




THE PROMISE OF REGENERATIVE AGRICULTURE

The Science-Backed Business Case and Mechanisms to Drive Adoption

Jock Gilchrist





Sponsored and supported by

Sponsored by E2 and Natural Capitalism Solutions
Design and cover art by Rosie Jewell | rosiejewell.com

Contents

Acknowledgments

This work was funded by E2, a program of NRDC, through a generous grant from Barry Sternlicht, Founder of 1 Hotels and CEO & Chairman of Starwood Capital Group. Natural Capitalism Solutions also provided support. Paul Zorner, Susan Nedell, and Hunter Lovins provided indispensable guidance and mentorship. Paul, Susan, and Hunter, as well as Augustine Obour, Arohi Sharma, Darya Watnick, Abbey Warner, and Max Neumeyer edited and strengthened this report.

In addition, many advocates, farmers, scientists, policy experts, and professionals shared crucial insights and helped me develop ideas, including Adam Chambers, Ann Hancock, Anne Haddix, Avery Ellis, Brandon Welch, Brian DeCorte, Chris McGurrin, David Kolsrud, Deborah Bossio, Elizabeth Black, Ellie Cohen, Erin Foster West, Jeff Creque, Lauren Hafford, Marcus McCauley, Mark Guttridge, MJ Pickett, Nicole Lederer, Renata Brillinger, Ross Kenyon, Roy Pfaltzgraff, Steven Keleti, and Tony Michaels. My gratitude goes out to everyone listed here, without whom this work would not have been possible.

Many thanks to Rosie Jewell (rosiejewell.com), who created the cover art and design for this report.

Photo: Jen Theodore on Unsplash

Photo: Randy Fath on Unsplash

EXECUTIVE SUMMARY

Regenerative agriculture is a topic of increasing interest to the agriculture, climate change, policy, and business communities. Supporters claim it is a rare solution that is a winning proposition for each of these parties. Much of the attention it receives is based on statements about its potential to increase soil health, sequester sizable quantities of carbon, create more profit for farmers, and improve food security and farm resilience.

This report explores two major questions: is the excitement around regenerative agriculture substantial? If so, what are the best ways to increase its adoption? To answer these questions, this report first examines the scientific literature around the impacts of regenerative agriculture. Studies confirm that it offers significant potential to draw carbon out of the atmosphere and fight climate change. Regenerative management can sequester 3% to 30% of annual greenhouse gas emissions, depending on the underlying assumptions and scale of adoption, although its technical potential may be even higher. The accrual of carbon and improvement of soil health can stabilize or increase crop yield while reducing fertilizer and chemical application. In the process, it offers farmers more reliable yields and a net increase in profits, mostly through a reduction in input costs.

Regenerative agriculture rebuilds soil structure and thus vastly improves the ability of farmland to absorb and retain water. This makes crops less vulnerable to droughts and floods, both are which are predicted to grow in frequency under most global warming scenarios. The complex soil microbiome provides an array of ecosystem services which include natural suppression of pests and plant disease, reduced chemical leaching and volatilization, and improved water filtration and downstream water quality. Agroecological methods may also produce food that is healthier and more nutrient dense. Managing land to generate these advantages, however, is less formulaic than conventional farming and likely involves a transition period before benefits become immediately apparent.

Given these multifaceted economic and ecological benefits, the report next explores the mechanisms public and private sector actors pursue to increase adoption of regenerative practices. Soil health policy activity has ramped up in recent years. The 2018 Farm Bill was the first to include funding for soil health demonstration plots. The agricultural conservation activities under the USDA's NRCS are as popular as ever and in need of increased funding. Soil health policies are in various stages of realization in almost half of U.S. states, and the number of state governments with soil health policies in place nearly doubled, from 5 to 9, between 2019 and 2020.

Efforts to create market valuation for the ecosystem and carbon benefits farmers offer society are underway. Developing reliable, fast, and affordable soil testing remains the most important barrier to solve. Still, carbon marketplaces like Nori and Indigo Carbon are gaining traction. Market operators achieved a milestone in October 2020, when Locus Ag and Nori facilitated the first high-volume carbon credit validation through the CarbonNOW marketplace. An Ohio farmer received roughly 20,000 carbon credits, worth over $300,000, and sold $75,000 of those credits to Shopify to offset their emissions. In addition to market approaches, commitments to responsible supply chains and climate mitigation from corporations large and small have signaled that business interest in regenerative agriculture is here to stay.

Finally, based on the broad array of solutions presented, the report makes recommendations that address the key leverage points to make regenerative practices more mainstream. First, create reliable, affordable, and fast soil testing. Second, expand federal initiatives that already enjoy popularity and have institutional infrastructure in place. Third, build on and replicate the immense success of state-level soil health policies. Fourth, improve access to farming opportunities, especially for young and socially disadvantaged farmers. Fifth, educate and build awareness to stimulate consumer demand for regeneratively labeled and certified products. Sixth and finally, invest more in scaling carbon and ecosystem service markets to better ensure their success.

Regenerative agriculture sits at the nexus of some of the most important problems we face. Investing in its expansion is a shrewd and responsible decision for climate change, economics, farm profitability, and food system viability.


Photo: Jan Kopriva on Unsplash

INTRODUCTION AND PURPOSE STATEMENT

Agriculture is a foundational human endeavor. Besides sustaining the plants and animals that feed the world's population, it is also the most important anthropic interface with landscapes and ecosystems. Approximately 50% of the world's habitable land is under agricultural management.

The importance and scale of agriculture breeds a complexity of methodologies and philosophies, each of which are influenced by cultural norms, geography, ecology, history, and political economy. Only in the last 60 to 100 years has the now dominant agricultural paradigm emerged, one characterized by industrial scale and mechanistic production systems.

This paradigm has propagated a model of monocultures that rely heavily on chemical inputs to maximize crop yield. The maintenance or enhancement of biodiversity, crop nutrient density, soil health, and climatic stability are secondary concerns. The emergence of this production model coincides with the

Photo: David Wirzba on Unsplash

degradation of the world's topsoil, loss of soil organic matter (SOM), and a sector-wide greenhouse gas (GHG) footprint second only to heat and electricity generation.

In many sites of intensive industrial agriculture, soil has withered from a teeming, living microbiome to dirt. In the process it becomes erosion-prone, which reduces soil fertility and pollutes air and water. Its ability to retain water diminishes, which, when combined with excessive fertilizer application, contributes to nitrate leaching and phosphorus losses to water bodies. This is responsible for hypoxic and dead zones of marine life and freshwater that requires expensive treatments to be potable.

Regenerative agriculture is a way of reimagining the human relationship with the land, climate, soil, and the food that comes from them. In fact, it is less a new formulation than a return to our ancestral agricultural roots. Many Indigenous production methods encompassed principles of biodiversity and land stewardship that today's regenerative movement seeks to reintegrate. The novel challenge faced today is to adapt regenerative management systems to the unique suite of challenges the 21st century offers. Agriculture sits at the nexus of climate change, food security, environmental quality, resource conservation and efficiency, social justice, and rural economic wellbeing for the farmers who feed the world. Supporters contend that regenerative agriculture offers improvements in each of these dimensions that conventional agriculture cannot.

The purpose of this paper is to describe the justification for this assertion and explain pathways for scaling up regenerative agriculture. It is divided into 2 major sections. First, the paper examines the multitude of benefits that regenerative agriculture can offer and reviews the science to support any claims made. A voluminous literature underpins its economic, ecological, and climate benefits. The literature review aims to support regenerative agriculture not just as a solution heralded by environmentalists, but as one that would make good business sense even in the absence of environmental benefits.

Having explored the variety of cobenefits offered by regenerative agriculture, the second half of this paper analyzes public and private mechanisms to drive its adoption. It examines federal, state, and local policies that have found success in promoting the adoption of regenerative agriculture. It also describes market-based mechanisms in the design or implementation phase that offer promise.

This paper is geared towards three main audiences. First, it is for the policymaking community, both legislators and advocates. This group will find this policy-relevant research helpful in grasping the economic and environmental advantages as well as practical steps that are most likely to increase adoption. Second, it is for the agricultural community, who may benefit from understanding the credibility of claims made about regenerative agriculture's benefits, as well as the many pathways to adoption that are being explored by public and private actors. Finally, it is for those interested in climate change mitigation, environmental improvement, and the design of multidisciplinary and inclusive social solutions.

Photo: Annie Spratt on Unsplash

What is Regenerative Agriculture?

Regenerative agriculture is a way of farming that replenishes the functional capacities of the land. It restores the complex soil ecosystem and improves its ability to produce food. In the process, it offers a suite of benefits including reduced input costs, stabilized or increased crop yields, carbon sequestration, SOM accrual, pollution reduction, and food security. These benefits can make farming and ranching more profitable.

Beyond this description, regenerative agriculture is a notoriously difficult concept to precisely define (Newton, Civita, Frankel-Goldwater, Bartel, & Johns, 2020). This is partly because local climatic, ecological, and sociocultural contexts influence which practices are feasible, so it may manifest differently at each site. The descriptor "regenerative" is not applied in a binary manner: no farm is simply regenerative or not regenerative. Introducing regenerative practices generally happens in stages over time. Many farms use some regenerative management; fewer use only regenerative management. Additionally, several terms exist that have similar meanings to regenerative agriculture, such as agroecology, biodynamic farming, soil health, and holistic management.


Photo: Pete Nuij on Unsplash

Perhaps the most important conceptual feature of regenerative agriculture is a shift in mindset. Instead of extracting nutrients from the soil, regenerative growers employ management techniques that rebuild soil biology. Regenerative agriculture seeks to understand, harness, and amplify natural systems in the service of healthy land and profitable food production.

Overall, regenerative practices tend to cause a dual, interrelated shift in farm outcomes: as it is practiced, soil biology is reinvigorated and becomes more capable of sustaining a healthy ecosystem. Soil health improves and crop production can increase. At the same time, as soil rebuilds, the need for chemical inputs such as fertilizers, herbicides, pesticides, fungicides, and nematicides is reduced or eliminated because their functions are sustained by soil biology. In this way, regeneratively managed farms and ranches can see an increase in income coupled with a decrease in input costs, thus improving the financial stability of the operation.

While pinning down a conceptual definition of regenerative agriculture can be challenging, its practices are clearer. A suite of well-understood principles and techniques define regenerative agriculture on a practical level. The “five principles” of soil health (or regenerative agriculture) are:

Maximize Ground Cover: Practices that maximize ground cover offer a variety of natural benefits to soil and crop production by protecting bare soil. Ground cover, through a cover crop, crop residue, or living mulch, insulates and buffers soil to keep temperature in an ideal range for its microbial life. It also dissipates raindrop energy, which, when unimpeded, can create soil compaction or a crust that reduces permeability. Adequate soil cover reduces the evaporation rate, which can increase water storage and reduce water input needs. Soil cover reduces erosion from water and wind and suppresses weed growth (Fuhrer, n.d.).

How this differs from conventional farming: Conventional farming often leaves the soil bare after crop harvest, or in between crop rows during the growing season.

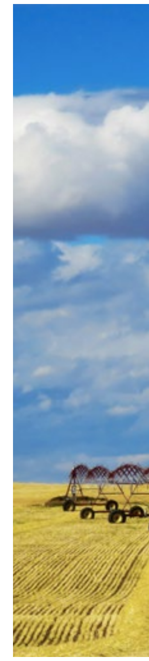
Continual Living Root in the Soil: Plants supply up to 40% of their photosynthetically fixed carbon as root exudates to nourish the soil microbiome (Badri & Vivanco, 2009). This helps foster a robust and diverse microbial community for a greater portion of the year. Certain species of crops can survive well in the cooler spring and fall months before planting and after harvest. These practices increase soil health and resilience (Fuhrer, n.d.).

How this differs from conventional farming: Conventional farming tends to focus on maximizing yield during the summer-centered growing season. It does not prioritize soil management in the remainder of the year, and outside of some preparatory work, it "leaves more time to go fishing," in the words of one farmer.

Minimize Soil Disturbance: Soil disturbance usually refers to forms of physical disturbance such as tillage, although chemical (e.g. over-application of fertilizer) and biological (e.g. overgrazing) disturbance can also occur. Tillage destroys soil structure. A stable soil structure is built with aggregates of minerals, organic matter, and water, with pore spaces in between. Maintaining soil structure is essential for allowing water and oxygen to infiltrate, facilitating the interactions of bacteria, fungi, and other members of the soil food web, and improving SOM content (Fuhrer, n.d.).

How this differs from conventional farming: Conventional farming often involves tilling fields 1 or more times per year. While it can temporarily stimulate microbial activity, it also leads to wind *and water erosion, soil crusting, and loss of SOM. Overuse of chemicals and livestock overgrazing can also disrupt the soil microbiome even without physical destruction the soil.*

Plant Diversity: Each plant species has characteristics that nourish different components of the soil microbiome. This diversity contributes to healthy soils that are less dependent on chemical inputs and have natural pest- and pathogen-suppressive qualities (Fuhrer, n.d.). Plant diversity can be temporal (e.g. crop rotation), spatial (e.g. intercropping), or both.



How this differs from conventional farming: Much of America's farmland was once a polyculture of perennial plants. It is now largely managed as monocultures of annual crops. This can deplete soil of its natural microbial biodiversity and promote a reliance on fertilizers and other chemical inputs.

Livestock Integration and Holistic Management: Livestock can be integrated into crop production systems or form a separate production enterprise. Animals can be managed in a way that stimulates plant photosynthesis and thus soil carbon sequestration (SCS); transforms plant residue from hard-to-decompose, carbon-rich material into low-carbon material that soil can use more readily; and reduces weed pressure. By restricting grazing duration and rotating animals through a series of paddocks, overgrazing is prevented, manure is recycled, and ecosystem and carbon benefits available through holistic livestock management accrue (Fuhrer, n.d.).

How this differs from conventional farming: Livestock are typically allowed to continuously graze whole fields until the plant life is nearly eliminated. In conventional farming, livestock are rarely integrated with crop production, which leads to minimal recycling of animal manure. Alternatively, some livestock live in concentrated animal feeding operations (CAFOs), which generate GHG emissions and pollution and present ethical issues.

A number of farming and ranching techniques translate these principles into action on the ground. Some of the most common regenerative practices include:

- **Cover Cropping**, a way of keeping soil covered and facilitating a more diverse soil ecology (e.g. legume cover crops can foster rhizobia growth which fix nitrogen from the


Photo: Pete Gonzalez on Unsplash

atmosphere and reduce fertilizer needs)

- **Reduced or No Tillage**, which leaves soil structures intact and prevents soil erosion and C emissions

- **Compost or Manure Application**, which diverts waste from landfills, supplies some or all fertilization needs, and rapidly builds SOM

- **Crop Diversity and Rotation**, which enhance ecosystem and soil health and can increase yields

- **Rotational Grazing**, a way of managing livestock that improves plant growth, restores grassland health, ameliorates ethical concerns around animals, and avoids some of the harm done by continuous grazing

- **Living Mulch or Crop Residues** keep the soil covered, help soils retain water, and improve resource efficiency

Many more practices improve soil health and thus could be considered part of a regenerative management system. Some of these include intercropping, alley cropping, agroforestry, silvopasture, biochar, and perennial cropping.

THE BUSINESS, CLIMATE, AND COBENEFIT CASE FOR REGENERATIVE AGRICULTURE

Regenerative agriculture offers improvements to a diverse mix of environmental, economic, and social problems. It can appeal to priorities on both sides of the political spectrum. It speaks to the concerns of the environmental and climate mitigation community, and it speaks equally to parties for whom farm profitability and farmer livelihoods are top priority (Carlisle, 2014). These eclectic cobenefits make regenerative agriculture a potent part of the solution for several complicated 21st century problems. This section reviews these benefits.

Photo: Federico Respini on Unsplash

Carbon Sequestration Potential

Soil carbon sequestration (SCS) improves a variety of soil functions, including soil fertility, water holding capacity, and microbial health. Storage of carbon in the soil via agricultural management reduces the concentration of atmospheric CO_2, which helps fight climate change. Exactly how much carbon can regenerative agriculture draw out of the atmosphere and sequester in the soil? The scientific literature offers a wide range of numbers for this quantity.

The variety of estimates corresponds to different field conditions and different assumptions about the multitude of variables that influence SCS rate and capacity. For example, studies with the highest estimates typically assume longer SCS time horizons, higher adoption rates, optimal political and societal support, and ideal climatic conditions and soil profiles. The context of the study often determines whether these assumptions are justified.

Practical constraints tend to reduce the total SCS potential below the theoretical limit. Ingram and Hernandes suggest that SCS capacity can be conceptualized by three concentric parameters: the soil type establishes the upper bound for SCS "**potential**"; climatic factors impact net primary productivity of plants, which establishes "**attainable**" SCS; and management practices determine how much "**actual**" SCS is achieved, if any (2001). Potential SCS is always greater than attainable SCS, which is greater than actual SCS (Figure 1). For example, even under ideal climatic conditions and management practices, a soil that is high in sand and low in clay will have lower SCS potential than a clay loam soil. On the other hand, a sandy soil with optimal management may store more C than a clay soil with conventional management. With this framework in mind, we can look at SCS estimates in the peer-reviewed literature.

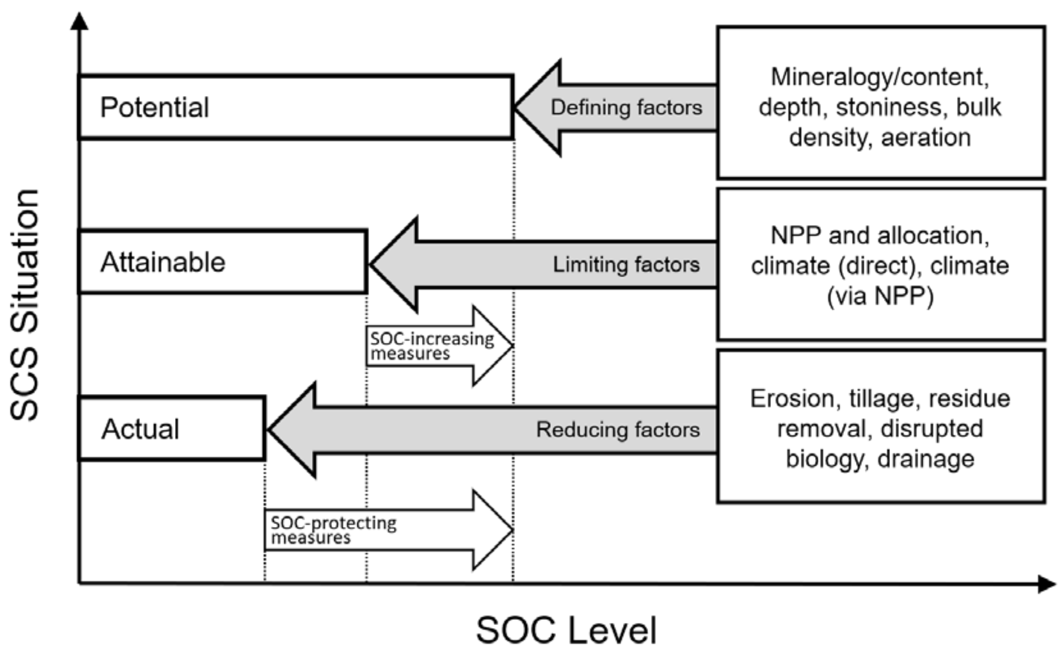


Figure 1. Adapted from Ingram and Hernandes, 2001.

Croplands: Estimating SCS Potential Based on Historic Soil C Loss

One way to understand SCS potential is to estimate the amount of C historically stored in soils, and then to assess how much C has been lost subsequently from soils. Lal estimates the global soil C pool to be 2500 Petagrams (Pg)[1] (2004). Paustian and colleagues say there are 2400 Pg of C down to a depth of 2 meters (2016). Similarly, Batjes puts the soil C to 2 m of depth between 2376 and 2456 Pg (2014).

The quantity of C lost from the soils is more difficult to assess, and there is less agreement on this figure. A study by Sanderman, et al., puts the historic C loss at 116 Pg (Sanderman, Hengl, & Fiske, 2017; Sanderman, Hengl, & Fiske, 2018). Early estimates ranged from 40 Pg on the low end to 500 Pg on the high-end (Houghton, 1998; Wallace, 1994). Lal has estimated 78 Pg (2004), but one of the most commonly cited figures is his later estimate of 135 Pg (2018).

To contextualize this, human activity added 555 Pg of C to the atmosphere between 1750 and 2011 (Ciais, et al., 2013). The threshold of 1000 Pg of added C is regarded as a climate change tipping point. Beyond this point, global atmospheric temperatures will surpass 2 degrees Celsius of warming above pre-Industrial levels (Allen, et al., 2009).

Between 1750 and 2011, the concentration of CO_2 in the atmosphere grew from 278 ppm to 390.5 ppm (Ciais, et al., 2013). Today, atmospheric CO_2 is around 413 ppm (NOAA, 2020).

If lost soil C could be fully restored, it would draw 116 Pg of C out of the atmosphere, using Sanderman, Hengl, and Fiske's estimate (2017). This translates to 426 Pg of CO_2 (because the molecular weight of CO_2 is 3.67 times that of C) and 54 ppm of CO_2 (because 1 ppm of CO_2 equates to 2.13 Pg C (Trenberth, 1981)). Thus, based on an atmospheric CO_2 increase of 135 ppm between 1750 and today, SCS can theoretically absorb about 40% of the total CO_2 humans have added to the atmosphere.

1 One Pg = 1 billion metric tons.

Based on a restoration of 116 Pg of lost C back to the soil, SCS can theoretically absorb 20% of the ~600 Pg C our industrial activities and land use have historically emitted.

There is little agreement on these figures. Soil scientist and 2020 World Food Prize recipient Rattan Lal puts the technical potential for SCS even higher. In 2018 he stated that regenerative agricultural practices can remove up to 75 ppm of CO_2 from the atmosphere through SCS (DeMartini). Elsewhere he has stated that regenerative agriculture, combined with an aggressive global tree-planting and revegetation campaign, could sequester up to 157 ppm of CO_2 in the world's soils (Chasan, 2019). If this figure is correct, it would effectively absorb all anthropogenic C emissions and restore the CO_2 concentration to pre-industrial levels.

These numbers may represent the upper limit of what is possible – either the "potential" or the "attainable" SCS in Ingram and Fernandes's framework (2001). But the Sanderman, et al., study, which put forth the figure of 116 Pg, itself goes on to say that the maximum SCS to be expected is around 28 Pg (2017). Restoring 116 Pg worth of SCS is not possible, according to the authors, because SCS benefits tend to accrue in soils for a ~20-year horizon before plateauing, and because of social, political, and technical barriers.[2]

This reasoning is up for debate. According to one argument, peer-reviewed climate change literature tends to be biased towards conservative estimates to avoid accusations of climate alarmism (Brysse, Oreskes, O'Reilly, & Oppenheimer, 2013), or, in the case of SCS, of unrealistic optimism. When an initial estimate for SCS potential is presented, some researchers then reduce that figure from a "theoretical" one to a "practical" one. They do so to account for SCS accrual plateaus; economic, social, and political barriers; adoption rates; and climatic conditions less conducive to SCS.

Other researchers, however, suggest that it may be possible to restore even more C to soils than they originally held. Soils were not "designed" by nature to be C storage banks, but if human

2 These barriers could include local norms around conventional farming practices ("this is the way we've always done it"), government policies that incentivize the status quo, lack of mentorship and training in new practices, poor soil testing capabilities, and inadequate funding to spur adoption of new practices.

management explicitly aims for that, it may be that soils can hold more C than they did in their prototypical state. Some field studies bear this out, which will be discussed in the next subsection.

While Sanderman and colleagues state that 116 Pg of C was lost from soils and that we can restore 28 Pg of C under optimal conditions, other studies refute the reduction of the original figure. For example, Sanderman and colleagues assume that SCS stops after 20 years, but a study by Conant, Paustian, and Elliott shows C accrual lasting for at least 40 years (2001). Lal has suggested that soil C can accrue for 50 years (2011). And a World Bank report also affirms that "theoretically, the potential soil carbon sequestration capacity is equivalent to the cumulative historical carbon loss" (2012).

The highest estimates, however, assume a suite of conditions ideal for SCS, and thus should properly be viewed as theoretical. For example, it may be the case that if regenerative management were practiced on all of the world's agricultural lands, all of the C historically lost from soils, and maybe more, could be sequestered. But is it feasible to expect adoption on all of the world's agricultural lands, which are managed by millions of stakeholders across a range of cultures, socioeconomic brackets, and institutional backing?

Carbon storage in soils is a critical element in the fight against climate change. If soils have lost 116-135 Pg of their historic C content, and contributed 426-495 Pg of CO_2 to the atmosphere, then sequestering even a fraction of that C is an important climate solution. SCS estimates based on restoring historically lost soil C vary from a few percentage points of annual emissions to the majority of annual emissions. Other studies take a different approach and offer further insight into agricultural SCS potential.

Croplands: Estimating SCS Potential Based on Technical Analyses

According to Lal's most recent estimate, global SCS technical potential is 2.45 Pg C/year (2018). This is significant because Lal has revised his SCS estimates upwards over the years as more data becomes available on soil carbon and climate dynamics. In

2004, he estimated the global SCS potential to be 0.9 Pg C/year (Lal). In 2008, he estimated 1 Pg C/year for 50 to 60 years (Lal). Later his research suggested that global SCS potential is 2.1 Pg C/year for up to 50 years, creating "a drawdown of 110 ppm of atmospheric CO_2 abundance" (Lal, 2011).

Other sources are on par with Lal's most recent estimate. The IPCC's Special Report on Climate Change and Land estimates SCS potential in grasslands and croplands to be between 0.4 and 8.6 Pg CO_2 (eq)/year, or up to 2.34 Pg C(eq)/year (Shukla, et al., 2019). Two studies by Paustian and colleagues estimate that "the overall mitigation potential of existing (and potential future) soil management practices could be as high as ~8 Pg CO_2(eq)/year," or 2.18 Pg C(eq)/year (Paustian, et al., 2016; Paustian, Larson, Kent, Marx, & Swan, 2019). Zomer, Bossio, Sommer, and Verchot find a global cropland SCS potential of 1.38 Pg C/year (2017). An annual review puts global SCS potential at up to 5 Pg CO_2/year, or 1.36 Pg C/year (Smith, et al., 2019). The UC Davis website suggests a range of between 1.5 and 5.5 Pg C/year (Kerlin, 2017).

Smith, Powlson, Glendining, and Smith find that a 100% conversion to no-till agriculture in Europe would, through enhanced SCS and reduced fossil fuel use, mitigate all agricultural fossil fuel C emissions in Europe (1998). Fargione and colleagues estimate that incorporating cover crops on 85% of U.S. cropland would sequester 100 Teragrams (Tg)[3] C each year, equivalent to 18% of emissions from agricultural production and 1.5% of the total U.S. carbon footprint (Fargione, et al., 2018).

To contextualize these estimates, global annual fossil fuel emissions are approximately 10 Pg C (EPA, 2019). If Lal's 2018 estimate is correct, then SCS can sequester 25% of the world's fossil fuel emissions each year (Table 1, opposite).

Some studies are explicitly cautionary, however, about promoting regenerative agriculture as a climate change solution. One paper, entitled, "Managing for soil carbon sequestration: Let's get realistic," says that the most promising techniques and practices are not likely to balance any more than 5% of global annual fossil fuel emissions (Schlesinger & Amundson, 2018). The authors warn that a focus on SCS through soils may distract from the importance of reducing reliance on fossil fuels, and that "no

3 One Teragram is equal to 1,000,000 Megagrams and to 0.1 Pg.

Technical estimate of global SCS potential, expressed as an approximate percentage of annual emissions[4]	Source
20% to 35%	Minasny, et al., 2017
25%	Lal, 2018
1.1% to 23%	Shukla, et al., 2019
22%	Paustian, et al., 2016
15%	Zomer, Bossio, Sommer, and Verchot 2017
14%	Smith, et al., 2019
3.6% to 7.5%[5]	Sommer and Bossio, 2014
5%	Schlesinger and Amundson, 2018
5%	Tan, 2018

Table 1.

coherent economic strategy has been offered that will induce millions of individual farmers to adopt and maintain prescribed practices on multidecadal timescales" (2018). Wilman makes estimates in a similar range and also encourages restraint (2011).

Other researchers have echoed the 5% figure as a more realistic estimate (Tan, 2018). Powlson, Whitmore, and Goulding suggest that some SCS studies are misleading in that adding organic matter such as manure or crop residues do not constitute a drawdown of C from the atmospheric C pool (2011). Converting land from annual cropping to perennial cropping, forest, or grassland would capture C, but could be negated by land use change from native vegetation to agricultural management elsewhere (Powlson, Whitmore, & Goulding, 2011). They caution that "an over-emphasis on the benefits of soil C sequestration may detract from other measures that are at least as effective in combating climate change, including slowing deforestation and increasing efficiency of N use in order to decrease N_2O emissions" (Powlson, Whitmore, & Goulding, 2011). A global modeling study predicted between 31 and 64 Pg of cumulative global SCS

4 Author's calculations. Assumes C emissions of 10 Pg/yr when figure not expressed as percentage in original research.

5 Assumes a continued emissions rate of 10 Pg C/year through 2100.

potential through 2100 and echoes a warning about the limited potential of agricultural SCS for climate mitigation (Sommer & Bossio, 2014). Many of the criticisms just enumerated, though, have been vehemently questioned by other members of the soil science community (Paustian, et al., 2020).

The French government launched an initiative called "4 per 1000," which aims to improve global soil quality while mitigating anthropogenic GHG emissions (Secrétariat Exécutif, 2018). This numerical goal was based on a blanket calculation of annual anthropogenic C emissions (~9 Pg) divided by the total estimated soil C stock to 2m (~2400 Pg) (Minasny, et al., 2017). If soils could sequester 0.4% of their total C stock each year, it would be enough to offset the increase in atmospheric CO_2.

The authors of a meta-analysis acknowledge that not all of the earth's land area is agricultural land, and if all of the agricultural land adopted best management practices, about 30%, not 100%, of anthropogenic C emissions could be absorbed (Minasny, et al., 2017). While the SCS goal rate of 0.4% per year is aspirational, the authors concluded that in many regions of the world, a SCS rate of 0.4%/year is achievable, and in some regions with low soil C saturation, a rate of 1% per year is achievable in the early adoption stage (Minasny, et al., 2017). This assumes heavy government investment and support and significant adoption rates. Chambers, Lal, and Paustian examine the feasibility of implementing 4 per 1000 in the United States, and conclude that, if brought into conjunction with existing U.S. soil health initiatives, could offset half of the U.S.'s agricultural carbon footprint by 2050, or about 5% of the U.S.'s total carbon footprint (2016).[6] Other studies dispute the feasibility of 4 per 1000 due to biophysical, socioeconomic, and political barriers (Baveye, Berthelin, Tessier, & Lemaire, 2018; Poulton, Johnston, Macdonald, White, & Powlson, 2018; Rumpel, et al., 2019).

6 Eagle, et al., however, find that a suite of regenerative practices could mitigate the entire GHG footprint of the U.S. agriculture sector (2012).

Croplands: Estimating SCS Potential Based on Field Studies

Perhaps more important than the theoretical or technical analyses common in the literature are real-world experiments gathering "ground-truthed" data. A multitude of field studies implement one, or some, regenerative practices, and quantify the resulting C accrual in soils.

At the field level, soil carbon stocks vary widely, with observations ranging from 1.41 Megagrams (Mg)[7] C per hectare (ha) in a Uruguayan soybean farm up to 197 Mg C/ha in an American grassland (Mazzilli, Kemanian, Ernst, Jackson, & Pineiro, 2015; Lee, Owens, & Doolittle, 2007). A study that compiled 281 soil C stock measurements from climates and soil types around the world found an average soil C stock of 56 Mg C/ha (Mathew, Shimelis, Mutema, & Chaplot, 2017). Figure 2 shows the global distribution of soil C stocks.

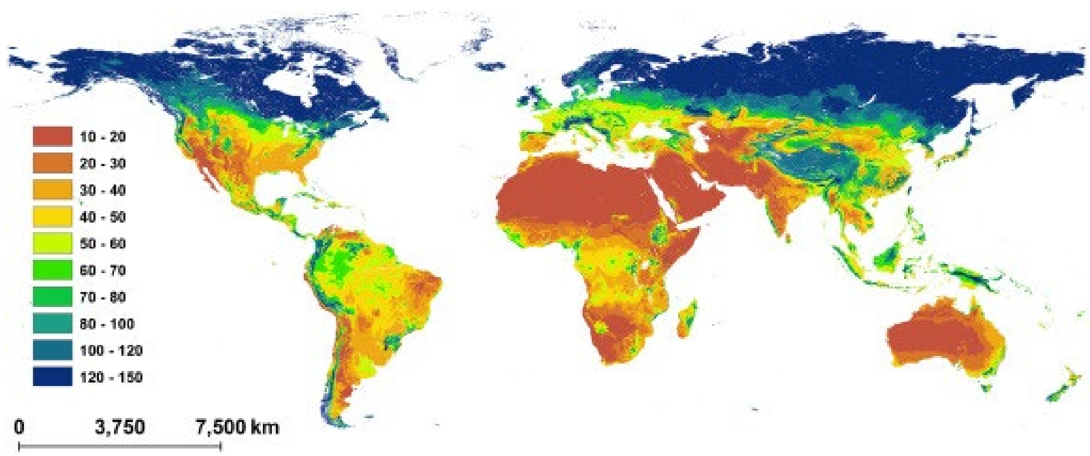


Figure 2. Global C stocks in the top 30 cm of soil, expressed in Mg C/ha. From Minasny, et al., 2017.

A quick calculation can put these numbers in context. It is commonly assumed that a "furrow slice," or the top 6.7 inches of an acre of soil, weighs roughly 2 million pounds (Landschoot, 2016). If a soil has 1% SOM, this means a furrow slide contains 20,000 pounds of SOM. This amounts to 11,600 pounds of C, because SOM is about 58% SOC (Lal, 2004). Converting pounds

7 One Megagram = 1 metric ton.

to megagrams, and acres to hectares, we find that there are about 13 Mg C in the top 6.7 inches of a hectare of soil with 1% SOM. Most field study soil measurements are deeper than 6.7 inches, however; many offer their numbers for the top meter of soil. SOC is usually most abundant in the top several dozen centimeters of the soil horizon rather than evenly distributed through the profile (Gregorich, Greer, Anderson, & Liang, 1998). Thus, a C content of 30 (± 15) Mg/ha in low C, arid, or degraded soils makes sense.

This fits with estimates from the literature. Lal has said that "the SOC pool to 1m depth ranges from *27 Mg/ha* in arid climates to *725 Mg/ha* in organic soils in cold regions, and a predominant range of *45 to 136 Mg/ha*" (italics indicate my own conversion from tons to Mg) (2004). The high upper bound is echoed by Hribljan and colleagues, who measured 1282 Mg C/ha to a 3.8m depth in high-altitude Ecuadorian peatlands (2016).

This also squares with estimates on soil degradation. Soils with the most severe degradation have likely lost between half and two-thirds of their original C content (Lal, 2004). According to Lal, "most croplands have lost 30-40 Mg C/ha and most degraded soils may have lost 40-60 Mg C/ha" (2004). Elsewhere he says "some soils have lost as much as *18 to 73 Mg C/ha* mostly emitted to the atmosphere" (2004). Thus, it is reasonable to assume that a healthy, undisturbed soil may have originally stored 60 to 120 Mg C/ha, depending on latitude, and SOC in degraded soils could be anywhere from 5 to 50 Mg C/ha.

Cover crops are one of the more promising regenerative practices for their SCS and soil health benefits. A field study in Brazil found that a maize production system that incorporated mucuna as a cover crop sequestered 1.9 Mg of C/ha/year (Amado, Bayer, Eltz, & Brum, 2001). Similarly, a 13-year field study in Brazil found that a crop rotation of oats–common vetch/maize–cowpea combined with conservation tillage and crop residue sequestered 2 Mg C/ha/year (Lovato, 2001). Both of these studies took place in southern Brazil. Assuming a SCS rate of 0.5 Mg/ha/year, widespread adoption of these regenerative practices in just this region of southern Brazil could sequester 5 Tg C per year (Bot & Benites, 2005). Brazil's national annual emissions at the time of these studies was 22.9 Tg of C (Bot & Benites, 2005).

A meta-analysis of the global SCS potential from only cover cropping found that SCS occurs at an average rate of 0.32 Mg C/ha/year for the first 50 years in the top 22 cm of soil, and that C saturation would not be reached for 155 years (Poeplau & Don, 2015). According to the authors, over 155 years, 16.7 Mg C/ha could be added to soils in the top 22cm, sequestering 0.12 Pg C/year globally (Poeplau & Don, 2015). A second global meta-analysis found that cover crops contribute 0.56 Mg C/ha/year of SCS (Abdalla, et al., 2019). In the U.S., cover cropping can result in SCS rates of between 0.1 and 0.88 Mg C/ha/year (Eagle, et al., 2012).

Compost amendments are another avenue to build SOC. A Technical Report for California's Fourth Climate Change Assessment found that a one-time quarter-inch compost amendment on 15 rangeland sites was enough to grow the carbon stock in soils by 2.1 Mg/ha in the first year (Silver, Vergara, & Mayer, 2018). In a Mediterranean vegetable farm, it was found that compost application for two years increased the SOC stock by 4.9 Mg/ha over that time period (Farina, et al., 2018). The authors extrapolate from their field trials that over 20 years, the application of green manure would increase SOC by 19.8 Mg C/ha, and compost application would increase SOC by 16.5 Mg C/ha (Farina, et al., 2018).

A field trial in New Mexico found that regenerative management that aimed to **enhance the soil microbial community and improve fungal health** increased soil C by 10.27 Mg/ha/year (this data is preliminary and has not yet been peer-reviewed) (Johnson, Ellington, & Eaton, 2015). Eric Toensmeier's book, "The Carbon Farming Solution," synthesizes research that has demonstrated SCS rates of 2 to 6 Mg/ha/year for organic annual crops with **rotation** and compost, 1 to 26 Mg/ha/year for perennial crops, and 3 to 41 Mg/ha/year for **agroforestry** (2016). A review of studies that practiced regenerative **grassland management** found that SCS ranged from 0.11 to greater than 1 Mg C/ha/year (Conant, Cerri, Osborne, & Paustian, 2017).

A meta-analysis of Chinese agricultural soils found that treatments of **organic fertilizer, organic and chemical fertilizer, and crop residue** each increased SOM significantly (Yu'e, et al., 2018). China's cropland topsoil once contained 5.1 Pg of C, but has lost 2 Pg of C due to cultivation, representing an immense level of soil degradation (Song, Li, Pan, & Zhang, 2005).

Perennial crops and grasses that establish deep root systems tend to amplify SCS potential (Guo & Gifford, 2002). Studies of South American savannas have indicated that the introduction of African grasses that are deep-rooted and store C deep in soils can result in SCS rates of between 7 and 13 Mg C/ha/year for at least the first several years (Fisher, et al., 1994; Fisher, et al., 2007; Post & Kwon, 2000). Similarly, a related study found that the conversion of cropland from annual to perennial cropping resulted in an average SCS rate of 0.3 Mg C/ha/year over 20 years in the top 30cm of soil, and 0.29 Mg C/ha/year over 20 years in the top 1m of soil (Ledo, et al., 2020). Interestingly, conversion from native pasture to perennial crops decreased SOC content by a total of 10% over a 20 year time period (Ledo, et al., 2020). In the U.S. Pacific Northwest, mixed perennial-annual cropping systems increase SCS by .69 Mg C/ha/year over 12 years compared to annual cropping alone (Brown & Huggins, 2012).

The impact of **conservation tillage** (reduced or no till) on SCS varies widely by region. Ogle, Breidt, and Paustian found that the conversion from conventional to no till increased SOC by 23% in tropical moist climates and by 10% in temperate dry climates over 20 years (2005). Sun, et al., found that reduced or no till resulted in a growth in SOC stocks only in warm, arid, and moderately humid regions (2020). Brown and Huggins found a similar result in the dryland cropping region of the U.S. Pacific Northwest, where conversion to no till increased SCS by 0.21 Mg C/ha/year over 12 years (2012). SOC stocks in cooler, wetter regions tend to have mixed responses to conservation tillage, and it can decrease SOC and crop productivity in some cases (Sun, et al., 2020; Ogle, Swan, & Paustian, 2012). A long-term study measured SCS after conversion to no till in semi-arid loam soils in Spain. It found significantly enhanced SCS under no till over the 17-year study duration, with a peak SCS rate of 8.43 Mg C/year 8 years after conversion (López-Fando & Pardo, 2011).

Gabe Brown is an American pioneer of regenerative farming based in North Dakota. Brown is often held up as the apogee of potential for regenerative agriculture, but it is important to hold success stories in the proper light. Brown's achievements, while trailblazing and impressive, may not be possible on every farm and ranch.

That said, when Brown took over operations of his farm in the early 1990s, SOM was around 1.7% (Brown G. , 2014). By 2014, his soils were 6% SOM (Brown G. , 2014). He reported that one of his plots of land reached 11.1% in 2013 (Brown G. , 2014). His soils contain about 215 Mg C/ha in the top 1.2m of earth, while 23 to 67 Mg C are the average for the conventionally managed lands in the same region (CSU Chico, 2019). Meanwhile he averages 127 bushels of corn per acre, whereas the county average is 100 (Tallman, 2012).

Pasture and Rangeland: SCS Potential and Ecosystem Benefits Using Managed Grazing

Livestock can be either a source or a sink of GHG emissions depending on how they are managed. When they are allowed to graze a field continuously, plants do not have time to recover. This leads to ailing plant life and bare soils that contain less SOM and erode more easily (Stika, 2016). In this "conventional grazing" scenario, livestock tends to have net positive GHG emissions.

Alternative livestock management has many names, such as Adaptive Multi-Paddock (AMP) grazing, rotational grazing, conservation grazing, management-intensive grazing, and holistic livestock management (Figure 3). Each of these practices

Figure 3. In rotational grazing schemes, livestock move from one plot to another in dense packs. Photo free for commercial use without attribution.

revolve around the same principles but might have minor differences in methodology. They modify the grazing patterns of livestock to be more beneficial to plants and soils. They generally require animals to move in a dense pack from one demarcated plot to another. As animals move, they graze such that plants are stimulated enough to promote new root and shoot growth, but not so much that they are overly damaged. The herd is then rotated to a new paddock, allowing the previous plot to recover. The urine and manure they leave behind, facilitated and funneled by the imprints of their hooves, fertilize the plot and improve soil health (Stika, 2016).

This grazing strategy emulates the mutual relationship that researchers think existed between ruminants and the native prairies and grasslands they once freely inhabited (Itzkan, 2012). Historically, these herds would have moved frequently in dense packs as they avoided predators. Retallack even posits that the "coevolution of grasses and grazers," and subsequent inception and proliferation of grasslands, drove the global cooling of the dominant climate regime in the last 40 million years, similar to how the Devonian inception of forests created new soils and climate regimes (2013). Thus, managed grazing restores the relationship that once existed between herds of ruminants on plains and the rich soils present at that time.

Proponents of this method claim that these practices can dramatically improve SCS, grass cover, surface water, biodiversity, invasive species suppression, farm profitability, and overall ecosystem health (Itzkan, 2012; Savory, 1983; Teague & Kreuter, 2020). There are also critics of this method. Both are examined below.

A study of north Texas prairie land found that AMP grazing, compared to heavy continuous grazing, resulted in significantly improved soil aggregate stability, SOM levels, cation exchange capacity, water holding capacity, and nutrient availability (Teague, et al., 2011). The SCS rate was 3 Mg C/ha/year for 10 years (Teague, et al., 2011; Teague, et al., 2016). A study that examined the conversion of heavy continuous grazing to AMP grazing in the southern Great Plains found that this conversion shifted the operation from a GHG source to a sink, absorbing 3.53 Mg/ha/year for what the authors believe to be decades (Wang, Teague, Park, & Bevers, 2015).

A study that examined the impact of bison grazing techniques on prairie health in South Dakota found that, compared to heavy continuous grazing, AMP grazing resulted in "increased fine litter, improved water infiltration, two to three times the available forage biomass, improved plant composition, decrease in invasive plants, and decrease in bare ground," along with greater C content (Hillenbrand, Thompson, Wang, Apfelbaum, & Teague, 2019, p. 156).

A life-cycle analysis of GHG emissions of grass-finished beef systems found that AMP grazing resulted in an SCS rate of 3.59 Mg/ha/year over a 4 year period, and changed the emissions rate per cow from 9.62 kg CO_2e/kg carcass weight to -6.65 kg CO_2e/kg carcass weight (Stanley, Rowntree, Beede, DeLonge, & Hamm, 2018). The authors caution that the high SCS rate may be indicative of a degraded soil that can capture C relatively quickly, whereas soils closer to C saturation may absorb C more slowly. For example, Conant, Six, and Paustian observed an average rate of 0.41 Mg C/ha/year over a multidecadal timespan (2003). Conant, Paustian, and Elliott studied improved pasture management, which included both managed grazing and other regenerative practices, and observed SCS rates of up to 3 Mg C/ha/year, with an average of 0.54 Mg C/ha/year for 40 years (2001).

Machmuller and colleagues found that soils converted from tilled cropland to pasture under management-intensive grazing in the southeastern U.S. accumulated C at a rate of 8 Mg/ha/year (2015). They also offer the striking extrapolation that "if just 10% of the 9 million hectares of cropland in the southeastern United States (average C stock: 10 Mg C/ha) were converted to management-intensive grazing land," 27 Tg C would accumulate over 6 years (2015).

Will Harris, another well-known regenerative farming innovator who considers his approach to be "radically traditional," uses holistic management for 10 species of livestock on a 1,300-ha farm. A life cycle assessment showed that his soils have increased from 1% to 5% SOM over an unspecified time period (White Oak Pastures, 2019). Using our calculations above, this implies that the SOC in the top 6.7 inches of each hectare went from 13 Mg C to 65 Mg C. These practices not only offset the emissions of the livestock themselves, but sequester enough carbon to offset the 85% of the farm's carbon footprint (Quantis, 2019).

Not everyone accepts uncritically the idea that livestock can be a solution to climate change and food security. Globally, ruminants are responsible for 12% of anthropogenic GHG emissions (compared to 14% from cropping and soil practices) (Teague, et al., 2016). While farms like Harris's show the potential that holistic management offers for SCS, most livestock production operations are managed without a thought to GHG emissions and have sizable carbon footprints (Quantis, 2019). It takes substantially more resources and land to produce a pound of beef than a pound of crops. West and colleagues note that "if current crop production used for animal feed and other nonfood uses (including biofuels) were targeted for direct consumption, ~70% more calories would become available, potentially providing enough calories to meet the needs of an additional 4 billion people" (2014, p. 326).

Similarly, a contentious divide in the scientific literature exists around the efficacy of rotational grazing. On the one side, numerous studies observe improved ecosystem functions and economic outcomes and advance holistic grazing strategies as an important solution for range and cropland health and carbon sequestration (Sherren, Fischer, & Fazey, 2012; Follett & Reed, 2010; Ferguson, et al., 2013; Weber & Gokhale, 2011; Teague, Provenza, Kreuter, Steffens, & Barnes, 2013; Teague R., 2013). The other side claims that these studies misinterpret the data and are too anecdotal and unscalable to be a viable solution (Holechek, Gomes, Molinar, Galt, & Valdez, 2000; Briske, Bestelmeyer, Brown, Fuhlendorf, & Polley, 2013; Briske, et al., 2008; Briske, Ash, Derner, & Huntsinger, 2014).

An Attempt at Our Own Calculation of SCS Potential

Given the numbers presented in the above sections, it is possible to attempt a calculation of SCS potential. Of the 13.003 billion ha of the Earth's total land area, there are approximately 10 billion ha of "habitable" land, and 4.889 billion ha of agricultural land (Ritchie & Roser, 2019). Roughly 1.6 billion ha are used for crop cultivation, and 3.3 billion ha for grazing (Ritchie & Roser, 2019).

If every ha of agricultural land could hypothetically sequester 1 Mg C every year for 50 years, this is the equivalent of pulling 245 Pg C out of the atmosphere and reducing CO_2 concentrations by 115 ppm (Clark, 1982, p. 467). Anthropogenic C emissions since the beginning of the Industrial Revolution are over 500 Pg (Allen, et al., 2009). A number of assumptions are at play here which modify the realism of this estimate. While agricultural soils likely have the technical potential to store that much C (some soils would sequester much less, some much more), the likelihood of every agricultural land manager or farmer around the world implementing these regenerative strategies on every ha of their land for decades is improbable (in the absence of a coordinated, permanent financial incentive scheme). However, other soils outside of agricultural management, such as in forests and wetlands, also sequester C under regenerative management, which may increase the upper bound of overall SCS potential.

A more realistic and strategic scenario would be to expect reduced implementation, but greater SCS rates on select swaths of land. This is possible if a more targeted approach is undertaken, where a smaller number of stakeholders that control the most highly degraded land are involved. The most degraded soils can absorb C at the greatest rates. And by choosing degraded soils in areas that originally had the largest C pools, the SCS ceiling potential is maximized. Thus, under the assumption that just 10% of agricultural land could sequester 5 Mg C/ha for 10 years, this would sequester 25 Pg C – though ultimately more, because SCS would continue but at a slower rate after the first 10 years. 25 Pg C is enough to offset 2.5 years of global anthropogenic C emissions.

These are purely hypothetical, non-expert estimates, but tinkering with the numbers is demonstrative of the SCS potential inherent in regenerative agriculture.

Final thoughts on Agricultural SCS Potential

We have already explored the debate around managed grazing in the scientific literature. An interesting analogue for croplands exists as well. Some studies dispute the evidence that conservation tillage sequesters carbon. These studies argue that tillage merely shifts the SOC closer to the surface of the soil horizon, which is where most soil measurements are taken, but depletes SOC at greater depths, thus leading to an overestimation of the SCS benefits of conservation tillage (Powlson, et al., 2014). Other authors echo this claim about tillage and question the SCS potential of regenerative agriculture more broadly (Ogle, Swan, & Paustian, 2012; Ranganathan, Waite, Searchinger, & Zionts, 2020).

As is common in scientific debates, however, there is also data that support the opposite conclusion. A meta-analysis concluded that no till does lead to increased SOC throughout the soil profile to both 60 cm and 1 m of depth, not just near the surface (Sun, et al., 2020). And similarly, just a few weeks after Ranganathan and colleagues expressed skepticism about the SCS capacity of regenerative management (2020), several prominent soil scientists responded critiquing the original piece and marshaling evidence to support a significant role for regenerative agriculture in climate mitigation (Paustian, et al., 2020).

Ultimately, the total amount of C that can be sequestered in agricultural lands depends on a sizable number of variables and the actions of millions of independent actors on every inhabited continent. The technical potential of agricultural soils to sequester C is likely tremendous – upwards of 100 Pg C or 47 ppm of CO_2. When other land use practices beyond agriculture are included, like wetland restoration, reforestation, afforestation, and vegetation management, the global SCS potential increases further. Barriers like economic risk in developing nations, political and policy support, farmer buy-in, social norms, and financial investment make achieving the upper ranges of SCS potential a monumental task. The assumptions that determine how each of these variables are modeled in studies produce the wide range of estimates in SCS potential present in the scientific literature.

As soils developed on the earth's surface, C was always an essential component, but soils do not exist for the sequestration of carbon. C is stored insofar as it enables important functions that support ecosystems and the soil microbiome. The human objective of maximizing C sequestration in soils is thus a novel management approach. It is possible that under expert management, soil C can be enhanced beyond the amount of C that a soil originally stored (Lovins, Wallis, Wikjman, & Fullerton, 2018). But it is important to remember that "carbon farming" is a relatively new phenomenon. Most farmers are not carbon farmers; they're farming for crops and livestock. The niche of carbon farming is growing (Velasquez-Manoff, 2018), but the vast majority of agricultural land is not managed specifically to maximize SCS.

Recognizing the massive benefits that regenerative farmers offer society by sequestering carbon and slowing climate change makes the prospect of payments for SCS a feasible policy or market solution. If payments were implemented in a coordinated manner and at scale, in avoidance of key design pitfalls, adoption of carbon farming could be widespread. This will be explored later in the report.

As we will see in the next section, however, increasing SOC mediates a variety of cobenefits beyond just climate mitigation. Increasing SOC plays a role in improving drought resistance, water holding capacity, nutrient availability, water pollution, and soil fertility, along with being correlated to other improvements in soil health that make it easier and more profitable to farm (Lehman, et al., 2015; Lines-Kelly, 1993). Arguably, these benefits are so immense that they would be worth pursuing even if they had no bearing on climate mitigation whatsoever.

Photo: Eini Trujillo on Unsplash

Cobenefits of Regenerative Agriculture

Stabilized or Improved Crop Yields and Enhanced Food Security

Global climate change and soil degradation present major issues for maintaining cropland productivity. Evidence suggests that climate change is reducing crop yields despite an increased CO_2 availability for plants. A global modeling study found that climate change was responsible for a 3.8% decrease in maize yields and 5.5% decrease in wheat yields between 1980 and 2008 (Lobell, Schlenker, & Costa-Roberts, 2011). Other studies predict even more significant losses for wheat, maize, and rice under the warmer temperature regimes expected in coming years (Challinor, et al., 2014). Food security impacts from climate change will be harshest for nations already suffering from high levels of hunger and will reduce their resilience to climate shocks (Wheeler & von Braun, 2013).

The impacts of soil and land degradation on agricultural productivity also reveals grim results. According to Otuk and Daniel (2015), estimates for the magnitude of global crop yield reduction caused by soil degradation range from 12.7% (Oldeman, 1998) and 13.4% (Crosson, 1997) to 19% (IIASA, 2000), and even as high as 30% (Pimentel, Allen, and Beer, 1993). A review by Eswaran, Lal, and Reich (2001) found that at the field and plot level, degraded soils reduced harvests by up to 40% in rowcrops in the U.S. Midwest (Fahnestock, et al., 1995; Schumacher, et al., 1994); by between 30% and 90% in west Africa (Mbagwu, et al., 1984; Lal, 1987; Charreau, 1972; Kayombo and Lal, 1994); by up to 50% in some parts of Europe (Ericksson, et al., 1974); and by 20% in India, China, Iran, Israel, Jordan, Lebanon, Nepal, and Pakistan (Dregne, 1992). Soil erosion causes economic losses to the U.S. agricultural sector of $44 billion per year (Eswaran, Lal, & Reich, 2001). A 100-year analysis of a continuously cropped field in the U.S. Midwest found that, even with fertility management, degraded soils had 60% lower corn yields than at the start of the 100-year period (Gantzer, Anderson, Thompson, & Brown, 1990). The worsening of soil quality threatens global food security and livelihoods in developing nations and exacerbates climate change (Sulaeman & Westoff, 2020).

Increasing SOM through regenerative management represents the reversal of the soil erosion process: adding SOM builds soil structure and aggregate stability and makes soil less vulnerable to erosion by wind and water. Research on the impact of regenerative agriculture implementation on crop yields generally shows that crop yields stabilize or increase, with a smaller number of studies showing yield declines after implementation. It is postulated that the increase in soil fertility and the resilience that allows soil to withstand shocks and stabilize yields is mediated by the increase in SOM (Soil Health Institute, 2018).

The Soil Health Institute reviewed some of the literature on the impacts of regenerative agriculture practices on crop yield. Of the 8 studies that had sufficient data, crop yield volume remained the same or increased in 7 (Soil Health Institute, 2018). The average change in crop yield in these studies was +17.6%, while the change in the one remaining study was -6.2% (Soil Health Institute, 2018). Six of the 8 studies showed that yield variability was the same or smaller from year-to-year (Soil Health Institute, 2018).

Van Es and Karlen analyzed 3 long-term field experiments in North Carolina, which primarily differed by tillage intensity and management disposition (organic or conventional). They found that tillage intensity was the most important variable in predicting soil health levels, with minimally tilled soils having the best scores for each variable at each site (van Es & Karlen, 2019). Especially important were levels of plant-available C and N, as well as manganese (which helps break down organic matter and make it available to plants). Soil health indicators were correlated with increased crop yields (van Es & Karlen, 2019).

A meta-analysis that compared conventional to organic crop production systems found that organic farms produce around 80% of the yields of conventional farms (de Ponti, Bert, & van Ittersum, 2012).[8] The study does not include data on farm profitability, which can be higher in organic operations due to premium pricing and reduced input costs, even if yields are lower.

A global meta-analysis that analyzed the relationship between SOM and yields of maize and corn found that increasing SOM levels increase the yields of both crops (Oldfield, Bradford, & Wood, 2019). They found that the yield benefits started to level off after SOM levels reached 2%, a threshold also found in other studies (Oldfield, Bradford, & Wood, 2019). Since about two-thirds of wheat and maize cropland globally are below 2%, small increases in SOM levels could have major yield benefits. Indeed, according to the authors, "potential yield increases of 10±11% (mean ± SD) for maize and 23±37% for wheat amount to 32% of the projected yield gap (the difference between observed and attainable yields) for maize and 60% of that for wheat" (parenthetical statement my own) (Oldfield, Bradford, & Wood, 2019). The increase in SOM would also reduce the fertilizer requirements by 7% for maize fields and by 5% for wheat fields (Oldfield, Bradford, & Wood, 2019). Fertilizer reductions may be even greater in some scenarios, as a 1% increase in SOM roughly equates to 20 pounds of N that a producer does not have to apply.[9]

Another global meta-analysis examined the impact of cover crops on crop yield and found that with a biodiverse mix of cover crops that includes legumes and non-legumes, primary crop yield improved by 13% (when cover crops were not biodiverse, primary crop yield dropped by 4%) (Abdalla, et al., 2019). While cover crops can negatively impact yield in water-scarce regions, livestock integration with cover crop grazing offers higher profits than monoculture crop production.[10]

---

8 While organic and regenerative operations are both more ecologically oriented, important differences can be present. For example, organic farms may till their soils, while regenerative farms often reduce or eliminate tillage; regenerative farms may choose to incorporate some chemical use, while strictly organic farms do not.

9 Augustine Obour, 2020, personal communication with author.

10 Ibid.

A large-scale set of field experiments in China showed that without any increase in fertilizer application, adopting agroecological and integrated crop management methods can increase rice, wheat, and maize yields by 18%, 24%, and 35% respectively (Chen, et al., 2014). The experiments also reduced nitrogen losses and GHG emissions.

In sub-Saharan Africa, intercropping of a legume tree in a maize monoculture and application of the tree's prunings as a soil amendment tripled maize yield (Makumba, et al., 2006). A country-wide study over dozens of farms in Malawi showed that a crop rotation that incorporated semi-perennial legumes allowed farmers to halve fertilizer use while maintaining the same yield and improving yield stability (Snapp, Blackie, Gilbert, Bezner-Kerr, & Kanyama-Phiri, 2010). Field trials in Botswana also showed that reduced tillage and manure application doubled maize yields (Falkenmark, Fox, Persson, & Rockström, 2001).

According to Lal, improving SOC levels by 1 Mg/ha globally would "increase crop yield by 20 to 70 kg/ha for wheat, 10 to 50 kg/ha for rice, 30 to 300 kg/ha for corn, and 10 to 20 kg/ha for beans," and by 0.5 to 1 kg/ha for cowpeas (2010, p. 717; 2004).

The benefits of regenerative management to crop yield and yield stabilization increase profitability and decrease economic risk for farmers. This service also improves global food security and fights climate change.

Improved Farm Profitability and Livelihoods

By transitioning to regenerative management practices, farms can become more profitable. This often occurs through some combination of yield increases, yield stabilization, reduced input costs, and/or premium prices due to high quality products. Some studies indicate that an increase in costs due to regenerative management, such as input expenses or time investment to learn new methods, are offset on a net basis by cost reduction elsewhere and/or revenue growth. Research and case studies offer insight into the possibility of increased farm profitability through regenerative management.

The American Farmland Trust compiled case studies of the economic impacts of switching to regenerative management on 8 farms across the U.S. (2019). The farms are in California, Ohio, Illinois, and New York, and represent a diversity of crop and livestock production. The case studies identify which practices on each farm created an increase or decrease in income and costs.

The most striking success stories come from two almond farmers in California. In the first, the 47-hectare Okuye Farms, additional financial outlays were more than made up for by increases in income. Okuye Farms reports an annual increase in per acre net income of $657 and an annual change in total net income of $76,155 (AFT, 2019).

The 71-hectare Rogers Farm reports even more significant gains, with an annual increase in per acre net income of $991, a return on investment of 553%, and an annual change in total net income of $173,345 (AFT, 2020). Both Okuye and Rogers Farms report increases in their crop yield as well.

The almond farms are the most dramatic of the 8 case studies. These remaining 6 farms ranged in size from 445 to 1821 hectares. These still reported meaningful growth in net per acre income, with increases ranging from $22 to $56 per acre and growth in net annual income of between $25,000 and $102,000 (see example in Figure 4).

Increases in Net Income				Decreases in Net Income			
Increase in Income				**Decrease in Income**			
Item	**Per Acre**	**Acres**	**Total**	**Item**	**Per Acre**	**Acres**	**Total**
Yield Impacts due to Cover Crops	$12.95	700	$9,067	None Identified			$0
Total Increased Income			**$9,067**	**Total Decreased Income**			**$0**
Decrease in Cost				**Increase in Cost**			
Item	**Per Acre**	**Acres**	**Total**	**Item**	**Per Acre**	**Acres**	**Total**
Nutrient Savings from Nutrient Mgmt	$66.00	700	$46,200	Nutrient Mgmt Learning Activities	$0.87	1400	$1,221
Reduced Machinery from Reduced Tillage	$17.68	1400	$24,746	Cover Crops Learning Activities	$1.74	700	$1,221
Reduced Machinery Cost from Nutrient Mgmt	$2.73	1400	$3,815	Cover Crop Costs	$39.00	700	$27,300
				Increased Pesticide Cost from Reduced Tillage	$5.00	1400	$7,000
Total Decreased Cost			**$74,761**	**Total Increased Cost**			**$36,742**
Annual Total Increased Net Income			$83,828	Annual Total Decreased Net Income			$36,742
Total Acres in this Study Area			1400	Total Acres in this Study Area			1400
Annual Per Acre Increased Net Income			$60	Annual Per Acre Decreased Net Income			$26
Annual Change in Total Net Income = $47,086							
Annual Change in Per Acre Net Income = $34							

Figure 4. Economic impacts of soil health implementation on Thorndyke Farms, IL. Adapted from AFT, 2019.

These case studies show that while the switch to regenerative management can sometimes entail greater costs for expenses like compost amendments, cover crop seeds, and added educational and labor commitments, they are typically more than offset by decreases in cost like reduced pesticide use and machinery usage, and/or by increases in income from improved yield.

South Dakota State University surveyed farmers to compare the profitability, resilience, and optimism of regenerative vs conventional farmers and ranchers. The poll found that 31% of regenerative practitioners increased their profitability in 2019, compared to just 12% of conventional practitioners; 83% of regenerative practitioners expected their operations to be more resilient to extreme weather, compared to 60% of conventional practitioners; and 69% of regenerative practitioners compared to 36% of conventional practitioners expected increased profits over the next 3 to 5 years (Griekspoor, 2020).

One study compared the profitability of several dozen conventional corn plots to regeneratively managed plots. It found that while regenerative plots had 29% smaller yields than conventional plots, they were 78% more profitable, due to reduced input costs and greater overall revenue (LaCanne & Lundgren, 2018).

According to a modeling study by Wang and colleagues, AMP grazing will improve both ecological outcomes and long-term profit for commercial scale ranches (2018). The study by Snapp and colleagues mentioned above showed that the incorporation of a semi-perennial legume rotation in Malawi not only stabilized yield and halved fertilizer use but also substantially increased farm profitability (2010).

It is an unfortunate truth that farming is a profession that can be exhausting, thankless, and hazardous. Many farmers scrape by on the margins of profitability. Opportunities to improve livelihoods in the industry that feeds the world are essential undertakings. In the U.S., farmers have the highest suicide rate of any profession; they commit suicide at a rate 5 times higher than the general public (McIntosh, et al., 2016). Studies have even linked depression to pesticide exposure, which is a sine qua non of conventional farming methods (Beard, et al., 2014).

Given this data, improving farm profitability and reducing chemical application are more than pathways towards climate mitigation, pollution reduction, and food security. They are vital strategies for improving the wellbeing of those practicing what is arguably one of the most important jobs on the planet.

Water Infiltration and Holding Capacity and Resilience to Drought and Extreme Weather

According to the IPCC, atmospheric warming around the globe is likely to lead to altered patterns of rainfall (Collins, et al., 2013). Some regions will get wetter, and some drier, though in both cases it is likely that precipitation events will be less frequent but more intense (Collins, et al., 2013). Climate change and growing water scarcity mean that between 5 and 6 billion people could live in water-scarce regions between 2050 and 2100 (Gosling & Arnell, 2016; Hanasaki, et al., 2013).

These trends speak to the need for society more broadly, and agriculture in particular, to adapt to different resource use patterns in coming years. Soils will need an expanded capacity to infiltrate and retain the water they receive. If water resources are more limited and costly, while farmers face greater demands than ever before in feeding a population of ~10 billion, then operations that use water most efficiently increase their chances of success.

A fundamental claim by proponents of regenerative agriculture is that as SOM and soil health increase, soil structure improves. As soil structure improves, it infiltrates water more quickly throughout the soil profile, retains more water for longer time periods, and reduces vulnerability to flooding and erosion. Each of these adaptations would make soil more resilient to extreme precipitation events and drought. Ability to infiltrate and store more water will be crucial for agriculture productivity in the semiarid regions of the U.S. Great Plains.

As with soil fertility, the improvement in soil's water holding capacity (WHC) and infiltration rate is mediated by SOM (FAO, 2005). According to soil scientists working with Natural Resources Defense Council, every 1% increase in SOM allows an acre of soil to hold an additional 20,000 pounds of water (Bryant, 2015).

Hudson found that as SOM grew from 0.5% to 3%, the available water capacity (AWC) of soil more than doubled (1994). Studies support the claim that cover crops, green mulch, and other regenerative practices increase SOM, WHC, and food security (Falkenmark, Rockström, & Karlberg, 2009).

A study that examined the impacts of holistic grazing on WHC found that after 3 years of treatment, holistically grazed fields held 54% more water than fallowed fields and 32% more water than mixed rest-grazed fields (Weber & Gokhale, 2011).

A long-term study that compared the effects of no tillage and conventional tillage in maize monocultures in China found that the no-till condition resulted in significantly higher water retention, water infiltration, pore space, and water conductivity (He, et al., 2009). A short-term experiment on maize and soybean fields in Italy found that after 2 years, conservation tillage provided yield and water use efficiency advantages compared to conventional tillage (Casa & LoCascio, 2008).

When soils are covered by cover crops or crop residues, the physical impact of rainfall causes less soil structure breakdown and reduces water evaporation. In the Brazilian Cerrados, it was shown that when 100% of soil was covered, water needs were reduced by 29% compared to fields which were 0% covered, leading to fewer irrigation applications needed and more time between each application (see Table 2) (FAO, 2004). Makumba and colleagues found that in sub-Saharan Africa, intercropping a maize monoculture with the legume tree gliricidia not only boosts primary crop yield but also greatly improved WHC: the intercropped fields held 50% more water 2 weeks after a rain than monoculture fields (Makumba, et al., 2006).

Soil cover (%)	Water requirement (m^3/ha)	Reduction in water requirement (%)	Irrigations during season	Days between irrigation
0	2,660	0	14	6
50	2,470	7	13	6
75	2,090	21	11	8
100	1,900	29	10	9

Table 2. Water use efficiency rates under varying soil cover conditions, Brazilian Cerrados. Data from FAO, 2004.

Many commodity crops grown in monocultures around the world today have little genetic variability, which makes food supply more vulnerable to shocks and disruption. By mixing standard varieties with wild landraces that exhibit improved performance under droughts and other abiotic stresses, yields, biodiversity, and food security can be improved (Lobell D. , 2009). For example, trials of hybrid crops in Africa improved yield by 15-20% under drought conditions (Lobell D. , 2009). Similarly, Gur and Zamir report that yield of a natural tomato hybrid outperformed control tomatoes by 25% in dry conditions (2004).

A modeling study compared the effects of better agronomic water management to irrigation on crop production. It found that while irrigation improves crop production by 17%, the combination of reducing evaporation from soils by 25% (accomplished by ground cover) and collecting 25% of water runoff after rain events improves crop production by 19% without any irrigation (Rost, et al., 2009).

An important consideration in Caribbean and Central American nations is how well their agricultural lands can withstand the intense wind and precipitation impacts of hurricanes. A study that compared the resilience of agroecological to conventional farms in Nicaragua after Hurricane Mitch found that agroecological farms had "more topsoil, higher field moisture, more vegetation, less erosion and lower economic losses after the hurricane than control plots on conventional farms" (Holt-Giménez, 2002). Similarly, another study compared the resilience of coffee growing operations near Chiapas, Mexico after Hurricane Stan. This hurricane brought heavy rains and mild winds. The study found that the farms with healthier vegetation (in terms of biodiversity and canopy structure) experienced fewer landslides after the hurricane (Philpott, Lin, Jha, & Brines, 2008). Farms incorporating regenerative principles were more resilient to extreme weather events.

In Northeast U.S., 1999 was characterized by a severe drought in the summer followed by "hurricane-driven torrential rains in September" (Lotter, Seidel, & Liebhardt, 2003). These conditions offered an important opportunity to examine how ecologically vs conventionally managed plots performed under such extreme conditions. A study analyzed two organic fields and one conventional field and found that AWC was 100% higher in the organic plots than the conventional one, and that the two organic plots yielded 96% and 52% more soybeans than the conventional one (Lotter, Seidel, & Liebhardt, 2003). Maize yield was 37% higher in one organic plot and 62% lower in the other due to weed pressure.

A voluminous literature from sites all over the world offers evidence for the yield, input efficiency, and water availability impacts of regenerative management. Bot and Benites offer an excellent summary of some of these studies (2005). They report that incorporation of perennial crops reduced sediment loss by 16%, fertilizer cost by 21%, and improved drinking water quality for a city in southern Brazil (2005). Unger showed that a treatment of crop residue increased WHC by 74%, sorghum yield by 124%, and water-use efficiency by 107% compared to bare plots with no crop residue (1978). In the semi-arid environment of Ethiopia's Rift Valley, fields with maize cultivar diversity yielded 30% more than maize monoculture in normal rain years, and 60% more than maize monoculture in drought years (Tilahun, 1995). Another study from southern Brazil found that untilled fields absorbed rainwater at a rate of 45 mm/hour, compared to a rate of 20 mm/hour for conventionally tilled fields (Calegari, 1998).

As soil health increases, its capacity to absorb and retain water grows. This allows for reduced soil erosion, reduced water and fertilizer input needs, improved resource efficiency, and better yields. The advantage of healthy soil seems particularly evident and emphatic in times of ecological stress: during and after extreme rainfall events and severe droughts, regeneratively managed systems incur less damage and maintain greater productivity compared to conventional systems.

Disease Suppression and Resistance

Weeds, pathogens, and animal and insect pests can cause potential losses of global crop production by 34%, 16%, and 18%, respectively (Oerke, 2006). According to Oerke, "despite a clear increase in pesticide use, crop losses have not significantly decreased during the last 40 years" (2006, p. 31). Research into disease suppressive qualities in soil is ongoing. Siegel-Hertz and colleagues define disease-suppressive soil as "soils in which specific soil-borne plant pathogens cause only limited disease although the pathogen and susceptible host plants are both present" (2018). It is thought that designing advantageous crop rotations and robust soil microbial communities improve plant and soil health in such a way as to be inhospitable to pests (Raaijmakers & Mazzola, 2016). This is analogous to human health, where a human body can contain a pathogen but not experience any sickness due to robust immune support.

A study by Wei, et al., found that the presence of beneficial bacteria in the soil microbiome, like *Pseudomonas* and *Bacillus*, were highly disease-suppressive and led to healthy plants, and that these bacteria can be nurtured by regenerative practices like the use of organic fertilizers (2019).

Fusarium wilt is a destructive disease that is unaffected by pesticides, can damage a variety of crop species, and results in sizable yield losses. Siegel-Hertz, et al., compared soils suppressive of the disease to those conducive to it, and found that suppressive soils hosted 17 key fungal species and 12 key bacterial species either exclusively or abundantly which mediated the resistance to *Fusarium* wilt (2018). Another study that examined *Fusarium* and a second wilt disease found that a compost amendment that contained a beneficial bacterial (e.g., *Actinobacteria*) and fungal consortium suppressed both types of wilt disease and improved overall plant health and productivity (Antoniou, Tsolakidou, Stringlis, & Pantelides, 2017). *Actinobacteria* were also found to be one of the keystone microbial taxa that conferred wilt disease suppression in Australian agricultural soils (Trivedi, et al., 2017).

Numerous studies have examined which microbial communities are associated with suppression of diseases common in wheat, tobacco, tomato, avocado, and other crops, and attempt to elucidate mechanisms for microbe-mediated disease suppression (Mendes, et al., 2011; Kyselková, et al., 2009; Yin, et al., 2013; Chng, et al., 2015; Vida, Bonilla, Vicente, & Cazorla, 2016).

The chthonic soil microbiome remains a frontier of understanding in soil science. Mysteries remain such as pathogen suppression pathways by microbes and the observation that singular bacterial strains sometimes offer no pathogen resistance alone but are transformed into disease suppression agents when included in the right bacterial consortia (Mendes, et al., 2011). The essential question to resolve in the context of regenerative agriculture is whether, and which, management practices can improve microbial biodiversity and disease suppression.

Research indeed suggests not only that regenerative management facilitates disease suppression, but that conventional commercial monocultures makes plants vulnerable to disease. Van Bruggen and colleagues suggest that the facilitation of beneficial species of bacteria and fungi, in terms of their activity levels, biodiversity, and nutrient processing, can be enhanced by greater levels of SOM inputs (2006). Van Bruggen and Semenov suggest that soil health indicators more broadly can be used as a method for predicting disease suppression (2000). Compost amendments offered disease suppression to avocado trees (Vida, Bonilla, Vicente, & Cazorla, 2016). The USDA examined a species of invasive grass that was killing native grasses, lowering crop yields, and destroying wildlife habitats, and found that inoculation with a beneficial strain of soil bacteria all but eliminated the invasive grass within 5 years (Buckley & Eve, 2017). And Wetzel and colleagues demonstrated that a diversity of plants that marshal a variety of nutrient types and levels offers natural insect pest suppression (2016).

Hodson and Lewis review several studies which demonstrate the effectiveness of regenerative management on disease control. For example, carefully designed cover crops and crop rotations, organic amendments like compost and mulches, reduced tillage, direct soil inoculation of beneficial microbes, and the selective breeding of disease-resistant rootstocks and cultivars can all inhibit pathogens (Hodson & Lewis, 2016).

On the other hand, a common wheat root disease called "take-all" often arises after continuous monocropping of wheat, which depletes the beneficial microbial community that contributes to disease suppression (Chng, et al., 2015). Similarly, Pollan describes how the reduced genetic diversity in monoculture apple orchards and potato fields has increased pest pressure and necessitated the use of ever greater quantities of pesticides (2001, p. 52).

As mentioned above, beneficial consortia of soil microbes confer natural disease suppression, but the exact mechanisms for pathogen inhibition are not yet well understood. Potential mechanisms include allelopathy (the chemical suppression of one organism by the secretion of inhibiting compounds by another organism), biocidal excretions by disease-suppressive microbes, and root exudates (compounds secreted by the plant that are responsive to, and supportive of, the microbial community) (Hodson & Lewis, 2016). Regardless of the exact biochemical pathways, research shows that regenerative management nurtures the diversity and abundance of microbes that offer natural disease suppression without chemical or physical soil disturbance.

Improved Air and Water Quality

Pollution is an immense environmental and public health burden, in which, unfortunately, agriculture is heavily complicit. Water and air pollution together cause 8.3 million deaths worldwide each year (Lancet, 2017). Low- and middle-income countries experience over 90% of pollution-related deaths (Lancet, 2017). Globally, agriculture is responsible for 70% of water use, and is the leading cause of water pollution (Khokhar, 2017; FAO, 2017). It is also the sector with the second largest GHG footprint worldwide (EPA, 2019). In China, Europe, Russia, and much of the U.S., agriculture is the leading emitter of fine particulate matter pollution. Fine particulate matter pollutants, when mixed with other industry-derived chemicals in the atmosphere, annually cause 3.3 million early deaths worldwide and 570,000 in India alone (Bauer, Tsigaridis, & Miller, 2016; Lelieveld, Evans, Fnais, Giannadaki, & Pozzer, 2015; Ghude, et al., 2016).

Much of the pollution generated by agriculture results from excessive or inefficient fertilizer use – particularly nitrogen- and phosphorus-based compounds. Water pollution is exacerbated when soil health is poor with limited SOM and water holding capacity. Soils retain pollutants either in particulate form, where they are adsorbed onto or incorporated into soil particles, or in moisture suspension (Novotny, 1999). When soils are degraded, they erode and produce runoff, which releases pollutants either in sediment form or dissolved in runoff flows.

A field demonstration during a conference in Oklahoma showed that tilled soils failed to infiltrate almost any water during a simulated heavy rainstorm while no-till soils and soils from forest rangeland produced almost no runoff (Figure 5) (Walton, 2015). One of the largest aquatic "dead zones" in the world, where the

Mississippi River empties into the Gulf of Mexico, is the result of nitrate leaching and runoff from the U.S. Midwest corn belt (Rabalais, Turner, & Wiseman Jr., 2002). When nitrogen fertilizer runoff reaches the Gulf of Mexico, the fertilizer fuels a rapid growth in algae, called an algae bloom. The algae die and are consumed by bacteria, which deplete the seawater of dissolved oxygen (Potera, 2008). This hypoxia is devastating to local marine life and to the fisheries that depend on it (Rabalais, Turner, & Wiseman Jr., 2002).

Figure 5. Results from a water runoff test. Soils from a tilled agricultural plot and a construction site retained the least water. Soils from a forested rangeland and a no-till, crop-rotated field produced negligible runoff. Bermuda grass pasture produced a medium amount of runoff. Photo by Brett Walton/Circle of Blue, from Walton, 2015. Reprinted with permission.

The Gulf of Mexico experienced runoff-related hypoxia beginning in the early 1900s, but it grew more severe after nitrogenous fertilizer use increased in the 1950s (Rabalais, Turner, & Wiseman Jr., 2002). (In Western Europe, chemical fertilizer use grew by an order of magnitude between 1950 and 1980 (Novotny, 1999).) During the ethanol boom in the early 2000s, farmers grew 37.6 million hectares of corn in 2007, which was a 19% increase from the prior year (Potera, 2008). Corn is more dependent on nitrogen fertilizer than other commodity crops like soybeans, which extract atmospheric nitrogen for some of their needs (Potera, 2008). Meeting the ethanol production goal set in a 2007 federal bill would have increased nitrogen loading in the Gulf of Mexico dead zone by up to 18% (Donner & Kucharik, 2008). Although ethanol demand has since dropped, nitrate leaching remains an issue: nutrient discharge in May 2019 was 67% higher than the 1980-2018 average (NOAA, 2019).

For decades Lake Erie has also experienced algae blooms and hypoxia related to nutrient runoff, especially phosphorus in this case (Baker, 1985; Forster & Rausch, 2002). The Great Lakes more broadly experience dead zones and algae blooms that are at times toxic (Circle of Blue, 2014). Similar issues also plague the Chesapeake Bay, Lake Okeechobee in Florida, and many other surface water bodies in the U.S. (Felver, 2019). It should be noted that nitrate, phosphate, and other types of excess nutrient runoff do not solely come from chemical application – they can come from organic amendments like manure and compost as well (Novotny, 1999). In both cases, however, a healthier underlying soil will be more likely to retain the nutrients that come from either organic or inorganic fertilizer.

Agricultural water pollution and runoff is not just an environmental quality issue – it is also costly in terms of human health and finances (Benmar, 2010). It is worth quoting a passage from an FAO report in full here:

> "Sediment and dissolved organic matter in surface water have to be removed from drinking-water supplies. Reduced erosion, and hence fewer soil particles in suspension, lead to lower costs for water treatment. Data from Chapecó, Brazil, indicate that the quantity of aluminium sulphate used for flocculating suspended solids fell by 46 percent in five years [after the planting of perennial crops to reduce soil erosion]. Where water is chlorinated to kill disease organisms, the chlorine reacts with dissolved organic matter to form trihalomethane (THM) compounds such as chloroform.
> THMs are suspected of causing cancers" (2005, p. 39).

According to the Illinois Environmental Council, Illinois is the biggest contributor of nutrient runoff that triggers the Gulf of Mexico dead zone (2019). In response, the state created a policy to encourage regenerative practices, such as cover crops and vegetative buffers, as a solution to reducing nutrient leaching (IEC, 2019). Indeed, soils with higher levels of SOM, moisture retention, and cation exchange capacity – or simply healthy soils – are better at filtering and retaining pollutants (Novotny, 1999). Smith and colleagues find that increasing soil health can contribute to the UN's Sustainable Development Goals by filtering, storing, and buffering chemicals and pollutants which protects coastal waters and enhances freshwater quality (2019).

Conventional agriculture also contributes to air pollution. From a climate change perspective, soil management, fertilizer production and use, and soil erosion are responsible for 13.7% of anthropogenic GHG emissions (Vermeulen, Campbell, & Ingram, 2012; Teague, et al., 2016); livestock management and production is responsible for 14.5% of anthropogenic GHG emissions (Ripple, et al., 2014). These emissions include GHGs other than CO_2, such as nitrous oxide (N_2O) and methane (CH4), which respectively trap 265 and 28 times more heat in the atmosphere than CO_2. Even though non-CO_2 GHGs are only a third of all GHGs emitted, they have an outsized effect on global warming (Ripple, et al., 2014). N_2O is also a culprit in ozone depletion (Park, et al., 2012).

Mitigating N_2O emissions is an important lever for reducing global warming. In the U.S., 6.5% of GHG emissions (based on total global warming potential) came from N_2O, and agricultural soil management practices (e.g. inefficient fertilizer use) were responsible for 78% of N_2O emissions (EPA, 2020; EIA, 2019). Globally, agriculture is responsible for about 60% of N_2O emissions, and anthropogenic N_2O has grown by 30% since 1980, a rate on track with the IPCC's worst case climate scenario through 2100 (Reay, et al., 2012; Tian, et al., 2020).

Nitrous oxide emissions are increased with errant or overapplication of nitrogenous fertilizers and manures. Management practices that optimize the volume, type, timing, and spatial placement (e.g. near the root zone as opposed to broadcast) can all reduce N_2O emissions (Millar, 2015). Ammonia (NH_3), another gas that can volatize from nitrogenous fertilizer use, is subject to similar dynamics. Best management practices, and overall soil health characteristics like cation exchange capacity and SOM content, can improve fertilizer efficiency and reduce NH_3 volatilization (Jones, Brown, Engel, Horneck, & Olson-Rutz, 2013; Dobbie, McTaggart, & Smith, 1999). In the absence of best management practices, up to 50% of nitrogen in fertilizer will not be used by plants but lost to the atmosphere via NH_3 and N_2O volatilization (Jones, Brown, Engel, Horneck, & Olson-Rutz, 2013; Reay, et al., 2012). Part of the challenge is that some of the conditions that minimize NH_3 volatilization can enhance N_2O emissions (Duncan, Dell, Kleinman, & Beegle, 2017), although selecting slow-release fertilizers may improve emissions of both gases (Sun, et al., 2016). One study found that the combination of organic and synthetic fertilizers can increase nitrogen efficiency, reduce input costs, and increase yield compared to either type of fertilizer on its own (Yang, Liu, Dong, Jiwang, & Zhao, 2020).

In addition to N_2O emissions, two long-term field studies suggest that synthetic nitrogenous fertilizers deplete SOM and that more diverse methods for nitrogen incorporation, like cover crops, be implemented (Khan, Mulvaney, Ellsworth, & Boast, 2007; Mulvaney, Khan, & Ellsworth, 2009).

Millar suggests that winter cover crops and reduced tillage can reduce N_2O emissions (2015). Packer, et al., also show that better matching the timing of fertilizer application to the phenological needs of plants can reduce N_2O emissions (2017). As several of the studies above demonstrate, regenerative management can reduce chemical fertilizer use, make it more efficient, or replace it with organic fertilizers, all while maintaining or improving crop yields (Yu'e, et al., 2018; Oldfield, Bradford, & Wood, 2019; FAO, 2005; Snapp, Blackie, Gilbert, Bezner-Kerr, & Kanyama-Phiri, 2010; Wei, et al., 2019; Francis, Harwood, & Parr, 1986).

Commercial scale conventional agriculture perpetuates production systems that prioritize yield and mechanization. While these approaches, many of which evolved out of the Green Revolution beginning in the 1960s, have intensified agricultural production and increased yields, they do so at great cost to the environment and public health (Pingali, 2012). The growing body of research on regenerative farming systems shows that in many cases, high yields can be maintained while environmental costs and financial inputs are minimized. The final subsection of the cobenefit section of this report ties this perspective together by examining the nutritional and health benefits that emerge with regenerative production systems.

Nutrient Dense Food and Human Health

A well-developed scientific literature exists on the teratogenic, carcinogenic, and otherwise harmful effects of many of the chemicals associated with industrial agriculture. A review of this literature and the impacts of these chemicals on humans, wildlife, and the environment is beyond the scope of this report. We focus here instead on the nutrient content of crops and the possibility for regenerative management to improve it.

The science on the depletion of nutrients in crops over the last several decades, and management methods to restore crop nutrient density, is inchoate and incomplete. There is some evidence that crops have lost nutrient density in recent years, though a strong scientific consensus has not crystallized. Proponents of regenerative agriculture support an intuitive premise that healthy soils lead to healthy plants, which lead to healthy food, which leads to healthy people (Kempf, 2018).

The incidence of chronic diseases like heart disease, stroke, diabetes, hypertension, bone loss, and others are linked to nutritional deficiencies (Marler & Wallin, 2015; Moyer, et al., 2020). Advocates often link these nutritional deficiencies to diet, and further to the depletion of soil mineral content (Marler & Wallin, 2015; Moyer, et al., 2020). The jury is still out on a causal link between soil mineral content and human illness. It is common to hear statements like "it takes 8 oranges today to get the same vitamin A that our grandparents would have gotten from 1" (Picard, 2002; Scheer & Moss, 2011), and "in 1991 you would have needed 10 tomatoes to get the same copper intake from 1 tomato in 1940" (The Guardian, 2005). Such tropes in the popular narrative, however, gloss over the nuance required to be scientifically sound statements.

Some widely cited studies do support claims about the nutritional decline of food. Davis, Epp, and Riordan examined changes in 13 critical nutrient levels across 43 crops from 1950 to 1999 (2004). In 6 of those nutrients – protein, calcium, phosphorus, iron, riboflavin, and vitamin C – they found declines of between 6% and 38% (Davis, Epp, & Riordan, 2004). Some of the nutrients did not change, and 28% of them increased. Another landmark study examined changes in 8 minerals in 20 fruits and 20 vegetables between the 1930s and the 1980s in the UK (Mayer, 1997). It found significant reductions in calcium, magnesium, copper, and sodium in vegetables and in magnesium, iron, copper, and potassium in fruit (Mayer, 1997). A review by Davis and a historical analysis by White and Broadley also found a strong case for nutrient declines (2009; 2005).

In trying to understand this decline in nutritional value, these studies attribute a potential cause to the depletion of minerals in soil. They also suggest roles for structural shifts in the food system (e.g. refrigeration; longer transport times and shelf lives for foods, over which nutrient content diminishes) and agronomy practices (e.g. the selection of cultivars that aim to maximize yield but not nutritional content).

A review by Marles expresses skepticism on the causal link between declining nutritional content of crops and poor soil quality. He examined several of the long-term analyses that study nutritional trends, including the studies by Davis et al. and Mayer, and found their methodologies to be flawed or their conclusions misleading. For example, some studies suggest that copper has declined by up to 81% in some crops, but Marles notes that plants have an enormous natural range in copper content (2017). For example, vegetables contain between 0.11 and 1.71 mg of copper (a range of 1555%), fruits between 0.01 to 2.06 mg (20,600%), and grains between 0.1 and 1.4 mg (1400%), so a change of 81% may have a negligible effect on crop nutritional quality (Marles, 2017).

That healthy soils produce healthier plants that can uptake and manufacture more nutrients is a robustly supported conclusion (Reeve, et al., 2016). The question of how much plant health translates to more nutritional crops and improved human health has yet to be answered. It is hypothesized that this causal link exists (Moyer, et al., 2020), but reliable evidence is lacking. According to Reeve, et al., 14 recently published reviews explore whether organically grown foods have higher nutritional content than conventional crops (2016). Seven of them show moderate support for this idea but acknowledge that many observed differences are minor and that different studies can present contradictory evidence (Reeve, et al., 2016). Five of the remaining studies say that there is insufficient evidence to make a claim one way or another, and two of them find that there is no meaningful nutritional difference between organically and conventionally grown produce (Reeve, et al., 2016).

That said, a meta-analysis of 343 studies by Barański and colleagues found that organic crops had dramatically improved levels of antioxidants and phytochemicals compared to conventional crops, as well as four times lower pesticide residues and significantly lower levels of the toxic heavy metal cadmium (Figure 6) (2014). Antioxidants can be classed as Plant Secondary Compounds (PSCs), which, aside from micro- and macronutrients, do appear to reliably increase in organically produced foods. Phytochemicals are associated with a reduction in risk of and morbidity from cancer, heart disease, diabetes, and hypertension (Craig, 1997).

			Positive Samples (%)	
Products	*n*	*P**	Mean, Organic	Mean, Conventional
All	66	<0.001	10.55	46.35
Fruits	22	<0.001	11.45	74.6
Vegetables	36	<0.001	10.25	31.95
Compound foods	6	<0.001	12.59	44.64

Figure 6. Frequency of occurrence of pesticide residues in organic and conventional crops. Conventionally grown food had measurable pesticide residue over 4 times as often as organic food. Adapted from Baranski, et al., 2014.

A definitive relationship between soil degradation and the nutrient content of foods remains to be established, though PSCs increase under ecological farming methods. It is likely that the dilution effect (see below) and breeding for yield instead of nutrition has led to a decline in the nutrient density of crops. Researchers have established, however, an undisputed relationship between climate change and crop nutrient content.

Elevated atmospheric CO_2 decreases the nutrient density of certain crops (Loladze, 2002). Global warming can increase some of the measurements of plant productivity due to a greater abundance of the CO_2 molecule plants need for photosynthesis. Part of the mechanism for this increased productivity, however, is a “dilution effect”: plants produce more empty carbohydrate calories from starches and sugars like glucose at the expense of micronutrients, vitamins, and protein (Prior, Runion, Rogers, & Torbert, 2008; Soares, Santos, Carvalho, Pintado, & Vasconcelos, 2019). Thus, while more calories may be available, the quality of calories declines, leading to the phenomenon of “hidden hunger” and ongoing nutrient deficiency (Loladze, 2014).

A well-known study by Myers and colleagues found that grains and legumes had compromised levels of iron, zinc, and protein when


Photo: William Moreland on Unsplash

grown under conditions of elevated CO_2 (2014). Manderscheid, et al., grew wheat and barley under conditions of increased CO_2 and found lower levels of macro- and micronutrients and protein (1995). Dietterich, et al., cite 14 studies that found decreased nutrient contents of crops under elevated CO_2 and 1 that saw no change (Dietterich, et al., 2015). Similarly, a meta-analysis by Loladze of over 7761 distinct observations and 130 cultivars reports diminished overall mineral concentrations under greater CO_2 conditions (2014). A review by Soares and colleagues found that elevated CO_2 causes diminished protein and micronutrient accumulation in crop plants (2019).

Multiple studies have examined the food security impacts of climate change-induced nutritional depletion. A study on rice confirmed declines in the crop's iron, zinc, protein, and vitamin B content (with a curious increase in vitamin E) and finds that 600 million people in low-income countries will be the most strongly impacted (Zhu, et al., 2018). Another study found that by 2050, 138 million people across Africa and South Asia will be especially vulnerable to climate change-induced zinc deficiency due to a lack of the micronutrient in food sources (Myers, Wessells, Kloog, Zanobetti, & Schwartz, 2015). The same pathway will contribute to iron deficiencies in 1.4 billion people, especially more vulnerable groups like children and women of child-bearing age, by 2050 (Smith, Golden, & Myers, 2017). Protein levels are also at risk: protein content will drop by between 6% and 14% for rice, wheat, barley, and potatoes by 2050, threatening 148 million largely in the Global South with protein deficiency (Medek, Schwartz, & Myers, 2017).

In summary, research on the factors relating to climate change, soil health, the nutritional value of crops, and human health is a growing realm of inquiry. The nutrient concentration of crops worldwide is decreasing due to climate change. It may also be decreasing due to overreliance on chemicals, the dominance of yield-oriented cultivars at the expense of nutrient-dense cultivars, and consumption patterns. Studies have yet to conclusively prove whether regenerative management and healthy soils lead to foods denser in macro- and micronutrients, but ecologically grown produce does contain higher levels of antioxidants and phytochemicals and lower levels of chemical residue. Given that the impoverishment of nutrients will most strongly impact vulnerable populations in the Global South, growing healthier food is a moral and ethical imperative, in addition to an environmental and economic one.

Regenerative agriculture can mitigate climate change through substantial levels of SCS, thus playing a role in slowing CO_2-induced nutrient loss in crops, and it can improve environmental quality by reducing dependence on and use of chemicals in the agricultural process. These are two pathways by which regenerative agriculture directly improves human health. It may also improve human health by fostering agroecosystems, soils, and microbial and plant communities that function at their full biological capacity, thus producing crops of exceptional quality.

Photo: Matthias Mitterlehner on Unsplash


Photo: Lambros Lyrarakis on Unsplash

MECHANISMS TO DRIVE ADOPTION

Given the broad suite of benefits offered by regenerative agriculture, the essential question to ask is, "what are the options for driving its widespread adoption?" This report divides these options into two major pathways: policy (government) or market (business) mechanisms. This section explores examples of government and business approaches that are in practice and successful, as well as promising solutions still coming to the fore. It also makes recommendations based on past successes.

It is important to note at the outset, however, that "policy or markets" is a false dichotomy. Policy mechanisms can create an enabling environment for economic approaches to be successful; market mechanisms can prototype solutions that government helps to support and spread. In addition to being mutually supportive, they can also be one and the same: governments can establish markets and private entities can be essential partners in the policy process.

While members of the business community are at times bullish on the potential for economics, market solutions, and corporate initiatives to drive change, members of the policy community often hold that broad government initiatives are the only way to make society-wide progress. Both are needed. This report does assume the perspective, though, that the precedent of state and (especially) federal government support is essential for wide-scale adoption. This perspective is supported by game-theoretic analysis and empirical evidence that shows that most firms and industries avoid transformative environmental change in the absence of government action (Press & Mazmanian, 2019).

Policy sets the playing field and establishes the rules of the game. Without governmental prioritization, private efforts may remain constrained to the companies who take it upon themselves to drive change through their business models. At present, these companies are in the minority, albeit a growing one. A fair critique of this perspective is that governments move too slowly and incrementally, fail to design elegant policies, and falter in ambition and imagination. For that reason, the report emphasizes the vitality of both sides working together, in roles of partnership and mutual learning, as the optimal way to spread regenerative practices at scale.


Photo: Raphael Rychetsky on Unsplash

Photo: Shyam on Unsplash

Policy

> The actions of governments […] are the most powerful drivers in the food and agriculture sector, capable of stimulating rapid and widespread change."
>
> — WEF, 2020

> "While these practices can be cost-beneficial for farmers or ranchers, and have important additional benefits, uptake of new approaches can be slow and may require significant incentives, outreach and education, and even more robust regulatory requirements. Whether agriculture will ultimately achieve carbon neutrality will depend on whether policies with that goal are adopted—and that is ultimately a question of political will, not a scientific one."
>
> —Lehner and Rosenberg, 2017

Policies that support regenerative agriculture, often referred to as soil health policy, are gaining momentum at all levels of government. Supportive policies can alter the economic and social terrain through which actors move and facilitate improved agriculture practices. Well-designed policy can change systems and behavior on a large scale through incentives, subsidies, regulations, education, and taxes. This scale is needed for society-level benefits to accrue.

Federal

There are several existing federal-level initiatives that aim to enhance agricultural conservation and soil health. Many more are in various phases of development, whether theoretical, under discussion, or proposed. This section examines this federal activity.

Existing Initiatives

Much of the federal activity that supports soil health is housed within the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS). The entity was originally called the Soil Conservation Service and formed in 1935 in response to intense soil erosion in the Midwest that was finally recognized by Congress as a "menace to national welfare" (NRCS, 2020). Housed within NRCS (except for CRP, which is an FSA program) are a few key initiatives that aim to restore land and soils:

- **Environmental Quality Incentives Program (EQIP):** EQIP[11] provides financial cost-sharing and technical planning to farmers and ranchers who implement conservation practices to improve the health of their land, soil, and water (NRCS, 2020). Target areas include reduced soil erosion, improved air and water quality, enhanced ecosystems and wildlife habitats, reduced water inputs, and resilience to extreme weather. EQIP may subsidize up to 75% of the costs for on-farm implementation, though that share increases to up to 90% for socially disadvantaged, beginning, and veteran farmers (NSAC, 2019).

11 There have been few attempts to quantify the impact of EQIP on environmental quality, but existing studies find mixed to positive results. Wallander and Hand found that "EQIP payments may have reduced water application rates but also may have increased total water use and led to an expansion in irrigated acreage" (2011). Water quality, however, does appear to have improved: a 10% EQIP payment significantly reduced downstream N and P concentrations (Liu, Wang, & Zhang, 2018). Growers taking advantages of EQIP's high tunnel initiative report greater economic stability and enhanced crop yield and quality (Bruce, Farmer, Maynard, & Valliant, 2017).

- **Conservation Stewardship Program (CSP):** CSP[12] has objectives similar to those of EQIP. CSP is the largest conservation program in the U.S. with over 70 million acres enrolled (NRCS, 2020; Fox & Johnson, 2018). CSP was established in its current form by the 2008 Farm Bill and it provides financial aid to farmers who either maintain high levels of soil, land, and water health, or farmers who wish to implement such practices (Fox & Johnson, 2018). It offers an annual results-based (as opposed to practice-based) payment for operation-level conservation improvements (NRCS, 2017). Contracts generally last 5 years.

- **Regional Conservation Partnership Program (RCPP):** RCPP has the same conservation goals as EQIP and CSP (NRCS, 2020). RCPP's main difference from EQIP and CSP is in its scale and administration. RCPP focuses on watershed scales or larger, and funding for implementation of innovative conservation practices is distributed through the state agencies, NGOs, or other RCPP partners. Since its inception in 2014, it has distributed $2.4 billion for agricultural conservation projects around the country (NSAC, 2019).

- **Conservation Reserve Program (CRP):** CRP is a Reagan-era program that pays farmers to remove environmentally sensitive land from agricultural production and rehabilitate it (FSA, 2020). It aims to protect highly erodible soils, critical wildlife habitat, water quality, and keystone ecosystems that have more value under conservation than under agricultural production (NSAC, 2019). Contracts are typically 10 to 15 years long. Under a CRP contract, farmers receive payments and cost-sharing to plant trees, grasses, and other species that rebuild soil and ground cover.

Another USDA program worth describing here is not specifically conservation focused. The **Farmer Opportunities Training and Outreach (FOTO)** program is the federal-level effort to support beginning and socially disadvantaged farmers (ERS, 2019). Such

---

12 CSP is cherished by farmers and ranchers who participate. The vast majority of participants rate it highly, want it prioritized in Farm Bills, and attribute improvements in their land resilience and productivity to CSP enrollment (Fox & Johnson, 2018). According to advocates, however, changes to the program enshrined in the 2018 Farm Bill may weaken the program's effectiveness (Campbell, 2020). These new changes limit contract renewals and may sideline the importance of long-term land stewardship (Campbell, 2020).

programs are essential to ensure the future of farming in the U.S. According to the USDA's most recent census, American farmers are 95% white and 64% male with an average age of 58 (NASS, 2019).

As the farming population continues to age, younger generations must fill the void, but many variables are stacked against them. One of these is institutionalized racism at the USDA. In the last decade, the USDA has settled separate class action lawsuits for discrimination against Latino/a, Black, Native American, and women farmers, and distributed billions of dollars of funds in compensation (NRCS, 2011; Melvin, 2010; NRCS, 2011). Similarly, young farmers face unprecedented barriers to entry. A survey by the National Young Farmers Coalition found that accessing affordable land is a major roadblock for young farmers. It is the number one reason that young farmers quit farming or that aspiring farmers do not start farming (Ackoff, Bahrenburg, & Shute, 2017). They are also burdened with student loan debt that makes living on a farming salary particularly difficult (Ackoff, Bahrenburg, & Shute, 2017). Unaffordable or inaccessible land lays the foundations for further consolidation in agriculture.

Based on 3,500 respondents to the survey by Ackoff, Bahrenburg, and Shute, young farmers are 60% female, twice as likely to identify as people of color or indigenous than respondents to the USDA's 2012 farmer census, and are more interested in sustainable and diversified farming operations than the dominant farming demographic (2017). In other words, the next generation of farmers is poised to usher in much-needed changes to the food system. Programs like FOTO that offer financial and technical assistance to these farming populations are an important federal tool to ensure that sustainable, profitable, and equitable farming operations continue well into the future (Paschal, 2018). By expanding the proportion of young farmers in the agriculture workforce, soil health is more likely to take root.

In addition to ongoing, federally authorized funding programs, new policy measures also create economic opportunities for soil health innovation. The 2018 Farm Bill allocated funds to support innovative soil health practices. Called **Soil Health Demonstration Trials (SHDTs)**, the bill apportioned $25 million for producers to implement soil health practices and track their impact (NRCS, 2020).

Proposed and Potential Initiatives

Some policymakers have formally introduced soil health policy mechanisms in legislation or discussion form. Other scholars have formulated recommendations that have yet to be formally proposed in legislative form, but nonetheless offer promise to guide future action.

In June 2020, in rare bipartisan cooperation on climate change, two Republican and two Democratic Senators introduced the **Growing Climate Solutions Act.** This proposed bill aims to mature the carbon removal marketplace by facilitating connections between carbon markets and farmers implementing carbon removal (Griffin & Babington, 2020). It would offer technical assistance to farmers and harmonize reliable SCS standards through the USDA. Market maturation could create new revenue streams for farmers as demands for carbon offsets from private entities like airlines grow (Volcovici, 2020). The content of this bill likely reflects and continues the momentum introduced in the 2018 Farm Bill's SHDTs.

Senator Bennet of Colorado has also suggested mechanisms for monetizing carbon removal for farmers. Yet to be packaged into legislation, his Discussion Draft recommends a modification to Section 45Q of the Internal Revenue Code. Created by the Energy Policy Act of 2005, 45Q currently offers a tax credit for C sequestration from industrial emissions (DOE, 2019). Credit amounts are scheduled to increase by 2026 to $50/metric ton of CO_2 for geologic storage and $35/metric ton for enhanced oil or gas recovery or carbon utilization (DOE, 2019). The DOE projects that full achievement of their program goals and a robust carbon capture, utilization, and storage sector could create up to 10 million jobs in the U.S. (2019). Senator Bennet's proposal expands **45Q tax credits to include agricultural (along with rangeland, forest, and wetland) C sequestration** (2019).

In July 2020, Congressman Neguse of Colorado introduced the **Study on Improving Our Lands (SOIL) Act** which would require a national survey of soil health on federal lands (2020). In February 2020, Senators Booker, Haaland, and Pingree introduced the **Farmer's Bill of Rights.** While not explicitly focused on soil health, the resolution affirms the needs and rights of rural communities and Indigenous, socially disadvantaged, and small-scale farms

(Booker, 2020). These groups can be negatively impacted by consolidation in agriculture, which tends to promote commercial-scale monocultures that neglect soil health.

In October 2020, Senator Wyden of Oregon, an original supporter of the 2018 SHDTs, introduced S.4850, the **Healthy Soils Healthy Climate Act of 2020** (Wyden, 2020). The bill would effectively expand SHDT funding from $25 million to $100 million, and house a permanent soil health program within EQIP (Wyden, Wyden Introduces Legislation to Improve Soil Health, Crop Resilience and Address the Climate Crisis, 2020). It also proposes to expand soil carbon and soil health research programs at universities.

In addition to the Congressional activity around soil health legislation, there are a variety of federal pathways that experts recommend to drive adoption of regenerative management and reduce or eliminate the incentivization of degrading practices.

A much-discussed federal-level action that could spur wider adoption of regenerative practices is **reforming crop insurance.** The current crop insurance structure provides protection to, and in a sense props up, conventional growing practices that produce a large volume of a small number of commodity crops. Farmers' insurance payouts are higher if they show they are using "Good Farming Practices" (GFPs), but regenerative practices are not considered GFPs despite their ability to enhance farm resilience and yield stability (Renton, Lafave, & Sierks, 2020). Similarly, through a practice called Yield Exclusion, farmers are able to exclude up to 12 years of low yield when reporting their average yields for the purposes of insurance payouts, which can promote the planting of "crops that fail more often than they succeed" (Schechinger & Cox, 2017, p. 6). Burdensome and complex insurance applications for diversified and specialty crops can deter farmers from pursuing these practices at all (Renton, Lafave, & Sierks, 2020). Schechinger and Cox argue that federal crop insurance policy is creating the conditions (i.e., soil erosion) to lead to another Dust Bowl (2017).

There are several ways to modify the current crop insurance structure so that it is not discouraging nor agnostic about resilience-enhancing, regenerative practices – or better yet, supportive of them. For example, the 2018 Farm Bill removed a harmful provision that made it impractical to insure cover crops.

However, NRCS-approved soil conservation practices currently are not incorporated into crop insurance via increased payouts or reduced premiums. Reform could change that (Renton, Lafave, & Sierks, 2020). NRDC and the Yale Center for Business and the Environment also recommend **eliminating Yield Exclusion,** which would remove a financial structure that makes it easy to continue practicing failed production models (2017; Renton, Lafave, & Sierks, 2020). Capping subsidies for the largest farms and reducing administrative hurdles for insuring diverse, complex farming operations could also usher in more regenerative implementation (Renton, Lafave, & Sierks, 2020).

Lehner and Rosenberg suggest going further. Together, crop insurance, conservation payments, and commodity programs (like agricultural risk coverage and price loss coverage) compose the federal "farm safety net" (2017). Annually, these programs cost $20 billion – about $10 billion, $6 billion, and $4 billion, respectively. Lehner and Rosenberg propose swapping some or all of the farm safety net for a **payments-for-ecosystem-services (PES)** system. If farmers were compensated at a rate of $16/acre, it would cost $15 billion to offer this payment for each of the 914 million agricultural acres in the United States (Lehner & Rosenberg, 2017). They suggest refining the PES structure to make it a progressive payment, in which payments are greater for small- and mid-sized farms, and/or limited to the first 1000 acres of a farm (Lehner & Rosenberg, 2017). In addition to costing $5 billion less each year than the existing farm safety net, this PES schema would provide powerful impetus for the adoption of soil health practices because it inherently recognizes, in monetary terms, the environmental and social value of healthy soil. It would reduce farmers' exposure to the vagaries of commodities markets and weather events and instead bolster their income through a reliable schedule of conservation payments. It would thus provide greater economic security for regenerative and small- and mid-sized farms (Lehner & Rosenberg, 2017).

Another oft-discussed approach involves implementing a federal **fertilizer fee** or increasing existing fertilizer fees. In addition to N_2O emissions associated with overapplication of nitrogenous fertilizer, the process of producing N fertilizers is highly polluting. The production and use of 1 ton of N fertilizer releases 13.5 tons of CO_2e in China and 9.7 tons of CO_2e in Europe (Zhanga, et al., 2013). A fee on fertilizers is one way to incentivize their use efficiency.

Most states impose a fertilizer fee between $0.10/ton and $1/ton (NEDA, 2020; MDA, 2020). By comparison, the federal gasoline tax is $0.184/gallon, and each gallon produces roughly 19 pounds of CO_2 when combusted, which means that each ton of gasoline CO_2 emissions is taxed at about $19.36 by the federal government.[13] If the same CO_2e tax were levied on N fertilizer emissions, and assuming a rate of 9.7 tons CO_2e per ton of N fertilizer produced, this would equate to a fee of $188/ton N fertilizer.[14] Similarly, the 45Q federal tax credit values CO_2 sequestered at $20/ton (OLRC, 2020), which equates to a fertilizer fee of $194/ton.[15] If the federal government squared fertilizer fees with gasoline fees, the former would increase by 200 to 2000 times.

In this light, the almost negligible fertilizer fees function as a subsidy, especially when also considering that fertilizer prices have dropped by almost 30% in the last decade (NASS, 2020). A 1% increase in fertilizer prices can cause a 1.87% reduction in fertilizer demand (Williamson, 2011). According to Lehner and Rosenberg, this implies that a 10% tax on fertilizers would create hundreds of millions of dollars of annual revenue while reducing fertilizer use by 19% and negligibly affecting overall yield and food prices (Lehner & Rosenberg, 2017). A massive set of coordinated field trials in China put the above reasoning to the test. The study spanned 38 million hectares and 21 million farmers and aimed to implement resource efficiency and best management practices. The study found that fertilizer use dropped by up to 18.1% while yields increased by 11% and CO_2e emissions dropped by 14%, 21%, and 22% for rice, wheat, and maize (Cui, et al., 2018). Reduced fertilizer application along with increased yields created an additional $12 billion of profit (Cui, et al., 2018). To prevent new fertilizer fees from being regressive for small farmers, the federal government could implement other payment or subsidy systems, such as PES (WEF, 2020).

These results show that federal-scale policies that encourage resource use efficiency and conservation practices can be good for the environment and for farmers' economic wellbeing. Fertilizer fees are one pathway to get there. Alternatively, policies that incentivize optimization and reduction of fertilizer use can also be effective. While N_2O emissions in the rest of

13 Steven Keleti, 2020, personal communication with author.

14 Ibid.

15 Ibid.

the world were increasing, Europe's N_2O emissions dropped by 21% between 1990 and 2010 following the adoption of the EU's Nitrates Directive (McKenna, 2020; Velthof, et al., 2014). Field studies demonstrate that following fertilizer efficiency practices can preserve and even increase crop yield when combined with agroecological management (Chen, et al., 2014).

Lehner and Rosenberg and the World Economic Forum recommend a variety of other federal policy actions to promote soil health (2017; 2020). Their suggestions include:

- **Expand funding for innovative agricultural research and development programs** that have high rates of returns on investment, and especially for projects that focus on soil health and carbon farming. Such federal programs include the Agricultural Research Service (ARS), National Institute of Food and Agriculture (NIFA), Sustainable Agriculture Research and Education (SARE), Foundation for Food and Agriculture Research (FFAR), and the extension system (which is administered by NIFA but largely funded through states).

- Use government **procurement policies** to drive demand for regeneratively-produced food in all government bodies, "including large-scale purchasers such as the U.S. Department of Defense" (Lehner & Rosenberg, 2017, p. 10875).

- Following the precedent of countries like Brazil, Denmark, and Sweden, encourage sustainability and regeneratively-produced food in **federal dietary guidelines**, which could drive consumer behavior at scale.

- Eliminate **agricultural use exemptions for concentrated animal feeding operations** (CAFOs), which are highly polluting and unethical.

    - Related to this, resist the pressure from the livestock industry to reinstate an exemption that once allowed the industry to avoid hazardous pollution reporting required under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Emergency Planning and Community Right-to-Know Act (EPCRA).

- **Incentivize rotational grazing**, and disincentivize degrading grazing patterns, on federally managed public lands. The U.S.

Forest Service (USFS) and Bureau of Land Management (BLM) oversee 40% of grazing lands in the U.S. Not all public lands are appropriate for incentivized rotational grazing, but these agencies can implement it where and when appropriate.

- **Expand the USDA's "Building Blocks" plan** for climate-smart agriculture, which aims to offset 120 Tg CO_2e annually by 2025 – the equivalent of taking 25 million passenger cars off the road (USDA, 2016).

- Create a **regenerative version of the "Organic Initiative,"** a pool of EQIP funds allocated solely for use on organic lands.

- Emulate a 2015 **rule change implemented by the Risk Management Agency (RMA)**, the USDA branch that administers federal crop insurance, that increased organic acreage enrollment in crop insurance by 34%. Farmers that use novel practices can have difficulty insuring their crops, but the new RMA rule expanded the geographic locale of experts that farmers were allowed to consult to vouchsafe their innovative practices. This made it easier for organic farmers to receive insurance. The USDA should create a similar rule for regenerative, soil health, conservation, or carbon farming.

There are a variety of tools in the federal toolbox that can be used to encourage regenerative agriculture. Countries around the world have implemented versions of them with positive results, and studies support the science that backs them. In many cases, the scaffolding of successful programs and agencies is already in place, and they simply need more funding. Federal-level initiative is needed for regenerative agriculture to achieve a scale that can benefit farmers, the environment, and society.

State

State governments have many of the same tools available to them as listed above in the section on federal policy. For example, like the federal government, states can raise their fertilizer fees, expand their funding of the extension system and research institutions, and prioritize regenerative production in procurement policies.

There are some actions only within the purview of the federal government, like USFS grazing land policy and crop insurance. At the same time, states also have special capacities that make them well positioned to enhance soil health within their borders. State and local politics are less likely to be polarized on key issues than the federal government (Jensen, Marble, Scheve, & Slaughter, 2019). Agricultural growing conditions, from climate characteristics to soil types and weather patterns, vary greatly between states. States are therefore better suited to design and execute a soil health policy package for their unique environmental and political conditions.

Existing and Proposed Initiatives

Many states have done just that. A 2019 presentation by the nonprofit Earthjustice stated that there were 5 states with soil health policies in place, 9 with proposed legislation, and an additional 5 in the process of drafting potential legislation (Lehner & Henderson). In the year and a half since the time of the presentation, momentum has quickened. Four more states (Vermont, Nebraska, Washington, and New Mexico) passed soil health policies, bringing the total to 9 states with existing legislation; 12 currently have legislation drafted (New Mexico Legislature, 2020; N4E, 2020). The Soil Health Institute lists 20 states with policies, passed or proposed, that directly relate or are adjacent to soil health (e.g. Utah's resolution that declares the importance of SCS on rangelands, New York's Green New Deal task force, or Minnesota's drinking water protection pilot program) (2020).

Given the ballooning number and type of policy actions states are taking, listing and describing all of them is beyond the scope and usefulness of this report.[16] Instead, what follows are several initiatives that are representative of the diverse design and impact of state-level soil health policies.

---

16 For further discussion of state soil health policies, review the following online sources with full citation information in the References section: Lehner & Henderson, 2019; Soil Health Institute, 2020; IATP, 2019; Izaak Walton League, 2019; N4E, 2020; Soil Solution, 2018.

- California's **Healthy Soils Program (HSP)**. HSP was the nation's first state-level program that paid producers to improve their soil and fight climate change through their farming methods (CalCAN, 2020). Established in 2017 by SB 859, HSP pays farmers for each acre on which they implement practices that improve soil health and sequester carbon (OEFI, 2020). Eligible practices include cover cropping, no or reduced till, composting, and mulching, among others. Its funding has fluctuated each year, but its 2020 allocation was the highest yet at $28 million (Lyle & Hernandez, 2020; Morning Ag Clips, 2020). HSP receives its funding through California's Greenhouse Gas Reduction Fund (GGRF), generated by payments into the state's cap and trade system. This funding is in jeopardy, though, as the 2021 proposed budget is smaller at $18 million, and California is expected to open the GGRF to projects not just focused on climate mitigation, leading to more competitors for GGRF.
  The California Department of Agriculture recently made changes to the program to improve its efficiency including streamlining the application process, increasing the maximum award amount, lengthening the application window, and better aligning payments to mirror EQIP payment structure (Shobe, 2020). These improvements stem from farmer critiques about the program (Shobe, 2019). The year 2020 was by far the program's most popular year in terms of applications received and funds requested (Shobe, 2020).
  In addition to HSP, California has three other programs that aim to enhance agricultural productivity, save costs, improve soil health, and fight climate change. They are the Adaptive Manure Management Program (AMMP), the State Water Efficiency and Enhancement Program (SWEEP), and the Sustainable Agricultural Lands Conservation (SALC) Program.

- Three thousand miles to the east, Maryland also implemented an initiative called the **Healthy Soils Program** (MDA, 2017). Maryland farmers already have a strong record in conservation practices, ranking first nationwide in the percentage of cropland that incorporate cover crops and second in no-till implementation (LaRose & Myers, 2019). HB 1063 created the HSP program with the support of the Maryland Farm Bureau, state climate activists, and a bipartisan group of state legislators (Via, 2018; N4E, 2020). The policy is modeled after California's HSP and supports similar goals towards soil health, yield, and SCS. The major difference is that Maryland's program has no funding source and is largely focused on research, technical assistance, and education as opposed to actually paying farmers per acre of implementation (N4E, 2020). However, Maryland is also home to the **Agricultural Water Quality Cost-Share Program**, which pays farmers up to $75 an acre to implement practices that conserve water resources, especially cover crops (Izaak Walton League, 2019).

- Some states pursue a model of creating **soil health task forces**. Hawaii created the Carbon Farming Task Force to identify best practices and make recommendations to the state government with the ultimate aim of establishing a carbon farming certification (Izaak Walton League, 2019). Nebraska established the Healthy Soils Task Force, which is charged with designing a comprehensive statewide soil health initiative, a plan and timeline to execute it, and a report back to state officials by the start of 2021 (Izaak Walton League, 2019). In both instances, establishing a task force is a scoping step ultimately intended to lead to the passage of a robust soil health policy.

- Iowa implemented a **cover crop cost share program**. New participants can receive $25/cover cropped acre, and returning users receive $15/cover cropped acre (Izaak Walton League, 2019). Nebraska has a similar law in the works, but farmers would receive $20/acre for single-species cover crops and $45/acre for multi-species cover crops (Izaak Walton League, 2019).

- Iowa has also negotiated with RMA to offer a **crop insurance discount** for farmers who use cover crops (Izaak Walton League, 2019). The Iowa Department of Agriculture and Land Stewardship uses funds generated by the Iowa Water Quality Initiative to offer farmers a discount of $5/acre if they use cover crops (Izaak Walton League, 2019). Illinois now offers a similar cover crop insurance discount (IDA, 2020). This has sparked interest from farmers who at present do not use cover crops. Since cover crops enhance farm resilience, using them to generate lower insurance rates alters crop insurance structure in such a way that regenerative practices are appropriately rewarded for the agricultural and societal benefits they offer.

- A Conservation District in Illinois created the Illinois **Saving Tomorrow's Agricultural Resources (STAR) Program**. This is an optional and free program for Illinois farmers to have their fields rated on a scale of 1 to 5 stars on key water quality and nutrient management metrics. Colorado is considering adapting this rating system to focus on soil health (see below). By evaluating these metrics, farmers can benefit from reduced nutrient loss and crop insurance premiums, better access to market premiums for sustainable farming, and improved chances of receiving local conservation cost shares (CCSWCD, 2012).

The Colorado Collaborative for Healthy Soils

The Colorado Collaborative for Healthy Soils[17] (CCHS) is a model soil health policy initiative. The program focuses on stakeholder engagement, coalition-building, policy design, and remaining producer-centered and -informed. Its proposals address critical leverage points for soil health implementation and provide an example for other coalitions to emulate.

The program has 5 major goals:

- **Create a soil health grant program** to producers and conservation districts for implementation, education, and research
- Increase technical assistance capacity at the Colorado Department of Agriculture (CDA) by hiring **soil health technicians**
- Bring **established programs** from around the nation to Colorado, including the Illinois STAR program and the Soil Health Partnership
- Offer free or reduced-cost **soil health testing**
- Complete a **soil health inventory** to understand Colorado's "current implementation of soil health practices, past successes and challenges by region, geospatial assessment of the state of our soils, impacts on water quality, and estimates of future carbon sequestration on agricultural lands."[18]

---

17 Disclaimer: the author is a member of CCHS and helps advocate for its policy proposals.

18 CCHS, 2020, internal documents.

Each of these priorities addresses an important need for soil health policy (e.g. reliable soil testing and technical assistance) or builds on successful adoption mechanisms elsewhere (e.g. the STAR program and soil health grants). There are many barriers to adoption of soil health practices, and CCHS aims not just to solve one of them, but several at once.

CCHS did not, however, arrive at these proposals through top-down discussions or academic analysis. The group is a coalition of organizations who vet overall direction and specific proposals. Allies include the Western Landowners Alliance, Colorado State Conservation Board, Colorado Cattlemen's Association, Rocky Mountain Farmers Union, and a consortium of NGOs, state agencies, universities, and local governments. These groups determined early on that any proposal should be voluntary and incentive-based as opposed to mandatory or regulatory. CCHS also held 7 geographically diverse listening sessions where 171 Colorado producers voiced their opinions, desires, and concerns. CCHS had planned 4 additional listening sessions but canceled them due to the COVID-19 pandemic. They instead solicited additional feedback from producers via online survey. The listening sessions and survey were intended to gain the buy-in and center the views of farmers since they hold the on-the-ground responsibility of changes in agricultural production methods. The recommendations of policy analysts and program managers are important, but farmers know their trade best. CCHS also has a Producer Advisory Council which evaluates CCHS proposals, and working groups for Science and Practice, Incentives and Policy, Knowledge Sharing, and Stakeholder Engagement.

Listening Session Results for Remaining Producer-Centered

The results of the producer listening sessions were informative and yielded valuable insight into what types of soil health policy is preferred, and therefore most likely to be utilized, by farmers. For example, the soil health practices that interested farmers most were cover crops and intercropping. Reduced- or no-till and perennial planting were also on the list but less of a priority (Figure 7). The largest barriers to soil health that farmers perceived were economic, regulatory, and educational. A representative quote from a farmer is "the more you get into soil health, the more you discover what you don't know."

When asked what help they needed to implement the soil health practices they were most interested in, the largest category by far was funding, followed by a close tie between market access, producer education, and technical assistance (Figure 8). Representative quotes include, “if you incentivized me, I would be running towards soil health practices,” and, “sure, there’s some people who won’t try these things, but most just need a little more convincing and are close to ready to start trying something.”

What soil health practices would you like to be using?

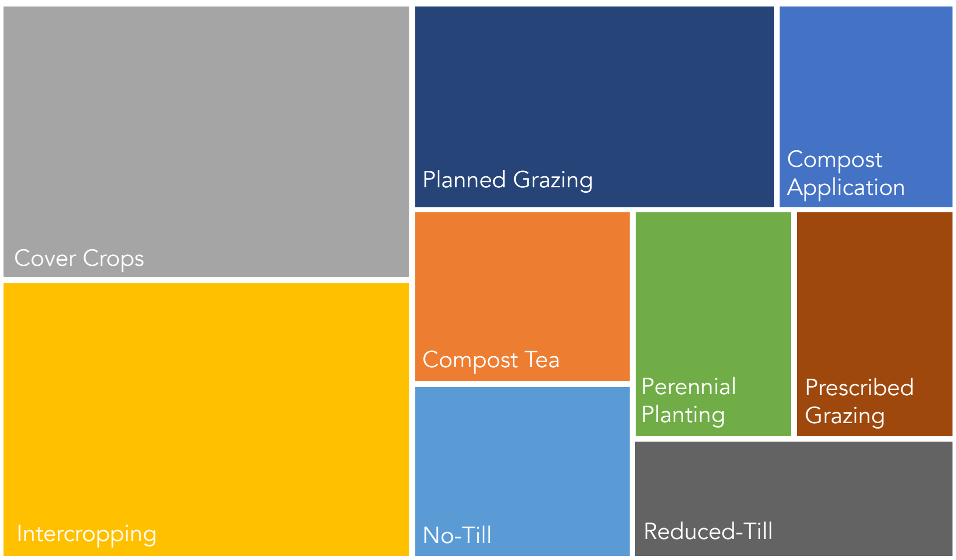


Figure 7. Results from survey of Colorado farmers, CCHS, 2020.

What help do you need to implement the soil health practices you would like to?

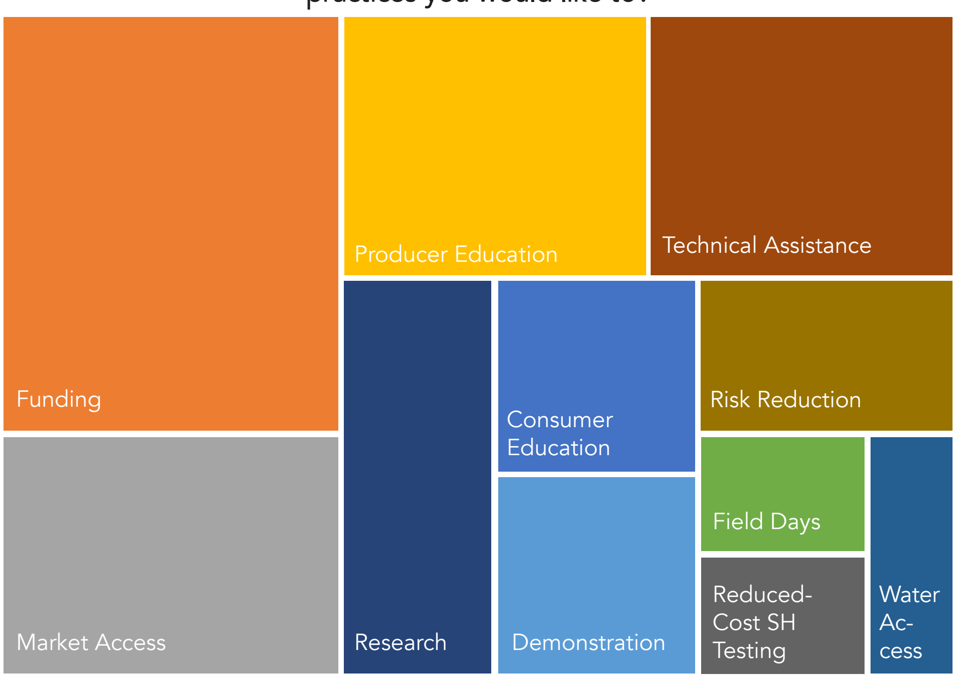


Figure 8. Results from survey of Colorado farmers, CCHS, 2020.

When asked how the CDA can best use soil health funds, the largest categories of responses were marketing and producer education, followed by consumer education and ecosystem service payments. Farmers were clear about their need for policy, financial, technical, and market support if they are to usher in a suite of new farming methods. Representative quotes include, "the State of Colorado needs to devote some money (even a very small amount per acre) to pay for carbon sequestration. If the state would pay $20/ton it could be the difference between going broke and making a profit," "spend time developing markets, or else you will throw $150k into the wind and someone will get a paycheck for a year and nothing will change," "you can hand a farmer a bunch of grant money, but if he's not properly educated it won't help anything," and, "put money in the pockets of the people who are already doing this. I'm not interested in telling farmers what they can do better."

When asked about their motivations around soil health practices currently in use, the most common responses were good farm management, sustainability, and reduced costs. Representative quotes include, "at the end of the day, we use these practices to stay in business. They create sustainability. When you make a living from soil you need to sustain it to make a living," and, "I used to regard soil as a kind of chemistry set, inputs came from elsewhere. Now, I see I can make the inputs right on the property."

Other important quotes include:

> If 'Big Ag' disappears, people starve to death. I want my conventional friends to farm what I call 'better'. Those people rotate, they only till once (not twice). My conventional friends are more sustainable than me; if I keep going I'll go broke. Question is: How do we get these people to do soil health so we can have 3 million acres of health soils instead of 300?

And:

> You need to look to Missouri as an example of a shared equipment program that works. Every county has multiple drills, they have a soil district technician in the office who takes care of O&E. Funding comes from a Parks and Soil Tax, which is $80M that provides $20M in cost share and personnel, equipment. They also do a low-interest share

program to help the transition to no-till. They have liability and insurance figured out.

The polling and quotes demonstrate a producer population deeply engaged in creating economically viable operations, committed to the health of their land and soil, and aware of potential risks in adopting new farming methods. Producer preferences elicited by this process informed CCHS programmatic priorities.

CCHS is currently working with their partners to draft legislation by the end of 2020 to be introduced in 2021. When initiatives establish broad coalitions, producer support, and a transparent process, they stand a better chance of success.

Local

The actions of local governments can also support regenerative agriculture. Similar to state-level actions, the practices implemented by local government policies are diverse and bespoke. Some examples from Boulder County may be instructive for other localities.

In 2016, Boulder County created a sustainability fund apportioned from local sales and use taxes (2020). In the most recent application year, $300,000 of the $7 million available was allocated for soil health and local food. Some recipients like Ollin Farms, for example, used the money to pay for tree planting, cover crops, pollinator habitat seeds, and other inputs. Other local operations have used the money to implement rotational grazing. Other counties or cities can tailor funds to their particular needs – for example, in eastern Colorado, where water is scarce, such funds could go towards irrigation equipment, center pivot upgrades, other water infrastructure, and roller crimpers (a tool that allows farmers to mechanically terminate cover crops and then plant directly into the residue in the same pass, which could conserve time, energy, and fuel) (Rodale Institute, 2020).

Another action local governments have some jurisdiction over is zoning codes and land access policies. Given that finding affordable land to lease or purchase is the number one challenge facing young farmers (Ackoff, Bahrenburg, & Shute, 2017), policies that make land more accessible to farmers will help sustain the future of American farming. In Boulder County, 25,000 acres of the 100,000 acres owned by the county open space division is available for low-cost agricultural leasing. The county leases land to qualified farmers and ranchers for between $10 and $100 per acre, an affordable rate that can give farmers a vital economic boost (Dula & McCracken, 2017). The county may provide some infrastructure and equipment as well as market access by agreeing to purchase half of the harvest from some farms (Dula & McCracken, 2017). These low-cost leases do come with some strings – for example, farmers also must comply with county agricultural guidelines as well as federal ones, and in Boulder's case, that means not planting any GMOs.

Local governments can also ease regulations around selling directly to consumers, housing laborers on their land, hosting commercial kitchens and farm stands, and offering educational events and tours. They can take action on county- or city-specific issues – for example, there is debate in Boulder County about the legal extermination of prairie dogs, which are overpopulated and cause damage to agricultural lands. Similarly, local governments can create labels to generate pride in the place of food origin and allow consumers to choose products grown nearby. State Conservation Districts, which, in Colorado, are entities under the State Conservation Board, are often trusted local sources of information for farmers and the best venues for information dissemination and technical assistance. Conservation Districts can partner with local governments to accomplish their mutual goals.

Incentives are ultimately needed at all levels of government. Local, state, and federal policies can each address different types and scales of issues, but all should align on the need to incentivize practices that improve the health of the land, soil, and water, make farms more economically viable, and help mitigate climate change.

Photo: Zoe Schaeffer on Unsplash

Business and Markets

A common critique of the policy process is that it sometimes moves more slowly and incrementally than advocates desire. Private efforts are often free of these constraints. The prerogatives of businesses and markets do not require working for the social good; it only requires making money. Government, on the other hand, is charged with protecting the public welfare. But when private efforts do assume the mantle of social and environmental responsibility, their impact can be swift and significant.

Carbon and Ecosystem Service Markets

The fundamental idea underpinning carbon and ecosystem service markets is to quantify, in monetary terms, the social and environmental value of improving environmental health and to allow entities to pay (or receive payments) for that value. Governments and private actors have shown that they value carbon removal by, for example, paying for industrial carbon capture (see the discussion on 45Q above), by paying to offset their own emissions (a la Google, Delta, Microsoft, and many other companies), and by capping how much carbon can be emitted and instating penalties if that limit is exceeded (as in California's cap-and-trade system). This logical precedent can be applied to create private carbon and ecosystem service markets for agriculture.

Another underlying concept is that society pays the cost of carbon emitted and ecosystem services lost downstream – and these downstream costs are often more expensive than preventing them at their source. This justifies pricing externalities to prevent downstream cost amplification. For example, if the social cost of a pound of CO_2 were reflected in the price of a gallon of gasoline, fuel prices would be higher, thereby encompassing the total cost of that gallon of gasoline (and reducing demand). Leaving the cost of these externalities unincorporated in product prices can be seen as a market failure. It would be more cost effective to stop these issues before they start.

Markets can acknowledge this reality by recognizing that climate change poses a societal threat and that mitigating it is a societal service. An agricultural carbon market could pay farmers a specified rate per ton of carbon removed from the atmosphere and sequestered in soils. An ecosystem services market could pay farmers per unit of environmental benefits they offer, whether that is reducing nutrient runoff, restoring riparian habitat, building SOM, or other services. Doing so at a large enough scale and for a long enough time would prevent the magnified costs that would occur downstream in the absence of market payments.

While market-based solutions are often heralded as business-smart and economically sound, the most common business objection is that implementing these environmental markets at a scale large enough to be meaningful is too expensive. This criticism is flawed in two ways. Arguably, enough money exists to implement a robust carbon or ecosystem services market – the question is where that money is allocated. If the price tag of such a program seems high, we should also examine the value of other programs with similar or higher price tags. Taking Lehner and Rosenberg's estimate of $15 billion annually to implement a nationwide PES system on all American farmland, and then doubling it, gives a cost of $30 billion. This is still dwarfed by federal defense spending, which was $676 billion in 2019 (CBO, 2020). The United States spends more on defense than the next 10 countries combined (PGPF, 2020). Whether that amount is appropriate is not the subject of this report. But in a balanced consideration of national priorities, averting climate catastrophe, ensuring farm viability, and engendering long term food security is at least as important as maintaining a powerful military presence. In this light, $30 billion per year may be a minimum figure we should invest in making our food system and soils resilient and regenerative. This is all to point out that funding a carbon market is not a matter of cost, it is a matter of priorities. Opponents to finding enough funds to support a carbon market should not blame their hesitance on cost but be plain in saying that they do not see it as a priority.

The second issue with saying carbon and ecosystem services markets are too expensive is that it overlooks an inconvenient truth alluded to above: society pays the costs of carbon emitted and ecosystems destroyed anyway. Climate change will be, among other things, a tremendously expensive problem. According to NOAA, the average cost of natural disasters costs the U.S. more each decade since the 1980s. Between 2017 and 2019, natural disasters cost the U.S. an average of $153.5 billion each year, compared to an annual average of $18 billion in the 1980s (NOAA, 2020). Whether forest fires, flooding, or hurricanes, each of these events are predicted to become more frequent and more intense with climate change. There are also significant public health costs associated with climate change. According to one study, climate change caused $10 billion in health-related expenses in 2012 (Limaye, Max, Constible, & Knowlton, 2019). A recent study estimated that the economic costs of California's 2018 wildfires was $149 billion, a figure which includes capital, health, and indirect losses (Wang, et al., 2020). Greater costs are likely in the future as climate change worsens. Low-income and minority communities suffer this burden most heavily. If society will bear the economic costs of climate change regardless, markets should be arranged so that that money is spent proactively in preventing greater future costs. Otherwise, we will continue to passively pay the ever-increasing costs that come from inaction, which will far eclipse the costs of prevention now.[19]

---

19 The seminal Stern Review by Lord Nicholas Stern estimates that an investment of 1% of GDP is needed now to avoid a 5%-20% insult to GDP in perpetuity if warming advances unchecked (2006). In other words, "the benefits of strong and early action far outweigh the economic costs of not acting" (Stern, 2006). Other attempts to quantify the economic impacts of climate change include Nobel-winning William Nordhaus's well-known work with a notoriously high discounting of future costs (Nordhaus, 2007). While Nordhaus's view that the future costs of climate change aren't costly enough to warrant disruptive action now has its adherents, it is strongly critiqued by many scientists and economists as being noncompliant with scientific targets set by the IPCC and UNFCCC (Diaz & Moore, 2017; Mackenzie, 2018; Komanoff, 2018). Nordhaus's more recent work prices the social cost of carbon more highly compared to his earlier work (Nordhaus, 2017).

Two noteworthy private efforts exist to implement agricultural carbon markets: Indigo Agriculture and Nori. Indigo Ag's major initiative in the carbon marketplace is called Indigo Carbon. Indigo Carbon proposes to pay farmers $15 per ton of C sequestered (2020). Indigo verifies initial soil C through a soil test and supplemental satellite analysis and then works with farmers to implement soil health practices like cover cropping, crop rotations, reduced chemical usage, no-till, and manure application (Poindexter, 2020). Indigo offers farmers the options of purchasing their proprietary microbial seed coatings, which they claim increases yields and profits and gives the farmer access to expert agronomists and data analytics who monitor seed performance (Merrill, 2019). Indigo reportedly expected 3 million acres of enrollment in 2020 – they are at 20 million as of this writing (Indigo Ag, 2020). They earned CNBC's #1 slot in their 2019 Disruptor 50 rankings (2020). Indigo expects the market for carbon credits to expand and mature rapidly in the coming years and has attracted large companies, like FedEx, that are interested in offsetting their carbon footprint (Poindexter, 2020).

Indigo's model is not without its critics. There is skepticism among farmers who have experienced carbon market failures like the Chicago Climate Exchange collapse.[20] Farmers can also be rightly suspicious of buying seeds from large agricultural corporations, having experienced how soils can become "addicted" to chemicals and unable to survive without regular, heavy, and expensive applications of fertilizers and pesticides (Pollan, 2001). Data is often a consumer's most valuable asset, and it is currently gathered and used for free by many tech companies. Indigo agronomists gather crop performance data, but it is unclear whether the farmers own the data their farms generate. If they do not, companies like Indigo are essentially using millions of acres of farmland for free field trials to improve their products. There is also precedent for the acquisition of disruptive and environmentally-minded startups by Big Ag giants who are uninterested in changing systems – some wonder if Indigo's destiny is the same (Merrill, 2019). According to Merrill, companies like Indigo may "create market winners that are often the large industrial producers and sellers," while leaving behind "a diversity of farmers, including small and mid-scale farmers and farmers of color… because of a lack of capital and technical assistance" (2019).

20 Renata Brillinger, 2020, conversation with author.

Proponents claim that Indigo's fixed price of $15/ton of carbon can avoid the fluctuations inherent in some market models (Merrill, 2019). Other supporters laud Indigo's "challenge" provision they have implemented in Brazil, where if a technology does not perform for farmers, Indigo does not charge the farmer for the treatment (Netto, 2019). One agronomist was pleased that Indigo will "not only share in the profits but also the losses" (Netto, 2019). It remains to be seen how exactly this scenario will play out, but so far, Indigo's carbon marketplace has garnered a sizable response.

Nori is another private carbon marketplace that pays farmers to sequester carbon. The similarities between Nori and Indigo largely end there. Nori connects corporations – and individuals – interested in offsets to farmers pulling carbon out of the atmosphere. While Indigo is creating agronomic tools like microbial seed coatings, Nori is more tech-oriented and the backbone of the Nori marketplace is a blockchain token. Its tokens are worth 1 ton of C and are valued at about $15 (Levy, 2020).[21] Nori makes money by serving as the middleman between farmers and purchasers of carbon removal credits (Nori, 2020). The company is still in an early phase of rapid growth and currently has more demand than it can handle. It ultimately plans to offer carbon removal through direct air capture, reforestation, blue carbon, and other methods, but is starting with agricultural soils (Davitt & Hirsh, 2019). This is a validation of Indigo's proclamation that compared to other options, agricultural soils are the most immediate, scalable, and affordable means to sequester carbon.

Nori validates carbon removal using COMET-Farm, the most sophisticated and widely used modeling software for agricultural soils and SCS, and other third-party GHG reduction verifiers. When farmers sign up for a 10-year Nori contract, their payments start more slowly as "restricted funds" for the first few years as SCS is modeled with COMET. This allows farmers to monetize SCS immediately even though the transition to regenerative practices may be more gradual. As their contract progresses, SCS data is ground-truthed for greater accuracy via soil sampling and testing, and farmer payments from "unrestricted funds" increase. As data increases in quality and quantity, so do farmer

21 The Colorado Collaborative for Healthy Soils was responsible for the first few farms that enrolled in the Nori marketplace.

payments.[22] This phased payment system is in part meant to avoid the use of the contracts' clawback provision, which would ask farmers to repay their SCS payments if data ultimately shows that they have not sequestered as much carbon as expected. With each purchase of a token, transactions are recorded on the unalterable blockchain, which ensures transparency and avoids double-counting.

Although Nori is a younger company than Indigo, and one that operates on a different model to create a carbon marketplace, the two companies represent well-funded and robust efforts to create long-term carbon markets.

Relatives to carbon markets are ecosystem services markets (although ecosystem services markets can include carbon credits in their marketplace). The Ecosystem Services Market Consortium (ESMC) is perhaps the largest such effort in the United States. It is a subsidiary of the Soil Health Institute and has dozens of corporate, NGO, and producer partners. The ESMC is aiming for a nationwide launch of its marketplace in 2022. It will offer credits for water quality improvement, water conservation, and carbon sequestration. A report by IHS Markit found that the potential demand for ecosystem service market credits is $14 billion in the U.S. (2019). This coincides well with Lehner and Rosenberg's proposal that a PES system replace some or all of the federal farm safety net, which they estimate would cost $15 billion.

It is also worth noting that private entities are not the only ones who can set up environmental markets. California's cap-and-trade system, the consortium of northeast states involved in the Regional Greenhouse Gas Initiative, and the Transportation & Climate Initiative are 3 government-established markets to improve environmental and climate outcomes.

There are substantial criticisms of using marketplace approaches to improve soil and climate action in the agricultural sector (and beyond it). One issue is establishing the right price. There is a wide gulf between current levels of demand for carbon and ecosystem service credits and the price needed to drive positive environmental outcomes at scale. Nori and Indigo both currently offer about $15/ton of C sequestered. But prices must be higher

22 Ross Kenyon, 2020, conversation with author.

to drive down GHG emissions – and to get farmers' attention. Some experts say $40-$50/ton would be needed (Yoder, 2018); others have said between $60-$100/ton is better.[23] To stay below 2C of warming, the IMF says that a price of $75/ton is needed by 2030, and that it should increase thereafter (Gaspar, Mauro, Parry, & Pattillo, 2019). Sweden is a step ahead and taxes carbon at $127/ton (and its emissions have decreased by 25% since 1995 while seeing a 75% economic growth rate) (Gaspar, Mauro, Parry, & Pattillo, 2019). The IPCC asserts that carbon emissions should cost $135/ton at minimum by 2030 to be consistent with 1.5C of global warming (2018). According to the World Bank's Carbon Pricing Dashboard, 61 governments have put a price, or are planning to put a price, on carbon (2020).

But the current average global price is $2 per ton (Gaspar, Mauro, Parry, & Pattillo, 2019). This is an area where government and private entities can work together. When governments set targets, incentives, and expectations, market systems can achieve the buy-in, engagement, and certainty they need to scale up.

Another major challenge with such markets is getting the accounting right. For carbon credits to be legitimate, they must meet requirements of additionality, permanence, non-double counting, and verifiability. This means credits need to generate carbon sequestration that happened solely because of the credit purchase; they need to not be reversed when land ownership changes hands or managers change practices; they can only be counted in one marketplace; and they need to be reliably ground-truthed and measured. Historically, carbon markets have failed at meeting these criteria.

Thorough soil testing to verify SOC and other metrics can be expensive. Alternatives to soil testing such as drone and satellite imagery for vegetation assessments, in-field sensors, and models like COMET-Farm are developing and, in some cases, well-respected. But they usually do not replace the need for ground-truthed verification at regular intervals through soil samples or probes. If the results that underpin carbon markets – or for that matter, government incentive programs – are to be trusted, reliable data is needed. Providing regular, affordable, and ubiquitous soil testing remains a puzzle to solve in order to implement these programs at scale.

23 Carbon Cycle Institute, 2020, conversation with author.

According to an investigation of forestry carbon markets by ProPublica, the authors found that "carbon credits hadn't offset the amount of pollution they were supposed to, or they had brought gains that were quickly reversed or that couldn't be accurately measured to begin with" (Song & Moura, 2019).[24] Accounting for how much deforestation was avoided (and forest preserved) by the purchase of forest carbon credits requires establishing a baseline of expected deforestation in the absence of credits. But these baselines are hypothetical and notoriously easy to manipulate in order to portray credits as highly effective and to keep attracting funds.

Song and Moura highlight one particularly egregious example from Cambodia in which 48,000 forest carbon credits were sold to protect a religiously significant tract of forest. The area was 88% forested when the market started, and 9 years later was only 46% forested. Yet these credits were sold and counted by firms as offsets to their GHG emissions. Similarly, "in Madagascar, deforestation in the reference area was already twice as high as in the project forest, so the project could claim to cut deforestation in half without doing a thing" (Song & Moura, 2019).

This is not a problem limited to the Global South. Critics of California's cap-and-trade market cite the well-known issue of leakage, wherein firms move their polluting activities to locales outside of the jurisdiction of the carbon market. This gives the appearance of an emissions reduction within the market geography but increases emissions outside the market geography. Similarly, the free credits issued each year by California allow firms to continue polluting. This affects low-income residents and communities of color most strongly because sources of pollution like factories, power stations, and waste disposal sites tend to be located near these neighborhoods (EPA, 2020; Brender, Maantay, & Chakraborty, 2011).

Critiques like this have led organizations like the Institute for Agriculture and Trade Policy to declare that "carbon markets won't work for agriculture" (Ritter & Treakle, 2020). It cites the above flaws, along with the volatility of credit prices on an open

24 Research by Dass and colleagues suggests that biophysically, grasslands may be superior to forests as carbon sinks in semi-arid regions, which make up about 40% of the Earth's land surface (2018). This is due to their belowground carbon storage and comparatively lower risk of carbon release from wildfires. These biophysical advantages still leave the design and management challenges listed here unaddressed.

market, which can either underpay farmers or leave them high and dry if the market collapses. They instead advocate for a robust, steady, holistic policy framework by federal and state governments (Ritter & Treakle, 2020). These entities have the power to "scale-up public resources for conservation practices while enacting common-sense checks on corporate concentration in the agriculture sector" (Ritter & Treakle, 2020).

Many critics do acknowledge, however, that carbon markets have not yet been given a proper chance to work. Without greater levels of participation and funding, shortcomings may continue to plague markets. But future markets with greater buy-in, funding, and accounting can succeed. According to Timothy Searchinger, they are "the worst possible idea – except for everything else" (Song & Moura, 2019). As a nod to their potential, in October 2020, Locus Ag completed the first large-scale, corporate carbon removal transaction using Nori's marketplace (Locus Ag, 2020). A row crop farmer in the Midwest, Kelly Garrett, received roughly $300,000 worth of carbon credits for the 20,000 tons of carbon his soil stores and then sold $75,000 of them to Shopify to offset their carbon emissions. This transaction is a milestone in the development of agricultural carbon markets.

Labeling and Value-Added Markets for Price Premiums

Between 1992 and 2018, total organic-certified acreage in the U.S. grew from 935,000 to 6.5 million (ERS, 2013; Ray, 2018). Preliminary estimates say organic acreage reached 8.3 million acres in 2019 (Knutson, 2019). Organic farms and ranches sold $7.6 billion of organic certified goods in 2016 – over twice as much as the $3.5 billion sold in 2011 (Bialik & Walker, 2019). Retail sales have grown from $2 billion in 1992 to $55 billion in 2019 (Greene, Wechsler, Adalja, & Hanson, 2016; OTA, 2020).

The expansive growth of the organic sector is in part a testament to the power of the clear, recognizable "USDA Organic" certification label. The organic label allows organic farmers to receive a price premium for their products because some consumers are willing to pay more for non-GMO food grown without chemicals. Studies confirm the enhanced profitability of organic operations. Cavigelli, et al., conducted a 6-year comparison of net returns on organic and conventional crop rotations and found that the organic system made between $3,933 and $5,446 per hectare, while conventional system made between $1,309 and $1,909 per hectare (Table 3) (2009). SARE found that organic farms may experience a small yield reduction, but that their net input costs decrease (even with added labor costs needed for chemical-free weed and pest management) and their profit margins increased. For example, a dairy farm that switched its cows to organic production found that they yielded up to 15% less milk but that their gross income grew from $125,000 to $165,000; in Vermont, conventional dairy producers received an annual return of $255 per cow while organic cows returned $477; another farmer received $4.70 per bushel of organic corn when the conventional average was $2.10 per bushel, and received $15 per bushel for organic soybeans compared to $3.80 per bushel of conventional beans (SARE, 2020).

Farm treatment	Cumulative value of net returns with organic price premium, 2000 – 2005 ($/ha)	Cumulative value of net returns without organic price premium, 2000 – 2005 ($/ha)
Organic 1	5446	94
Organic 2	4796	187
Organic 3	3933	1411
Conventional 1 (with no till)	n/a	1909
Conventional 2 (with chisel till)	n/a	1309

Table 3. Farm profits with and without organic price premiums, which shows how significant premiums are for organic products and how helpful they could be for regenerative products. Data from Cavigelli, et al., 2009.

Currently there is little formal, large-scale market recognition of regeneratively grown products, especially in commodity markets. Accordingly, one position supported by some farmers and advocates in the regenerative community is that creating a certification and/or label for regeneratively grown food could result in well-deserved price premiums. While the following opinion may not represent a consensus, one Colorado farmer told me that "farmers don't want handouts. They like to earn their money." In other words, he would prefer to get paid more for producing high-quality food. Regenerative management can be less formulaic and more complex than conventional farming – and it offers a societal good by providing soil health, resource efficiency, and climate mitigation – so growers who perform this service arguably should receive a higher price for their products.

One of best-known efforts to create such a certification is the Regenerative Organic Certification (ROC). Spearheaded by the Rodale Institute and supported by partners like Patagonia, Dr. Bronner's, and White Oak Pastures, the certification encompasses and builds on the organic certification (Regen Organic, 2020). It requires three additional pillars of product quality: soil health, animal welfare, and social and labor fairness. It ultimately aims to be complementary to existing certifications with related but more limited scopes, like the organic certification, Animal Welfare Approved certification, Climate Neutral Certification, and the Fair Trade and Food Justice Certified labels. The ROC completed a pilot in the summer of 2020 and expects a phased launch starting in late 2020.

Another effort is the Savory Institute's Land to Market program, which uses their Ecological Outcome Verification process to offer a certification (Savory, 2020). This program is focused on ensuring a diversity of ecological benefits that accrue from regenerative land management, including improved SOM, water infiltration, biodiversity, and SCS. It also attempts to be producer-centered and results-based rather than practice-based, which, according to the Savory Institute, ensures that regeneration is actually taking place, not just that certain techniques are being implemented (2020). The certification is offered for meat, dairy, wool, and leather products.

Beyond certification schemes that involve clear labeling and reliably tested criteria, a more informal approach is using regenerative products as a value-added input in retail markets.

Research shows that younger generations of consumers like Millennials are much more willing than older generations to pay extra for products that are environmentally friendly and socially responsible (Nielsen, 2018). Sales of sustainable products grew by 20% between 2014 and 2018, while sales of conventional products shrunk (Nielsen, 2018).

Many such products may not have a specific certification or label to apply to their product but use innovative marketing and copy to make clear that their products were grown with environmental and social health in mind. For example, Patagonia Provisions' Long Root Ale is brewed with kernza, a deep-rooting perennial grain that improves soil and stores carbon (2020). As such, Patagonia's marketing makes these benefits clear and appeals to those who want to "vote with their dollar" by purchasing goods that have positive impact. Similarly, Fibershed helps spread awareness about regeneratively produced textiles. Buyers of such materials can subsequently boast that the cotton or wool in their blankets and button-downs improved the land. They can thus charge a premium for their garments that environmentally-minded consumers are willing to pay (2020). There is also discussion about using regeneratively grown, carbon-sequestering corn to produce ethanol. With the right technologies, it is theoretically possible to make a carbon-negative gasoline.[25] While ethanol prices are likely to remain low – and perhaps should remain low – for other reasons (Irwin, 2019), one can imagine that some consumers hypothetically would be willing to pay more for a gallon of carbon-negative fuel than a gallon of carbon-positive fuel. This is the power of value-added markets for regenerative products.

Like efforts to price carbon, the certification and value-added approach to driving adoption of regenerative practices also has its challenges. For one, research shows that "label fatigue" is a drawback: the proliferation of labels and certifications may overwhelm consumers or dilute the meaning of each, such that a new label may not offer much advantage (Monaco, 2019). A related concern is that consumers need to actually understand terms like "regenerative" and "soil health" to properly value the labels that proclaim them. This could involve marketing and education efforts, which can be expensive, time-consuming, and produce ambiguous results.

25 Paul Zorner, 2020, conversation with author.

One technological development that could ameliorate this issue is increased use of consumer-available Brix meters. Brix is a measure of sugar suspended in solution within a plant and is a proxy metric for nutrient density and flavor. In theory, a consumer could take a quick Brix reading while evaluating produce in the grocery store and choose the healthiest specimens. Assuming the healthiest options are regeneratively grown food, this could help expand consumer demand for such products. However, this seems unlikely given the need for a separate device. More promising is the potential to create a smartphone app that could take an optical Brix reading. While some consumer segments are willing to purchase regenerative food based on their broader social and environmental concerns, others may only be motivated to purchase regenerative food if it meets their self-interest. If science can show that regenerative foods are more nutrient dense, it could reach a larger segment of consumers,[26] with convenient Brix scanners the enabling technology.

While price premiums for regenerative products would help convince more farmers to adopt regenerative practices, the upshot is that high prices may prevent lower-income consumers from affording this food. Organic produce is purchased more often by higher income and educated demographic groups (Curl, et al., 2013). In an ideal world, regenerative farming would be the norm and its products would be affordable for everyone instead of a privilege for the wealthy. The early stages of growth in regenerative agriculture presents the paradox that while such techniques may offer numerous societal and ecological benefits, the resulting food may be less accessible than conventionally grown food.

Food, Fuel, Fiber, Fashion – Corporate Efforts towards Regenerative Supply Chains

Agriculture sits at the origin of industries that create our food, fuel, fiber, and fashion. Companies in these industries can lead efforts to incorporate regenerative agriculture into their supply and value chains.

26 Tony Michaels, 2020, conversation with author.

General Mills committed to transitioning 1 million acres of the farms that grow its ingredients to regenerative practices (2019). Unilever is investing $1 billion in its Climate and Nature Fund, which includes goals like sharing a new Regenerative Agriculture Code with all of its suppliers, achieving a deforestation-free supply chain by 2023, reaching net zero emissions by 2039, and improving water stewardship (2020). Danone, the largest B Corporation in the world, also zeroed in on regenerative agriculture in its supply chains, which includes partnering with the 4 per 1000 Initiative and starting its own Soil Health Initiative (2020). Together, these 3 companies have a market capitalization of almost $200 billion, hundreds of brands, and a global reach (Macrotrends, 2020). Perhaps most telling of the growing business logic of regenerative management, Walmart recently committed to becoming a "regenerative company" in part by restoring 50 million acres of land and 1 million square miles of ocean by 2030 (Walmart, 2020). Walmart's market capitalization is $432 billion (Macrotrends, 2020). These companies' focus on regenerative agriculture could spur greater investment by other corporations.

Stock for biofuels constitutes a significant portion of American farmland. In 2011, 40% of the U.S. corn harvest went to ethanol (though the number has since dropped) (Mumm, Goldsmith, Rausch, & Stein, 2014). The biofuel industry can thus be a leverage point to advance regenerative agriculture. Gevo is an alternative fuels company that produces what it calls "renewable gasoline" and "sustainable aviation fuel" (2020). As discussed above, if inputs are carbon-sequestering crops, then the resulting fuels can be low-carbon or carbon neutral and would drive adoption of regeneratively grown corn. Many biofuels skeptics point out that the trend in transportation is towards electrification. Still, the City of Seattle purchased a minimum of 800,000 gallons of renewable gasoline per year for 4 or more years to power its vehicle fleet (Gevo, 2020).

The clothing and fashion industries are obvious leverage points for driving adoption of regenerative agriculture. The question of how exactly these industries can make this transition is receiving more attention (RI, 2020), and information like the Responsible Brands Directory by Regeneration International make those choices easier for consumers (2020). Companies like Prana, Patagonia, and Kering are early supporters of this movement

(Bauck, 2019), and the message continues to receive more mainstream media attention (Farra, 2020).

Potent alliances between corporations, NGOs, and farmers are also emerging. The Midwest Row Crop Collaborative (MRCC) is a "diverse coalition working to expand agricultural solutions that protect air and water quality and enhance soil health while meeting our global demand for food… including Bayer, Cargill, Environmental Defense Fund, General Mills, Kellogg Company, Land O'Lakes, McDonald's, PepsiCo, The Nature Conservancy, Unilever, Walmart, and World Wildlife Fund" (WBCSD, 2018, p. 28). A related project spearheaded by the National Corn Growers Association and led by farmers is the Soil Health Partnership. This public-private partnership includes many of the same partners as the MRCC as well as NRCS, FFAR, Rabobank, and large foundations (WBCSD, 2018). It aims to support farmers in researching bespoke soil health practices on their farms, improving their climate resilience, and enhancing their economic viability (SHP, 2020).

In addition to regenerative supply chains, some organizations seek to create platforms to direct private finance towards regenerative projects. Groups like Raise Green, Regen Future Capital, and Aspen Leaf Wealth Management use socially responsible and/or impact investing to finance climate mitigation and sustainable agriculture. For example, rePlant Capital has a "Soil Fund" that offers low-interest, flexible loans to farmers to fund their transition to regenerative practices. Marshaling private funds towards regenerative solutions is a vital approach given the multitrillion-dollar global investment required to meet ambitious climate change targets.

BOX 1: Can Regenerative Agriculture Feed the World?

One of the common concerns about regenerative and organic agriculture is whether they can be practiced at a scale that can feed the world's growing population. Since regenerative systems are more complex to manage, they are only feasible at small scale, as the argument goes. This means more land will need to be converted from native vegetation to agricultural production to sustain current levels of food production, and this land use conversion is a major driver of deforestation and GHG emissions. The climate and ecosystem benefits of regenerative agriculture would thus be negated.

There is evidence to suggest that this scenario is far from inevitable for two major reasons. First, the view that there is a supply-side problem of inadequate food production is untenable. Globally, only 55% of calories grown go to human consumption; the remainder go to biofuels and animal feed (Cassidy, West, Gerber, & Foley, 2013). If 100% of the calories grown went to human consumption, we could feed an additional 4 billion people (Cassidy, West, Gerber, & Foley, 2013). Similarly, of the food that currently goes to human consumption, the amount wasted is sufficient to feed an additional 2 billion people (FAO, 2013). Other studies show that even a slight reduction in the meat-intensity of global diets would reduce emissions and free up land for human consumption (and improve public health outcomes) (Tilman & Clark, 2014). Crops used for biofuels and livestock feed can be produced regeneratively and thus create benefits. Still, together, these figures suggest that we already produce enough calories to feed a population well in excess of the 10-billion-person peak expected by 2050. Eliminating inefficiencies in our food distribution systems, reducing food waste, improving the purchasing power of residents of the Global South, and devoting more food production to human consumption means that no additional land need be converted to meet demand.

The above argument also tends to imply that large-scale, conventional agriculture is the only way to meet our food production demand. The scientific literature suggests otherwise. There is a wide range of estimates on how much food the world's small-scale farms produce, although much of the discrepancies can be traced to different ways of defining "small-scale farm." One oft-cited figure is small-scale farms make up over 70% of agricultural land and produce up to 80% of the world's food (FAO, 2014). Another study found that small-scale farms produce 30-34% of global food supply on just 24% of the world's agricultural land (Ricciardi, Ramankutty, Mehrabi, Jarvis, & Chookolingo, 2018). A third estimates that 53% of agricultural land is managed by small farmers who produce at least 53% of the world's food supply (Graeub, et al., 2016). In any case, small-scale farms more than pull their weight when it comes to production and food security. And according to an UNCTAD report, the future of food requires us to see that "a farmer is not only a producer of agricultural goods, but also a manager of an agro-ecological system that provides quite a number of public goods and services" (2013). Small-scale farms are more agile and better poised to adopt this essential praxis. The foregone conclusion that large-scale agriculture is the only way to feed the world lacks empirical support.


Photo: Joban Khangura on Unsplash

Photo: J Remus on Unsplash

RECOMMENDATIONS

So far, the second half of this report has described a broad array of actions that could increase adoption of regenerative agriculture practices. Each of the mechanisms has the potential to be impactful and appropriate in different scenarios. With sufficient funding and political will, all of them would be worthy approaches, and the urgency of the problems we face may warrant a "pursue every option" strategy. Still, with constrained resources, there are key actions that may offer the best opportunity for driving adoption. It also worthwhile to filter and prioritize the most promising actions to enhance usefulness to policymakers and advocates. Therefore, this report identifies six recommendations below (Table 4). They aim to address critical leverage points to speed the adoption of regenerative practices at scale.

Recommendation	Rationale and Details	Specific Action to Take	Relevant Parties
1. Create affordable, reliable, and fast soil testing	• Quality data underpins every effort to improve soil health • Carbon markets and offsets, as well as policy-based incentive programs, require it to function • Soil testing is a linchpin that needs to be solved for many other priorities to be accomplished	• Create or expand research focus within ARPA-E,[27] ARS, and other agencies to develop and scale soil testing technology • Offer free or discounted soil testing in soil health programs limiting step	Federal government agencies (e.g. ARPA-E), universities, private corporations
2. Expand the federal programs that are popular, successful, and enabling of soil health implementation	• NRCS programs are popular with farmers, have an established institutional framework, and achieve important conservation goals • Programs with institutional infrastructure in place can easily be scaled up with more funding	• Pass S.4850 to expand SHDTs • Expand CSP, EQIP, CRP, and others at the NRCS • The RMA should incorporate regenerative practices into crop insurance guidelines and remove provisions that prop up inefficient production systems	Federal government: USDA, Congress, RMA

Table 4.

27 In September 2020, the Department of Energy's Advanced Research Projects – Energy (ARPA-E) awarded $16.5 million to 6 projects that aim to improve on-farm soil and gas measurements using machine learning, LiDAR, remote sensing, and other innovative technologies (ARPA-E, 2020).

Recommendation	Rationale and Details	Specific Action to Take	Relevant Parties
3. Build on and replicate the immense success of state soil health policies	• In many ways, state-level policies innovate and lead the way on soil health • State-level policies like California's HSP have been some of the most significant drivers of soil health adoption – more are needed • State policies can be customized to local growing conditions, political feasibility, and farmer preferences	• Form more producer-centered coalitions to advance state policy • In the model of CCHS, diverse coalitions should be established that enhance proposal legitimacy and gain buy-in of key groups	Advocates, activists, and concerned citizens; producers; trade and labor organizations; NGOs; state government agencies; universities; scientists; private organizations; farmers and ranchers
4. Improve access and opportunity in the farming community, especially for young farmers	• Studies show that young farmers tend to be the demographic most interested in the changes to the food system this report advocates for, including soil health and diversified farming • Young farmers are more likely to be gender and racially diverse, and these groups have faced discrimination from the USDA • They are hampered in their farming efforts by difficulty in accessing affordable land and significant student loan debt	• Include farming in the Public Service Loan Forgiveness Program • Expand funding for FOTO • Offer workshops, training, mentoring, and networking at a local level for beginning farmers to navigate the process of securing leases	Congress, state government, local government

Table 4 ctd.

5. Educate, inspire, and market to build consumer demand for regeneratively labeled or certified products	• The growth of organic farmland and organic food and product sales indicates a growing public interest in environmentally responsible purchasing • Market demand can create price signals that may be a more sweeping motivator than government programs to drive farmer adoption • Many labels already exist, so consumers need education and clarity on new regenerative-based labels	• Consolidate labels and certifications to reduce label fatigue and make consumer options understandable • Corporations should work to meet certification criteria, use the label or certification, and develop education and marketing programs so that consumers know the benefits and are motivated to seek out the label • Governments and NGOs can also spread awareness • If they can, consumers should purchase food and products with regenerative labels	Corporations, NGOs, interest groups, advocates, individuals, government

Table 4 ctd.

Recommendation	Rationale and Details	Specific Action to Take	Relevant Parties
6. Invest in the success of carbon and ecosystem markets, genuine corporate social responsibility, and regenerative finance	• Success of carbon and ES markets can largely be fueled by meaningful (i.e., not greenwashing) corporate commitments to regenerative principles • With cultural and financial support from the private sector, carbon and ES markets can continue to grow and provide market operators with more opportunities to work out kinks and bugs • Many of the shortcomings of markets are due to a lack of buy-in and capital • Private investment is needed to meet climate change targets	• Corporations should continue making commitments to regenerative supply chains, net-zero or negative emissions, and offsets via nature-based solutions • Corporations should charter and lead partnerships like the MRCC to commit funding and personnel to regenerative praxis • Individuals and entities should invest their finances in socially responsible and regenerative wealth management funds	Investors, private organizations, individuals

Table 4 ctd.

Photo: Dave Hoefler on Unsplash

Photo: Kalin Dimchev on Unsplash

CONCLUSION

Regenerative agriculture is in vogue. It is receiving attention from governments, corporations, scientists, farmers, and advocates as a way to improve climate resilience, farm economic viability, the ongoing loss of topsoil, and ecosystem health. But unlike many trends that come into fashion and depart as quickly, the excitement behind regenerative agriculture is substantive. Hundreds of scientific studies and field trials show that restored soils sequester carbon, improve resource efficiency, cleanse air and water, and enhance farm profitability. While the climate and environmental implications are powerful justifications for adopting regenerative agriculture, it would be a savvy decision even without these benefits due to its improvements in food security and cost effectiveness. Accordingly, much of the previous federal and state policy activity has enjoyed bipartisan cooperation.

As with any smart solution, regenerative agriculture now needs coordinated and widespread support for its promise to become a reality. This report aimed to highlight critical leverage points in the policy and economic space that can drive adoption. Governments at every scale around the world are beginning to recognize the potency of this solution and tailor policies to support it. Business consortia, corporations, startups, NGOs, and public-private partnerships are designing innovative models to integrate regenerative agriculture into their value chains and business models.

But will it happen fast enough? The food-water-climate nexus presents humanity with an existential threat that demands working at a faster pace than we are accustomed to setting. As of this writing, farm income is poised to drop 9% in 2020 and wildfires recently scorched over 4 million acres in Colorado and California (ERS, 2020). Our food and climate systems are under strain, and regenerative agriculture is more than a cogent and elegant idea. It is a vital component of a world that heals rather than doubles down on broken systems.

Accordingly, below are steps readers can take to support regenerative agriculture and soil health in the near and long term.

Advocates:

- Review the map created by N4E to determine if there is soil health policy activity in your state. If there is, contact your state representatives to express your support. Consider getting involved with the groups spearheading the effort.

- Call, email, and use social media to contact Congressional representatives to express your support for expanded funding for programs like EQIP, CSP, CRP, RCPP, FFAR, FOTO, and SARE. Tell them that farming should be considered a public service, along with professions like teaching, medicine, and public legal defense, thereby making it eligible for student loan forgiveness. Recommend that your representative support or co-sponsor federal policies like the Soil Health Demonstration Trials, the Healthy Soils Healthy Climate Act (S.4850), the SOIL Act, the Farmer's Bill of Rights, the inclusion of agricultural C sequestration in 45Q tax credits.

- If you can afford to, purchase food and clothing grown using regenerative practices.

- If you can afford the time, offer to volunteer for a day on a local farm.

Farmers and ranchers:

- If you are not signed up already, considering enrolling some of your acreage in NRCS programs like EQIP and CSP. Consider applying for the next round of SHDT funding.

- Work with your local extension agent or conservation district to see what soil health practices might be feasible for you to implement. They may also be knowledgeable about other resources you can connect with, like funding, mentoring, and technical assistance.

- As a practitioner, your voice carries extra weight when speaking to legislators about agricultural issues. Contact your state and federal representatives to express support for soil health policy. Many of the recommendations above for advocates are applicable for farmers and are especially impactful coming from farmers.

- Consider enrolling some of your acreage in emerging private marketplaces like CarbonNOW, ESMC, Nori, Land to Market, or Indigo Carbon.

- Reach out to existing initiatives like the SHP and MRCC to get involved and share best practices with other farmers.

Policymakers:

- Vote for or co-sponsor existing soil health legislation.

- Using the policy principles outlined in this report, draft and introduce new legislation to support soil health.

- Support policies that advance the needs of socially disadvantaged farmers and facilitate the just transition of the rural economy. At the federal level, support making farming a public service and including it in the Public Service Loan Forgiveness program.

- Support reforms to the federal crop insurance system and new provisions in the Farm Bill that advance soil health. Support climate mitigation and adaptation projects more broadly.

- Be willing to allocate funds or to finance soil health projects.

- Invest in infrastructure for diversified food and farming systems that allows regenerative growers of all sizes to find and sustain market access.

- Build bipartisan consensus on soil health policy.

About the Author

Jock Gilchrist is a 2020 E2 1Hotels Fellow, and a researcher with The Climate Center and Natural Capitalism Solutions. He holds an M.S. in Environmental Science and Policy, with a concentration in climate change policy, from Johns Hopkins University. His previous research has focused on electric vehicles, theory of change, ecological rationality, and the psychology of social change. He is an avid musician and outdoorsman and lives in Boulder, Colorado.

Contact: ajgg77@gmail.com

References

Abdalla, M., Hastings, A., Cheng, K., Yue, Q., Chadwick, D., Espenberg, M., . . . Smith, P. (2019). A critical review of the impacts of cover crops on nitrogen leaching, net greenhouse gas balance and crop productivity. Global Change Biology, 25(8), 2530-2543. doi:10.1111/gcb.14644

Ackoff, S., Bahrenburg, A., & Shute, L. (2017). Building a Future with Farmers II: Results and Recommendations from the National Young Farmer Survey. National Young Farmers Coalition. Retrieved from https://www.youngfarmers.org/wp-content/uploads/2019/03/NYFC-Report-2017_LoRes_Revised.pdf

AFT. (2019). Soil Health Case Study: Ralf Sauter, Okuye Farms, CA. Retrieved from https://s30428.pcdn.co/wp-content/uploads/sites/2/2020/02/CA_OkuyeFarms_Soil_Health_Case_Study_AFT_NRCS.pdf

AFT. (2020). Soil Health Case Study: Tom and Dan Rogers, CA. Retrieved from https://s30428.pcdn.co/wp-content/uploads/sites/2/2020/02/CA_RogersFarm_Soil_Health_Case_Study_AFT_NRCS.pdf

Allen, M., Frame, D., Huntingford, C., Jones, C., Lowe, J., Meinshausen, M., & Meinshausen, N. (2009, April 30). Warming caused by cumulative carbon emissions towards the trillionth tonne. Nature Letters, 458, 1163-1166.

Amado, T., Bayer, C., Eltz, F., & Brum, A. (2001). Potencial de culturas de cobertura em acumular carbono e nitrogenio no solo no plantio direto e a melhoria da qualidade ambiental. Rev. Bras. Cien. Solo, 25, 189-197. Retrieved from https://www.scielo.br/pdf/rbcs/v25n1/20.pdf

American Farmland Trust. (2019). Soil Health Case Studies. Retrieved from Farmland Information Center: https://farmlandinfo.org/publications/soil-health-case-studies/

Antoniou, A., Tsolakidou, M.-D., Stringlis, I., & Pantelides, I. (2017). Rhizosphere Microbiome Recruited from a Suppressive Compost Improves Plant Fitness and Increases Protection against Vascular Wilt Pathogens of Tomato. Frontiers in Plant Science, 8, 1-16. doi:10.3389/fpls.2017.02022

ARPA-E. (2020). SMARTFARM—Systems for Monitoring and Analytics for Renewable Transportation Fuels from Agricultural Resources and Management. Department of Energy, Advanced Research Projects Agency - Energy. Retrieved from https://arpa-e.energy.gov/sites/default/files/documents/files/SMARTFARM_Project_Descriptions_FINAL.pdf

Badri, D., & Vivanco, J. (2009). Regulation and function of root exudates. Plant Cell and Environment, 32(6), 666-681. doi:10.1111/j.1365-3040.2008.01926.x

Baker, D. (1985). Regional water quality impacts of intensive row-crop agriculture: A Lake Erie Basin case study. Journal of Soil and Water Conservation, 40(1), 125-132.

Barański, M., Średnicka-Tober, D., Volakakis, N., Seal, C., Sanderson, R., Stewart, G., . . . Tahvonen. (2014). Higher antioxidant and lower cadmium concentrations and lower incidence of pesticide residues in organically grown crops: a systematic literature review and meta-analyses. British Journal of Nutrition, 112(5), 794-811. doi:10.1017/S0007114514001366

Batjes, N. (2014). Total carbon and nitrogen in the soils of the world. European Journal of Soil Science, 65(1), 10-21. Retrieved from https://onlinelibrary-wiley-com.proxy1.library.jhu.edu/doi/full/10.1111/ejss.12114_2

Bauck, W. (2019, March 27). The Next Wave of Sustainable Fashion is All About Regenerative Farming. Fashionista. Retrieved from https://fashionista.com/2019/03/regenerative-agriculture-farming-sustainable-fashion

Bauer, S., Tsigaridis, K., & Miller, R. (2016). Significant atmospheric aerosol pollution caused by world food cultivation. Geophysical Research Letters, 43(10), 5394-5400. doi:10.1002/2016GL068354

Baveye, P., Berthelin, J., Tessier, D., & Lemaire, G. (2018). The "4 per 1000" initiative: A credibility issue for the soil science community? Geoderma, 309, 118-123. Retrieved from https://doi.org/10.1016/j.geoderma.2017.05.005

Beard, J., Umbach, D., Hoppin, J., Richards, M., Alavanja, M., Blair, A., . . . Kamel, F. (2014). Pesticide Exposure and Depression among Male Private Pesticide Applicators in the Agricultural Health Study. Environmental Health Perspectives, 122(9), 984-991. doi:10.1289/ehp.1307450

Benmar, C. (2010, March 2). Tracking down the public-health implications of nitrogen pollution. Grist. Retrieved from https://grist.org/article/public-health-implications-of-nitrogen-pollution/

Bennet, M. (2019, December 13). Bennet Unveils Discussion Draft to Create New Tax Credit for Farmers and Ranchers to Capture Carbon in the Land Sector. Retrieved from Michael Bennet: U.S. Senator for Colorado: https://www.bennet.senate.gov/public/index.cfm/2019/12/bennet-unveils-discussion-draft-to-create-new-tax-credit-for-farmers-and-ranchers-to-capture-carbon-in-the-land-sector

Bialik, K., & Walker, K. (2019, January 10). Organic farming is on the rise in the U.S. (Pew Research Center) Retrieved from FactTank: https://www.pewresearch.org/fact-tank/2019/01/10/organic-farming-is-on-the-rise-in-the-u-s/

Booker, C. (2020, February 6). Booker, Haaland, Pingree Introduce Farmers Bill of Rights Resolution. Retrieved from Cory Booker: https://www.booker.senate.gov/news/press/booker-haaland-pingree-introduce-farmers-bill-of-rights-resolution

Bot, A., & Benites, J. (2005). The importance of soil organic matter: Key to drought-resistant soil and sustained food production. United Nations, Food and Agriculture Organization. Rome: FAO. Retrieved from http://www.fao.org/3/a-a0100e.pdf

Boulder County. (2020). Environmental Sustainability Matching Grant. Retrieved from Boulder County: https://www.bouldercounty.org/environment/sustainability/matching-grant-program/

Brender, J., Maantay, J., & Chakraborty, J. (2011). Residential Proximity to Environmental Hazards and Adverse Health Outcomes. American Journal of Public Health, 101, S37-S52. doi:10.2105/AJPH.2011.300183

Briske, D., Ash, A., Derner, J., & Huntsinger, L. (2014, March). Commentary: A critical assessment of the policy endorsement for holistic management. Agricultural Systems, 125, 50-53. Retrieved from https://doi.org/10.1016/j.agsy.2013.12.001

Briske, D., Bestelmeyer, B., Brown, J., Fuhlendorf, S., & Polley, H. W. (2013). The Savory Method Can Not Green Deserts or Reverse Climate Change: A response to the Allan Savory TED video. Rangelands, 35(5), 72-74. Retrieved from https://doi.org/10.2111/RANGELANDS-D-13-00044.1

Briske, D., Derner, J., Brown, J., Fuhlendorf, S., Teague, W., Havstad, K., . . . Willms, W. (2008). Rotational Grazing on Rangelands: Reconciliation of Perception and Experimental Evidence. Rangeland Ecology & Management, 61(1), 3-17. Retrieved from https://doi.org/10.2111/06-159R.1

Brown, G. (2014). Gabe Brown: Keys To Building a Healthy Soil. Idaho Center for Sustainable Agriculture. Transcend Productions. Retrieved from https://www.youtube.com/watch?v=9yPjoh9YJMk&

Brown, T., & Huggins, D. (2012). Soil carbon sequestration in the dryland cropping region of the Pacific Northwest. Journal of Soil and Water Conservation, 67(5), 406-415. doi:10.2489/jswc.67.5.406

Bruce, A., Farmer, J., Maynard, E., & Valliant, J. (2017). Assessing the Impact of the EQIP High Tunnel Initiative. Journal of Agriculture, Food Systems, and Community Development, 7(3), 159-180. doi:10.5304/jafscd.2017.073.012

Bryant, L. (2015, May 27). Organic Matter Can Improve Your Soil's Water Holding Capacity. Retrieved from NRDC: https://www.nrdc.org/experts/lara-bryant/organic-matter-can-improve-your-soils-water-holding-capacity

Brysse, K., Oreskes, N., O'Reilly, J., & Oppenheimer, M. (2013, February). Climate change prediction: Erring on the side of least drama? Global Environmental Change, 23(1), 327-337. doi:10.1016/j.gloenvcha.2012.10.008

Buckley, E., & Eve, M. (2017, February 21). 'Soil and Air' - Where Crops Meet the Environment. Retrieved from U.S. Department of Agriculture: https://www.usda.gov/media/blog/2016/05/31/soil-and-air-where-crops-meet-environment

CalCAN. (2020). (California Climate and Agricultural Network) Retrieved from Healthy Soils: https://calclimateag.org/solutions/healthysoils/

Calegari, A. (1998). The effects of winter green manure and no-tillage on soil chemical properties and maize yield. Paraná, Brasil: Agronomic Institute. Retrieved from http://natres.psu.ac.th/link/soilcongress/bdd/symp7/2220-t.pdf

Campbell, L. (2020, March 15). Conservation Stewardship Program is Falling Short, Say Critics. Modern Farmer. Retrieved from https://modernfarmer.com/2020/03/conservation-stewardship-program-is-falling-short-say-critics/

Carlisle, L. (2014, November 26). The Downside of Eating Too Locally. The New York Times. Retrieved from https://www.nytimes.com/2014/11/27/opinion/the-downside-of-eating-too-locally.html

Casa, R., & LoCascio, B. (2008, August). Soil Conservation Tillage Effects on Yield and Water Use Efficiency on Irrigated Crops in Central Italy. Journal of Agronomy & Crop Science, 194(4), 310-319. doi:10.1111/j.1439-037X.2008.00316.x

Cassidy, E., West, P., Gerber, J., & Foley, J. (2013). Redefining agricultural yields: from tonnes to people nourished per hectare. Environmental Research Letters, 8. doi:10.1088/1748-9326/8/3/034015

Cavigelli, M., Hima, B., Hanson, J., Teasdale, J., Conklin, A., & Lu, Y.-c. (2009, June). Long-term economic performance of organic and conventional field crops in the mid-Atlantic region. Renewable Agriculture and Food Systems, 24(2), 102-119. doi:10.1017/S1742170509002555

CBO. (2020). The Federal Budget in 2019: An Infographic. Retrieved from Congressional Budget Office: https://www.cbo.gov/publication/56324

CCSWCD. (2012). S.T.A.R. for 2020. Retrieved from Champaign County Soil and Water Conservation District: http://www.ccswcd.com/S.T.A.R./

Challinor, A. J., Watson, J., Lobell, D. B., Howden, S. M., Smith, D. R., & Chhetri, N. (2014). A meta-analysis of crop yield under climate change and adaptation. Nature Climate Change, 4, 287-291. doi:10.1038/nclimate2153

Chambers, A., Lal, R., & Paustian, K. (2016). Soil carbon sequestration potential of US croplands and grasslands: Implementing the 4 per Thousand Initiative. Journal of Soil and Water Conservation, 71(3), 68A-74A. doi:10.2489/jswc.71.3.68A

(2018). Chapter 2: Mitigation pathways compatible with 1.5°C in the context of sustainable development. United Nations, Intergovernmental Panel on Climate Change. United Nations. Retrieved from https://report.ipcc.ch/sr15/pdf/sr15_chapter2.pdf

Chasan, E. (2019, October 30). Al Gore Is Opening a New Front In the War On Climate Change. Bloomberg. Retrieved from https://www.bloomberg.com/news/articles/2019-10-30/al-gore-says-regenerative-farming-can-help-slow-climate-change

Chen, X., Cui, Z., Fan, M., Vitousek, P., Zhao, M., Ma, W., . . . Huang, J. (2014). Producing more grain with lower environmental costs. Nature, 514, 486-489. doi:10.1038/nature13609

Chng, S., Cromey, M., Dodd, S., Stewart, A., Butler, R., & Jaspers, M. (2015). Take-all decline in New Zealand wheat soils and the microorganisms associated with the potential mechanisms of disease suppression. Plant and Soil, 397, 239-259. doi:10.1007/s11104-015-2620-4

Ciais, P., Sabine, C., Bala, G., Bopp, L., Brovkin, V., Canadell, J., . . . M. Heimann, C. (2013). Carbon and Other Biogeochemical Cycles. In Climate Change 2013: The Physical Science Basis. Contribution to Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 465-571). Cambridge: Cambridge University Press. Retrieved from https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter06_FINAL.pdf

Circle of Blue. (2014, May 30). Map: Harmful Algal Blooms in the Great Lakes Basin. Retrieved from Circle of Blue: https://www.circleofblue.org/cpx/great-lakes-algae/map-harmful-algal-blooms-in-the-great-lakes-basin/

Clark, W. (1982). Carbon Dioxide Review. New York: Oxford University Press.

CNBC. (2020, June 9). 1. Indigo Ag. CNBC. Retrieved from https://www.cnbc.com/2019/05/14/indigo-ag-2019-disruptor-50.html

Collins, M., Knutti, R., Arblaster, J., Dufresne, J.-L., Fichefet, T., Friedlingstein, P., . . . Wehner, M. (2013). Long-term Climate Change: Projections, Commitments, and Irreversibility. In T. Stocker, D. Qin, G. Plattner, M. Tignor, S. Allen, J. Boschung, . . . P. Midgley, Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 1029-1136). Cambridge, UK; New York, NY: Cambridge University Press. Retrieved from https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

Conant, R., Cerri, C., Osborne, B., & Paustian, K. (2017). Grassland management impacts on soil carbon stocks: a new synthesis. Ecological Applications, 27(2), 662-668. doi:10.1002/eap.1473

Conant, R., Paustian, K., & Elliott, E. (2001). Grassland Management and Conversion into Grassland: Effects on Soil Carbon. Ecological Applications, 11(2), 343-355. Retrieved from https://doi.org/10.1890/1051-0761(2001)011[0343:GMACIG]2.0.CO;2

Conant, R., Six, J., & Paustian, K. (2003, July 29). Land use effects on soil carbon fractions in the southeastern United States. I. Management-intensive versus extensive grazing. Biology and Fertility of Soils, 38, 386-392. Retrieved from https://doi.org/10.1007/s00374-003-0652-z

Craig, W. (1997). Phytochemicals: Guardians of our Health. Journal of the Academy of Nutrition and Dietetics, 97(10), S199-S204. doi:10.1016/S0002-8223(97)00765-7

CSU Chico. (2019). Brown's Ranch, Bismarck, ND. (California State University, Chico) Retrieved from Center for Regenerative Agriculture and Resilient Systems: https://www.csuchico.edu/regenerativeagriculture/demos/gabe-brown.shtml

Cui, Z., Zhang, H., Chen, X., Zhang, C., Ma, W., Huang, C., . . . Sun, Y. (2018). Pursuing sustainable productivity with millions of smallholder farmers. Nature, 555, 363-366. doi:10.1038/nature25785

Curl, C., Beresford, S., Hajat, A., Kaufman, J., Moore, K., Nettleton, J., & Diez-Roux, A. (2013). Associations of Organic Produce Consumption with Socioeconomic Status and the Local Food Environment: Multi-Ethnic Study of Atherosclerosis. PLoS One, 8(7), e69778. doi:10.1371/journal.pone.0069778

Danone. (2020). Regenerative Agriculture. Retrieved from Impact: https://www.danone.com/impact/planet/regenerative-agriculture.html

Dass, P., Houlton, B., Wang, Y., & Warlind, D. (2018). Grasslands may be more reliable carbon sinks than forests in California. Environmental Research Letters, 13(7). doi:10.1088/1748-9326/aacb39

Davis, D. (2009). Declining Fruit and Vegetable Nutrient Composition: What Is the Evidence? HortScience, 44(1), 15-19. doi:10.21273/HORTSCI.44.1.15

Davis, D., Epp, M., & Riordan, H. (2004). Changes in USDA Food Composition Data for 43 Garden Crops, 1950 to 1999. Journal of the American College of Nutrition, 23(6), 669-682. doi:10.1080/07315724.2004.10719409

Davitt, L., & Hirsh, S. (2019, October 2). Carbon Removal Now Easily Available to All as Nori Launches Online Path to Support Farmers and Reverse Climate Change. Business Wire. Retrieved from https://www.businesswire.com/news/home/20191002005263/en/Carbon-Removal-Easily-Nori-Launches-Online-Path

de Ponti, T., Bert, R., & van Ittersum, M. (2012). The crop yield gap between organic and conventional agriculture. Agricultural Systems, 108, 1-9. doi:10.1016/j.agsy.2011.12.004

DeMartini, A. (2018, June 6). Rattan Lal: Our Soils Rock Star. From Studying Under Street Lights to Distinguished Professor. (Ohio State University) Retrieved from College of Food, Agriculture, and Environmental Sciences: https://cfaes.osu.edu/stories/rattan-lal-our-soils-rock-star

Diaz, D., & Moore, F. (2017, November 2). Quantifying the economic risks of climate change. Nature Climate Change, 7, 774-782. doi:10.1038/nclimate3411

Dietterich, L., Zanobetti, A., Kloog, I., Huybers, P., Leakey, A., Bloom, A., . . . Sakai, H. (2015). Impacts of elevated atmospheric CO_2 on nutrient content of important food crops. Nature Scientific Data, 2. doi:10.1038/sdata.2015.36

Dobbie, K., McTaggart, I., & Smith, K. (1999). Nitrous oxide emissions from intensive agricultural systems: Variations between crops and seasons, key driving variables, and mean emission factors. JGR Atmospheres, 104(D21), 26891-26899. doi:10.1029/1999JD900378

DOE. (2019). Internal Revenue Code Tax Fact Sheet. United States Department of Energy, Fossil Energy. Retrieved from https://www.energy.gov/sites/prod/files/2019/10/f67/Internal%20Revenue%20Code%20Tax%20Fact%20Sheet.pdf

Donner, S., & Kucharik, C. (2008). Corn-based ethanol production compromises goal of reducing nitrogen export by the Mississippi River. Proceedings of the National Academy of Sciences, 105(11), 4513-4518. doi:10.1073/pnas.0708300105

Dula, J., & McCracken, V. (2017, February 3). Access to Land: Boulder County Land Lease Program. National Farmers Union. Retrieved from https://nfu.org/2017/02/03/access-to-land-boulder-county-land-lease-program/

Duncan, E., Dell, C., Kleinman, P., & Beegle, D. (2017). Nitrous Oxide and Ammonia Emissions From Injected and Broadcast-Applied Dairy Slurry. Journal of Environmental Quality, 46(1), 36-44. doi:10.2134/jeq2016.05.0171

Eagle, A., Olander, L., Henry, L., Haugen-Kozyra, K., Millar, N., & Robertson, G. P. (2012). Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States: A Synthesis of the Literature. Duke University, Nicholas Institute for Environmental Policy Solutions. Retrieved from https://nicholasinstitute.duke.edu/sites/default/files/publications/ni_r_10-04_3rd_edition.pdf

EIA. (2019, June 19). Energy and the environment explained. Retrieved from U.S. Energy Information Administration: https://www.eia.gov/energyexplained/energy-and-the-environment/where-greenhouse-gases-come-from.php#:~:text=In%202017%2C%20carbon%20dioxide%20(CO2,total%20U.S.%20anthropogenic%20CO2%20emissions.

EPA. (2019). Global Greenhouse Gas Emissions Data. (United States Environmental Protection Agency) Retrieved from US EPA: https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

EPA. (2020, May 28). Overview of Greenhouse Gases. (United States Environmental Protection Agency) Retrieved from Greenhouse Gas Emissions: https://www.epa.gov/ghgemissions/overview-greenhouse-gases#N_2O-references

EPA. (2020). Population Surrounding 1,857 Superfund Remediation Sites. United States Environmental Protection Agency, Office of Communications, Partnerships, and Analysis. Retrieved from https://www.epa.gov/sites/production/files/2015-09/documents/webpopulationrsuperfundsites9.28.15.pdf

ERS. (2013, September 27). Organic Production. (E. R. Service, Producer, & United States Department of Agriculture) Retrieved from USDA: https://www.ers.usda.gov/data-products/organic-production/organic-production/#National%20Tables

ERS. (2019). Beginning, Socially Disadvantaged, and Veteran Farmers and Ranchers. (E. R. Service, Producer, & United States Department of Agriculture) Retrieved from Agriculture Improvement Act of 2018: Highlights and Implications: https://www.ers.usda.gov/agriculture-improvement-act-of-2018-highlights-and-implications/beginning-socially-disadvantaged-and-veteran-farmers-and-ranchers/

ERS. (2020). 2020 Farm Sector Income Forecast. (United States Department of Agriculture) Retrieved from Economic Research Service: https://www.ers.usda.gov/topics/farm-economy/farm-sector-income-finances/farm-sector-income-forecast/

Eswaran, H., Lal, R., & Reich, P. (2001). Land Degradation: An overview. In E. Bridges, I. Hannam, L. Oldeman, F. P. Vries, S. Scherr, & S. Sompatpanit (Eds.), Responses to Land Degradation. New Delhi: Oxford Press. Retrieved from https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/use/?cid=nrcs142p2_054028

Falkenmark, M., Fox, P., Persson, G., & Rockström, J. (2001). Water Harvesting for Upgrading of Rainfed Agriculture. Stockholm: Stockholm International Water Institute. Retrieved from http://dlc.dlib.indiana.edu/dlc/bitstream/handle/10535/5297/Report11_Water_Harvesting_for_Upgrading_Rainfed_Agriculture_2001.pdf?sequence=1&isAllowed=y

Falkenmark, M., Rockström, J., & Karlberg, L. (2009). Present and future water requirements for feeding humanity. Food Security, 1, 59-69. doi:10.1007/s12571-008-0003-x

FAO. (2004). Creating drought-resistant soil -technologies and impacts of improved soil moisture management at field level. Retrieved from Discussion Papers: http://www.fao.org/3/a0072e/a0072e07.htm

FAO. (2005). The importance of soil organic matter. United Nations, Food and Agriculture Organization, Rome. Retrieved from http://www.fao.org/3/a-a0100e.pdf

FAO. (2013, October 21). Monitoring food loss and waste essential to hunger fight. (Food and Agriculture Organization of the United Nations) Retrieved from http://www.fao.org/news/story/en/item/203149/icode/

FAO. (2014). The State of Food and Agriculture: Innovation in Family Farming. United Nations, Food and Agriculture Organization, Rome. Retrieved from http://www.fao.org/3/a-i4040e.pdf

FAO. (2017). Water pollution from agriculture: a global review. United Nations, Food and Agriculture Organization. Retrieved from http://www.fao.org/3/a-i7754e.pdf

Fargione, J., Bassett, S., Boucher, T., Bridgham, S., Conant, R., Cook-Patton, S., . . . Megonigal, J. (2018). Natural climate solutions for the United States. Science Advances, 1-14. doi:10.1126/sciadv.aat1869

Farina, R., Testani, E., Campanelli, G., Leteo, F., Napoli, R., Canali, S., & Tittarelli, F. (2018). Potential carbon sequestration in a Mediterranean organic vegetablecropping system. A model approach for evaluating the effects of compostand Agro-ecological Service Crops (ASCs). Agricultural Systems, 162, 239-248. doi:10.1016/j.agsy.2018.02.002

Farra, E. (2020, May 12). Regenerative Agriculture Can Change the Fashion Industry—And the World. But What Is It? Vogue. Retrieved from https://www.vogue.com/article/regenerative-agriculture-sustainable-fashion-christy-dawn-fibershed#:~:text=In%20addition%20to%20omitting%20chemicals,in%20the%20sustainable%20fashion%20conversation.

Felver, R. (2019, December 3). Bay sees worst dead zone in the past five years. Retrieved from Chesapeake Bay Program: https://www.chesapeakebay.net/news/blog/bay_sees_worst_dead_zone_in_the_past_five_years

Ferguson, B., Diemont, S., Alfaro-Arguello, R., Martin, J., Nahed-Toral, J., Álvarez-Solís, D., & Pinto-Ruíz, R. (2013). Sustainability of holistic and conventional cattle ranching in the seasonally dry tropics of Chiapas, Mexico. Agricultural Systems, 120, 38-48. doi:10.1016/j.agsy.2013.05.005

Fibershed. (2020). Our Mission & Vision. (Fibershed) Retrieved from About: https://fibershed.org/about/

Fisher, M., Braz, S., Dos Santos, R., Urquiaga, S., Alves, B., & Boddey, R. (2007). Another dimension to grazing systems: Soil carbon. Tropical Grasslands, 41, 65-83. Retrieved from http://tropicalgrasslands.info/public/journals/4/Historic/Tropical%20Grasslands%20Journal%20archive/PDFs/Vol_41_2007/Vol_41_02_2007_pp65_83.pdf

Fisher, M., Rao, I., Ayarza, M., Lascano, C., Sanz, J., Thomas, R., & Vera, R. (1994, September). Carbon storage by introduced deep-rooted grasses in the South American savannas. Nature, 371(6494), 236-238. Retrieved from https://doi.org/10.1038/371236a0

Follett, R., & Reed, D. (2010). Soil Carbon Sequestration in Grazing Lands: Societal Benefits and Policy Implications. Rangeland Ecology & Management, 63(1), 4-15. doi:10.2111/08-225.1

Forster, L., & Rausch, J. (2002). Evaluating Agricultural Nonpoint Source Pollution Programs in Two Lake Erie Tributaries. Journal of Environmental Quality, 31(1), 24-31. doi:10.2134/jeq2002.2400

Fox, C., & Johnson, A. (2018). A Farmer's View: A Look at the Conservation Stewardship Program. Center for Rural Affairs. Lyons, NE: Center for Rural Affairs. Retrieved from https://cfra.org/sites/default/files/publications/A%20Farmers%20View%20A%20look%20at%20the%20Conservation%20Stewardship%20Program.pdf

Francis, C., Harwood, R., & Parr, J. (1986). The potential for regenerative agriculture in the developing world. American Journal of Alternative Agriculture, 1(2), 65-74. doi:10.1017/S0889189300000904

FSA. (2020). Conservation Reserve Program. (United States Department of Agriculture) Retrieved from Farm Service Agency: https://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/

Fuhrer, J. (n.d.). Soil Health: Principle 1 of 5 - Soil Armor. (USDA) Retrieved from Natural Resources Conservation Services: https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/nd/soils/health/?cid=nrcseprd1300631

Fuhrer, J. (n.d.). Soil Health: Principle 2 of 5 – Minimizing Soil Disturbance. (USDA) Retrieved from Natural Resources Conservation Service: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/nd/soils/health/?cid=nrcseprd1300910

Fuhrer, J. (n.d.). Soil Health: Principle 3 of 5 – Plant Diversity. (USDA) Retrieved from Natural Resources Conservation Service: https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/nd/soils/health/?cid=nrcseprd1300918

Fuhrer, J. (n.d.). Soil Health: Principle 4 of 5 – Continual Live Plant/Root. (USDA) Retrieved from Natural Resources Conservation Service: https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/nd/soils/health/?cid=nrcseprd1300919

Fuhrer, J. (n.d.). Soil Health: Principle 5 of 5- Livestock Integration. (USDA) Retrieved from Natural Resources Conservation Service: https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/nd/soils/health/?cid=nrcseprd1300922

Gantzer, C. J., Anderson, S. H., Thompson, A. L., & Brown, J. R. (1990). Estimating soil erosion after 100 years of cropping on Sanborn Field. Journal of Soil and Water Conservation, 45(6), 641-644. Retrieved from https://www.jswconline.org/content/45/6/641

Gaspar, V., Mauro, P., Parry, I., & Pattillo, C. (2019, October 10). IMF: $75 Per Ton Carbon Price Needed by 2030 to Meet Climate Challenge. (International Monetary Fund) Retrieved from IMFBlog: https://blogs.imf.org/2019/10/10/fiscal-policies-to-curb-climate-change/

General Mills. (2019, March 4). General Mills to advance regenerative agriculture practices on one million acres of farmland by 2030. Retrieved from News Releases: https://www.generalmills.com/en/News/NewsReleases/Library/2019/March/Regen-Ag

Gevo. (2020). Low Carbon, Sustainable Gasoline: Isooctane and More. Retrieved from Gevo: https://gevo.com/products/renewable-gasoline/

Gevo. (2020). Reducing Greenhouse Gases One City at a Time. Retrieved from Gevo: https://gevo.com/markets/clean-cities/

Ghude, S., Chate, D., Jena, C., Beig, G., Kumar, R., Barth, M., . . . Pithani, P. (2016). Premature mortality in India due to PM2.5 and ozone exposure. Geophysical Research Letters, 43(9), 4650-4658. doi:10.1002/2016GL068949

Gosling, S., & Arnell, N. (2016). A global assessment of the impact of climate change on water scarcity. Climatic Change, 134, 371-385. doi:10.1007/s10584-013-0853-x

Graeub, p., Chappell, J., Wittman, H., SamuelLedermann, Kerr, R. B., & Gemmill-Herrena, B. (2016). The State of Family Farms in the World. World Development, 87, 1-15. doi:10.1016/j.worlddev.2015.05.012

Greene, C., Wechsler, S., Adalja, A., & Hanson, J. (2016). Economic Issues in the Coexistence of Organic, Genetically Engineered (GE), and Non-GE Crops. EIB-149, United States Department of Agriculture, Economic Research Service. Retrieved from https://www.ers.usda.gov/webdocs/publications/44041/56750_eib-149.pdf?v=0

Gregorich, E., Greer, K., Anderson, D., & Liang, B. (1998, July). Carbon distribution and losses: erosion and deposition effects. Soil and Tillage Research, 47(3-4), 291-302. doi:10.1016/S0167-1987(98)00117-2

Griekspoor, P. (2020, March 12). Poll finds regenerative ag brings less stress, more profits. Kansas Farmer. Retrieved from https://www.farmprogress.com/soil-health/poll-finds-regenerative-ag-brings-less-stress-more-profits

Griffin, P., & Babington, S. (2020, June). The Growing Climate Solutions Act of 2020. Retrieved from Senator Mike Braun: https://www.braun.senate.gov/sites/default/files/2020-06/Growing%20Climate%20Solutions%20Act%20One%20Pager_0.pdf

Guo, L., & Gifford, R. (2002). Soil carbon stocks and land use change: a meta analysis. Global Change Biology, 8(4), 345-360. doi:10.1046/j.1354-1013.2002.00486.x

Gur, A., & Zamir, D. (2004). Unused Natural Variation Can Lift Yield Barriers in Plant Breeding. PLOS Biology, 2(10), e245. doi:10.1371/journal.pbio.0020245

Hanasaki, N., Fujimori, S., Yamamoto, T., Yoshikawa, S., Masaki, Y., Hijioka, Y., . . . Kanae, S. (2013). A global water scarcity assessment under Shared Socio-economic Pathways – Part 2: Water availability and scarcity. Hydrology and Earth Systems Sciences, 17, 2393-2413. doi:10.5194/hess-17-2393-2013

He, J., Wang, Q., Li, H., Tullberg, J., Mchugh, A., Bai, Y., . . . Gao, H. (2009, September). Soil physical properties and infiltration after long-term no-tillage and ploughing on the Chinese Loess Plateau. New Zealand Journal of Crop & Horticultural Science, 37(3), 157-166. doi:10.1080/01140670909510261

Hillenbrand, M., Thompson, R., Wang, F., Apfelbaum, S., & Teague, R. (2019). Impacts of holistic planned grazing with bison compared to continuous grazing with cattle in South Dakota shortgrass prairie. Agriculture, Ecosystems & Environment, 279, 156-168. doi:10.1016/j.agee.2019.02.005

Hodson, A., & Lewis, E. (2016). Managing for soil health can suppress pests. California Agriculture, 70(3), 137-141. doi:10.3733/ca.2016a0005

Holechek, J., Gomes, H., Molinar, F., Galt, D., & Valdez, R. (2000). Short-Duration Grazing: The Facts in 1999. Rangelands, 18-22.

Holt-Giménez, E. (2002). Measuring farmers' agroecological resistance after Hurricane Mitch in Nicaragua: a case study in participatory, sustainable land management impact monitoring. Agriculture, Ecosystems & Environment, 93(1-3), 87-105. doi:10.1016/S0167-8809(02)00006-3

Houghton, R. (1998). The annual net flux of carbon to the atmosphere from changes in land use 1850-1990*. Tellus, 50B(2), 298-313. Retrieved from https://cdiac.ess-dive.lbl.gov/epubs/ndp/ndp050/tellus51b.pdf

Hribljan, J., Suarez, E., Heckman, K., Lilleskov, E., & Chimner, R. (2016). Peatland carbon stocks and accumulation rates in the Ecuadorian paramo. Wetlands Ecology Management, 24, 113-127. doi:10.1007/s11273-016-9482-2

Hudson, B. (1994, March). Soil organic matter and available water capacity. Journal of Soil and Water Conservation, 49(2), 189-194. Retrieved from https://www.jswconline.org/content/49/2/189

IATP. (2019, February 18). State soil health initiatives respond to climate change. Retrieved from Institute for Agriculture and Trade Policy: https://www.iatp.org/blog/201902/state-soil-health-initiatives-respond-climate-change#:~:text=Massachusetts%2C%20New%20Mexico%20and%20Nebraska,to%20and%20mitigate%20climate%20change.

IDA. (2020). Cover Crops Premium Discount Program. Retrieved from Illinois Department of Agriculture: https://www2.illinois.gov/sites/agr/Resources/LandWater/Pages/Cover-Crops-Premium-Discount-Program.aspx

IEC. (2019, December 13). Cover Crops and the 200 Year Nutrient Pollution Gap. Retrieved from Illinois Environmental Council: https://ilenviro.org/cover-crops-and-the-200-year-nutrient-pollution-gap/

IHS Markit. (2019). Economic Assessment for Ecosystem Service Market Credits from Agricultural Working Lands. IHS Markit & Agribusiness Consulting. Retrieved from https://ecosystemservicesmarket.org/wp-content/uploads/2019/09/Informa-IHS-Markit-ESM-Study-Sep-19.pdf

Indigo Ag. (2020, August). Enrich Your Soil, Improve Your Profit. (Indigo Agriculture) Retrieved from Indigo Ag: https://www.indigoag.com/for-growers/indigo-carbon

Ingram, J., & Fernandes, E. (2001, October). Managing carbon sequestration in soils: concepts and terminology. Agriculture, Ecosystems & Environment, 87(1), 111-117. Retrieved from https://doi.org/10.1016/S0167-8809(01)00145-1

Irwin, S. (2019, February 8). Why are Ethanol Prices So Low? (University of Illinois) Retrieved from Farm Doc Daily: https://farmdocdaily.illinois.edu/2019/02/why-are-ethanol-prices-so-low.html

Itzkan, S. (2012, November 12). What is holistic livestock management? (C. Dreibelbis, Interviewer) Resilience. Retrieved from https://www.resilience.org/stories/2012-11-12/what-is-holistic-livestock-management/#:~:text=Holistic%20management%20seeks%20to%20restore,evolved%20with%20and%20depend%20on.&text=This%20natural%20herd%20action%20is,and%20water%20recycling%20and%20distribu

Izaak Walton League. (2019). State & Local Soil Health Strategies. Retrieved from https://www.iwla.org/docs/default-source/conservation-docs/agriculture-documents/state-soil-health-policies.pdf?sfvrsn=2

Jensen, A., Marble, W., Scheve, K., & Slaughter, M. (2019). City Limits to Partisan Polarization in the American Public. Princeton, Stanford, and Dartmouth Universities. Retrieved from https://williammarble.co/docs/CityLimits-Mar2019.pdf

Johnson, D., Ellington, J., & Eaton, W. (2015). Development of soil microbial communities for promoting sustainability in agriculture and a global carbon fix. PeerJ PrePrints. Retrieved from https://doi.org/10.7287/peerj.preprints.789v1

Jones, C., Brown, B., Engel, R., Horneck, D., & Olson-Rutz, K. (2013). Management to Minimize Nitrogen Fertilizer Volatilization. Montana State University, MSU Extension. Retrieved from http://www.landresources.montana.edu/soilfertility/documents/PDF/pub/UvolBMPEB0209.pdf

Kempf, J. (2018). The Regenerative Agriculture Podcast. Retrieved from http://regenerativeagriculturepodcast.com/

Kerlin, K. (2017, May 15). A Climate Change Solution Beneath Our Feet. (UC Davis) Retrieved from Science & Climate: https://climatechange.ucdavis.edu/news/climate-change-solution-beneath-feet/

Khan, S., Mulvaney, R., Ellsworth, T., & Boast, C. (2007). The Myth of Nitrogen Fertilization for Soil Carbon Sequestration. Journal of Environmental Quality, 36(6), 1821-1832. doi:10.2134/jeq2007.0099

Khokhar, T. (2017, March 22). Chart: Globally, 70% of Freshwater is Used for Agriculture. Retrieved from World Bank: https://blogs.worldbank.org/opendata/chart-globally-70-freshwater-used-agriculture#:~:text=In%20most%20regions%20of%20the,percent%20increase%20in%20water%20withdrawals.

Knutson, J. (2019, September 12). Report: US organic acres set record. Ag Week. Retrieved from https://www.agweek.com/business/agriculture/4657799-report-us-organic-acres-set-record

Komanoff, C. (2018, October 15). IPCC: Not just a carbon price, but a really high one. (Carbon Tax Center) Retrieved from Carbon Tax Center: Pricing carbon efficiently and equitably: https://www.carbontax.org/blog/2018/10/15/ipcc-not-just-a-carbon-price-but-a-really-high-one/

Kyselková, M., Kopecký, J., Frapolli, M., Défago, G., Ságová-Marečková, M., Grundmann, G., & Moënne-Loccoz, Y. (2009). Comparison of rhizobacterial community composition in soil suppressive or conducive to tobacco black root rot disease. Multidisciplinary Journal of Microbial Ecology, 3, 1127-1138. doi:10.1038/ismej.2009.61

LaCanne, C., & Lundgren, J. (2018). Regenerative agriculture: merging farming and natural resource conservation profitably. PeerJ. doi:10.7717/peerj.4428

Lal, R. (2004, June). Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. Science, 304, 1623-1627.

Lal, R. (2004). Soil carbon sequestration to mitigate climate change. Geoderma, 123, 1-22. doi:10.1016/j.geoderma.2004.01.032

Lal, R. (2008). Promise and limitations of soils to minimize climate change. Journal of Soil and Water Conservation, 63(4), 113A-118A.

Lal, R. (2010). Managing Soils and Ecosystems for Mitigating Anthropogenic Carbon Emissions and Advancing Global Food Security. BioScience, 60(9), 708-721. doi:10.1525/bio.2010.60.9.8

Lal, R. (2011). Sequestering carbon in soils of agro-ecosystems. Food Policy, 36, S33-S39. doi:10.1016/j.foodpol.2010.12.001

Lal, R. (2018, January). Digging deeper: A holistic perspective of factors affecting soil organic carbon sequestration in agroecosystems. Global Change Biology, 24, 3285-3301. doi:10.1111/gcb.14054

Lancet. (2017). The Lancet commission on pollution and health. The Lancet Commissions, 391(10119), 462-512. doi:10.1016/S0140-6736(17)32345-0

Landschoot, P. (2016, November 10). What is an “Acre Furrow Slice” of Soil? Retrieved from Penn State Extension: https://extension.psu.edu/what-is-an-acre-furrow-slice-of-soil

LaRose, J., & Myers, R. (2019). Progress Report: Adoption of Soil Health Systems Based on Data from the 2017 U.S. Census of Agriculture. Soil Health Institute. Soil Health Institute. Retrieved from https://soilhealthinstitute.org/wp-content/uploads/2019/07/Soil-Health-Census-Report.pdf

Ledo, A., Smith, P., Zerihun, A., Whitaker, J., Vicente-Vicente, J. L., Qin, Z., . . . Hillier, J. (2020, February 10). Changes in soil organic carbon under perennial crops. Global Change Biology, 26, pp. 4158-4168. doi:10.1111/gcb.15120

Lee, D., Owens, V., & Doolittle, J. (2007). Switchgrass and Soil Carbon Sequestration Response to Ammonium Nitrate, Manure, and Harvest Frequency on Conservation Reserve Program Land. Agronomy Journal, 99(2), 462-468. doi:10.2134/agronj2006.0152

Lehman, R. M., Cambardella, C., Stott, D., Acosta-Martinez, V., Manter, D. K., Buyer, J., . . . Karlen, D. (2015). Understanding and Enhancing Soil Biological Health: The Solution for Reversing Soil Degradation. Sustainability, 7(1), 988-1027. doi:10.3390/su7010988

Lehner, P., & Henderson, E. (2019). State Soil Health Initiatives: Building Momentum. Retrieved from Earthjustice: https://earthjustice.org/sites/default/files/files/Summary-State-Soil-Health-Initiatives.pdf

Lehner, P., & Rosenberg, N. (2017). Legal Pathways to Carbon Neutral Agriculture. Environmental Law Reporter, 47(10), 10845-10876. Retrieved from https://earthjustice.org/sites/default/files/files/Legal-Pathways-Carbon-Neutral-Agriculture.pdf

Lelieveld, J., Evans, J., Fnais, M., Giannadaki, D., & Pozzer, A. (2015). The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature, 525, 367-371. doi:10.1038/nature15371

Levy, N. (2020, January 21). Seattle startup Nori raises cash for blockchain marketplace to fight climate change. GeekWire. Retrieved from https://www.geekwire.com/2020/seattle-startup-nori-raises-cash-blockchain-marketplace-fight-climate-change/

Limaye, V., Max, W., Constible, J., & Knowlton, K. (2019). Estimating the Health-Related Costs of 10 Climate-Sensitive U.S. Events During 2012. GeoHealth, 3(9), 245-265. doi:10.1029/2019GH000202

Lines-Kelly, R. (1993). Soil Organic Matter. (New South Wales Government) Retrieved from Department of Primary Industries: https://www.dpi.nsw.gov.au/agriculture/soils/structure/organic-matter

Liu, P., Wang, Y., & Zhang, W. (2018). The Influence of Environmental Quality Incentives Program (EQIP) on Local Water Quality: Evidence from Monitoring Station Level Data. Proceedings of the 2018 Agricultural & Applied Economics Association Annual Meeting, 1-31. doi:10.22004/ag.econ.274311

Lobell, D. (2009). Climate Extremes and Crop Adaptation: Summary Statement from a Meeting at the Program on Food Security and Environment, Stanford, CA Held on June 16-18, 2009. Stanford University. Retrieved from https://fsi-live.s3.us-west-1.amazonaws.com/s3fs-public/kendall_summary_aug1809.pdf

Lobell, D. B., Schlenker, W., & Costa-Roberts, J. (2011). Climate Trends and Global Crop Production Since 1980. Science, 333(6042), 616-620. doi:10.1126/science.1204531

Locus Ag. (2020, October 13). Shopify Will Be First High-Volume Corporate Buyer of Carbon Credits From A U.S. CarbonNOW™ Farmer. Retrieved from Locus Agricultural Solutions: https://locusag.com/shopify-will-be-first-high-volume-corporate-buyer-of-carbon-credits-from-a-us-carbonnow-farmer/

Loladze, I. (2002). Rising Atmospheric CO_2 and Human Nutrition: Toward Globally Imbalanced Plant Stoichiometry? Trends in Ecology and Evolution. doi:10.1016/S0169-5347(02)02587-9

Loladze, I. (2014). Hidden shift of the ionome of plants exposed to elevated CO_2 depletes minerals at the base of human nutrition. eLife, 3, e02245. doi:10.7554/eLife.02245

López-Fando, C., & Pardo, M. (2011). Soil carbon storage and stratification under different tillage systems in a semi-arid region. Soil and Tillage Research, 111(2), 224-230. doi:10.1016/j.still.2010.10.011

Lotter, D., Seidel, R., & Liebhardt, W. (2003). The performance of organic and conventional cropping systems in an extreme climate year. American Journal of Alternative Agriculture, 18(3), 146-154. doi:10.1079/AJAA200345

Lovato, T. (2001). Dinâmica do carbono e nitrogênio do solo afetada por preparos do solo, sistemas de cultura e adubo nitrogenado. PhD Thesis, Porto Alegre UFRGS. Retrieved from https://www.ufrgs.br/agronomia/materiais/128td.pdf

Lovins, H., Wallis, S., Wikjman, A., & Fullerton, J. (2018). A Finer Future: Creating an Economy in Service to Life. Gabriola Island, Canada: New Society Publishers.

Lyle, S., & Hernandez, V. (2020, February 24). CDFA Announces Changes for Next Round of Healthy Soils Program Grants. (Natural Resources Conservation Service) Retrieved from NRCS California: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/ca/newsroom/releases/?cid=NRCSEPRD1549218

Machmuller, M., Kramer, M., Cyle, T., Hill, N., Hancock, D., & Thompson, A. (2015). Emerging land use practices rapidly increase soil organic matter. Nature Communications, 1-5. doi:10.1038/ncomms7995

Mackenzie, K. (2018, October 18). What's the damage (of that climate change cost-benefit model)? Financial Times. Retrieved from https://ftalphaville.ft.com/2018/10/18/1539847800000/What-s-the-damage--of-that-climate-change-cost-benefit-model---/

Macrotrends. (2020). Danone Net Worth 2006-2019. Retrieved from https://www.macrotrends.net/stocks/charts/DANOY/danone/net-worth

Macrotrends. (2020). General Mills Net Worth 2006-2020. Retrieved from https://www.macrotrends.net/stocks/charts/GIS/general-mills/net-worth

Macrotrends. (2020). Unilever Net Worth 2006 - 2020. Retrieved from https://www.macrotrends.net/stocks/charts/UN/unilever/net-worth

Macrotrends. (2020, November 17). Walmart Market Cap 2006-2020 | WMT. Retrieved from Macrotrends: https://www.macrotrends.net/stocks/charts/WMT/walmart/market-cap

Makumba, W., Janssen, B., Oenema, O., Akinnifesi, F., Mweta, D., & Kwesiga, F. (2006). The long-term effects of a gliricidia–maize intercropping system in Southern Malawi, on gliricidia and maize yields, and soil properties. Agriculture, Ecosystems & Environment, 116(1-2), 85-92. doi:10.1016/j.agee.2006.03.012

Manderscheid, R., Bender, J., Jäger, H.-J., & Weigel, H. (1995). Effects of season long CO_2 enrichment on cereals. II. Nutrient concentrations and grain quality. Agriculture, Ecosystems & Environment, 54(3), 175-185. doi:10.1016/0167-8809(95)00602-O

Marler, J., & Wallin, J. (2015). Human Health, the Nutritional Quality of Harvested Food and Sustainable Farming Systems. Nutrition Security Institute. Retrieved from https://www.europeanmedicalmassageco.com/wp-content/uploads/2015/06/Mineral-depletion-summary.pdf

Marles, R. (2017). Mineral nutrient composition of vegetables, fruits and grains: The context of reports of apparent historical declines. Journal of Food Consumption and Analysis, 56, 93-103. doi:10.1016/j.jfca.2016.11.012

Mathew, I., Shimelis, H., Mutema, M., & Chaplot, V. (2017). What crop type for atmospheric carbon sequestration: Results from a global data analysis. Agriculture, Ecosystems & Environment, 243, 34-46. Retrieved from https://doi.org/10.1016/j.agee.2017.04.008

Mayer, A.-M. (1997). Historical changes in the mineral content of fruits and vegetables. British Food Journal, 99(6), 207-211. doi:10.1108/00070709710181540

Mazzilli, S., Kemanian, A., Ernst, O., Jackson, R., & Pineiro, G. (2015). Greater humification of belowground than aboveground biomass carbon into particulate soil organic matter in no-till corn and soybean crops. Soil Biology & Biochemistry, 85, 22-30. Retrieved from http://dx.doi.org/10.1016/j.soilbio.2015.02.014

McIntosh, W., Spies, E., Stone, D., Lokey, C., Trudeau, A.-R., & Bartholow, B. (2016). Suicide Rates by Occupational Group — 17 States, 2012. Morbidity and Mortality Weekly Report, 65(25), 641-645. Retrieved from https://www.jstor.org/stable/24858148

McKenna, P. (2020, October 7). Emissions of Nitrous Oxide, a Climate Super-Pollutant, Are Rising Fast on a Worst-Case Trajectory. Inside Climate News. Retrieved from https://insideclimatenews.org/news/07102020/nitrous-oxide-fertilizer-emissions-nature-study

MDA. (2017, May 4). House Bill 1063. Retrieved from Lawrence J. Hogan, Jr., Governor: https://mda.maryland.gov/resource_conservation/counties/Ch_373_hb1063T.pdf

MDA. (2020). Fertilizer License. (D. o. Agriculture, Producer, & State of Minnesota) Retrieved from ELicensing: https://mn.gov/elicense/a-z/?id=1083-231490#/list/appId//filterType//filterValue//page/1/sort//order/

Medek, D., Schwartz, J., & Myers, S. (2017). Estimated Effects of Future Atmospheric CO_2 Concentrations on Protein Intake and the Risk of Protein Deficiency by Country and Region. Environmental Health Perspectives, 125(8). doi:10.1289/EHP41

Melvin, J. (2010, February 18). Black farmers win $1.25 billion in discrimination suit. Reuters. Retrieved from https://www.reuters.com/article/us-usa-farmers-pigford/black-farmers-win-1-25-billion-in-discrimination-suit-idUSTRE61H5XD20100218

Mendes, R., Kruijt, M., Bruijn, I. d., Dekkers, E., Voort, M. v., Schneider, J., . . . Raaijmakers, J. (2011). Deciphering the Rhizosphere Microbiome for Disease-Suppressive Bacteria. Science(332), 1097-1100. doi:10.1126/science.1203980

Merrill, J. (2019, July 11). Will Indigo Ag's New Private Carbon Market Pay Off for Farmers? (California Climate and Agricultural Network) Retrieved from CalCAN: https://calclimateag.org/will-indigo-ags-new-private-carbon-market-pay-off-for-farmers/

Millar, N. (2015). Management of Nitrogen Fertilizer to Reduce Nitrous Oxide Emissions from Field Crops. Michigan State University, MSU Extension. Retrieved from https://www.canr.msu.edu/resources/management_of_nitrogen_fertilizer_to_reduce_nitrous_oxide_emissions_from_fi

Minasny, B., Malone, B., McBratney, A., Angers, D., Arrouays, D., Chambers, A., . . . Paustian, K. (2017). Soil carbon 4 per mille. Geoderma, 292, 59-86. Retrieved from http://dx.doi.org/10.1016/j.geoderma.2017.01.002

Monaco, E. (2019, May 7). Is Label Fatigue Diluting the Meaning of Certified Organic? Organic Authority. Retrieved from https://www.organicauthority.com/buzz-news/is-label-fatigue-diluting-the-meaning-of-the-certified-organic-label

Morning Ag Clips. (2020, March 2). Funding available for Healthy Soils Program. Morning Ag Clips. Retrieved from https://www.morningagclips.com/funding-available-for-healthy-soils-program/

Moyer, J., Stoll, S., Schaeffer, Z., Smith, A., Grega, M., Weiss, R., & Fuhrman, J. (2020). The Power of the Plate: The Case for Regenerative Organic Agriculture in Improving Human Health. Kutztown, PA: The Rodale Institute. Retrieved from https://rodaleinstitute.org/wp-content/uploads/Rodale-Institute-The-Power-of-the-Plate-The-Case-for-Regenerative-Organic-Agriculture-in-Improving-Human-Health.pdf

Mulvaney, R., Khan, S., & Ellsworth, T. (2009). Synthetic Nitrogen Fertilizers Deplete Soil Nitrogen: A Global Dilemma for Sustainable Cereal Production. Journal of Environmental Quality, 38(6), 2295-2314. doi:10.2134/jeq2008.0527

Mumm, R., Goldsmith, P., Rausch, K., & Stein, H. (2014). Land usage attributed to corn ethanol production in the United States: sensitivity to technological advances in corn grain yield, ethanol conversion, and co-product utilization. Biotechnology for Biofuels, 7(61). doi:10.1186/1754-6834-7-61

Myers, S., Wessells, R., Kloog, I., Zanobetti, A., & Schwartz, J. (2015). Effect of increased concentrations of atmospheric carbon dioxide on the global threat of zinc deficiency: a modelling study. The Lancet, 3(10), E639-E645. doi:10.1016/S2214-109X(15)00093-5

Myers, S., Zanobetti, A., Kloog, I., Huybers, P., Leakey, A., Bloom, A., . . . Sartor, K. (2014). Increasing CO_2 threatens human nutrition. Nature, 510, 139-142. doi:10.1038/nature13179

N4E. (2020). Maryland Healthy Soils Policy. Retrieved from https://nerdsforearth.com/maryland-healthy-soils-policy/

N4E. (2020). State Healthy Soil Policy Map. Retrieved from Nerds for Earth: https://nerdsforearth.com/state-healthy-soils-policy/

NASS. (2012). 2012 Publications. (N. A. Service, Producer, & United States Department of Agriculture) Retrieved from Census of Agriculture: https://www.nass.usda.gov/Publications/AgCensus/2012/

NASS. (2019). 2017 Census of Agriculture Highlights: Farm Producers. United States Department of Agriculture, National Agriculture Statistics Service.

NASS. (2020, July 31). Paid Indexes by Non-farm Origin and Month, Chemicals, Fertilizers, and Fuels - United States: 2011=100. (N. A. Service, Producer, & United States Department of Agriculture) Retrieved from Charts and Maps: https://www.nass.usda.gov/Charts_and_Maps/Agricultural_Prices/prod1.php

NEDA. (2020). Fertilizer Program. (D. o. Agriculture, Producer, & State of Nebraska) Retrieved from Fertilizer & Ag Lime: https://nda.nebraska.gov/plant/fertilizer/index.html

Neguse, J. (2020, July 24). Joe Neguse's Bipartisan Regenerative Agriculture Proposal Passes the House Along with Interior Appropriations. Retrieved from Joe Neguse: U.S. Congressman for Colorado's Second District: https://neguse.house.gov/media/press-releases/joe-neguses-bipartisan-regenerative-agriculture-proposal-passes-the-house-along-with-interior-appropriations

Netto, M. N. (2019, May 9). A Look at Indigo Ag's Successful Entry into the Brazilian Market. PrecisionAg. Retrieved from https://www.precisionag.com/digital-farming/a-look-at-indigo-ags-successful-entry-into-the-brazilian-market/

New Mexico Legislature. (2020). 2019 Regular Session - HB 204. (State of New Mexico) Retrieved from Legislation: https://www.nmlegis.gov/Legislation/Legislation?chamber=H&legtype=B&legno=204&year=19

Newton, P., Civita, N., Frankel-Goldwater, L., Bartel, K., & Johns, C. (2020, October 26). What Is Regenerative Agriculture? A Review of Scholar and Practitioner Definitions Based on Processes and Outcomes. Frontiers in Sustainable Food Systems, 4, 1-11. doi:10.3389/fsufs.2020.577723

Nielsen. (2018, December 17). Was 2018 the Year of the Influential Sustainable Consumer? (The Nielsen Company) Retrieved from Insights: https://www.nielsen.com/us/en/insights/article/2018/was-2018-the-year-of-the-influential-sustainable-consumer/

NOAA. (2019, June 12). NOAA forecasts very large 'dead zone' for Gulf of Mexico. (National Oceanic and Atmospheric Administration) Retrieved from NOAA: https://www.noaa.gov/media-release/noaa-forecasts-very-large-dead-zone-for-gulf-of-mexico

NOAA. (2020). Billion-Dollar Weather and Climate Disasters: Overview. (National Oceanic and Atmospheric Administration) doi:10.25921/stkw-7w73

NOAA. (2020, April). Global Monitoring Laboratory. Retrieved from Earth System Research Laboratories: https://www.esrl.noaa.gov/gmd/ccgg/trends/mlo.html

Nordhaus, W. (2007, September). A Review of the Stern Review on the Economics of Climate Change. Journal of Economic Literature, XLV, 686-702. Retrieved from http://piketty.pse.ens.fr/files/Nordhaus2007b.pdf

Nordhaus, W. (2017). Revisiting the social cost of carbon. Proceedings of the National Academy of Sciences, 114(7), 1518-1523. doi:10.1073/pnas.1609244114

Nori. (2020). The Nori Carbon Removal Marketplace. Retrieved from Nori: https://nori.com/

Novotny, V. (1999). Diffuse Pollution from Agriculture - A Worldwide Outlook. Water Science & Technology, 39(3), 1-13. Retrieved from https://www.ircwash.org/sites/default/files/244-99DI-15648.pdf

NRCS. (2011, November 17). Native American Farmer and Rancher Class Action Settlement - Keepseagle v. Vilsack. (N. R. Louisiana, Producer, & United States Department of Agriculture) Retrieved from News Release: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/la/newsroom/?cid=nrcs141p2_015776

NRCS. (2011). USDA Notice to Women and Hispanic Farmers and Ranchers. (N. R. Montana, Producer, & United States Department of Agriculture) Retrieved from Press Releases: https://www.nrcs.usda.gov/wps/portal/nrcs/mt/newsroom/releases/NRCS144P2_058017/

NRCS. (2017). Conservation Stewardship Program - Payment for Performance. (United States Department of Agriculture) Retrieved from Natural Resources Conservation Service: https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/programs/financial/csp/?cid=nrcs143_008316#:~:text=Program%20Description,level%20environmental%20benefits%20they%20produce.

NRCS. (2020, March). CIG On-Farm Conservation Innovation Trials. (N. R. Service, Producer, & United States Department of Agriculture) Retrieved from https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/financial/cig/?cid=nrcseprd1459039

NRCS. (2020). Conservation Stewardship Program. (N. R. Service, Producer, & United States Department of Agriculture) Retrieved from https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/csp/

NRCS. (2020). Environmental Quality Incentives Program. (N. R. Service, Producer, & United States Department of Agriculture) Retrieved from https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/

NRCS. (2020). Honoring 85 Years of NRCS – A Brief History. (N. R. Service, Producer, & United States Department of Agriculture) Retrieved from https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/about/history/?cid=nrcs143_021392#:~:text=On%20April%2027%2C%201935%20Congress,SCS)%20as%20a%20permanent%20agency

NRCS. (2020). Regional Conservation Partnership Program. (N. R. Service, Producer, & United States Department of Agriculture) Retrieved from https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/rcpp/

NRDC. (2017). Covering Crops: How Federal Crop Insurance Program Reforms Can Reduce Costs, Empower Farmers, and Protect Natural Resources. Issue Paper, Natural Resources Defense Council. Retrieved from https://www.nrdc.org/sites/default/files/federal-crop-insurance-program-reforms-ip.pdf

NSAC. (2019, August). Conservation Reserve Program. Retrieved from National Sustainable Agriculture Coalition: https://sustainableagriculture.net/publications/grassrootsguide/conservation-environment/conservation-reserve-program/

NSAC. (2019, May). Environmental Quality Incentives Program. (National Sustainable Agriculture Coalition) Retrieved from https://sustainableagriculture.net/publications/grassrootsguide/conservation-environment/environmental-quality-incentives-program/

NSAC. (2019, July). Regional Conservation Partnership Program. (National Sustainable Agriculture Coalition) Retrieved from https://sustainableagriculture.net/publications/grassrootsguide/conservation-environment/cooperative-conservation-partnership-initiative/

OEFI. (2020). Healthy Soils Program. (California Department of Food and Agriculture) Retrieved from Office of Environmental Farming and Innovation: https://www.cdfa.ca.gov/oefi/healthysoils/

Oerke, E.-C. (2006). Crop losses to pests. Journal of Agricultural Science, 144, 31-43. doi:10.1017/S0021859605005708

Ogle, S., Breidt, J., & Paustian, K. (2005). Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. Biogeochemistry, 72, 87-121. doi:10.1007/s10533-004-0360-2

Ogle, S., Swan, A., & Paustian, K. (2012, March). No-till management impacts on crop productivity, carbon input and soil carbon sequestration. Agriculture, Ecosystems & Environment, 1, 37-49. doi:10.1016/j.agee.2011.12.010

Oldfield, E., Bradford, M., & Wood, S. (2019). Global meta-analysis of the relationship between soil organic matter and crop yields. SOIL, 5, 15-32. doi:10.5194/soil-5-15-2019

OLRC. (2020). Internal Revenue Code. (O. o. Council, Producer, & United States House of Representatives) Retrieved from United States Code: https://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title26-section45Q&num=0&edition=prelim

OTA. (2020). Organic Market Overview. Organic Trade Association. Retrieved from https://ota.com/resources/market-analysis#:~:text=The%20U.S.%20organic%20sector%20posted,percent%20from%20the%20previous%20year.

Otuk, I., & Daniel, E. (2015). Land Degradation: A Threat to Food Security: A Global Assessment. Journal of Environment and Earth Sciences, 5(8), 13-21. Retrieved from https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1021.6036&rep=rep1&type=pdf#:~:text=The%20importance%20of%20land%20degradation,and%20quality%20of%20the%20environment.&text=Loss%20in%20the%20value%20of,the%20environmental%20cost%20of%20agricultur

Packer, A. P., Ramos, N. P., Cabral, O. M., Silva, I. R., Moltocaro, R. C., Bettanin, V. C., . . . Teixeira, W. G. (2017). Management of nitrogen fertilizer to reduce nitrous oxide (N_2O) emission and ammonia (NH_3) volatilization from coffee plantation. Ministério da Agricultura, Pecuária e Abastecimento , Empresa Brasileira de Pesquisa Agropecuária. Brasilia: Embrapa. Retrieved from https://www.embrapa.br/busca-de-publicacoes/-/publicacao/1085625/management-of-nitrogen-fertilizer-to-reduce-nitrous-oxide-n2o-emission-and-ammonia-nh3-volatilization-from-coffee-plantation

Park, S., Croteau, P., Boering, K., Etheridge, D., Ferretti, D., Fraser, P., . . . Trudinger, C. (2012). Trends and seasonal cycles in the isotopic composition of nitrous oxide since 1940. Nature Geoscience, 5, 261-265. doi:doi.org/10.1038/ngeo1421

Paschal, O. (2018, December 16). A Boost for Young, Diverse Farmers. The Atlantic. Retrieved from https://www.theatlantic.com/politics/archive/2018/12/farm-bill-funds-programs-new-and-diverse-farmers/578260/

Patagonia Provisions. (2020). Why Beer? Retrieved from Patagonia Provisions: https://www.patagoniaprovisions.com/pages/why-beer

Paustian, K., Chenu, C., Conant, R., Cotrufo, F., Lal, R., Smith, P., & Soussana, J.-F. (2020). Climate Mitigation Potential of Regenerative Agriculture is significant! Retrieved from https://www.agri-pulse.com/ext/resources/pdfs/ResponsetoWRI-FINAL.pdf

Paustian, K., Larson, E., Kent, J., Marx, E., & Swan, A. (2019). Soil C Sequestration as a Biological Negative Emission Strategy. Frontiers in Climate, 1(8), 1-11. doi:10.3389/fclim.2019.00008

Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G. P., & Smith, P. (2016). Climate-smart soils. Nature, 532, 49-57. doi:10.1038/nature17174

PGPF. (2020, May 13). U.S. Defense Spending Compared to Other Countries. Retrieved from Peter G. Peterson Foundation: https://www.pgpf.org/chart-archive/0053_defense-comparison

Philpott, S., Lin, B., Jha, S., & Brines, S. (2008). A multi-scale assessment of hurricane impacts based on land-use and topographic features. Agriculture, Ecosystems & Environment, 128(1-2), 12-20. doi:10.1016/j.agee.2008.04.016

Picard, A. (2002, July 2). Today's fruits, vegetables lack yesterday's nutrition. The Globe and Mail. Retrieved from https://www.theglobeandmail.com/life/todays-fruits-vegetables-lack-yesterdays-nutrition/article4137315/

Pingali, P. (2012). Green Revolution: Impacts, limits, and the path ahead. Proceedings of the National Academy of Sciences, 109(31), 12302-12308. doi:10.1073/pnas.0912953109

Poeplau, C., & Don, A. (2015). Carbon sequestration in agricultural soils via cultivation of cover crops – A meta-analysis. Agriculture, Ecosystems & Environment, 200, 33-41. doi:10.1016/j.agee.2014.10.024

Poindexter, O. (2020, April 23). Indigo Ag's plan to compensate farmers for carbon removal is attracting funders such as FedEx. GreenBiz. Retrieved from https://www.greenbiz.com/article/indigo-ags-plan-compensate-farmers-carbon-removal-attracting-funders-such-fedex

Pollan, M. (2001). The Botany of Desire. New York: Random House.

Post, W., & Kwon, K. (2000). Soil Carbon Sequestration and Land-Use Change: Processes and Potential. Global Change Biology, 6, 317-328.

Potera, C. (2008). Fuels: Corn Ethanol Goal Revives Dead Zone Concerns. Environmental Health Perspectives, 116(6). doi:10.1289/ehp.116-a242

Poulton, P., Johnston, J., Macdonald, A., White, R., & Powlson, D. (2018). Major limitations to achieving "4 per 1000" increases in soil organic carbon stock in temperate regions: Evidence from long-term experiments at Rothamsted Research, United Kingdom. Global Change Biology, 24, 2563-2584. doi:10.1111/gcb.14066

Powlson, D. S., Stirling, C. M., Jat, M. L., Gerard, B. G., Palm, C. A., Sanchez, P. A., & Cassman, K. G. (2014, July 30). Limited potential of no-till agriculture for climate change mitigation. Nature Climate Change, 678-683. doi:10.1038/nclimate2292

Powlson, D., Whitmore, A., & Goulding, K. (2011). Soil carbon sequestration to mitigate climate change: a critical re‐examination to identify the true and the false. European Journal of Soil Science, 62(1), 42-55. Retrieved from https://doi.org/10.1111/j.1365-2389.2010.01342.x

Press, D., & Mazmanian, D. (2019). Towards Sustainable Production: Finding Workable Strategies for Government and Industry. In N. Vig, & M. Kraft, Environmental Policy: New Directions in the Twenty-First Century (10 ed., pp. 269-296). Los Angeles: CQ Press.

Prior, S., Runion, B., Rogers, H., & Torbert, A. (2008). Effects of Atmospheric CO_2 Enrichment on Crop Nutrient Dynamics under No-Till Conditions. Journal of Plant Nutrition, 31(4), 758-773. doi:10.1080/01904160801928364

Quantis. (2019). Carbon Footprint Evaluation of Regenerative Grazing at White Oak Pastures. Retrieved from https://blog.whiteoakpastures.com/hubfs/WOP-LCA-Quantis-2019.pdf

Raaijmakers, J., & Mazzola, M. (2016). Soil immune responses. Science, 352(6292), 1392-1393. doi:10.1126/science.aaf3252

Rabalais, N., Turner, E., & Wiseman Jr., W. (2002). Gulf of Mexico Hypoxia, A.K.A. “The Dead Zone”. Annual Review of Ecology and Systematics, 33, 235-263. doi:10.1146/annurev.ecolsys.33.010802.150513

Ranganathan, J., Waite, R., Searchinger, T., & Zionts, J. (2020, May 12). Regenerative Agriculture: Good for Soil Health, but Limited Potential to Mitigate Climate Change. Retrieved from World Resources Institute: https://www.wri.org/blog/2020/05/regenerative-agriculture-climate-change

Ray, K. (2018, October 16). U.S. Boasts 6.5 Million Acres of Organic Certified Land with 460 New Operations in 2018. Global News Wire. Retrieved from https://www.globenewswire.com/news-release/2018/10/16/1621990/0/en/U-S-Boasts-6-5-Million-Acres-of-Organic-Certified-Land-with-460-New-Operations-in-2018.html

Reay, D., Davidson, E., Smith, K., Smith, P., Melillo, J., Dentener, F., & Crutzen, P. (2012). Global agriculture and nitrous oxide emissions. Nature Climate Change. doi:10.1038/NCLIMATE1458

Reeve, J., Hoagland, L., Villalba, J., Carr, P., Atucha, A., Cambardella, C., . . . Delate, K. (2016). Chapter Six - Organic Farming, Soil Health, and Food Quality: Considering Possible Links. Advances in Agronomy, 137, 319-367. doi:10.1016/bs.agron.2015.12.003

Regen Organic. (2020). Farm like the world depends on it. Retrieved from Regenerative Organic Certified: https://regenorganic.org/

Renton, C., Lafave, C., & Sierks, K. (2020, April 8). The Case for Crop Insurance Reform. Conservation Finance Network. Retrieved from https://conservationfinancenetwork.org/2020/04/08/the-case-for-crop-insurance-reform

Retallack, G. (2013). Global Cooling by Grassland Soils of the Geological Past and Near Future. Annual Review of Earth and Planetary Sciences, 41, 69-86. doi:10.1146/annurev-earth-050212-124001

RI. (2020). Care What You Wear: Campaigning for Ecological & Ethical Clothing. Retrieved from Regeneration International: https://regenerationinternational.org/care-what-you-wear/

RI. (2020). Care What You Wear: Responsible Brands Directory. Retrieved from Regeneration International: https://regenerationinternational.org/responsible-brand-directory/

Ricciardi, V., Ramankutty, N., Mehrabi, Z., Jarvis, L., & Chookolingo, B. (2018). How much of the world's food do smallholders produce? Global Food Security, 17, 64-72. doi:10.1016/j.gfs.2018.05.002

Ripple, W., Smith, P., Haberl, H., Montzka, S., McAlpine, C., & Boucher, D. (2014). Ruminants, climate change and climate policy. Nature Climate Change, 4, 2-5. doi:10.1038/nclimate2081

Ritchie, H., & Roser, M. (2019). Land Use. Our World in Data. University of Oxford; Global Change Data Lab. Retrieved from https://ourworldindata.org/land-use#:~:text=Definitions%20of%20agricultural%20land%20use,%25%20of%20the%20Land%20Area).

Ritter, T., & Treakle, J. (2020). Why Carbon Markets Won't Work for Agriculture. Institute for Agriculture and Trade Policy and National Family Farm Coalition. Retrieved from https://www.iatp.org/sites/default/files/2020-02/2020_01_CarbonMarketsAndAg_FINAL.pdf

Rodale Institute. (2020). Organic No-Till. Retrieved from Rodale Institute: https://rodaleinstitute.org/why-organic/organic-farming-practices/organic-no-till/#:~:text=The%20roller%20crimper%20is%20a,the%20stems%20every%20seven%20inches.

Rost, S., Gerten, D., Hoff, H., Lucht, W., Falkenmark, M., & Rockström, J. (2009). Global potential to increase crop production through water management in rainfed agriculture. Environmental Research Letters, 4(4), 1-9. doi:10.1088/1748-9326/4/4/044002

Rumpel, C., Amiraslani, F., Chenu, C., Cardenas, M. G., Kaonga, M., Koutika, L.-S., . . . Wollenberg, E. (2019). The 4p1000 initiative: Opportunities, limitations and challenges for implementing soil organic carbon sequestration as a sustainable development strategy. Ambio, 49, 350-360. Retrieved from https://doi-org.proxy1.library.jhu.edu/10.1007/s13280-019-01165-2

Sanderman, J., Hengl, T., & Fiske, G. (2018). Correction for Sanderman et al., Soil carbon debt of 12,000 years of human land use. PNAS, 115(7), E1700. Retrieved from https://doi.org/10.1073/pnas.1800925115

Sanderman, J., Hengl, T., & Fiske, G. J. (2017). Soil carbon debt of 12,000 years of human land use. PNAS, 114(36), 9575-9580. doi:10.1073/pnas.1706103114

SARE. (2020). Organic Systems Make Good Economic Sense. (Sustainable Agriculture Research and Education) Retrieved from Economics of Organic Production: https://www.sare.org/publications/transitioning-to-organic-production/Economics-of-Organic-Production/

Savory. (2020). EOV: The Science Inside Land to Market. Retrieved from Savory Institute: https://savory.global/land-to-market/eov/

Savory Institute. (2020). Chapter 1: EOV Summary. Retrieved from https://savory.global/wp-content/uploads/2020/08/CHAPTER_1_-_SUMMARY-1.pdf

Savory, A. (1983, August). The Savory Grazing Method or Holistic Rangeland Management. Rangelands, 5(4), 155-159.

Schechinger, A., & Cox, C. (2017). Is Federal Crop Insurance Policy Leading to Another Dust Bowl? Environmental Working Group. Retrieved from https://cdn.ewg.org/sites/default/files/u352/EWG_DustBowlReport_C07.pdf

Scheer, R., & Moss, D. (2011, April 27). Dirt Poor: Have Fruits and Vegetables Become Less Nutritious? Scientific American. Retrieved from https://www.scientificamerican.com/article/soil-depletion-and-nutrition-loss/

Schlesinger, W., & Amundson, R. (2018). Managing for soil carbon sequestration: Let's get realistic. Global Change Biology, 25, 386-389. doi:10.1111/gcb.14478

Secrétariat Exécutif. (2018). Welcome to the "4 Per 1000" Initiative. Retrieved from 4p1000: https://www.4p1000.org/

Sherren, K., Fischer, J., & Fazey, I. (2012). Managing the grazing landscape: Insights for agricultural adaptation froma mid-drought photo-elicitation study in the Australian sheep-wheat belt. Agricultural Systems, 106, 72-83. doi:10.1016/j.agsy.2011.11.001

Shobe, B. (2019, November 12). Want to scale up the Healthy Soils Program? Here's where to start. (California Climate and Agricultural Network) Retrieved from CalCAN: https://calclimateag.org/want-to-scale-up-the-healthy-soils-program-heres-where-to-start/

Shobe, B. (2020, February 27). Application Period Open for Record $25 Million Round of Healthy Soils Program — Here's What You Need to Know. (California Climate and Agricultural Network) Retrieved from CalCAN: https://calclimateag.org/application-period-open-for-record-25-million-round-of-healthy-soils-program-heres-what-you-need-to-know/

Shobe, B. (2020, May 21). Healthy Soils Program Sees Record Demand Despite Pandemic, $22 Million in Incentives Grants Announced. (California Climate and Agricultural Network) Retrieved from CalCAN: https://calclimateag.org/healthy-soils-program-sees-record-demand-despite-pandemic-22-million-in-incentives-grants-announced/

SHP. (2020). Soil Health Partnership. Retrieved from https://www.soilhealthpartnership.org/

Shukla, P., J. Skea, E. C., Masson-Delmotte, V., Pörtner, H.-O., Roberts, D. C., Zhai, P., . . . Malley, J. (2019). Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Intergovernmental Panel on Climate Change. IPCC. Retrieved from https://www.ipcc.ch/site/assets/uploads/2019/11/SRCCL-Full-Report-Compiled-191128.pdf

Siegel-Hertz, K., Edel-Hermann, V., Chapelle, E., Terrat, S., Raaijmakers, J. M., & Steinberg, C. (2018). Comparative Microbiome Analysis of a Fusarium Wilt Suppressive Soil and a Fusarium Wilt Conducive Soil From the Châteaurenard Region. Frontiers in Microbiology, 9. doi:10.3389/fmicb.2018.00568

Silver, W., Vergara, S., & Mayer, A. (2018). Carbon Sequestration and Greenhouse Gas Mitigation Potential of Composting and Soil Amendments on California's Rangelands. University of California, Berkeley. California Natural Resources Agency. Retrieved from https://pdfs.semanticscholar.org/aa66/22e603b65cd5f63a34a77708d671462afedc.pdf

Smith, M., Golden, C., & Myers, S. (2017). Potential rise in iron deficiency due to future anthropogenic carbon dioxide emissions. GeoHealth, 1(6), 248-257. doi:10.1002/2016GH000018

Smith, P., Adams, J., Beerling, D., Beringer, T., Calvin, K., Fuss, S., . . . Keesstra, S. (2019). Land-Management Options for Greenhouse Gas Removal and Their Impacts on Ecosystem Services and the Sustainable Development Goals. Annual Review of Environment and Resources, 44, 255-286. Retrieved from https://doi.org/10.1146/annurev-environ-101718-033129

Smith, P., Powlson, D., Glendining, M., & Smith, J. (1998). Preliminary estimates of the potential for carbon mitigation in European soils through no‐till farming. Global Change Biology, 4(6), 679-685. doi:10.1046/j.1365-2486.1998.00185.x

Snapp, S., Blackie, M., Gilbert, R., Bezner-Kerr, R., & Kanyama-Phiri, G. (2010). Biodiversity can support a greener revolution in Africa. PNAS, 107(48), 20840-20845. doi:10.1073/pnas.1007199107

Soares, J., Santos, C., Carvalho, S., Pintado, M., & Vasconcelos, M. (2019). Preserving the nutritional quality of crop plants under a changing climate: importance and strategies. Plant Soil, 443, 1-26. doi:10.1007/s11104-019-04229-0

Soil Health Institute. (2018). Soil Health and Yield Stability: Summary of Literature Analysis. Retrieved from https://soilhealthinstitute.org/wp-content/uploads/2019/01/Yield-Variability_08-2018_Final.pdf

Soil Health Institute. (2020). Soil Health Policy Resources Catalog. (Soil Health Institute) Retrieved from https://soilhealthinstitute.org/resources/catalog/

Soil Solution. (2018). State Policy. Retrieved from https://soilsolution.org/u-s-state-policy/

Sommer, R., & Bossio, D. (2014, November). Dynamics and climate change mitigation potential of soil organic carbon sequestration. J Environ Manage, 144, 83-87. doi:10.1016/j.jenvman.2014.05.017

Song, G., Li, L., Pan, G., & Zhang, Q. (2005). Topsoil organic carbon storage of China and its loss by cultivation. Biogeochemistry, 74, 47-62. doi:10.1007/s10533-004-2222-3

Song, L., & Moura, P. (2019, May 22). An Even More Inconvenient Truth: Why Carbon Credits For Forest Preservation May Be Worse Than Nothing. ProPublica. Retrieved from https://features.propublica.org/brazil-carbon-offsets/inconvenient-truth-carbon-credits-dont-work-deforestation-redd-acre-cambodia/

Stanley, P., Rowntree, J., Beede, D., DeLonge, M., & Hamm, M. (2018). Impacts of soil carbon sequestration on life cycle greenhouse gas emissions in Midwestern USA beef finishing systems. Agricultural Systems, 162, 249-258. Retrieved from https://doi.org/10.1016/j.agsy.2018.02.003

Stern, N. (2006). Stern Review on the Economics of Climate Change. (HM Treasury) Retrieved from Stern Review final report: https://webarchive.nationalarchives.gov.uk/20100407172811/http://www.hm-treasury.gov.uk/stern_review_report.htm

Stika, J. (2016). A Soil Owner's Manual: How to Restore and Maintain Soil Health. USA: CreateSpace Independent Publishing Platform.

Sulaeman, D., & Westoff, T. (2020, February 7). The Causes and Effects of Soil Erosion, and How to Prevent It. Retrieved from World Resources Institute: https://www.wri.org/blog/2020/01/causes-effects-how-to-prevent-soil-erosion

Sun, W., Canadell, J. G., Yu, L., Yu, L., Zhang, W., Smith, P., . . . Huang, Y. (2020, June). Climate drives global soil carbon sequestration and crop yield changes under conservation agriculture. Global Change Biology, 26(6), 3325-3335. doi:10.1111/gcb.15001

Sun, X. X., Li, D. P., Wu, Z. J., Cui, Y. L., Han, M., Li, Y. H., . . . Cui, Y. K. (2016). [Characteristics of Ammonia Volatilization and Nitrous Oxide Emission From a Paddy Soil Under Continuous Application of Different slow/controlled Release Urea]. Journal of Applied Ecology, 27(6), 1901-1909. doi:10.13287/j.1001-9332.201606.039

Tallman, S. (2012). No-Till Case Study, Brown's Ranch: Improving Soil Health Improves the Bottom Line. National Center for Appropriate Technology, National Sustainable Agriculture Information Service. Retrieved from https://attra.ncat.org/product/no-till-case-study-browns-ranch-improving-soil-health-improves-the-bottom-line/

Tan, J. (2018, March 18). Keeping carbon in the ground can cut emissions and boost food security, study finds. Mongabay. Retrieved from https://news.mongabay.com/2018/03/keeping-carbon-in-the-ground-can-cut-emissions-and-boost-food-security/

Teague, R. (2013, November 17). Deficiencies in the Briske Estimates of Carbon Sequestration on Rangelands. Retrieved from Real Climate: http://www.realclimate.org/index.php/archives/2013/11/cows-carbon-and-the-anthropocene-commentary-on-savory-ted-video/comment-page-3/#comment-426736

Teague, R., & Kreuter, U. (2020). Managing Grazing to Restore Soil Health, Ecosystem Function, and Ecosystem Services. Frontiers in Sustainable Food Systems, 4, 534187. doi:10.3389/fsufs.2020.534187

Teague, R., Provenza, F., Kreuter, U., Steffens, T., & Barnes, M. (2013). Multi-paddock grazing on rangelands: Why the perceptual dichotomy between research results and rancher experience? Journal of Environmental Management, 128, 699-717. Retrieved from https://doi.org/10.1016/j.jenvman.2013.05.064

Teague, W., Apfelbaum, S., Lal, R., Kreuter, U., Rowntree, J., Davies, C., . . . Byck, P. (2016). The role of ruminants in reducing agriculture's carbon footprint in North America. Journal of Soil and Water Conservation, 71(2), 156-164. doi:10.2489/jswc.71.2.156

Teague, W., Dowhower, S., Baker, S., Haile, N., DeLaune, P., & Conover, D. (2011). Grazing management impacts on vegetation, soil biota and soil chemical, physical and hydrological properties in tall grass prairie. Agriculture, Ecosystems & Environment, 141(3-4), 310-322. Retrieved from https://doi.org/10.1016/j.agee.2011.03.009

The Guardian. (2005, May 15). It's supposed to be lean cuisine. So why is this chicken fatter than it looks? The Guardian. Retrieved from https://www.theguardian.com/lifeandstyle/2005/may/15/foodanddrink.shopping3

The World Bank. (2012). Carbon Sequestration in Agricultural Soils. Washington, DC: The World Bank. Retrieved from https://secureservercdn.net/184.168.47.225/02f.e55.myftpupload.com/wp-content/uploads/2016/03/world-bank-CARBON-SEQUESTRATION-IN-AGRICULTURAL-SOILS-673950REVISED000CarbonSeq0Web0final.pdf

The World Bank. (2020). Carbon Pricing Dashboard. Retrieved from The World Bank: https://carbonpricingdashboard.worldbank.org/

Tian, H., Xu, R., Canadell, J., Thompson, R., Winiwarter, W., Suntharalingam, P., . . . Shi, H. (2020, October). A comprehensive quantification of global nitrous oxide sources and sinks. Nature, 586, 248-256. doi:10.1038/s41586-020-2780-0

Tilahun, A. (1995). Yield Gain and Risk Minimization in Maize (Zea Mays) through Cultivar Mixtures in Semi-arid Zones of the Rift Valley in Ethiopia. Experimental Agriculture, 31(2), 161-168. doi:10.1017/S0014479700025242

Tilman, D., & Clark, M. (2014). Global diets link environmental sustainability and human health. Nature, 515, 518-533. doi:10.1038/nature13959

Toensmeier, E. (2016). The Carbon Farming Solution: A Global Toolkit of Perennial Crops and Regenerative Agriculture Practices for Climate Change Mitigation and Food Security. White River Junction, VT: Chelsea Green Publishing.

Trenberth, K. (1981, June). Seasonal variations in global sea level pressure and the total mass of the atmosphere. JGR Oceans, 86(C6), 5238-5246. Retrieved from https://doi.org/10.1029/JC086iC06p05238

Trivedi, P., Delgado-Baquerizo, M., Trivedi, C., Hamonts, K., Anderson, I., & Singh, B. (2017). Keystone microbial taxa regulate the invasion of a fungal pathogen in agro-ecosystems. Soil Biology and Biochemistry, 111, 10-14. doi:10.1016/j.soilbio.2017.03.013

UNCTAD. (2013). Trade and Environment Review 2013: Wake Up Before It's Too Late: Make Agriculture Truly Sustainable Now for Food Security in a Changing Climate. United Nations, Conference on Trade and Development. Retrieved from https://unctad.org/system/files/official-document/ditcted2012d3_en.pdf

Unger, P. (1978). Straw□mulch Rate Effect on Soil Water Storage and Sorghum Yield. Soil Science Society of America Journal. doi:10.2136/sssaj1978.03615995004200030023x

Unilever. (2020, June 15). Unilever sets out new actions to fight climate change, and protect and regenerate nature, to preserve resources for future generations. Retrieved from Press Releases: https://www.unilever.com/news/press-releases/2020/unilever-sets-out-new-actions-to-fight-climate-change-and-protect-and-regenerate-nature-to-preserve-resources-for-future-generations.html

USDA. (2016). USDA Building Blocks for Climate Smart Agriculture and Forestry. United States Department of Agriculture. Retrieved from https://www.usda.gov/sites/default/files/documents/building-blocks-implementation-plan-progress-report.pdf

van Bruggen, A., & Semenov, A. (2000). In search of biological indicators for soil health and disease suppression. Applied Soil Ecology, 15(1), 13-24. doi:10.1016/S0929-1393(00)00068-8

van Bruggen, A., Semenov, A., van Diepeningen, A., de Vos, O., & Blok, W. (2006). Relation between Soil Health, Wave-like Fluctuations in Microbial Populations, and Soil-borne Plant Disease Management. European Journal of Plant Pathology, 115, 105-122. doi:10.1007/s10658-005-1250-8

van Es, H., & Karlen, D. (2019, May). Reanalysis Validates Soil Health Indicator Sensitivity and Correlation with Long‐term Crop Yields. Soil Science Society of America Journal, 83(3), 721-732. doi:10.2136/sssaj2018.09.0338

Velasquez-Manoff, M. (2018, April 18). Can Dirt Save the Earth? The New York Times. Retrieved from https://www.nytimes.com/2018/04/18/magazine/dirt-save-earth-carbon-farming-climate-change.html

Velthof, G., Lesschen, J., Webb, J., Pietrzak, S., Miatkowski, Z., Pinto, M., . . . Oenema, O. (2014). The impact of the Nitrates Directive on nitrogen emissions from agriculture in the EU-27 during 2007-2008. Science of the Total Environment, 468-469, 1225-1233. doi:10.1016/j.scitotenv.2013.04.058

Vermeulen, S., Campbell, B., & Ingram, J. (2012). Climate Change and Food Systems. Annual Review of Environment and Resources, 37, 195-222. doi:10.1146/annurev-environ-020411-130608

Via, S. (2018). Maryland's Healthy Soils Initiative: Developing a program for sequestering carbon in agricultural soils. University of Maryland. Retrieved from https://www.c-agg.org/wp-content/uploads/C-AGG-talk-Oct-2018-_Via.pdf

Vida, C., Bonilla, N., Vicente, A. d., & Cazorla, F. (2016). Microbial Profiling of a Suppressiveness-Induced Agricultural Soil Amended with Composted Almond Shells. Frontiers in Microbiology, 7(4), 1-14. doi:10.3389/fmicb.2016.00004

Volcovici, V. (2020, June 4). In rare bipartisan bill, U.S. senators tackle climate change via agriculture. Reuters. Retrieved from https://www.reuters.com/article/us-usa-climatechange-agriculture/in-rare-bipartisan-bill-u-s-senators-tackle-climate-change-via-agriculture-idUSKBN23B23J#:~:text=WASHINGTON%20(Reuters)%20%2D%20U.S.%20senators,rare%20collaboration%20on%20climate%20change.

Wallace, A. (1994). Soil organic matter must be restored to near original levels. Communications in Soil Science and Plant Analysis, 25(1-2), 29-35. doi:10.1080/00103629409369000

Wallander, S., & Hand, M. (2011). Measuring the Impact of the Environmental Quality Incentives Program (EQIP) on Irrigation Efficiency and Water Conservation. Proceedings of the 2011 Annual Meeting of the Agricultural & Applied Economics Association, 1-20. doi:10.22004/ag.econ.103269

Walmart. (2020, September 21). Walmart Sets Goal to Become a Regenerative Company. Retrieved from Walmart: https://corporate.walmart.com/newsroom/2020/09/21/walmart-sets-goal-to-become-a-regenerative-company

Walton, B. (2015, October 13). Healthy Soils Reduce Water Pollution. Circle of Blue. Retrieved from https://www.circleofblue.org/2015/world/healthy-soils-ater-pollution/

Wang, D., Guan, D., Zhu, S., MacKinnon, M., Geng, G., Zhang, Q., . . . Davis, S. (2020, December 7). Economic footprint of California wildfires in 2018. Nature Sustainability. doi:10.1038/s41893-020-00646-7

Wang, T., Teague, R., Park, S., & Bevers, S. (2015). GHG Mitigation Potential of Different Grazing Strategies in the United States Southern Great Plains. Sustainability, 7(10), 13500-13521. Retrieved from https://doi.org/10.3390/su71013500

Wang, T., Teague, R., Park, S., & Bevers, S. (2018). Evaluating long-term economic and ecological consequences of continuousand multi-paddock grazing - a modeling approach. Agricultural Systems, 165, 197-207. doi:10.1016/j.agsy.2018.06.012

WBCSD. (2018). The Business Case for Investing in Soil Health. World Business Council for Sustainable Development. Retrieved from https://docs.wbcsd.org/2018/12/The_Business_Case_for_Investing_in_Soil_Health.pdf

Weber, K., & Gokhale, B. (2011). Effect of grazing on soil-water content in semiarid rangelands of southeast Idaho. Journal of Arid Environments, 75(5), 464-470. Retrieved from https://doi.org/10.1016/j.jaridenv.2010.12.009

WEF. (2020). Incentivizing Food Systems Transformation. World Economic Forum in collaboration with McKinsey & Company. Geneva: World Economic Forum. Retrieved from http://www3.weforum.org/docs/WEF_Incentivizing_Food_Systems_Transformation.pdf

Wei, Z., Gu, Y., Friman, V.-P., Kowalchuk, G. A., Xu, Y., Shen, Q., & Jousset, A. (2019). Initial soil microbiome composition and functioning predetermine future plant health. Science Advances, 5(9), eaaw0759. doi:10.1126/sciadv.aaw0759

West, P. C., Gerber, J. S., Engstrom, P. M., Mueller, N. D., Brauman, K. A., Carlson, K. M., . . . Siebert, S. (2014). Leverage points for improving global food security and the environment. Science, 345(6194), 325-328. doi:10.1126/science.1246067

Wetzel, W., Kharouba, H., Robinson, M., Holyoak, M., & Karban, R. (2016). Variability in plant nutrients reduces insect herbivore performance. Nature, 539, 425-427. doi:10.1038/nature20140

Wheeler, T., & von Braun, J. (2013). Climate Change Impacts on Global Food Security. Science, 341(6145), 508-513. doi:10.1126/science.1239402

White Oak Pastures. (2019, May 1). Study: White Oak Pastures Beef Reduces Atmospheric Carbon. PR Newswire. Retrieved from https://www.prnewswire.com/news-releases/study-white-oak-pastures-beef-reduces-atmospheric-carbon-300841416.html

White, P., & Broadley, M. (2005). Historical variation in the mineral composition of edible horticultural products. The Journal of Horticultural Science and Biotechnology, 80(6), 660-667. doi:10.1080/14620316.2005.11511995

Williamson, J. (2011). The Role of Information and Prices in the Nitrogen Fertilizer Management Decision: New Evidence from the Agricultural Resource Management Survey. Journal of Agricultural and Resource Economics, 36(3). doi:10.22004/ag.econ.119180

Wilman, E. (2011). Carbon Sequestration in Agricultural Soils. Journal of Agricultural and Resource Economics, 36(1), 121-138. doi:10.22004/ag.econ.105535

Wyden, R. (2020). S.4850. Retrieved from Ron Wyden, United States Senator for Oregon: https://www.wyden.senate.gov/imo/media/doc/Healthy%20Soils%20Healthy%20Climate%20Act%20of%202020%20Bill%20Text.pdf

Wyden, R. (2020, October 23). Wyden Introduces Legislation to Improve Soil Health, Crop Resilience and Address the Climate Crisis. Retrieved from Ron Wyden, United States Senator for Oregon: https://www.wyden.senate.gov/news/press-releases/wyden-introduces-legislation-to-improve-soil-health-crop-resilience-and-address-the-climate-crisis

Yang, Q., Liu, P., Dong, S., J. Z., & Zhao, B. (2020). Combined application of organic and inorganic fertilizers mitigates ammonia and nitrous oxide emissions in a maize field. Nutrient Cycling in Agroecosystems, 117, 13-27. doi:10.1007/s10705-020-10060-2

Yin, C., Hulbert, S., Schroeder, K., Mavrodi, O., Mavrodi, D., Dhingra, A., . . . Paulitz, T. (2013). Role of Bacterial Communities in the Natural Suppression of Rhizoctonia solani Bare Patch Disease of Wheat (Triticum aestivum L.). Applied and Environmental Microbiology, 79(23), 7428-7438. doi:10.1128/AEM.01610-13

Yoder, K. (2018, October 9). Carbon tax debate: Nobels and IPCC vs. Trump and Doug Ford. Grist. Retrieved from https://grist.org/article/carbon-tax-debate-nobels-and-ipcc-vs-trump-and-doug-ford/

Yu'e, L., Shi, S., Waqas, M. A., Zhou, X., Li, J., Wan, Y., . . . Wilkes, A. (2018). Long-term (≥20 years) application of fertilizers and straw return enhances soil carbon storage: a meta-analysis. Mitigation & Adaptation Strategies for Global Change, 23(4), 603-619. doi:10.1007/s11027-017-9751-2

Zhanga, W.-f., Dou, Z.-x., He, P., Ju, X.-T., Powlson, D., Chadwick, D., . . . Zhang, F.-S. (2013). New technologies reduce greenhouse gas emissions from nitrogenous fertilizers in China. Proceedings of the National Academy of Sciences, 110(21), 8375-8380. doi:10.1073/pnas.1210447110

Zhu, C., Kobayashi, K., Loladze, I., Zhu, J., Jiang, Q., Xu, X., . . . Ziska, L. (2018). 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), eaaq1012. doi:10.1126/sciadv.aaq1012

Zomer, R., Bossio, D., Sommer, R., & Verchot, L. (2017). Global Sequestration Potential of Increased Organic Carbon in Cropland Soils. Nature Scientific Reports, 1-8. doi:10.1038/s41598-017-15794-8