again. Wetlands are also at risk due to increasing temperatures, which increase the rate of decomposition and greenhouse gas emissions from wetlands. Large-scale drainage continues despite these risks, particularly in Asia.

Though global climate agreements have largely neglected wetland protection as a possible climate solution, some progress has been made at lower levels. For example, Canada has restricted development that would disturb wetland areas. US farmers are ineligible for crop insurance subsidies if they do not comply with wetland protection regulations. The Netherlands have embarked on an ambitious project to restore previously drained wetlands and improve carbon storage capacities. Continued efforts to preserve and restore wetland areas are an important climate change mitigation strategy. The long-term benefits of healthy wetland ecosystems far outweigh the short-term economic benefits of development.

Sources: **EPA, 2001; Moomaw, Davies and Finlayson, 2018.**

2.2 Human Driven Soil Degradation

Human activities have drastically increased global rates of soil degradation. Soil degradation is the decline in soil condition caused by its improper use or poor management, usually for agricultural, industrial or urban purposes. Degradation may involve the loss of organic matter, decrease in fertility, water and wind erosion, a change in acidity, alkalinity, or salinity, and the effects of toxic chemicals and pollution. It is estimated that 25% of the Earth's land area is either highly degraded or undergoing high rates of degradation (UNCCD, 2015), and that more than half of fertile land has been degraded at some level.[14]

During the last 40 years, nearly one-third of the world's arable land has been lost to erosion and continues to be lost at a rate of more than 10 million hectares per year. An increasing percentage of land mass globally is considered "dry" due to soil degradation. In total, land use change and

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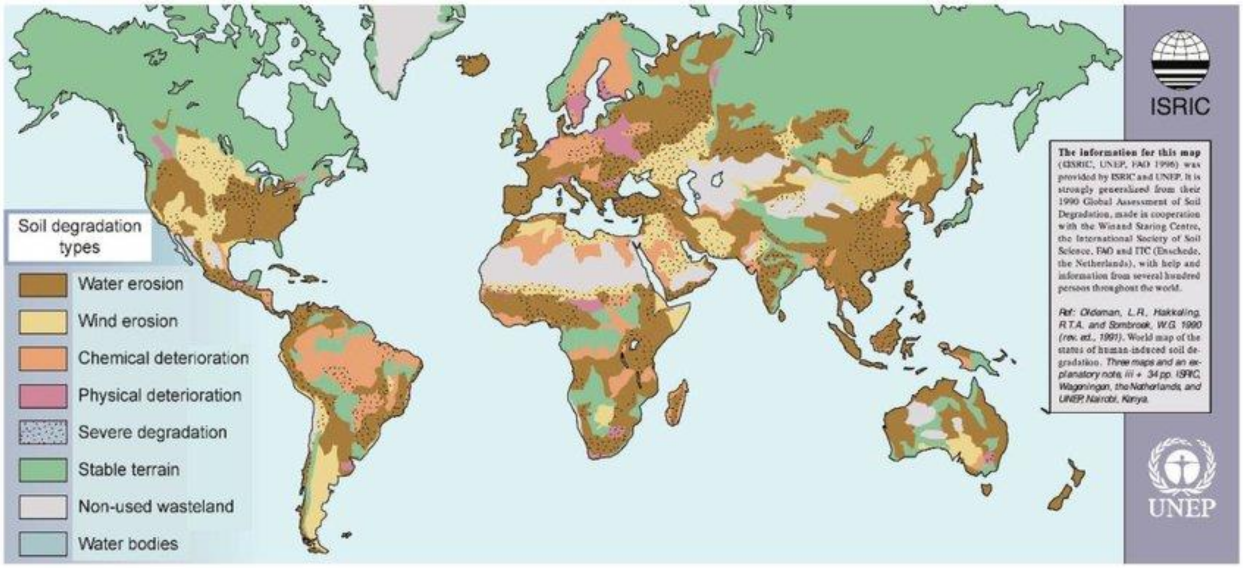
[13] Moomaw et al., 2018.

[14] Young, Orsini and Fitzpatrick, 2015.

degradation are responsible for about 20% of carbon emissions globally. Figure 3 illustrates the global scale of land degradation.

Figure 3. *Global Soil Degradation*



Source: International Soil Reference and Information Center, 2017. Retrieved from G.S. Gupta, 2019.

2.3 Agricultural Soil Health and Greenhouse Gas (GHG) Emissions

Erosion

A large portion of soil erosion is due to agriculture. When forests and grasslands are converted to cultivated cropland, the deep root systems that hold the soil in place are removed and the soil is tilled. Tilling the soil turns it over and breaks up soil aggregates. This makes it easier for seeds to germinate, but also increases rates of oxidation and decay and increases its susceptibility to water and wind erosion. Soils with a medium to fine texture, a low level of organic matter content, and weak structural development are most easily eroded.[15]

Sometimes soil erosion is imperceptible, as wind and water carry the top layer of a field away, millimeter by millimeter. Other times, soil erosion leaves vast gullies that cannot be farmed and are difficult to fill. The UN estimates that in the past two centuries, humans have cleared or converted 70% of the world's original grasslands, 50% of the savannah, 45% of temperate forests, and 27% of tropical forests to agricultural lands.[16]

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[15] Pimentel and Burgess, 2013.

[16] FAO, 2011.

In the U.S., only 3% of the original tallgrass American prairies remain.[17] When European settlers came to America, the prairies had rich topsoil up to 10 feet deep. Organic soil carbon had accumulated over thousands of years as the result of the dynamic interaction between herbaceous plants and the ruminant animals that grazed them, particularly the North American bison. The near disappearance of the bison and conversion of the prairies to croplands led to rapid erosion (see Box 3 on the historical crisis of the Dust Bowl in the 1930s).

Today the topsoil in some areas of the world is barely a few inches deep. Scientists fear that if we continue at the current rate of soil erosion, all of the world's topsoil could be eroded within less than sixty years.[18]

Nitrogen

Presently, agriculture is the largest source of reactive nitrogen emissions to the atmosphere. Nitrous oxide (N_2O) is a far more potent GHG than carbon dioxide (CO_2).[19] Nitrogen emissions result from excess application of nitrogen fertilizers, urea, and manure to fields. Because nitrogen is often the limiting factor for plant growth, farmers may apply large amounts of nitrogen to the soil. If the soil has no plant cover at the time of application, or nitrogen is applied in excess of what the available plants and microbes are able to utilize, the excess nitrogen may be emitted as N_2O, or lost to agricultural runoff, where it contributes to the eutrophication of bodies of water, producing dead zones in lakes and oceans.[20] Nitrogen loss is problematic for farmers, who may experience decreased yields as a result, which in turn may lead to even heavier applications of fertilizer.[21]

Other Concerns

Agriculture can also lead to soil compaction, an increase in the density of soil due to pressure from heavy machinery. Compaction decreases the pore spaces in soil, which lowers water capacity, making it more difficult for plants to survive, and increases susceptibility to erosion.[22] Other concerns for soil health include salinization due to the build-up of salt, which decreases soil organic matter and osmotic capacity. Salinization can occur naturally, especially in semi-arid regions, or can be caused by management practices such as deep tillage.[23]

A loss of soil organic matter due to salinization or agrichemical usage leaves ecosystems more susceptible to erosion and drought. A 1% decrease in soil organic matter decreases its water holding capacity by an estimated 3.7%.[24] Many agricultural operations use chemical inputs to kill weeds and pests. While they eliminate competition for nutrients and prevent diseased crops, these chemicals also kill bacteria, insects, and other beneficial components of the soil ecosystem.

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[17] Schwartz, 2014.
[18] Arsenault, 2016.
[19] Hull, 2009.
[20] See map of dead zones in the Gulf of Mexico, in National Geographic: https://education.nationalgeographic.org/resource/dead-zone
[21] EPA, 2018a & 2018b.
[22] Duiker, 2005.
[23] NRCS, 1998.
[24] FAO, 2005.

BOX 3: THE DUST BOWL

Early agricultural policies in the United States favored increased production over all else. The Homestead Act of 1862 offered potential farmers 160 acres in the Great Plains region if they agreed to settle and farm the land. Technological improvements in farming equipment and an uncharacteristically wet period in the Plains region soon led the government to believe that "rain follows the plow." This, in combination with increased demand for US agricultural products during WWI led to a dramatic expansion of farming in the United States. But demand decreased following the war and food prices plummeted. Concurrently, the Plains region experienced a period of severe drought and devastating windstorms that literally blew the soil away on entire farms. This devastated farmers, many of whom lost their land or went bankrupt (Ganzel, 2003).

In response to the Dust Bowl, the US government shifted its focus to erosion prevention and market controls. While efforts to prevent agricultural market crashes were largely unsuccessful, efforts to decrease erosion have been effective to some extent. Mandatory soil conservation laws in the United States center around preventing the farming of marginal, or "highly erodible" lands.

Land retirement programs like the Conservation Reserve Program pay farmers not to grow crops on environmentally sensitive land. Similar programs established in the 1985 Farm Bill include the Grassland Reserve Program and Wetland Reserve Program, aimed at protecting, restoring, and enhancing grasslands and wetlands. There were more than 20 million acres enrolled in land retirement in 2018.

Working lands conservation programs like the Conservation Stewardship Program and Environmental Quality Incentives Program provide financial support to farmers who wish to implement conservation practices on land in production. Participation in these programs is voluntary, and demand consistently outstrips allocated funding (NRCS, 2018).

While the Dust Bowl inspired the implementation of soil conservation practices like hedgerows, contour farming, and reduced tillage, their use is not sufficiently widespread. Land degradation continues in the Plains region, as fiercely competitive markets force farmers to forgo conservation in favor of production. Expansion of policies that empower producers to employ sustainable practices will be vital for reversing soil degradation due to agriculture in the United States.

***Sources*: Ganzel, 2003; NRCS, 2018a & 2018b.**

3. AGRICULTURE, CLIMATE, AND ENVIRONMENT

3.1 The Agriculture-Climate Nexus

Agriculture is a significant contributor to climate change. Agricultural GHG emissions have grown continuously since the 1960s, as shown in Figure 4. Agriculture emissions doubled during that period, while the world population multiplied by a factor of 2.6 (from 3 to 8 billion people). According to the World Resources Institute (WRI), agricultural GHG emissions represented 11.8% of all emissions in 2016.[25] Another 6.5% arises from land use change, much of which is driven by forest conversion to agriculture. These totals may underestimate total GHG emissions attributable to agriculture due to other emissions associated with agricultural inputs such as fertilizer, which could put agriculture's contribution to as high as 30% of global emissions.[26]

While emissions are generally standardized to C or CO_2 equivalents, agricultural emissions are primarily N_2O and methane (CH_4). Figure 4 shows the composition of agricultural emissions, which are comprised of 46% N_2O, 45% CH_4, and 9% CO_2. Both N_2O and CH_4 are more potent GHGs than CO_2. One ton of CH_4 is equivalent to 25 tons of CO_2 emissions and one ton of N_2O is equivalent to 298 tons of CO_2.[27] Using these multiplying factors, all types of emissions can be translated into CO2 equivalent emissions and added to represent the total emissions of agriculture in CO2 equivalent (as shown in Figure 4).

Agricultural CH_4 emissions originate primarily from livestock, manure management, and rice cultivation. N_2O emissions originate primarily from nitrogen fertilizers and soil erosion. Modern agriculture also contributes to climate change through land use changes such as deforestation for agricultural expansion.[28]

In addition to its contribution to climate change, agriculture is also a driver of several other global ecological crises (see Box 4).

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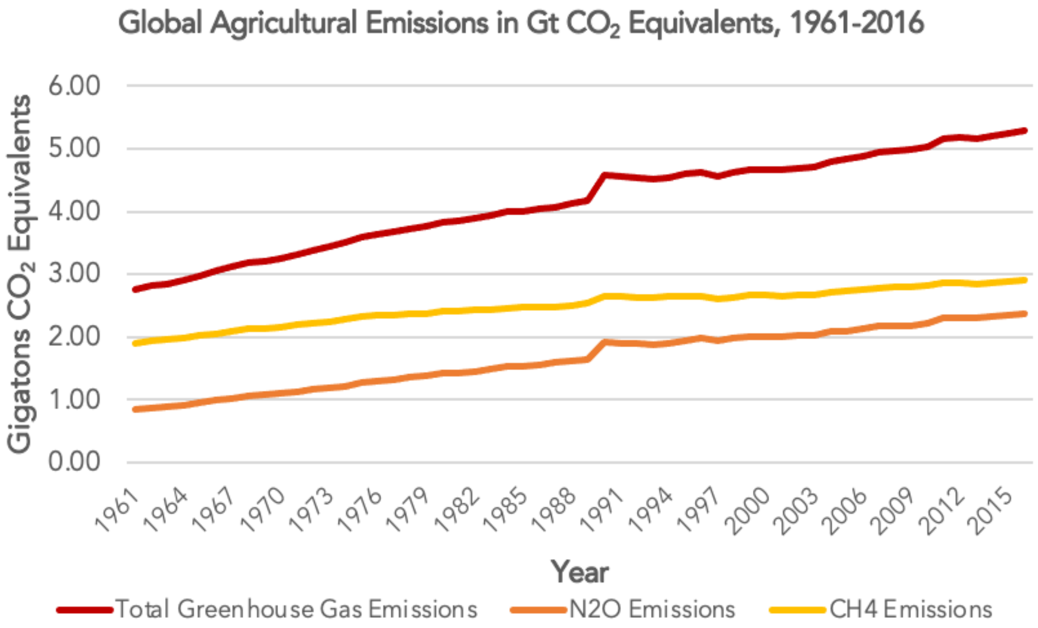
[25] World Resources Institute, https://www.wri.org/data/world-greenhouse-gas-emissions-2016
[26] McMahon, 2019.
[27] Hull, 2009.
[28] EPA, 2018a & b.

Figure 4. *Global Agricultural Emissions, 1961-2016*



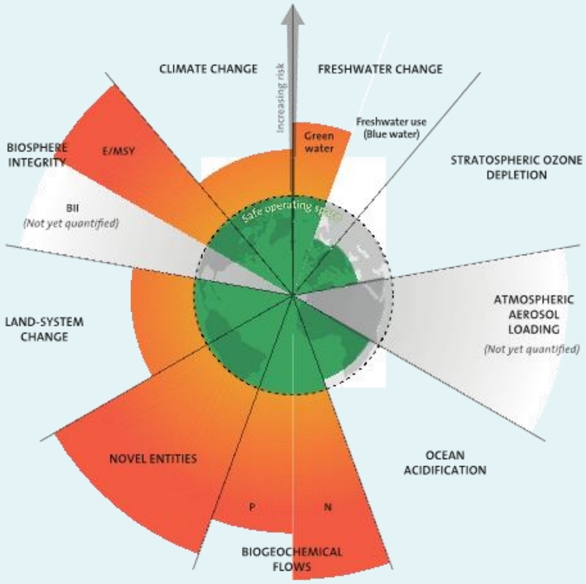
Source: World Resources Institute, data from FAOSTAT, retrieved 12/4/2018.

BOX 4: PLANETARY BOUNDARIES: AGRICULTURE AS DRIVER OF GLOBAL ECOLOGICAL UNBALANCE

In their analysis of the earth’s limits, the Stockholm Resilience Center developed the Planetary Boundaries concept in 2009, assessing the current state of nine earth system processes: Stratospheric ozone depletion, Loss of biosphere integrity (biodiversity loss and extinctions), Chemical pollution and the release of novel entities, Climate change, Ocean acidification, Freshwater consumption and the global hydrological cycle, Land system change, nitrogen and phosphorus flows to the biosphere and oceans (causing **eutrophication** and oceans’ “dead zones”), Atmospheric aerosol loading.

As of 2022, as shown in Figure 5, four boundaries: nitrogen and phosphorous flows, loss of biosphere integrity, pollution and novel entities (such as plastics), and green water (the water available to plants) have already been crossed; while two others: climate change, and land system change are in the zone of increasing risk. Chemically based agriculture is a leading cause of five of these six global threats to the integrity of the earth and its physical and ecological boundaries.

Figure 5. *Planetary Boundaries*



***Sources*: Steffen et al., 2015; Azote for Stockholm Resilience Centre, based on analysis in Wang-Erlandsson et al., 2022.**

3.2 Food, Fiber, and Fuel

Agriculture includes the production of crops for use as food, fiber, fuel, and feed. A large portion of agricultural products are nonfood crops, such as cotton, tobacco, and biofuels. Cotton and tobacco production are extremely water-intensive processes and may rely on irrigation practices in semi-arid areas. They often require pesticides, fungicides, and herbicides and offer little anchorage for the soil, increasing concerns for erosion.[29]

The global land area used for biofuel production is rapidly increasing. **Biofuels** include ethanol and biodiesel**.** Ethanol comes from corn, soybeans, sugar cane, and other crops, while biodiesel comes from oil-producing crops, including annuals like rapeseed, sunflower, groundnut, and soybean and perennials such as oil palms and coconut palms. Replacing fossil fuels with biofuels has been promoted as a climate solution, but serious concerns have arisen from the rapid growth of biofuel production and resulting ecological damage and forest loss.[30]

In 2007, the U.S. Congress passed the Energy Independence and Security Act, also known as the 2008 Energy Bill, which significantly expanded biofuel promotion programs and mandated that all gasoline have a minimum 10% biofuel content. Unfortunately, the expansion of US biofuel

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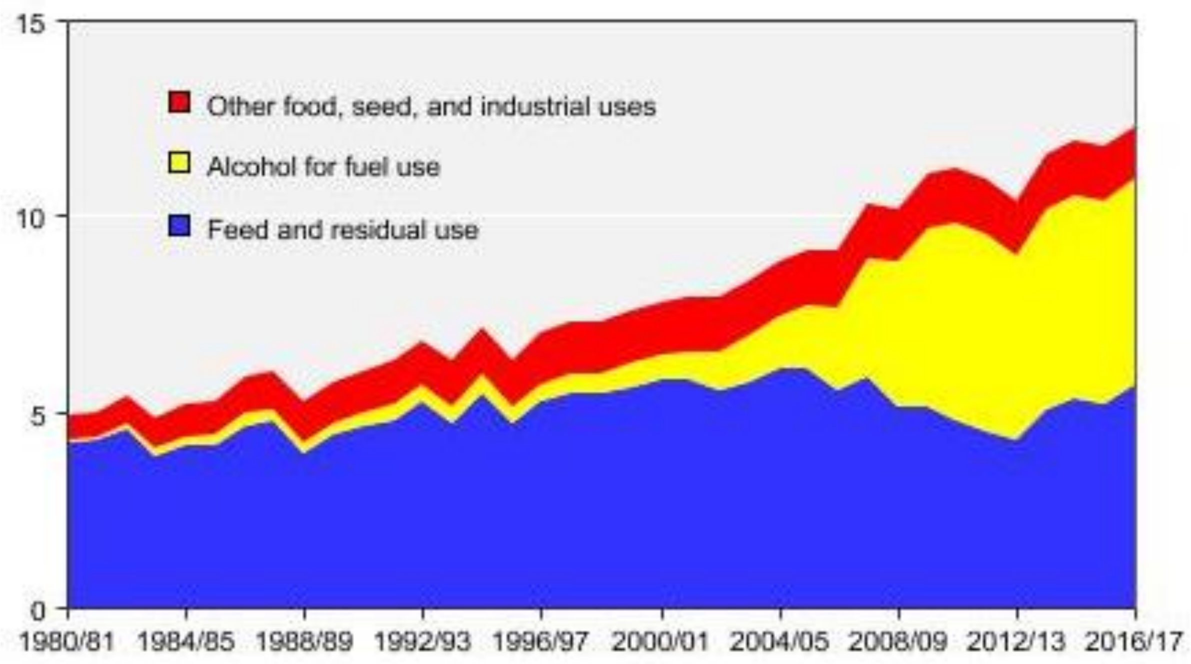
[29] FAO, 2019.
[30] Institute of Medicine, 2014.

production and rapid growth of plantations devoted to biofuels has had negative ecological and social consequences. To meet the American fuel mandate, producers turned to palm oil. Almost 90% of palm oil is imported from Malaysia and Indonesia, where biofuel demand is a key driver of deforestation and loss of biodiversity.[31]

U.S. biofuel production has increased dramatically in the past 15 years (see Figure 6). 40% of corn grown in the US is now used for ethanol production. Rising demand for biofuels has dramatically affected global markets, including raising the prices of basic crops and putting millions of people at risk for hunger. In addition to decreasing food availability, the land diverted from food production to grow biofuel crops is often subject to land-grabbing. This has been documented in several developing countries.[32]

Figure 6: *U.S. Domestic Corn Use in Billions of Bushels, 1980/81-2016/17*



Source: U.S. Department of Agriculture,
http://www.ers.usda.gov/topics/crops/corn/background.aspx

Many crops that are cultivated for biofuels, including maize and soy, require large water inputs. Water scarcity is a concern in many regions of the world that is predicted to worsen as climate change progresses. Increasing reliance on biofuels may pose serious threats to both **water security** and **food security**.[33]

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[31] Lustgarten, 2018.
[32] Wise, 2019.
[33] Wise, 2013; UNU-IWEH, 2013.

Attempts to produce more efficient, second-generation biofuels from non-food crops and third generation biofuels from algae may yield more efficient technology that could mitigate some of the negative impacts. Some smaller-scale biofuel production may use agricultural wastes efficiently and reduce methane emissions. But large-scale biofuel use is still associated with negative environmental and social effects.

3.3 Bio-Engineered Crops

Genetically modified (GM) foods were introduced in the 1990's with the intended goal of overcoming limitations of non-GM crops. Corporations such as Monsanto (now Bayer), BASF, Dupont, Dow Chemical Company, and Syngenta started bio-engineering GM-seeds tailored to whichever purpose the commodities were used for – with the claim that they could engineer crops that would be drought-resistant, more nutritious, chemical resistant, pest-resistant, or disease-resistant.

Advocates frame GM-crops as a necessary solution to combat hunger and feed a growing population. But growing critics have pointed out some of the negative impacts of GM-crops as detrimental to human health and causing environmental damage, including habitat destruction, weed and pest resistance, and contamination of native food crops from uncontrolled genetic drift. There are significant environmental and health concerns raised by increased chemical usage associated with GM-crops. A well-known example is the herbicide Roundup, which contains glyphosate, a chemical derived from a neurotoxic gas used in the Vietnam War called Agent Orange. Glyphosate exposure poses health risks to farm workers and is classified as a probable carcinogen by the World Health Organization.[34] Other notable examples of herbicides are Atrazine and Metolachlor. Both of these are highly soluble compounds that are dangerous to human health and have been found in groundwater and streams.[35]

The use of agrichemicals can also be detrimental to soil health. While they may kill weeds and pests, they can also harm soil microbes and other organisms that contribute to the soil ecosystem. As soil organic matter decreases, so does the soil's ability to hold water, making it more susceptible to erosion.[36]

Farmers in many developing countries, organizing in cooperatives and collectives, have been fighting against the pressures of their governments to adopt GM-crops.[37] In industrial countries, 19 European countries out of the 27 members of the European Union have either partially or fully banned GM crops.[38] In the United States, GM crops are widely used by large-scale farmers primarily to grow commodities, including most corn, soy, and cotton[39] (see Figure 7).

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[34] Myers et al., 2016.

[35] Barbash et al., 2001.

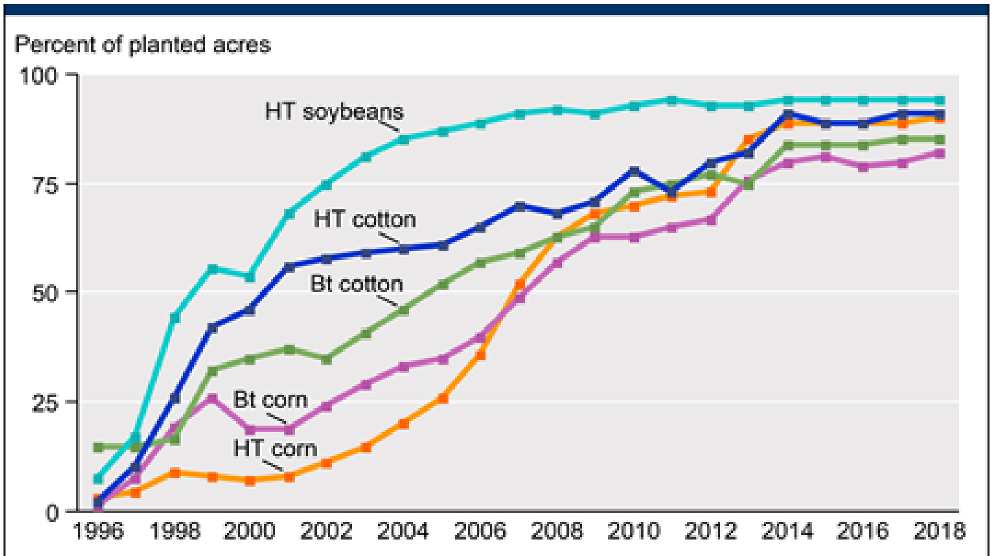
[36] Wasim Aktar, Sengupta and Chowdhury, 2009.

[37] Wise, 2019.

[38] European Commission, 2019.

[39] ERS, 2018.

Figure 7. *Adoption of GM-Crops in the United States, 1996-2018*



Note: HT indicates herbicide-tolerant varieties; Bt indicates insect-resistant varieties (containing genes from the soil bacterium Bacillus thuringiensis). Data for each crop category include varieties with both HT and Bt (stacked) traits.
Source: USDA, Economic Research Service using data from the 2002 ERS report, *Adoption of Bioengineered Crops* (AER-810) for the years 1996-99 and National Agricultural Statistics Service, (annual) June Agricultural Survey for the years 2000 to 2018.

3.4 Expected Impacts of Climate Change on Agriculture

The Intergovernmental Panel on Climate Change[40] projects that all aspects of food security will potentially be affected by climate change, including food access, utilization, and price stability. The potential impacts on food production systems will include:

- Increased inter-annual variability of crop yields, especially due to changes in precipitation. Figure 8 shows the projected changes in precipitation. Drier conditions will be prevalent in the Mediterranean basin, China and Southeast Asia, Australia, West Africa and South Africa, Central and South America, and the Western United States.
- Increased spread of invasive weeds, pests, and crops diseases.
- For the major crops (wheat, rice, and maize) in most regions of the world, an increase in the average global temperature of more than approximately 2°C will have negative effects on yields.[41]
- Nutritional quality of food and fodder, including protein and micronutrients, will be negatively affected by elevated CO_2 concentrations.

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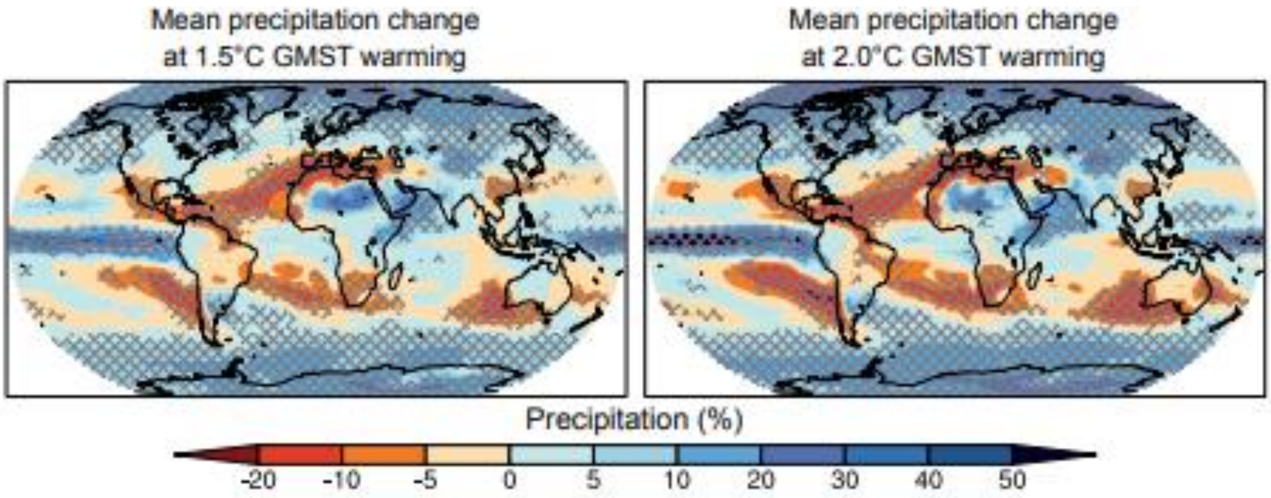
[40] IPCC, 2014, 2018.

[41] Martin and Sauerborn, 2013.

Figure 8. *Projected changes in average precipitation*



Source: IPCC, 2018. Chapter 3, p. 188.
Note: GMST means Global Mean Surface Temperature – the two models show the variations in projected mean precipitation at 1.5°C (left) and 2°C (right) of global warming compared to the pre-industrial period (1861–1880).

As global temperatures rise and precipitation changes, crop production will shift geographically. Crop ecologists in several countries have assessed the relationship between temperature and crop yields. For example, a 2-degree C rise in temperature decreased wheat yields from 37-58% in some experiments.[42] Harvard researchers found that increased temperatures lead to decreased nutritional quality of staple crops that sustain much of the world's developing countries.[43] As some regions become too hot or dry to sustain production, agriculture will shift to areas of the world that may previously have been unsuitable for crop cultivation. The question remains whether this shift will be enough to continue feeding the world's population.

As increasing food and biofuel demand and the threat of climate change loom, it is crucial to improve the **environmental sustainability** of agricultural production and take advantage of ecosystem services that could be provided by ecologically sound production practices.

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[42] Brown, 2009.
[43] Myers et al., 2017.

4. TRANSFORMING AGRICULTURE INTO A CLIMATE SOLUTION

4.1 Potential for Greenhouse Gas Mitigation in Agriculture

While agriculture is currently a net contributor to climate change, it could play a positive role in mitigation and adaptation strategies with widespread implementation of sustainable farming practices. Rattan Lal, a leading soil scientist, estimates that since the beginnings of agriculture, as much as 486 gigatons of carbon (GtC) have been lost from the terrestrial biosphere and emitted into the atmosphere.

Through land use conversion and adoption of best management practices, it may be possible to return almost 500Gt of carbon to the terrestrial biosphere.[44] Lal estimates that the world's soils have the potential to sequester carbon at a rate of between 1.8 and 4.4 GtC per year, a significant portion of the 10 GtC of global annual emissions[45] (see Table 1).

***Table 1:** Technical potential of carbon sequestration in world soils for 50 to 100 years*

Ecosystem Type	**Technical Potential Gt C/year**
Croplands	0.6 – 1.2
Grazing lands (grasslands and rangelands)	0.5 – 1.7
Restoration of salt affected soils	0.4 – 1.0
Desertification control	0.3 – 0.5
Total	**1.8 – 4.4**

Source: Adapted from Lal (2010).

According to Lal, regenerating soils leads to a variety of positive impacts which would positively affect human health, productivity, food security, water quality, and air quality, in addition to GHG emissions.[46] Table 2 lists some of the direct and indirect benefits and ecosystem services associated with improved soil organic matter content.[47]

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[44] Lovins et al., 2018.

[45] Lal, 2010.

[46] Lal, 2010.

[47] Lal, 2008.

Table 2: *Direct and ancillary benefits and ecosystem services provided by the soil organic matter pool*

Direct benefits	Ancillary benefits and ecosystem services
1. Improves soil structure and tilth	1. Sequesters atmospheric CO_2
2. Reduces soil erosion	2. Enhances soil's ability to oxidize CH_4
3. Decreases non-point source pollution	3. Restores degraded ecosystems
4. Purifies water	4. Increases soil/terrestrial biodiversity
5. Denatures pollutants	5. Enhances water and nutrient use efficiencies
6. Increases plant available water	6. Improve wildlife habitat
7. Stores plant nutrients	7. Decreases nutrient and water loss from the ecosystem
8. Improves crop/biomass yield	8. Enhances ecosystem resilience
9. Provides food/energy for soil biota	9. Strengthens recycling mechanisms
10. Buffers impact of perturbation on soil properties	10. Improves the environment

4.2 Sustainable Diets and Climate Change

As countries increase in prosperity, per-capita demand for food also increases, which generally means increased demand for meat. The meat-intensive diet that is characteristic of many developed countries requires much higher levels of grain production per person in order to feed livestock. In 2012−2014, global grain production was 2.7 billion metric tons, which made up about half of all crop production.[48] If a mostly vegetarian diet were adopted globally, this level of global food production would be more than sufficient to feed every human on earth with reduced environmental and climate impact.

An assessment of the environmental impact of the three healthy dietary patterns recommended by the 2015-2020 US Dietary Guidelines found that a vegetarian diet (VEG) had 42–84% lower burdens on the environment compared with meat-containing dietary patterns in every category except water depletion. Of particular relevance to climate change, the VEG pattern caused approximately 50% less carbon emissions and required approximately 45% less land for production than the meat-containing patterns.[49]

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[48] FAO, 2019.

[49] Tichenor Blackstone et al., 2018.

The 2019 EAT-Lancet Commission, sponsored by the medical journal *The Lancet*, recommends the global adoption of the "planetary health diet," which is high in vegetables and relies heavily on nuts and legumes for protein, rather than meat and eggs. The report asserts that a global shift to the "flexitarian" diet they outline would decrease GHG emissions, preserve water, limit the expansion of farmland, protect biodiversity, and improve human health.[50]

4.3 Regenerative Grazing as a Climate Solution

While some suggest that a reduction in the number of ruminant animals could decrease agricultural greenhouse gas emissions, others propose a transformation in grazing techniques for cattle and other ruminants that could lead to increased net soil carbon sequestration.

Cattle begin their lives in relatively small grazing operations. Once they reach a certain size, cattle are usually "finished" in animal feeding operations (AFOs) or concentrated animal feeding operations (CAFOS). There, cattle are quickly fattened for slaughter with high-calorie grain and oil crops. Cattle are able to digest fibrous grains that would otherwise be unsuitable through enteric fermentation, but the resulting burping and flatulence leads to high levels of methane emissions. The widespread antibiotic usage necessary to prevent the spread of disease among crowded cattle may further increase methane emissions.[51]

In 2016, methane emissions from enteric fermentation in grazing animals represented approximately 25.9 percent of total CH_4 emissions in the United States.[52] Additionally, CAFOs are linked to groundwater contamination, reduced air quality, decreased property values, and respiratory diseases in nearby communities.[53]

Grazing animals like cattle and bison have coevolved with grassland ecosystems for millions of years. Large migratory herds moved constantly and grazed intensely. They left behind manure, which fertilized the soil, and avoided fouled grazing sites, allowing the foliage to recover completely before being grazed again. The paleo record suggests that this relationship led to the expansion of carbon rich soils and induced multiple cooling periods during Earth's history.[54]

The "cows save the planet" movement advocates for the return of all cattle to natural grazing patterns. Adaptive multi-paddock (AMP) grazing mimics natural patterns by intensive grazing for a short period followed by moving the cattle to a different area, allowing vegetation to regrow. Teague, et al. posit that if farmers adopted both conservation cropping practices and regenerative or adaptive multi-paddock grazing practices, the soil carbon sequestered by improved pastoral ecosystems would surpass emissions from enteric fermentation and manure management.[55]

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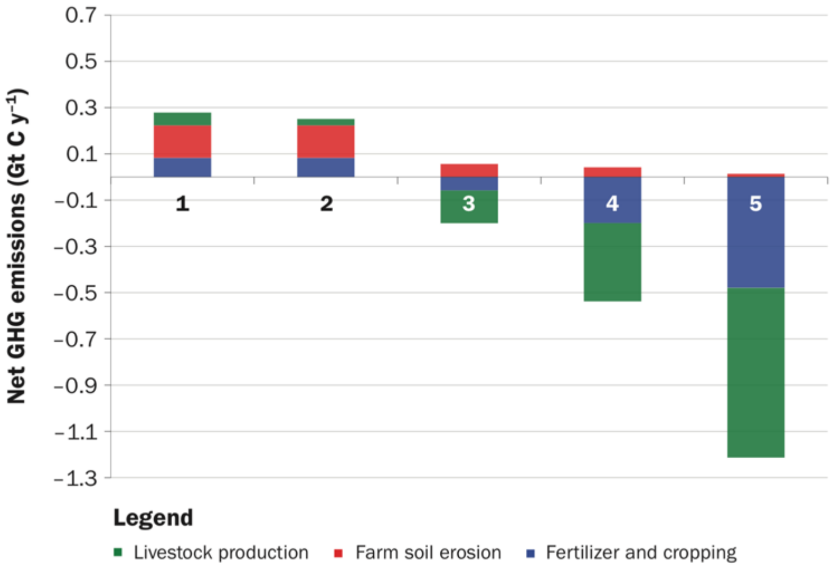
[50] Willett et al., 2019.
[51] Axt, 2016.
[52] EPA, 2018a & 2018b.
[53] CDC, 2009.
[54] Retallack, 2013.
[55] Teague et al, 2016.

Figure 9 illustrates the net carbon balance for North American agriculture in five hypothetical scenarios. In Scenario 1, current agricultural practices persist. In Scenario 2, current agricultural practices persist, but with a 50% reduction in ruminant (grazing) animals. These scenarios continue the trend of net agricultural carbon emissions, though they would be lower in scenario 2.

Scenarios 3-5 depict increasing adaptation of conservation cropping and AMP grazing, resulting in annual net GHG sequestration. Scenario 5, in which there is a 100% adoption of conservation cropping and AMP grazing, estimates net carbon sequestration of 1.2 Gt C per year and greatly reduced emissions due to soil erosion.

Figure 9. *Hypothetical Net GHG Emission Scenarios*

Hypothetical North American net greenhouse gas (GHG) emission scenarios for: (1) current agriculture; (2) current agriculture with 50% current ruminants; (3) 25% conservation cropping and adaptive multipaddock (AMP) grazing with current numbers of ruminants; (4) 50% conservation cropping and AMP grazing with current numbers of ruminants; and (5) 100% conservation cropping and AMP grazing with current numbers of ruminants.



Source: Teague et al, 2016.

Most currently available data supporting regenerative grazing practices consists of models, rather than data from large scale experiments, and studies have yielded conflicting results thus far. There are impressive individual cases of soil regeneration through improved grazing practices, but these would need to be expanded to a much larger scale. While the body of research is still developing, regenerative grazing could be a promising component of the solution to agricultural GHG emissions.

4.4 Principles of a Sustainable Agricultural System

Soil Cover

Soil should be covered by vegetation whenever possible. This includes the use of cover crops and leaving crop residue on the field after harvesting. Land areas covered by plant biomass are more resistant to wind and water soil erosion. The soil cover provides a barrier for wind and water and the biomass holds together the topsoil.[56] Mulching of crop residues adds to soil fertility and carbon retention.

Reduce or Eliminate Tillage

Soil tillage leads to the oxidation of soils, damage to mycorrhizal fungi networks and ultimately to loss of organic carbon, and therefore of fertility.[57] There are a number of "conservation tillage" strategies available to farmers. This includes strip tillage, where planting rows are tilled but vegetation is left between the rows, and no till systems, where only the soil in which crops are directly planted is disturbed.

Alternative Strategies for Pest, Weed, and Disease Management

In order to preserve the biodiversity of soil ecosystems, it is important to minimize the use of potentially harmful chemicals. Strategies to reduce the need for chemical inputs include but are not limited to crop rotations, cover crops, and mulching. Farms with the financial means to invest in sensors and other technology sometimes employ "precision agriculture," in which a small amount of chemicals are applied only when absolutely necessary.[58]

Manage Soil Nutrients

Soil nutrient management is a multifaceted task that overlaps with many of the principles outlined above. An important strategy to minimize nutrient loss in soils is to provide soil cover, which will prevent the loss of nutrients via erosion and leaching. Cover cropping can also preserve soil nutrients, as some crops store specific nutrients. For example, leguminous plants can help prevent nitrogen losses and fix nitrogen from the atmosphere. In addition to maintaining already existing soil nutrients, soil can be nourished with natural compost or manure that can bolster soil microbiology, mycorrhizal fungi and microorganisms. The application of nutrient sources should be done incrementally, so that plants have the capability to utilize the nutrients, and accounting for weather, so that nutrients do not leach into water from a large storm.[59]

Appropriate Grazing Management

On grazing land, a regenerative approach based on the concept of holistic grazing management is gaining traction globally. This technique mimics the patterns of wild herds grazing in natural conditions in the savannahs and prairies. As noted earlier, current research is assessing its potential to improve soil organic matter and carbon storage capacity.

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[56] Pimentel and Burgess, 2013.

[57] Kabir, 2015.

[58] Lechenet et al., 2017.

[59] Clark and Beegle, 2017.

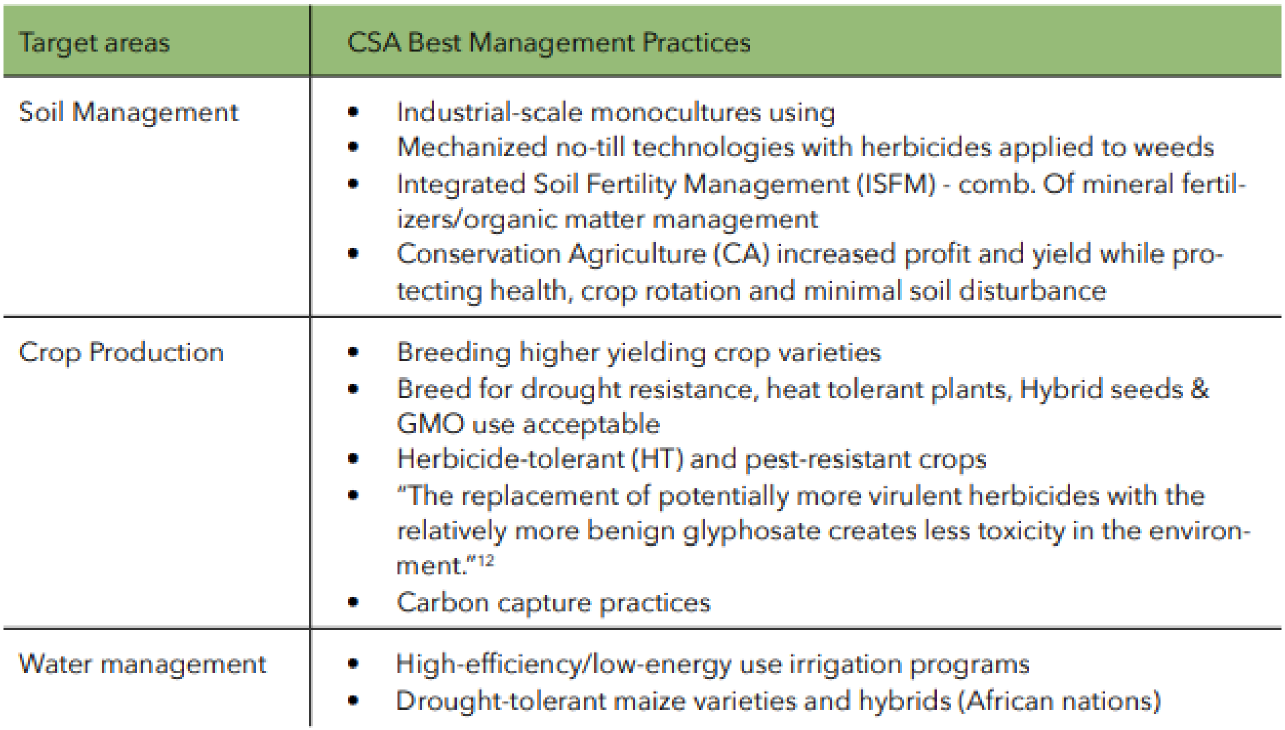
5. TWO PARADIGMS OF AGRICULTURE AND CLIMATE

Increasing attention to the environmental impact of agricultural practices have given rise to various climate-focused initiatives. Most of these fall under the umbrella of either Climate Smart Agriculture (CSA) or Regenerative Agriculture (RA).[60]

5.1 "Climate-Smart" Agriculture

The "Climate-Smart Agriculture" (CSA) paradigm was defined by the FAO and the World Bank in 2010 as "agricultural practices that sustainably increase productivity and system resilience while reducing greenhouse gas emissions."[61] The CSA paradigm includes mechanized no-till technologies, crop rotation, herbicides, GMO crops, and high efficiency irrigation systems. CSA best management practices are designed to help large-scale growers implement changes that decrease their contributions to soil erosion and other environmental degradation but do not require an entire restructuring of their production methods.[62] The principles of CSA are outlined in Table 3.

Table 3. *Climate-Smart Agriculture Best Management Practices*



Target areas	CSA Best Management Practices
Soil Management	• Industrial-scale monocultures using • Mechanized no-till technologies with herbicides applied to weeds • Integrated Soil Fertility Management (ISFM) - comb. Of mineral fertilizers/organic matter management • Conservation Agriculture (CA) increased profit and yield while protecting health, crop rotation and minimal soil disturbance
Crop Production	• Breeding higher yielding crop varieties • Breed for drought resistance, heat tolerant plants, Hybrid seeds & GMO use acceptable • Herbicide-tolerant (HT) and pest-resistant crops • "The replacement of potentially more virulent herbicides with the relatively more benign glyphosate creates less toxicity in the environment."[12] • Carbon capture practices
Water management	• High-efficiency/low-energy use irrigation programs • Drought-tolerant maize varieties and hybrids (African nations)

Source: https://csa.guide/csa/practices#article-35

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[60] Codur and Watson, 2018.

[61] FAO, 2010.

[62] Ibid.

5.2 Regenerative Agriculture

The term “regenerative agriculture” was coined in the 1980s by Robert Rodale. He defined it as a series of practices that improve, rather than deplete, the resources used for agricultural production. It is a holistic systems approach to agriculture that encourages continual on-farm innovation for environmental, social, economic and spiritual well-being.[63]

Regenerative agriculture is driven by farmer experimentation and innovations. It is based on the principles of **agroecology**, which is the application of ecological science to the study, design and management of sustainable agroecosystems.[64] The goal of regenerative agriculture is to maintain viable farming systems and eliminate manufactured inputs through the use of agroecological practices that mimic naturally occurring ecosystem processes.

In 2018, the Rodale Institute introduced a standardized certification for Regenerative Organic Agriculture based on principles of soil health, animal welfare, and social fairness.[65] Examples of “regenerative” practices include recycling nutrients and energy on the farm, integrating crops and livestock, diversifying crop species, and using crop rotation systems, cover cropping, and reduced tillage.

By focusing on interactions and productivity across the agricultural system rather than individual species, farmers can improve the overall health of their soil. Evidence shows that it is possible for healthy microbial communities to produce sufficient nutrients for high crop yields, as well as promote biodiversity on farmland, which acts as a natural pest control system.[66] The Rodale Institute also published evidence of a direct link between the type of agriculture used and human health, making a case that organic regenerative agriculture produces more nutritious healthy food, which improves human health.[67]

Regenerative agricultural techniques have been widely adopted, but mostly on a small scale. Much smallholder agriculture in the developing world is based on similar principles to the regenerative model, emphasizing crop diversity and use of animal and green (plant-based) manures.

5.3 Contradictory Approaches

While there may be some overlap between the CSA framework and the Regenerative Agriculture paradigm, there is also a significant difference between the two. The CSA framework is a clearly defined set of practices that can be implemented on large agricultural operations with comparatively low risk to the farmers. Critics of the CSA framework fear that agribusiness advocacy has rendered CSA strategies increasingly one-dimensional, rather than encouraging holistic reform of the supply chain.[68] They also question its effectiveness as a strategy for carbon

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[63] Lovins et al., 2018.

[64] Gliessman, 2007.

[65] Rodale Institute, 2019.

[66] Lori et al., 2017.

[67] Moyer et al., The Rodale Institute, 2020.

[68] Climate, Land, Ambition and Rights Alliance (CLARA), 2017.

storage and environmental protection, suggesting that some of its major strategies—such as the increased use of herbicides—are counterproductive. At the COP27 global climate conference in 2022, critics complained that “agribusiness and governments offered a series of patented patches designed not to transform the food system, but to keep it the same,” ignoring indigenous communities and small farmers promoting agroecology.[69]

Regenerative agriculture, in contrast, takes a multi-dimensional approach to environmental conservation and addresses the entire agroecological system as a whole, rather than in individual parts. Implementing an entirely regenerative system on a large scale, however, would take an enormous investment of time and resources, and the transition period is a potentially high-risk factor for farmers.

Because the needs of farmers vary widely depending on the scale of their operations, the policies designed to incentivize farmers to adopt carbon sequestration measures will therefore be quite different. Currently, the financing available to regenerative agriculture practices at the local small-scale level pales in comparison to CSA funding.[70]

5.4 Addressing Farm Size and Scale

In North America, Australia, and Latin America (especially Brazil), large scale farming operations of several hundred hectares are the norm (see Figure 10). Large farms produce most of the crops grown for livestock feed or biofuels. These farms are generally highly mechanized, often use chemical inputs, and are more likely to use monoculture cropping systems (though most crops like corn, soy, and wheat are grown in rotation). Though farm policy is often quite complicated, the overarching reason for the expansion of farm size is simple: per acre, it is less expensive to farm a large plot of land. Low input costs per acre lead to increased profit margins, which are especially important for low-priced commodity crops like corn, soy, wheat, and sugar.[71]

Because large-scale operations use 75% of arable lands globally, many interventions, including the CSA framework, feature policies that primarily apply to large-scale farming. If true conservation practices were adopted by the majority of large-scale farming operations, it could have an enormous positive impact on the global environment for soil health, GHG emissions, water pollution, and other factors. But, as noted, critics argue that CSA techniques will not fundamentally change the nature of large-scale farming.

In the remainder of the world, the average size of farming operations is much smaller. The International Assessment of Agricultural Science and Technology for Development (IAASTD) reported that in 2009, there were 1.5 billion men and women farmers working on 400 million small-scale farms of less than 2 ha.[72] The majority of farmers worldwide grow their crops on small or even micro-operations. Particularly in developing countries, small-holder farmers adapt to

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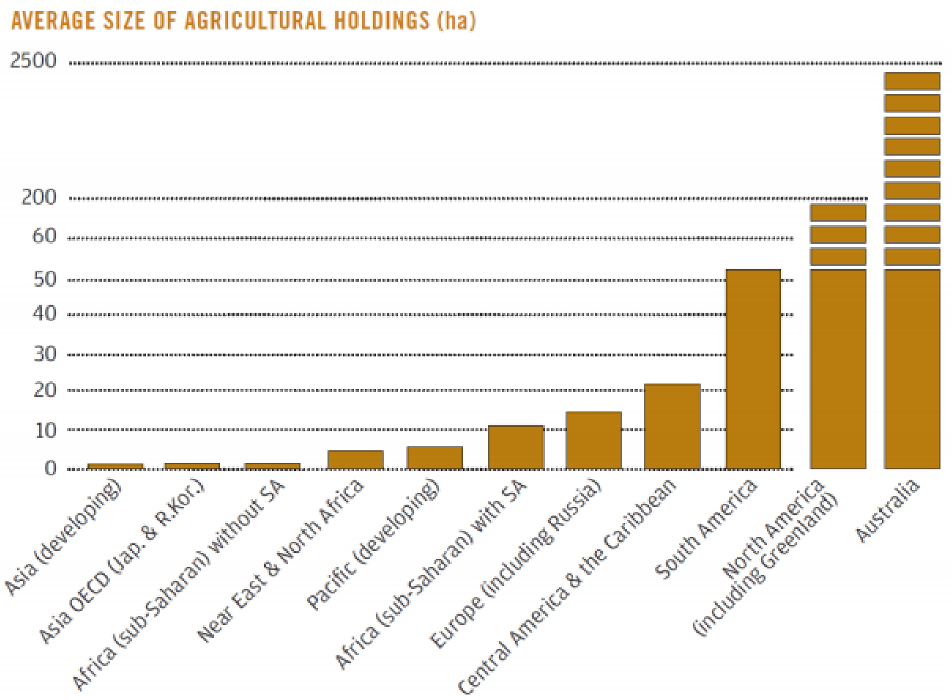
[69] Lakhani, 2022. Quote from Raj Patel.
[70] Codur and Watson, 2018.
[71] MacDonald and Hoppe, 2018.
[72] IAASTD, 2008.

environmental and climate concerns by necessity, but often face hardship due to competitive global markets and trade policies that favor agribusiness.

Figure 10. *Average size of agricultural holdings (ha)*



Source: FAO (2012) "Smallholders and Family Farmers Fact Sheet."

If provided with adequate support, such as funding for infrastructure improvements, access to credit, and educational resources, small-holder farmers could provide a more secure source of food and income for their families and communities while improving the health of the soil and their local environments. Because much of the world relies on smallholder farmers for food, it is important to recognize and strengthen the role of smallholder farms in creating a sustainable agricultural system.[73] The expansion of agroecological practices on small-holder farms could prove a winning strategy for both the environment and communities in developing areas.

Climate change provides an impetus for the global farming community to adopt more agroecologically sound practices, regardless of scale. Innovative farmers of all types have adapted to changing conditions based on a deep understanding of their local ecosystems. From the Great Plains region in the US to the villages of developing countries, innovative forms of adaptation to climate change are found, such as Yacouba Sawadogo from Burkina Faso, who combats desertification by implementing ancient forms of agroforestry (See Box 5).

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[73] FAO, 2012.

BOX 5: YACOUBA SAWADOGO, THE MAN WHO STOPPED THE DESERT

Since the 1980s, the Sahel region has experienced recurrent episodes of drought. Like other farmers, Yacouba Sawadogo would dig “zai”, shallow pits that collect and concentrate scarce rainfall onto the roots of crops. To adapt to droughts, he increased the size of the zai in hopes of capturing more rainfall. He experimented with adding manure to the zai during the dry season, and his yields increased significantly. The most important result was one he had not anticipated: trees began to sprout amid his rows of millet and sorghum, thanks to the seeds contained in the manure. As one growing season followed another, it became apparent that the trees – now a few feet high – were contributing to his increased millet and sorghum yields while restoring the degraded soils’ vitality.

The improved planting pits and other water-harvesting techniques developed by Sawadogo have enabled more water to infiltrate the soil. Underground water tables that plummeted after the droughts of the 1980s began recharging in the 1990s. As his tree cover expanded, Sawadogo sold wood for cooking, furniture making and construction, which increased and diversified his income. Over time, trees grew in numbers and in size. Today his land looks more like a forest than a farm – a forest that provides shade, livestock fodder, drought protection, firewood, and the return of hares and other small wildlife. The regeneration of his land prevented the desertification and regrew a forest, restoring biodiversity and water resources and providing food security and a high quality of life for Sawadogo and his family.

Agro-forestry has spread from village to village as farmers see the results and move to adopt the practice. During a 20-year period in Niger alone, farmers have grown 200 million trees and rehabilitated 12.5 million acres of land. African farmers have learned that nurturing trees alongside one’s crop brings many benefits, and together, they are regreening the Sahel. For having developed this drought-fighting technique and sharing it with thousands of farmers, Yacouba Sawadogo was awarded the Right Livelihood Award in 2018.

***Sources:* Hawken, 2017; Right Livelihood Award, 2018**

Thousands of local initiatives worldwide have emerged to reclaim degraded lands, and arid semi-desert land through similar agroforestry practices. The case of SEKEM (meaning "vitality from the sun" in Ancient Egyptian) offers an example of regeneration at the scale of thousands of hectares in some of the poorest and most degraded lands in Egypt. SEKEM has been led by small-scale farmers for more than 40 years, under the leadership of the Abuleish family, for which Helmy Abuleish was awarded the Right Livelihood Award.[74] This case study was promoted at the United Nations 2022 climate conference COP27 at Sharm-El-Sheikh as an inspirational story for small-scale farmers all around the world, and as a concrete example to establish **carbon credits** sourced from verified organic agriculture projects.[75]

6. EMERGING POLICIES TO ENHANCE SOIL CARBON SOLUTIONS

Soil-based carbon storage strategies are being recognized in national and global policy forums, earning attention for their value in climate change mitigation and adaptation, international food security, and land degradation reversal.[76] In the 2015 Paris Agreement on climate change, countries pledged to meet **Nationally Determined Contributions (NDCs)** for carbon emissions reduction. But these pledges, even if fully implemented, are insufficient to limit global warming to 1.5°C or even 2.0°C. Substantial additional carbon removal for the atmosphere will be needed if there is to be any chance of reaching these agreed-on targets.

6.1 The 4 per 1000 Initiative: Climate and Food Security

The 4 per 1000 initiative is an international effort launched by the French Ministry of Agriculture in 2015 to accompany the Paris Agreement on global climate policy. It calls for global action to enhance soils' carbon sink capacities. A Scientific Committee composed of leading agronomists and soil scientists reviewed existing research and estimated that 3.4 gigatons of carbon per year is the maximum "technical potential" for additional carbon sequestration in topsoil. Given that the topsoil layer contains 860 Gt of carbon worldwide, the annual percentage addition of carbon to topsoil would be 3.4/860 = 0.4%, hence the name 4 per 1000.[77]

The 4per1000 initiative emphasizes the twin benefits of soil enhancement: 1) capturing carbon as a climate change mitigation strategy, and 2) enhancing soil fertility and agricultural yields to address global food security. It is an independent, international initiative that includes more than 40 nation-states and regional authorities and hundreds of non-profit organizations, research centers, farmers associations and unions, and businesses.[78]

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[74] SEKEM, 2022.

[75] Heliopolis University for Sustainable Development, 2022.

[76] Codur et al., 2017.

[77] International 4 per 1000 Initiative. 2022.

[78] https://4p1000.org/wp-content/uploads/2022/05/updated_partners_members.pdf

A team of researchers at the French National Institute of Agronomy and the Environment (INRAE) has analyzed the maximum potential for carbon storage at the scale of the whole French territory and concluded that it would be possible to store an additional 1.9 per thousand per year of carbon through agricultural practices, with an average cost of 39 Euros per hectare per year. The overall cost would be 800 Million euros, which represents a fraction of the current total of subsidies of 9 billion euros given every year to French farmers through the framework of European Common Agricultural Policy.[79]

The full implementation of the 4 per 1000 initiative, with a yearly additional sequestration of 3.4 Gt of carbon in soils worldwide, would cost an estimated $500 billion per year. This would translate into an additional $160 per year in revenue for each of the 3 billion people living in poor, rural areas. The projected cost is approximately equivalent to current worldwide funding for agricultural subsidies. A restructuring of that funding to support more agroecologically sound farming practices could have enormous environmental, health, and economic benefits at all farm scales.[80]

6.2 Healthy Soils Initiatives in the United States

In the United States, the State of California was first to launch an initiative promoting soil regeneration in 2016. Because of California's water scarcity, which is expected to worsen with climate change, the watershed protection and enhancement that comes with healthier soils was a major incentive.[81]

The Healthy Soils Program (HSP) provides financial incentives for implementation and/or demonstration of on-farm conservation management practices that improve soil health, sequester carbon and reduce greenhouse gas emissions.[82] The California Department of Food and Agriculture has awarded 940 projects in 2021, totaling $66 million, as part of the HSP Incentives Program providing financial incentives to California growers and ranchers to implement such conservation management practices.

Other states have followed, and in 2022, 23 States (including California) have already passed healthy soils bills. Twelve more states are currently discussing such bills in their legislature, which are pending for a vote.

Figure 11 presents the status of Healthy Soils bills in the legislatures of all 50 US States as of July 2022.

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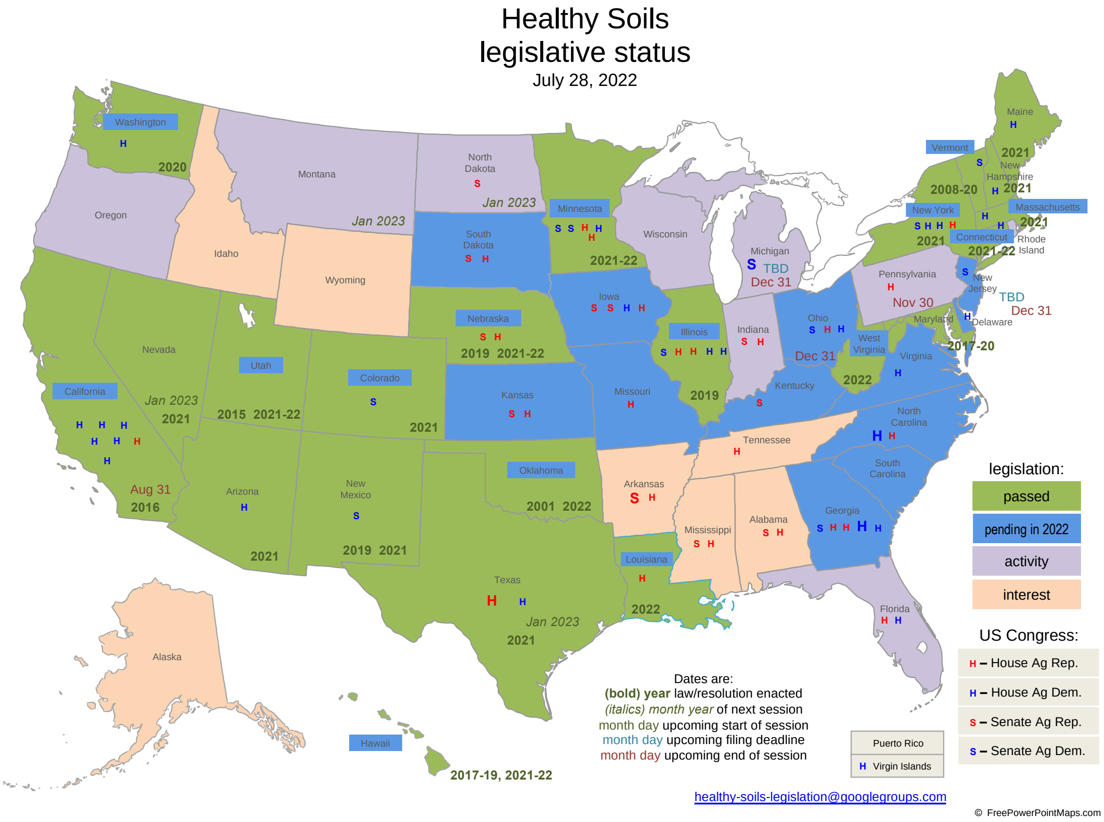
[79] INRAE, 2019.

[80] Biron, 2014.

[81] CDFA, 2019.

[82] California Department of Food and Agriculture, 2022.

Figure 11. *Healthy Soils Bills in the United States*



Source: Steven Keleti, PowerPoint presentation at the Soil Health Leadership Lab, May 31, 2022. https://sustainablefoodlab.org/initiatives/soilhealthleadershiplab/

6.3 Financing Mechanisms to Foster Carbon Storage in Soils

While sustainable agriculture practices are undoubtedly beneficial for the environment, farmers' income relies on the agricultural productivity of their land. As a result, they face significant barriers when implementing conservation practices. For many farmers, profit margins are incredibly slim per acre, so an increase in the cost of inputs per acre is prohibitive. For example, while cover cropping requires only the purchase of additional seed, this cost alone may be prohibitive when it must be applied to hundreds or thousands of acres. Management practices such as strip tillage and no till agriculture require the purchase of expensive machinery. While implementing conservation practices may eventually increase soil health, and subsequently yields, it may be 3-5 years before farmer income increases.[83]

Most current policies do not sufficiently incentivize conservation practices. For example, the United States requires adherence to basic conservation standards in order to participate in crop

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[83] Roesch-McNally et al., 2017.

insurance and other farmer support programs.[84] However, as discussed in Box 3, these programs only exclude marginal land from production. Participation in working lands conservation programs is entirely voluntary. Global policy standards for agricultural practices generally prioritize increased production over mitigating environmental degradation.

Of the expected $428 billion budget of the 2023 Farm Bill, only $21 million was originally projected to support key climate priorities within the Natural Resources Conservation Service.[85] A broad coalition of farmers, food advocates, businesses, non-profits, and individuals, "Regenerate America 2023" was formed to influence key policymakers in Washington D.C. to promote integration of regenerative agriculture into the 2023 Farm Bill.[86]

6.4 Strategies to Support Farmers

An important policy debate concerns whether farmers' participation in conservation practices should be mandated. This would require a global shift in policy and a dramatic increase in the level of support for farmers as they transition to more ecologically sound practices. There are various mechanisms to do this, which could include any of the following:

- Governments could support farmers by sharing payments to implement conservation practices. For example, if a farmer wanted to implement strip tillage, the government could pay a percentage of the cost of new machinery.
- Governments could also subsidize certain practices, such as paying farmers a designated amount per acre where cover crops are utilized, or subsidize performance, such as providing farmers with a stipend that is proportional to an increase in their soil health or decrease in environmental hazards associated with their operation.
- Additionally, it is vital to provide farmers with access to credit, especially long-term, low interest loans. This is especially important to small farmers in areas where there is not a well-established system of credit, as it could provide them with the ability to expand production, increase their income, and access conservation resources that are not currently available to them due to lack of capital.[87]

Governments could also take a "problem-focused approach" by identifying the farming operations who are the largest sources of pollution or environmental degradation and working with those farmers to implement improved farming practices. This could involve negative incentives, such as fines for pollution or failing to properly address soil erosion.

In general, a collaborative approach may be more effective, such as pairing environmentally underperforming operations with neighboring farms who have successfully implemented conservation practices and local governments who can support farmers in improving their land.

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[84] Ibid.
[85] Kiss the Ground, 2022
[86] Regenerate America, 2022.
[87] Awotide et al., 2015.

These “regional conservation efforts” are currently implemented in conjunction with the NRCS in the United States.[88]

Large farms may be particularly well-positioned to take advantage of carbon markets. International and national policies, motivated by the necessity of storing vast amounts of carbon in soils, will increasingly design and implement various instruments allowing agricultural systems to engage in **carbon farming**. One of them is national or international **carbon trading**, where farmers who implement plans to reduce emissions or store carbon can be granted **carbon credits** through a process of certification, and then sell these permits to firms that are emitting carbon. This mechanism has the effect of providing an **offset** to carbon emissions in one location by reducing or storing carbon in another.[89]

Crucial to any of these methods is the development of standard metrics to evaluate soil health and environmental degradation and the establishment of a monitoring system. This process is costly, and ongoing research is under way to determine effective and practical metrics.

6.5 Risks of Land-Grabbing

A critical concern of international NGOs is the risk of repeating the human rights abuses and ecological damages caused by other international initiatives. Ill-designed policies that involve payments of any kind for soil carbon sequestration or other ecosystem services can lead to the expulsion of poor rural farmers and indigenous people from their lands. Because land tenure in rural areas and on indigenous lands is often informal, corporations may formally purchase those lands and remove residents in order to take advantage of Carbon payments.

The Climate, Land, Ambition and Rights Alliance (CLARA) is a coalition of more than 30 international NGO’s that monitor any United Nations climate framework and advocate for the inclusion of human and land rights safeguards in any carbon-storage agricultural development projects. They warn that these safeguards are necessary to ensure that smallholder farmers are not victimized by land grabbing schemes and scams.[90]

CLARA states that land use action in agriculture must be clearly framed with social and environmental priorities to prevent false solutions and that “climate finance must be directed towards building resilience and adaptive capacity at community and landscape levels, while also focusing on biodiversity outcomes” and that local communities and indigenous peoples (LCIPs) “should be able to build assets based on their stewardships of land, water and carbon resources, outside of the currently proposed market mechanisms, which are mostly designed to serve traders, speculators and project developers”.

As soil carbon sequestration strategies are integrated into climate policies, countries must balance the implementation of their national climate commitments to the Paris Agreement with the protection of human rights, food security, and ecosystem integrity.

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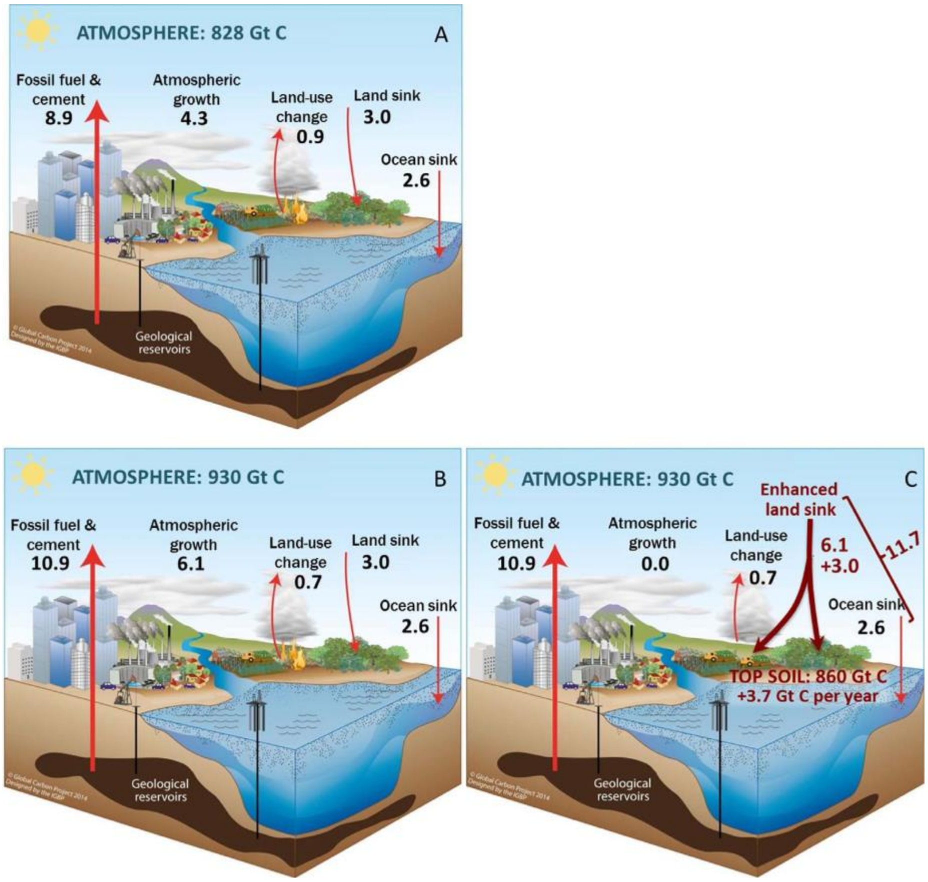
[88] NRCS, 2018.
[89] Ribaudo et al. 2010.
[90] Climate, Land, Ambition and Rights Alliance (CLARA), 2022.

7. CONCLUSION: SOIL HEALTH FOR A SUSTAINABLE FUTURE

The topic of climate change is often perceived as overwhelming and insurmountable. While we face an enormous challenge, successfully mitigating the worst effects of climate change is not impossible, and the role of natural climate solutions including regenerative agricultural techniques is essential.

The importance of soils, forests, and ecosystems is shown in a study that compares current emissions with future emissions with and without enhanced natural carbon sinks. Figure 12 depicts carbon flows into and out of the atmosphere. Figure 12A shows emissions as of 2011, with a net carbon flow to the atmosphere of 4.3 gigatons of carbon. Figure 12B shows the situation during the period 2030-2040, assuming that countries fully comply with their Paris Agreement commitments, but without any action on enhancing carbon sinks in soils and forests. Figure 12C shows the potential contribution of enhanced natural absorption of carbon.

Figure 12. *Global Carbon Cycle With and Without Natural Climate Solutions*



Source: Soussana et al., 2017.

The difference is dramatic. In Figure 12B we see that 10.9 Gt C would be released every year from fossil fuel and cement usage, an increase of approximately 2 Gt C from 2011. In this scenario, ocean sinks would absorb 2.6 Gt, land and biomass sinks would absorb 3Gt, unchanged from 2011, leading to a net atmospheric growth of 6.1 Gt C annually. Despite the Paris Agreement efforts, *more* carbon would be added to the atmosphere each year.

But in Figure 12C, with a theoretical maximum of an additional 3.7 Gt C per year being absorbed by the world's soils, and an additional 2.4 Gt C absorbed by forests and ecosystems, the additional "land sink" absorption of 6.1 Gt C means that net atmospheric increase falls to zero. This scenario assumes full implementation of the "4 per 1000" soil initiative and comprehensive forest protection and reforestation.

According to the authors of the study, the scenario outlined in Figure 12C is "at the limits of technical potential", and would be unlikely to be accomplished due to social and economic barriers. But it indicates the importance of including soils, forests, and ecosystems in any effective climate response strategy.

Through addition of the enhancement and restoration of natural ecosystems to the existing strategies adopted in the Paris Climate Agreement, it would be possible to achieve the goals of the agreement, which are currently out of reach given existing national commitments to emissions reduction. Strengthening emissions reduction efforts remain crucial, but will not be enough without additional carbon sequestration in soils, forests, and wetlands. It will take a global effort at all scales of government and in all economic sectors, including agriculture and forestry to achieve the goal of climate stabilization.

8. KEY TERMS AND CONCEPTS

Agroecology – The application of ecological concepts to the design and management of sustainable food systems.

Biodiversity – The total diversity and variability of living things and the systems (e.g., coral reefs), of which they are part.[91]

Biofuels – Fuels derived from biomass including crops, crop wastes, animal wastes, or other biological sources

Carbon credits – Credits created by a regulatory body allowing emissions of a certain amount of carbon, sometimes representing verified carbon sequestration projects such as forests or regenerative agriculture.

Carbon cycle – The process by which carbon is emitted from terrestrial sources and reabsorbed by oceans and terrestrial biomass. The increased emissions by humans since the industrial revolution have unbalanced the global carbon cycle.

Carbon farming – The use of agricultural systems to store carbon, especially when credits for the stored carbon can be sold.

Carbon trading – National or international systems under which permits to emit carbon can be traded subject to a regulatory limit.

Environmental sustainability – the continued existence of an ecosystem in a healthy state, during which the ecosystem may change over time but does not significantly degrade in scope or function.

Eutrophication – excessive nutrient concentration in lakes or other body of water, frequently due to runoff from agricultural and urban sources, causing a dense growth of algae and degradation of the aquatic ecosystem due to lack of oxygen.

Food security – Adequate availability of food, especially to people in low-income areas.

Nationally Determined Contributions (NDCs) – Pledges made by countries under the 2015 Paris Agreement to reduce carbon emissions over time. The total NDCs currently pledged will reduce emissions below "business as usual" but are considered insufficient to meet global goals of limiting temperature increase to no more than 1.5°C.

Offset – Reduction or removal of carbon dioxide or other greenhouse gas emissions that compensates for emissions made elsewhere.

Regenerative agriculture – A system of farming principles and practices that enriches soils, increases biodiversity, improves watersheds, and enhances ecosystem services.

Water security – Adequate availability of water, particularly in areas challenged by water scarcity.

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[91] World Resource Institute glossary, http://www.wri.org

9. DISCUSSION QUESTIONS

1. How significant are agricultural systems in global climate change? What roles do they play in the emissions and absorption of carbon dioxide and other greenhouse gases? Why do you think that agricultural systems have played a relatively small role until recently in policies to combat climate change?

2. What economic principles are important in the formulation of policies to mitigate carbon emissions through agricultural practices? What market processes may strengthen or undermine policies for carbon reduction through forestry and agriculture?

3. Are biofuels a positive or a negative factor in climate policy? How would you distinguish the impacts of different biofuels and what might this imply for policies regarding biofuels?

4. What is the potential for reformed agricultural systems to contribute to climate policy and meet the carbon reduction goals set out by the Intergovernmental Panel on Climate Change and adopted in the Paris Climate Agreement? What kinds of policies are needed to achieve this potential?

10. WEB LINKS

1. **https://sites.tufts.edu/gdae/soils-forests-and-biomass-policy/**
   A selection of articles from the Tufts University Global Development and Environment Institute on soils, forests, and biomass policy, including information about the unique carbon storage value of mature forests and wetlands.

2. **https://4p1000.org/?lang=en**
   Website of the International "4 per 1000" Initiative, promoting "a transition towards a regenerative, productive, highly resilient agriculture, based on appropriate land and soil management, which creates jobs and income and thus leads to sustainable development."

3. **https://sites.tufts.edu/gdae/conferences-panels-and-events/**
   Forums and publications recording the activities of the Northeast Healthy Soils Network, bringing together farmers, academics, students, and policymakers from throughout the Northeast U.S. to promote regenerative agricultural policies.

4. **https://www.clara.earth**
   Website of the Climate Land Ambition and Rights Alliance, "charting ambitious paths for responding to climate change rooted in social justice and agroecology.

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