★ U.S. Farmers & Ranchers Alliance® ★

2019

THE POWER OF RESILIENCY IN AGRICULTURE'S ECOSYSTEM SERVICES

U.S. Farmers & Ranchers Alliance
Ecosystem Services Science Advisory Council

CONTENTS

FOREWORD

We are honored to present this first briefing paper from the U.S. Farmers & Ranchers Alliance Ecosystem Services Science Advisory Council. This publication was enabled and supported by U.S. farmers and ranchers and is the result of the collaboration of leading scientific experts within agriculture, business, government, academia, and conservation. We share the latest science and thought leadership on our collective opportunity to harness agricultural ecosystem services to build the sustainable food systems of the future.

In these pages, we present a range of agricultural ecosystem service solutions for greenhouse gas mitigation, improved water quality and supply, and biodiversity, enabled by climate-smart agricultural practices. Further, we outline the opportunity to use new and innovative forms of capital and financing to address the impacts of climate change on our food, fuel and fiber productions systems.

The U.S. Farmers and Ranchers Alliance Ecosystem Services Advisory Council serves as a center and platform for science-based agriculture to inspire collaboration among all stakeholders in the agriculture ecosystem. We believe that, through a multi-stakeholder, cross-sectoral approach, based on the latest, most credible science and innovative thinking on sustainable agriculture practices, we can meet one of the greatest challenges of our era - climate change.

We hope you will join us in these efforts to advance agricultural ecosystem service solutions.

The U.S. Farmers & Ranchers Alliance Ecosystem Services Science Advisory Council

Steven Brock
Council on Strategic Risks

Pipa Elias
The Nature Conservancy

Greg Gershuny
The Aspen Institute

Dr. Nicholas Goeser
U.S. Farmers & Ranchers Alliance

Dr. Jerry Hatfield
USDA-ARS

Dr. Brett Kaysen
National Pork Board

Dr. Marty Matlock
University of Arkansas

Dr. Frank Mitloehner
University of California - Davis

Dr. John Newton
American Farm Bureau Federation

Dr. Dan Northrup
Benson Hill Biosystems

Dr. LaKisha Odom
Foundation for Food and Agriculture Research

Dr. John Reily
Massachusetts Institute of Technology

Dr. Chuck Rice
Kansas State University

Dr. Mickey Rubin
Egg Nutrition Center

Dr. Alain Vidal
World Business Council for Sustainable Development

Dr. Ying Wang
Innovation Center for U.S. Dairy

Full biographies are included in the Appendix

EXECUTIVE SUMMARY

By 2050, the global population is expected to reach 9.8 billion,[1] requiring a 70 percent increase in food production,[2] in a business-as-usual (BAU) scenario. The U.S. population is expected to cross the 400-million threshold in 2058.[3] At the same time, climate change poses serious risks for agriculture and food systems.[4] Despite these challenges, we see huge potential to set a path for achieving sustainable future food systems and to build momentum for action across all sectors of society.

Agriculture has unique capability to **spur innovation** and provide climate-smart solutions and vital ecosystem services. The U.S. Farmers & Ranchers Alliance identifies **agriculture as a solution for ecosystem services** as one of five pathways towards creating the sustainable food systems of the future.[5]

Another important pathway is the potential for **mitigation and adaptation** to natural resource constraints while improving production efficiencies for yield and quality, including nutrient content, food safety, environmental outcomes, resistance to pestilence and climate shocks.

Other pathways include **collaboration with farmers** across the food value chain to enhance shared solutions and further research on sustainable food systems; **nourishing the global population** by meeting the nutritional needs of a diverse and growing population; and **recognizing food as a natural resource, with distinct economic and socio-cultural dimensions**, and working to reduce food waste and loss across the value chain.

Agriculture as a solution for ecosystem services and mitigation and adaptation are at the heart of this paper, which **sets out a path forward** to:

- Reap the full potential of **agricultural contributions to ecosystem service solutions** including soil carbon sequestration, water quality, and biodiversity through climate-smart practices.
- Provide context on how creativity and advanced knowledge of agricultural business dynamics can **drive greater innovation, enterprise risk mitigation and supply chain resiliency** in U.S. food production systems.
- Improve understanding of **investment opportunities through realized agricultural ecosystem service co-benefits** and identify research and programming gaps.

Most starkly, credible data shows the significant potential of agriculture to address climate change through carbon sequestration. With technology available today, we are on a trajectory to reduce agricultural greenhouse gas (GHG) emissions by 50 percent. Harnessing further innovation and investment, the sector's emissions become net-negative, up to 147 percent. These estimates are very conservative and pulled from expert reports from the UN Intergovernmental Panel on Climate Change (IPCC), the U.S. Environmental Protection Agency (EPA), the National Academies of Science, Engineering and Medicine (NASEEM) and others. These reports and estimates do not fully account for food waste emissions reductions and the positive contributions from animal agriculture towards moving the sector to net-negative carbon emissions. One-third of food produced worldwide gets lost or wasted, so addressing this issue represents another critical pathway to altering the BAU scenario.

The solutions offered by agricultural ecosystems offer an unprecedented opportunity to deliver environmental, social and economic benefits across society and the economy. By stepping up our investment in more sustainable, climate-resilient agriculture, we better secure our future, and those of next generations, to confront our global challenges.

INTRODUCTION

Today's world increasingly requires that our food systems adapt to meet the demands of a growing population, the urgency of climate change and the importance of environmental conservation in the face of a range of planetary pressures. Consumers are also making more demands on the sustainability of the food they purchase and transparency around the food supply chain.

The U.S. food and agriculture sector contributes more than $2.8 trillion of economic impact, directly employs more than 22 million people (about 15 percent of U.S. employment)[6] and represents about 10 percent of consumer spending.[7]

There are 3 million farmers in the U.S. today, representing less than 2 percent of the population.[8] But farmers manage 45.5 percent of U.S. land area[9] and update their technology each year through genetic improvements, feed efficiencies and other measures.

As stewards of the land, they are responsible not only for primary food production but also for maintaining and enhancing the goods and services derived from natural ecosystems, such as water cycling, carbon sequestration and pollination. It is this dual role that we examine in this paper and the unprecedented opportunity for innovation, investment and science-based solutions to tackle some of the greatest challenges of the 21st century.

> $2.8 trillion of economic impact is contributed by the U.S. food and agriculture sector annually.
>
> – U.S. Department of Agriculture

> 45.5 percent of all the land in the continental U.S. is in farming and ranching.
>
> – American Farmland Trust

Recognizing the challenges

Finding a balance between the risks and opportunities to agricultural resiliency under climate change means recognizing the realities for farmers and ranchers in the U.S. today. Agricultural land is vanishing at an alarming rate as it is converted to other forms of development: 175 acres an hour, or 3 acres every single minute, according to the American Farmland Trust.[10]

Housing a growing population while losing land to a changing climate will likely accelerate this rate of loss, and farmers and ranchers will have to produce more food, fiber and energy on the agricultural lands that remain. Even as farmers and ranchers work to reduce greenhouse gas (GHG) emissions, the effects of climate change are already being felt, creating unpredictability, disruption, and destruction. Increases in average temperature, extreme heat conditions, heavy rainfall, droughts and extreme weather events contribute to excessive runoff, flooding, and soil erosion, loss of soil carbon and reduce the availability and quality of water.[11]

There are economic challenges, too. Farmers are currently under tremendous real estate and non-real estate debt. Current farm debt for land, machinery, seed, calves and other farm and ranch costs is at the highest point since 1980. (See Figure 1). Much of the nonreal estate debt carried to maintain the farm business operations is carried under short term (<3 year) loans. Farm debt often carries personal guarantees that extend beyond business assets to include personal assets such as farmers' or ranchers' homes, bank accounts, and vehicles.

In addition, while food prices have increased, economic benefits to farmers have not increased at the same rate. According to the UN Food and Agriculture Organization (FAO), food prices have increased five fold over the last 30 years. Prices paid to farmers have also changed over the last 30 years – but much often less than half.[12] Further, the prices farmers are paying for inputs to produce food have increased substantially over the same period of time; [13][14] inflation adjusted prices for crops were up more than 38 percent above their 2005 levels.

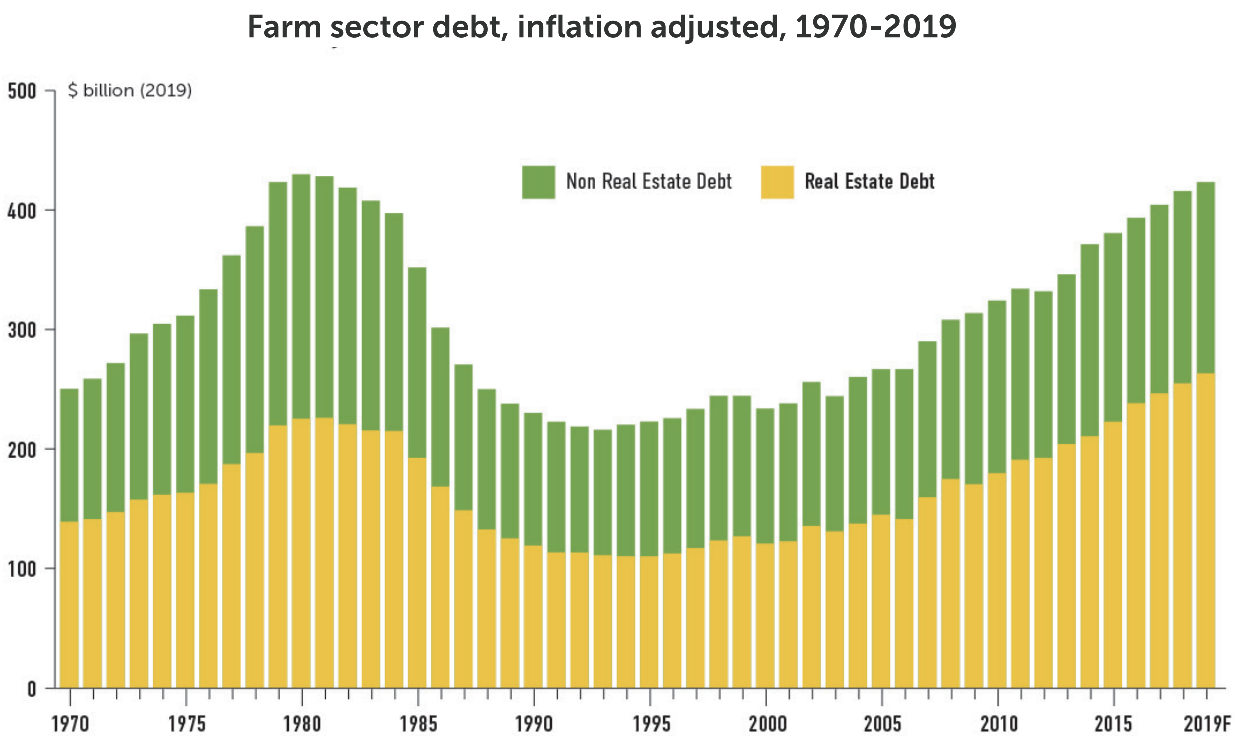

Figure 1

Note: F = forecast; data for 2018 and 2019 are forecasts. Values are adjusted for inflation using the chain-type GDP deflator. 2019=100.
Source: USDA, Economic Research Service, Farm Income and Wealth Statistics. Data as of March 6, 2019. https://www.ers.usda.gov/topics/farm-economy/farmsector-income-finances/assets-debt-and-wealth/

The discrepancy in price increases for food and commodities, coupled with increased inputs required to grow food, means farmers are receiving a smaller share of every dollar spent on food but paying more to produce it. Farmers and ranchers get 7.8 cents out of every dollar, one of the lowest numbers since USDA began keeping track in 1993. The rest of the dollar — 92.2 cents — covers off-farm costs, including processing, wholesaling, distribution, marketing, and retailing.

Advancing the solution

Despite these challenges, the data and science-based solutions presented here demonstrate that farmers and ranchers have untapped potential to bank carbon in soils, improve water quality and quantity, and support biodiversity. By investing in the resiliency of farmers to advance sustainable agriculture and maximize agricultural ecosystem service solutions, farmers, businesses and society safeguard national food security while reversing climate change.

The carbon drawdown opportunity is especially striking: climate-smart practices, if widely deployed in the U.S. and globally, could "materially increase carbon storage," according to the National Academy of Sciences, Engineering and Medicine (NASEM), reducing the sector's GHG emissions by 46 percent, or, with more frontier technologies, as much as 147 percent.

The estimates provided here and throughout this paper are very conservative and represent the best available figures from sources such as the National Academies of Science, Engineering and Medicine, U.S. EPA, United Nations Intergovernmental Panel on Climate Change – and do not account for food waste emissions reductions and many of the positive contributions from animal agriculture (such as extracting nitrogen, phosphorus and soil amendments through manure fractionation and feed ingredient efficiency gains) towards moving the sector to net-negative carbon emissions. Further, the integration of row crop and livestock agriculture provides enhanced carbon and nitrogen cycling benefits for plants, animals and humans.

> For each dollar spent by American consumers on food, farmers get 7.8 cents, one of the lowest numbers since USDA began keeping track in 1993.
>
> – U.S. Department of Agriculture
> Economic Research Service

Climate smart land management systems are rapidly increasing. These systems include advancements in crop protection, soil health, harvesting techniques, integrated pest management, animal care, diet and nutrition, machinery and housing, data sensing and internet connectivity. They focus on using inputs efficiently, improving resiliency for inevitable climate shocks, and strengthening outcomes to both food production and ecosystems services.

A smart investment

There is a strong economic case for investing in climate-smart agriculture practices. The economic benefits accrue not only to farmers but also to others in the food value chain, such as food retailers and processors, as well as other industries, the financial sector, the economy and society as a whole. This is particularly true for the economic value in maintaining healthy soil, not least for its critical role as a natural carbon sink. As the World Business Council for Sustainable Development argues in its report, "The Business Case for Investing in Soil Health," soils underpin value chains by supporting crop productivity, biodiversity and livelihoods, and address two top business risks: water crises and climate change.[17]

Investments in soil, for instance, deliver multiple co-benefits such as water quality, carbon sequestration, biodiversity, economic resilience, job growth and food. For example, increasing soil carbon sequestration increases soil organic matter which can enhance infiltration, support biodiversity, and increase crop productivity and climate resilience, resulting in benefits for farmer livelihoods. Crop productivity and improved resiliency are co-benefits to all investors. In fact, data show that the average return on investment across agricultural value chains from 2010 to 2014 ranged from 7 to 28 percent[18] (See Figure 2).

Profitability and growth rate across value chain, crops and geography

Figure 2

Growth rate and value can differ significantly by the role in the value chain, crop and geography.
Source: FAOStat; McKinsey analysis

Current soil stocks in the U.S. store as much carbon as about 123.2 billion cars driven for a year, nearly equivalent to the current cars to be driven in America for the next 150 years.[16] Climate-smart systems could reduce the agricultural sector's GHG emissions between 46 percent and 147 percent.

- "Second State of the Carbon Cycle Report (SOCCR2): A Sustained Assessment Report"

The Nature Conservancy, in its report, "reThink Soil," estimates that for each one percent of cropland in the U.S. that adopt an adaptive soil health system, annual economic benefits translate into $226 million of societal value through increased water capacity, reduced erosion and nutrient loss to the environment, and reduced GHG emissions, as well as $37 million of on-farm value through greater productivity. In the most optimistic case, it estimates soil health solutions could address up to $50 billion in social and environmental impacts annually across the U.S.[19]

Supporting farmers to adopt climate-smart agricultural practices, through shared risk, financial incentives or innovative partnerships has many positive knock-on effects to the economy, food systems and the changing climate. There is a need to improve and scale mechanisms that provide recognition and financial incentives for strong environmental stewardship by farmers and ranchers. The stakes are higher than ever and demand collaboration and partnership across all industries that results in lasting environmental, social, and economic sustainability solutions.

> For each one percent of cropland in the U.S. that adopt an adaptive soil health system, annual economic benefits translate into $226 million of societal value.
>
> – The Nature Conservancy

NEXT STEPS

Businesses and lenders need to drive more creative financing and incentives through collaborations and partnerships with business to help achieve new and innovative market models.

Partner with food processors, brands and retailers to invest in research that can illuminate food system security gaps.

AGRICULTURAL ECOSYSTEM SERVICE SOLUTIONS

Farmers, ranchers and others in the agriculture and food system have a shared responsibility for stewardship: to provide for the current population while also preserving and enhancing the land for the next generation. This chapter will look at ecosystem services, those goods and services derived from natural ecosystems, such as water cycling, carbon sequestration and pollination, and how climate-smart agricultural practices are essential to good stewardship of those services.

The same climate-smart agricultural systems, as we explore in the next section, "Sustaining the Land," bring multiple co-benefits: from improved soil health for carbon storage to reduced water consumption to enhanced biodiversity, while also benefitting farmers economically through increased crop productivity. Innovation deployed in enhancing ecosystem services supports new profit centers and strengthens risk mitigation strategies for supply chain resiliency.

Ecosystem services are often categorized in four distinct ways:

1. **Provisioning services:** the material or energy outputs from an ecosystem, including food, forage, fiber, fresh water and other resources
2. **Regulating services:** benefits obtained through moderation or control of ecosystem processes, including regulation of local climate, air, or soil quality; carbon sequestration; flood, erosion, or disease control; and pollination
3. **Supporting services:** services that maintain fundamental ecosystem processes, such as habitat for plants and wildlife, or the maintenance of genetic and biological diversity
4. **Cultural services:** non-material benefits including opportunities for recreation, tourism, aesthetic or artistic appreciation, and spirituality[20]

The right solutions, and their ability to scale, depend on many factors, such as sourcing regions, transportation pathways, geographic markets as well as soil type, precipitation, and novel support structures. Every farm exists in a unique environmental system and needs unique solutions to achieve shared goals.

NEXT STEPS

Improve the overall understanding of economic, environmental and social investment opportunities and determine how that helps agricultural supply chains drive toward improved outcomes.

Enhance and build programs that will help farmers develop more resilient and adaptive approaches to manage their lands.

Agricultural supply chains need to deploy cross-sector reputational, financial, physical and other risk management models across agricultural supply chains.

SUSTAINING THE LAND

U.S. agricultural land supports a regionally diverse food and farming system. Of the 2.3 billion acres of total land in the U.S., 28.5 percent is rangeland and 17 percent is cropland (total of 45.5 percent of U.S. land).[9] Land use differs throughout the country. The Lake States, Corn Belt and Northern Plains have the greatest percentage of crop land while grassland pasture and rangeland dominate the Southern Plains and Mountain regions.

Practices that sustain the land are important to enterprise risk management processes and to increase supply chain resiliency. But as discussed earlier, farmers and ranchers face enormous challenges. One of the biggest challenge is retaining the land upon which they—and the country—depend for their food supply. The U.S. converted almost 31 million acres of agricultural land between 1992 and 2012, equivalent to the land mass of New York State, according to the American Farmland Trust. More than 70 percent of urban development and 62 percent of all development took place on prime, highly-productive agricultural land.[10]

Major uses of land in the United States, 2012

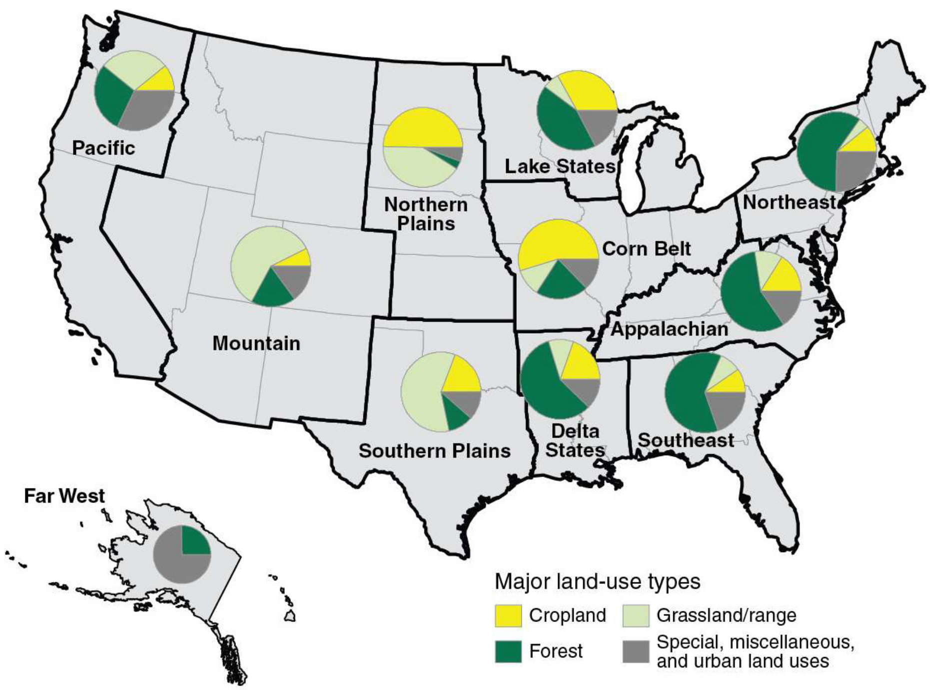

Figure 3

Of the 2.3 billion acres of total land in the U.S., 28.5 percent is rangeland and 17 percent is cropland (total of 45.5 percent of U.S. land). Land use differs throughout the country. The Lake States, Corn Belt and Northern Plains have the greatest percentage of crop land while grassland pasture and rangeland dominate the Southern Plains and Mountain regions.
Source: USDA Economic Research Service. (2012)

Of the 2.3 billion acres of total land in the U.S., 28.5 percent is rangeland and 17 percent is cropland.

We lose 175 acres of farmland every hour, mostly to urban encroachment.

– American Farmland Trust

The country is losing prime agricultural production land at a time when a growing population and climate change impacts require farmers to be more efficient and sustainable than ever. In less than one generation, the U.S. irreversibly lost nearly 11 million acres of the best land for food and crop production.[10] As that farmland disappears, precious ecosystem services that enable carbon sequestration are also lost, among other benefits.

That puts pressure on farmers and ranchers to not only use existing land more efficiently but also to protect valuable ecosystem services. A vital aspect of maintaining existing agricultural land for ecosystem services is protecting the soil, not least for its ability to store carbon, explored in the next section.

Deploying climate-smart practices

Throughout this paper, we use the term climate-smart to describe technologies and practices that transform agricultural systems to support food security under the new realities of climate change.[21] Climate-smart agriculture (CSA) is an approach that helps to guide actions needed to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate.[22]

Opportunity Matrix for Agribusiness Investment

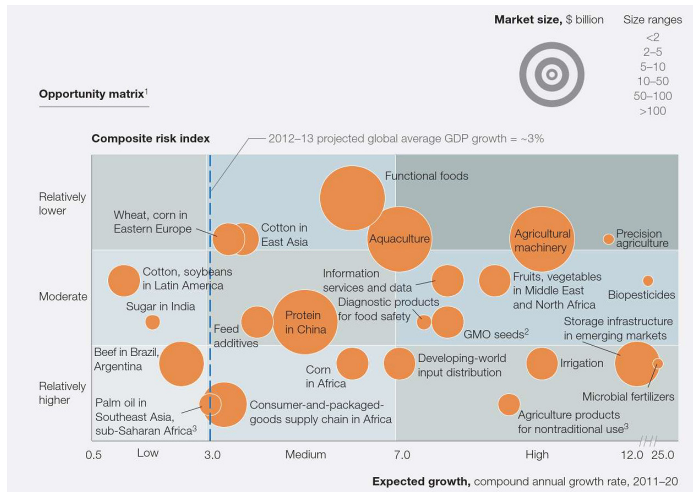

Figure 4

24 hotspots where agribusiness investment is likely to focus in from 2011-2020.
Source: Ag2020: Growth and investment opportunities in food and agribusiness, a joint report from McKinsey and Paine + Partners, 2013

There are many ways to reduce soil erosion and protect other ecosystem services through use of a wide variety of climate-smart practices (see p. 10). Sustainable agricultural technologies (e.g. precision agriculture, biopesticides, microbial fertilizers) are projected to have high growth and low risk (see Figure 4). These practices are already being put to use, as illustrated by the Soil Health Partnership. These practices are also known as climate smart agricultural practices and have been recently termed “regenerative agriculture practices” (referring to the regeneration of renewable resources essential to achieving a more sustainable form of agriculture).[23] Precision agriculture is another strategy, which employs detailed, site-specific information to precisely manage production inputs,[23] business cost allocation, and environmental services.

Flexibility in using individual practices as part of systems provides farmers and ranchers the ability to innovate to manage their crops and livestock to meet constantly changing weather, market, and industry demands.

Climate-smart farming systems:

Climate-smart agriculture (CSA) is an approach that helps to guide actions needed to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate.[22]

The following climate-smart practices[24] are increasingly being implemented across the U.S. today:

- **No-tillage:** planting crops without disrupting the soil surface
- **Conservation tillage** (e.g. strip-till or vertical tillage): reduced disturbance of the soil surface
- **Cover crops:** crops planted after a main crop like corn or soybeans are harvested to grow through winter – examples are rye, radishes, wheat.
- **Variable rate fertilizer application technology:** changing the source of nitrogen, slow-release nitrogen products, changing placement and using nitrogen inhibitors together.
- **Land-based animal manure applications** for fertilizers and to improve soil health, carbon sequestration and nutrient cycling.[25]
- **Split applications of nitrogen:** nitrogen is applied in several doses when the crop is actively growing.
- **Rotational grazing:** grazing is managed to meet livestock needs and pasture resources, contributing to carbon sequestration.
- **Manure fractionation:** livestock farmers using manure processing technologies to create high-quality soil products.

Soil Health Partnership

The Soil Health Partnership, a farmer-led initiative of the National Corn Growers Association, engages with and offers technical assistance to farmers at a local level, providing trained field managers and agronomists to help them test practices that can improve soil health for environmental, economic and production resiliency. Over 140 farmers in 14 states conduct research on cover cropping, nutrient management and conservation tillage.[26]

The Soil Health Partnership is a unique example of a farmer-led consortium approach that was launched and draws support from a diversity of organizations across grower, industry, foundation, academic, governmental sectors.

The land's ability to provide ecosystem services is largely a matter of how it is managed to retain higher production, versatility and resiliency values. This depends on the same factors that determine potential productivity, such as topography, relatively static soil properties and climate[10 27] and the integration of animals and crops on farmland. Higher levels of management are necessary to prevent deterioration when soils are cultivated on less productive acres.[28]

Over the last two decades, improved management practices have made it possible for producers to reduce soil erosion on cropland by 44 percent[29] but nutrient losses and GHG emissions for agriculture still must drop dramatically to restore and maintain clean water and stabilize the climate by 2050.[30] This may require a significant increase in the use of conservation practices on about 20 percent of U.S. cropland and additional conservation practices on about 46 percent to prevent the continuing losses of soil and nutrients.[31]

> Non-operating landowners control 41 percent of U.S. farmland and 62 percent of Midwest farmland. Approximately 70 percent of rented farmland acres in the Midwest is on a cash-rent basis, often for annual leases.
>
> – The Nature Conservancy

Conservation incentives for rented farmland

When farmers do not own the land they cultivate, barriers to investment in climate-smart systems can arise. The high number of farmers who do not own their own land contributes to these barriers.[32] Annual leases, even if renewed over multiple years, provide no assurance to a farmer implementing soil health practices that the same farmer will have access to the land when the expected benefits of reduced input costs and improved yields might be realized.

As the next section explores, a missed opportunity to deliver improved soil health has significant implications not only for the farmer but for climate mitigation and adaptation.

NEXT STEPS

Greatly expand climate-smart land management systems to help maintain or improve soil quality and minimize environmental impacts.

Build public-private partnerships in support of soil health that bring together stakeholders across farming, industry, academia, government and environmental organizations.

BANKING THE CARBON

Agriculture currently produces 8.4 percent of U.S. agricultural emissions and represents an opportunity to sequester carbon to turn the sector carbon sequestration positive, which we explore in the section, Mitigation and Adaptation. The potential exists to bank more carbon than is emitted each year. Agricultural carbon banking comes from inputs such as crop plant photosynthesis (productivity), crop residues, animal manure incorporation, no-till farming and cover crops.

Agricultural greenhouse gases

The primary greenhouse gases (GHGs) across both crop and animal agricultural systems are methane (CH_4), nitrous oxide (N_2O), and carbon dioxide CO_2, with more GHGs coming from livestock production than from crop production.[33]

These emissions come primarily from:

- Enteric fermentation (i.e., during digestion) in domestic livestock and livestock manure management
- Agricultural soil management
- Soil liming, nitrogen (urea) fertilizer[33,34]

CO_2 emissions from U.S. agricultural activities increased by more than 26 percent and CH_4 emissions by almost 16 percent between 1990 and 2016, while N_2O emissions fluctuated from year to year but increased by more than 14 percent overall.[33]

Currently, global soils store three to four times the amount of carbon in the atmosphere.[36] In the U.S., soil is currently storing a significant amount of carbon (154 petagrams of C to 1-meter depth).

U.S. CO_2 Eq. emissions by sector, soil carbon stocks and agricultural CO_2 Eq. cycles

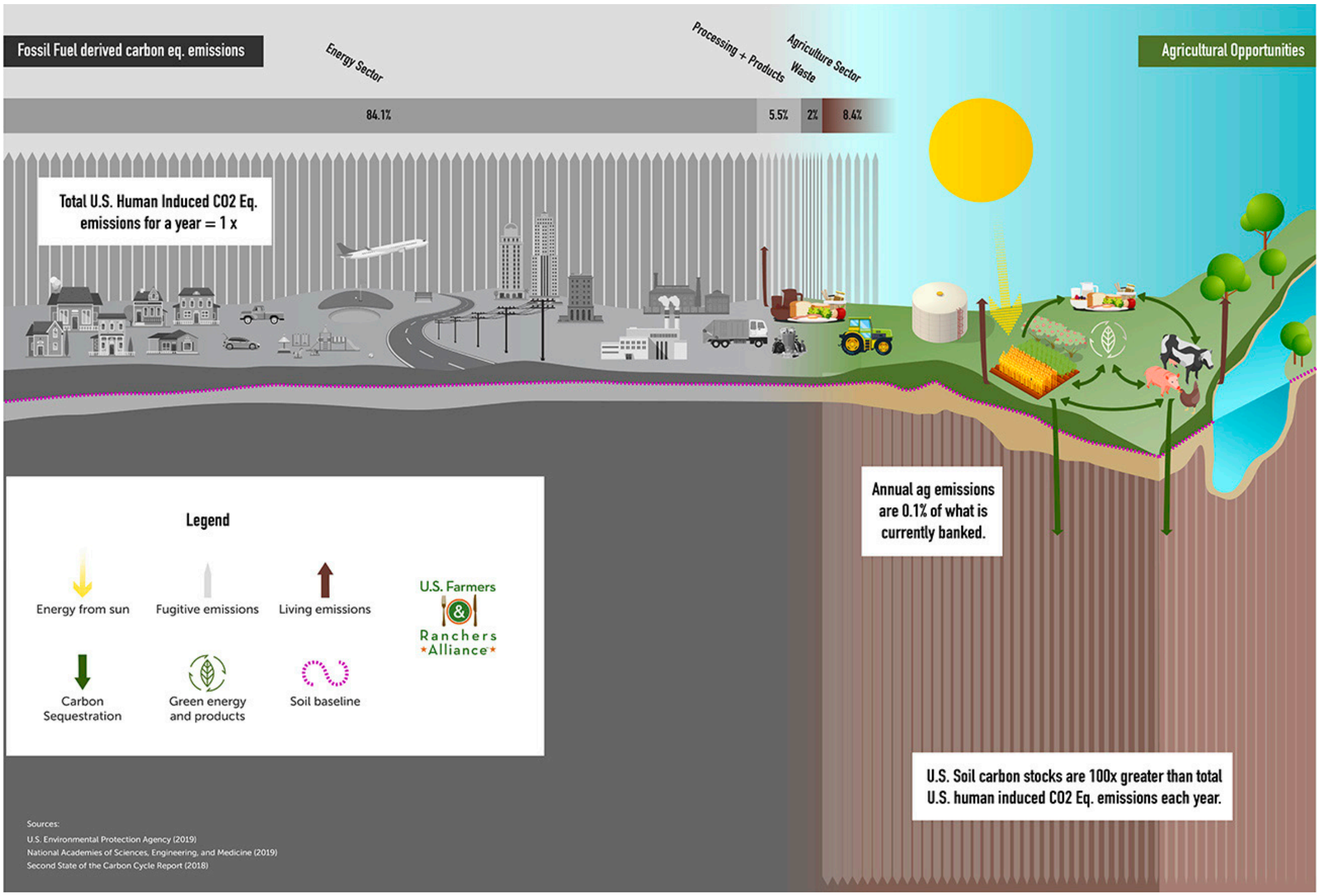

Figure 5

Current U.S. emissions is 6.54 Gigatons CO_2 Eq. or 1.77 Gigatons C. We are currently storing in our soils 154 Gigatons C. This is just under 100 times as much carbon stored in our soil than total U.S. emissions for a year.

Total U.S. CO2 Eq. emissions can by sectors. The energy sector emits 84 percent of total U.S. CO2 Eq. emissions. Within the energy sector, approximately 30 percent is transportation, 30 percent is housing and recreation, and 40 percent is energy used to make goods. Processing and products represent 5.5 percent of total U.S. CO2 Eq. emissions that have been derived from fossil fuels (e.g. plastics), 2 percent is a result of the waste sector, these emissions are primarily from food waste and lawn that generates methane gas.

The agriculture sector represents 8.4 of total U.S. CO2 Eq. emissions. Agriculture CO2 Eq. emissions come from areas including soil management, growing of crops, energy conversion in feeding animals, nitrous oxide from fertilizer, rice patties, and manure.

Agriculture also cycles carbon and represents opportunities for greater sequestration through climate smart systems. Climate smart agricultural systems provide farmers innovation pathways and can include practices such as cover crops, no-till, manure fractionation, feed additives for conversion efficiency amongst many others.

Source: U.S. Environmental Protection Agency. (2019). Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2016.
National Academies of Sciences, Engineering, and Medicine. (2019). Negative Emissions Technologies and Reliable Sequestration: A Research Agenda. Second State of the Carbon Cycle Report. (2018)

The opportunity beneath our feet

Soil includes living carbon in the form of fungi, microbes, legumes and grasses. Actions that convert atmospheric carbon to forms that enhance soil nutrition is considered carbon positive.[35] Through climate smart agricultural systems, farmers and ranchers can enhance the uptake of carbon during the growing process and retain it—sometimes for years or decades—after the harvest.

Because of soil's carbon cycling properties, growing scientific literature shows that agriculture has the potential to offset its own GHG emissions and become a net carbon sink. In fact, soils represent the largest carbon sink in land-based systems (see figure 5).

Looking towards the future, the potential becomes even more striking. The estimated 392 million acres of U.S. cropland represents an increase to the soil carbon sink of 270-800 million metric tons CO_2 Eq. per year over the next 30 years.[37 38]

Rangeland and pastureland (655 million acres) also present substantial carbon sequestration potential.[41 42 43]

At a rate of 270 million metric tons CO_2 Eq. per year, U.S. cropland's potential as a soil carbon sink is equivalent to the same amount of greenhouse gases avoided by 57,216 windmills, similar to the number of windmills across the U.S. in 2018.[39 40]

– U.S. Environmental Protection Agency and Diffendorfer et al., 2015

The value of healthy soil

Under future scenarios, anticipated climate shocks could increase loss of soil carbon due to episodic and extreme events. Given their importance to global sustainable development, soils are explicitly mentioned in four of the UN Sustainable Development Goals targets.[17] An initiative gaining global attention is the "4 per 1000" project, launched at COP21 in Paris in 2015, which states that if soil carbon was increased worldwide by 0.4 percent (or 4 parts per thousand) annually, it would stop the increase in atmospheric carbon.[44]

Soil managed for agricultural purposes in the U.S. has degraded, losing as much as 60 percent of its original organic carbon content[45] and we have lost much of the topsoil.[46 47] However, we have been able to start to reverse that loss through cover-cropping, animal manure applications, conservation tillage and precision management applications.

Much of this will depend on the implementation of climate-smart soil health systems. As Figure 6 shows, each of these systems contributes to a significant reduction in CO_2 Eq. per acre per year. For example, no-tillage applied to a potential 232 million acres, could reduce 1.49 tons of CO_2 Eq. per acre per year. Banking carbon in agricultural soils does not require major changes to how we use land (e.g. conversion of farmland to sub-urban developments) and is largely driven by operations across farm and ranch enterprises.[38]

Estimated sheet and rill erosion rates on cropland 1982-2012 (tons per acre per year)

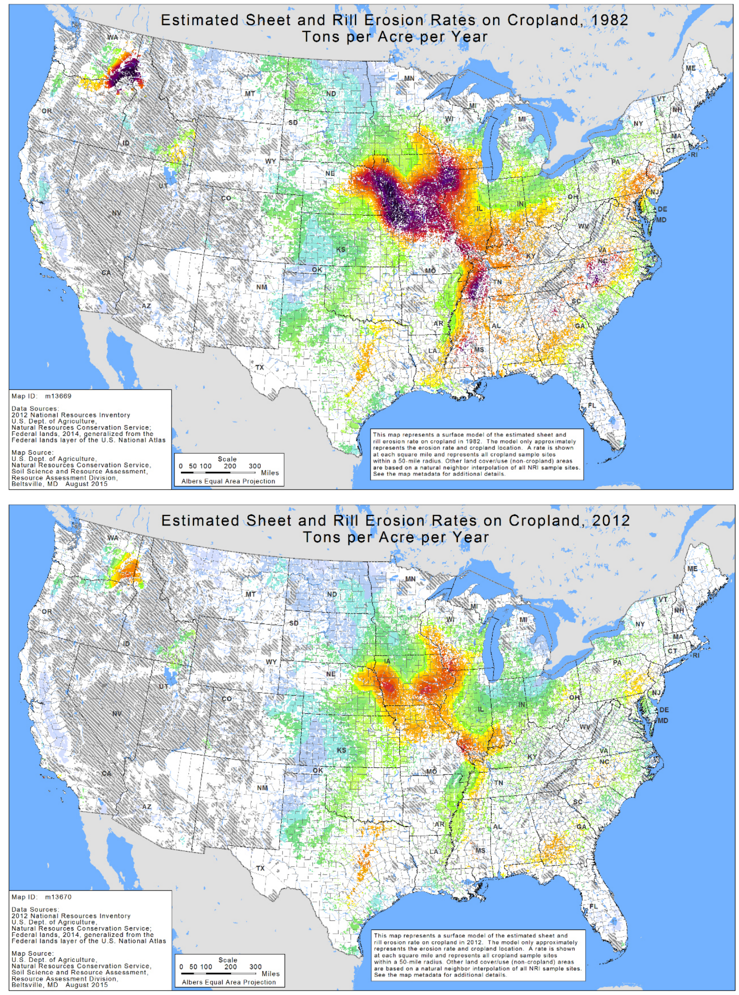

Figure 6

Soil erosion on cropland has decreased 44 percent from 1982 to 2012. This decrease in erosion has been due to several factors including greater use of no-till and conservation tillage and cover crops.
Source: U.S. Department of Agriculture Natural Resources Conservation Service (2015). Summary Report: 2012 National Resources Inventory.

Banking soil carbon through soil health improving practices can provide stacked benefits to water quality, biodiversity, economic resiliency. These co-benefits are gained through improvements in water infiltration and availability, soil nutrient cycling, soil structure, and reduced erosion.[38 48 49]

Valuing ecosystems

Through greater innovation, risk management and recognition of the multiple co-benefits of climate-smart agricultural practices, it is possible to address barriers to adopting soil health practices, such as farmers' initial costs and capital investments, which can be considerable.

Mitigation potential of agricultural management practices

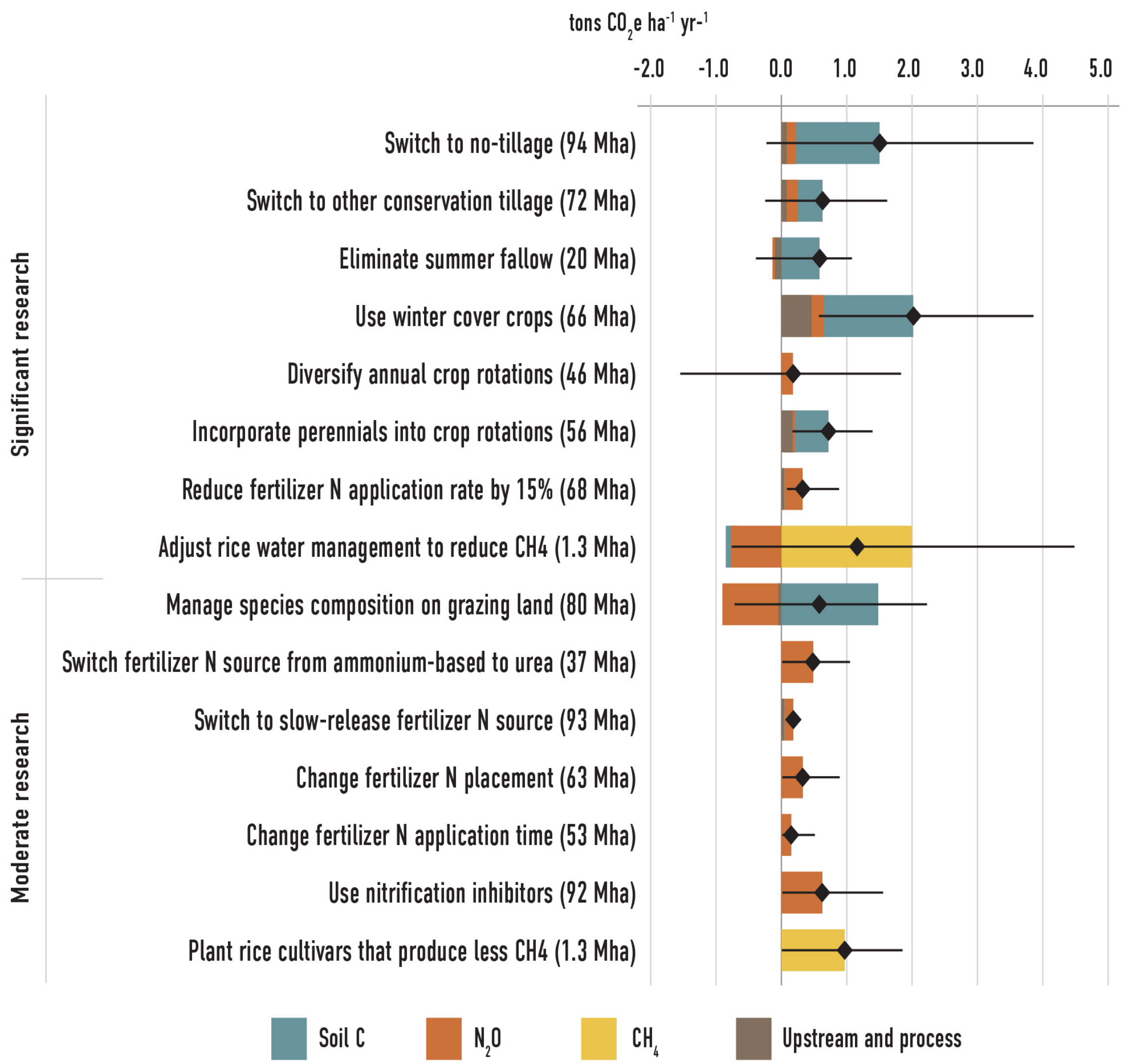

Figure 7

Mitigation potential in terms of net greenhouse gases per hectare per year for practices that (1) do not result in land use changes or significant crop mixture changes; (2) are backed by significant research, about which scientific certainty is moderate to high; and (3) are likely to result in a net GHG reduction.
Source: Olander and Eagle (2011) Greenhouse gas mitigation opportunities for agricultural land management in the United States.

Private sector investment models are increasingly shifting towards more sustainable production practices and there is growing interest in ecosystem services markets.

Ecosystem services markets have grown from just a few in the mid-1980s to more than 2,400 in 2015, with most emerging east of the Mississippi and on the West Coast.[50] These markets can deliver substantial funding for conservation activity; transactions in watershed markets, for instance, have generated tens or hundreds of millions of dollars in several states since their inception. Their success is already seen in places like Oregon and Maryland.[51]

These trends can be further promoted by providing the right economic and other value-based incentives to agricultural producers and consumers by means of market-based economic instruments (e.g. taxes, permits, reputational enhancements, regulatory support, payments for ecosystem services, etc.).[52 53]

One such example is crop insurance, which has sometimes penalized carbon-sequestering climate smart agricultural system, but could be a tool to empower farmers. The AGree Conservation and Crop Insurance Task Force, for instance, aims to lay the groundwork for greater conservation practices in the U.S. while maintaining a viable federal crop insurance program.[54]

While the science of soil health is still evolving and more research is needed, evidence of its potential as a carbon sink is clear as a strong societal investment in meeting climate commitments that yield benefits across society.

NEXT STEPS

Build the systems to provide economic, reputational or other incentives for investment in soil health and carbon sequestration and the means to use them.

Support voluntary carbon markets for climate smart agricultural systems, agro-forestry, land management and other measures.[54]

WATER WISE AND WEATHER RESILIENT

Freshwater makes up just a small fraction of all the water on the planet and 2/3 of this freshwater is captured in glaciers and polar ice. That remaining 1 percent of freshwater must be shared for drinking, growing plants, raising livestock, recreation and other uses.[55]

Agriculture is highly dependent on water and has a responsibility to protect this vital resource. Agricultural land receive much of the precipitation in the United States and accounts for 80 to 90 percent of the nation's consumptive water use, including both ground and surface water use in the U.S., and farmers and ranchers are committed to using water wisely.[9 56] Agriculture provides ecosystem services for water in the form of water infiltration and other services. But it also has a responsibility to adopt practices that conserve water and maintain water quality including the use of fertilizers such as nitrogen.

Climate change and extreme weather events underscore the need for resiliency to protect water quality and quantity. A changing climate has already caused shifts in food and fiber production and is intensifying competition for land with available water.[10]

Smart water practices

Total water use across agricultural production systems has remained relatively consistent from 1984 to 2013. Over the same time, farmers have changed irrigation practices to grow more crops with the same amount of water. Farmers have switched from flood irrigation (flooding fields) to use more efficient sprinklers and hoses to drip water onto growing crops.[57]

As shown in Figure 8, total irrigated water use in[17] Western U.S. states has remained constant from 1984 to 2013. The type of irrigation has changed to improve water use efficiency – toward more use of low-pressure sprinkler and drip irrigation.

Irrigated acres and applied water use, 17 western states, 1984-2013

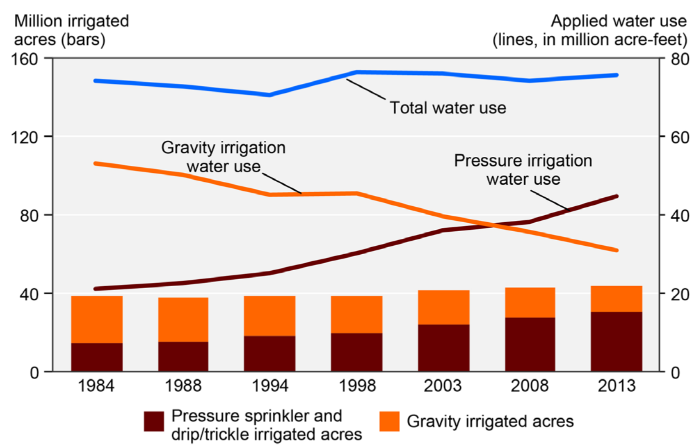

Figure 8

Total water use across agricultural production systems has remained relatively consistent from 1984 to 2013. Over the same time, farmers have changed irrigation practices to grow more crops with the same amount of water. Farmers have switched from flood irrigation (flooding fields) to use more efficient sprinklers and hoses to drip water onto growing crops.
Source: U.S. Department of Agriculture Economic Research Service. (2019). Irrigation & Water Use.

Managing nutrients for better water quality

Water flow, sediment, nitrogen and phosphorus are all important in understanding water quality. This means the amount of water in the rain, moving through the soil and in the lakes and streams is important. Similarly, the amount of nitrogen, sediment or phosphorus in that moving water is also critical in assessing the quality of water and opportunities for improvement. While nitrogen and phosphorus are essential nutrients for growing plants, animals and people, they also move within ecosystems (soil and water) and can cause problems such as algal blooms. Heavy rains bring more water than the plants and soil can handle.

The amount of nitrogen applied to a crop and the time of applications have an impact on N_2O emissions, water quality, crop yields and farmer economic profitability. Nitrogen application rates have been relatively flat or declining for much of the U.S. Potash, phosphate, and nitrogen use in the United States for agriculture has remained approximately the same since 1980 (see Figure 9).

However, some nitrogen is still applied in the fall due to weather and labor constraints in preparing for planting of crops in the spring, posing challenges.

Commercial fertilizer in the U.S., 1960-2014

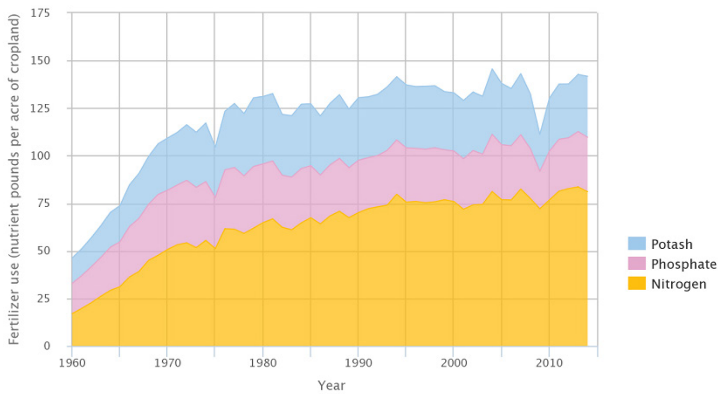

Figure 9

Nitrogen application rates have been relatively flat or declining for much of the U.S. Potash, phosphate, and nitrogen use in the United States for agriculture has remained approximately the same since 1980.
Source: U.S. Department of Agriculture Economic Research Service. (2019) Fertilizer Use and Price.

Middle Cedar Partnership Project

Cities and farmers can work together to reduce the potential for flooding in cities, made more severe by rising temperatures. The city of Cedar Rapids, Iowa, has partnered with farmers upstream to form the Middle Cedar Partnership Project in the Middle Cedar watershed to use cover crops, nutrient management, wetlands and saturated buffers to improve water quality, water quantity (reducing flooding risk) and soil health. This type of project could be further utilized to bring cities and farmers closer together and bring solutions to climate change.

The Midwest and Delta regions contribute significantly to nitrogen and phosphorus loading into the Gulf of Mexico.[58] Climate-smart practices can help address this problem. Farmers have changed the type of nitrogen fertilizer and reduced energy use from 1960 to 2015 by close to 50 percent.

Precision agricultural technology or "variable rate technology" for application of nitrogen is currently used on approximately 10-15 percent of the main corn and wheat growing regions of the United States while broader use of the 4Rs (applying the right fertilizer source, fertilizer rate, at the time and at the right place). For example, see Figure 9, showing progress made to reduce ag contributions to water quality with the Hypoxia Task Force. Several states within the Mississippi River Basin have developed nutrient loss reduction strategies that focus on collaborative plans to improve water quality.

A substantial increase in specialized spring-based nitrogen applications, precise utilization of animal manure for nitrogen and phosphorus, split timing and use of variable rate technology will be needed across cropland to meet the full potential for climate solutions through crop production. One innovative example is the Middle Cedar Partnership Project.

Nitrogen and phosphorus yield estimates from the landscape delivered to the Gulf of Mexico

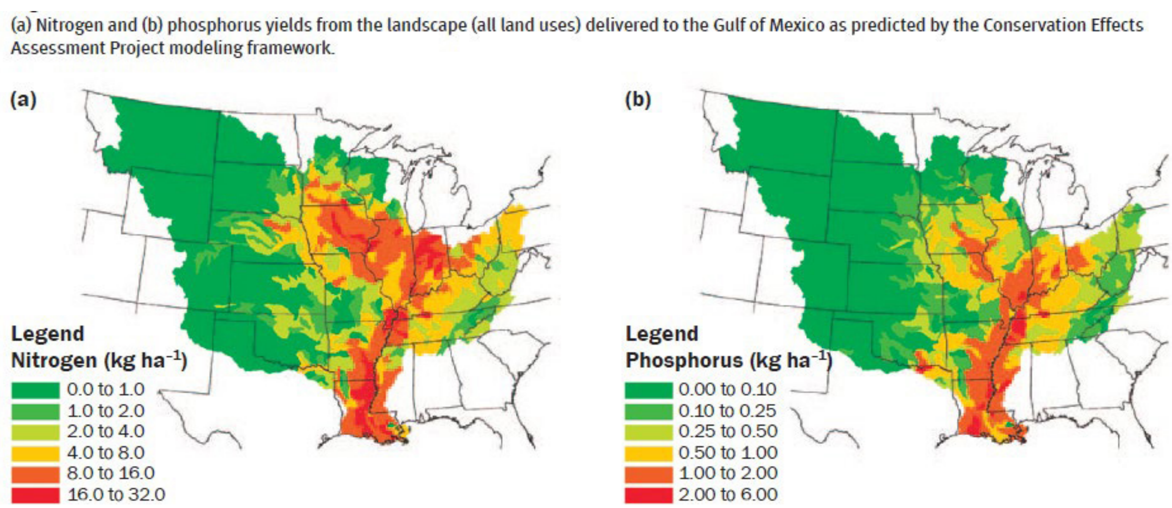

Figure 10

Water flow, sediment, nitrogen and phosphorus are all important in understanding water quality. This means the amount of water in the rain, moving through the soil and in the lakes and streams is important. Similarly, the amount of nitrogen, sediment or phosphorus in that moving water is also critical in assessing the quality of water and opportunities for improvement. While nitrogen and phosphorus are essential nutrients for growing plants, animals and people, they also move within ecosystems (soil and water) and can cause problems. Heavy rains bring more water than the plants and soil can handle and can move into the environment.

Source: White, et. al., (2014). Nutrient delivery from the Mississippi River to the Gulf of Mexico and effects of cropland conservation.

Weather resiliency

Weather-related changes make it riskier to raise livestock and produce crops – and require greater resiliency. Rising temperatures can reduce fertility of livestock, reduce rate of gain in livestock, and reduce crop yields. Further, changes have increased the length of the frost-free period (and corresponding growing season), increases in precipitation and heavy downpours, and increased frequency of extreme weather events: droughts, floods, fires, and heat waves.[10]

The U.S. Office of Management and Budget and Council of Economic Advisors (2016)[10] expects increased extreme heat and drought, more intense precipitation and soil erosion, growing stress from disease and pests, shifting soil moisture and water availability for irrigation, and higher concentrations of ozone, which will continue to increase uncertainty for producers.

Resiliency to episodic events

In most years, exposure to short-term weather stresses decreases crop yield between 15-20 percent from the potential yield. These stresses can be characterized as periods in which soil water is not available to meet the atmospheric demand for the crops or the temperatures are not in the optimal range for growth.[59]

The droughts of 1988 and 2012 each caused approximately $40 billion in mostly agricultural losses.[60] The drought of 2012 affected agriculture across 23 states and reduced crop and animal production. Drought stress causes 41 percent of crop losses in the U.S. annually.

Other changing weather patterns cause additional stresses on agricultural lands. Rain storms are getting worse in the Midwest and snowfall patterns are changing and moving north. The length of time of ice coverage of the Great Lakes declined by 71 percent from 1973 to 2010, and between 1975 through 2004, the number of days with land snow cover decreased by an average of 15, with the average snow depth decreasing by 2 inches (5.1 cm). Snow and ice levels on the Great Lakes and on land will likely continue to decrease. Reduced lake freezing will result in more exposed water that could increase lake-effect precipitation that affects spring planting and fall harvests.[61] The number of extreme precipitation events (rain, snow, hail, sleet) has increased from 1895 to 2000.

Additional spring rains coupled with more intense storms creates the potential for increased water quality impact (sediment, nitrate-N, and phosphorus). In an analysis of the Raccoon River watershed in Iowa, Lucey and Goolsby (1993) observed nitrate-N concentrations were related to streamflow in the river.[62] Hatfield et al. (2009) showed that annual variations in nitrate-N loads are related to the annual precipitation amounts because the primary path into the stream and river network was leaching through sub-surface drains.[59 63]

The economic cost

Disaster events due to extreme weather are becoming more frequent, and their cost is enormous. Six of the last 10 years in the U.S. have experienced greater than the average number of billion-dollar disaster events, many of them from intense storms (thunderstorms, tornadoes, hurricanes, and blizzards).

Farmers and ranchers have taken steps to prepare for disasters – but despite their best efforts, the scale of the disaster can lead to widespread crop damage and losses. A large swath of the country experienced record winter precipitation in 2019, in some areas up to 200 percent above normal, leading to major flooding.[64] North Carolina farmers and livestock growers experienced more than $1.1 billion in losses from Hurricane Florence in 2018.[65] The 2016 California drought was also devastating, resulting in $247 million loss of farm-gate revenues and up to $600 million in value losses with the spillover effects to the rest of the economy.[66]

U.S. billion-dollar weather and climate disasters and frequency

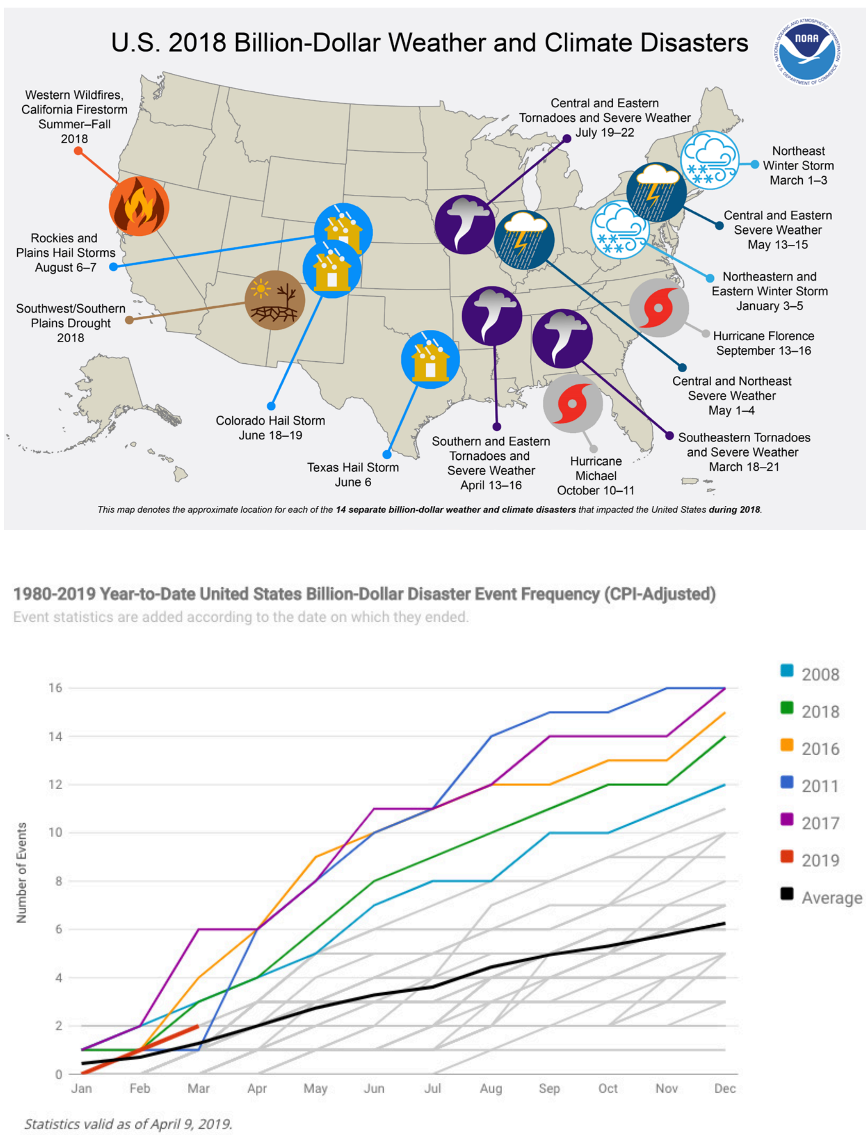

Figure 11

Disaster events due to extreme weather are becoming more frequent, and their cost is enormous. Six of the last 10 years in the U.S. have experienced greater than the average number of billion-dollar disaster events, many of them from intense storms (thunderstorms, tornadoes, hurricanes, and blizzards).
Source: National Oceanic and Atmospheric Administration -National Centers for Environmental Information. (2019). Billion-Dollar Weather and Climate Disasters: Overview.

> The catastrophic and largely uninsured stored-crop losses of corn and soybeans from the widespread flooding in the Midwest in March 2019 was estimated at a value of $2 billion.[67 64]
>
> – Iowa Farm Bureau. (2019).

Toward greater resiliency

Extreme weather events can interrupt food supply and affect food security, especially with events occurring back to back. What's more, increases in crop yields that farmers have long been accustomed to can lead to a false sense of security and the risk that food security can be taken for granted. Crop yields have increased year on year for past 75 years. Corn and soybean yields have increased from 1988 to 2018 – despite increases in intense storms, loss of suitable planting days and static water and fertilizer use (see Fig 12).

Everyone has a stake in water-wise and climate-smart systems. Farmers, ranchers, aggregators, processors, retailers and consumers all share benefits from supporting the resiliency and quality of the food supply chain in the face of scarce resources and increasing natural disasters.

Soybean yield - United States

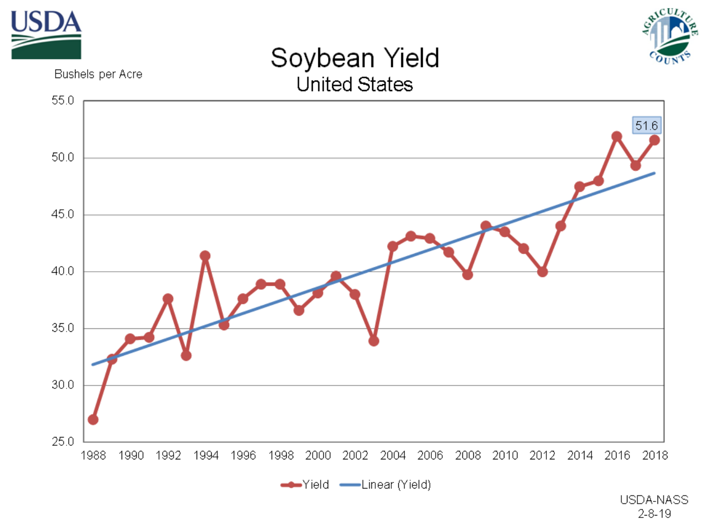

Figure 12

Corn and soybean yields have increased from 1988 to 2018 – despite increases in intense storms, loss of suitable planting days and static water and fertilizer use.
Source: U.S. Department of Agriculture National Agricultural Statistics Service. (2019). Soybean Yield.

NEXT STEPS

Form broad-based partnerships or coalitions across communities, municipalities, businesses, government, conservation organizations to leverage impact and scale up results.

Create novel pathways to connect retailers and customers with farmers in adoption of climate smart farming systems with technologies that improve environmental outcomes.

ENHANCING BIODIVERSITY

Agricultural biodiversity is a broad term that includes all the components of biological diversity of relevance to food and agriculture. It includes a wide number of animals, plants and micro-organisms, at different genetic, species and ecosystem levels, spread across different habitats and surrounded by interdependent biologically diverse systems.[68]

Agriculture has always been reliant on biodiversity and it must be protected going forward. Genetic and phenotypically expressed diversity helps agricultural systems adapt to climate change, providing the ability to create more drought resistant crops, adapt animal species, etc.[69]

Habitats and profits

Integrated, collaborative approaches help us better understand and develop ecological practices and businesses—such as habitat restoration, conservation, public health management, biosecurity, agriculture, agroforestry, aquaculture, and environmental monitoring.

Precision agriculture can play a large role here; examples include: EFC Systems' AgSolver[70] or Ecopractices by Sustainable Environmental Consultants,[71] which both have a suite of tools used to target field areas with lower productivity and profitability for habitat construction to enhance biodiversity. These technologies analyze several static (topography, soil type) and management factors (crop, manure application, fertilizer, tillage, cover crops, transportation) in combination with precision agricultural and publicly available data to optimize planning for crop production and conservation practice implementation.

Ecosystems services enhancing biodiversity

There are many components of biodiversity that support ecosystem services upon which agriculture is based, according to the UN Convention on Biological Diversity. These include a diverse range of organisms that contribute, at various scales to nutrient cycling, pest and disease regulation, pollination, pollution and sediment regulation, maintenance of the hydrological cycle, erosion control, climate regulation and carbon sequestration.

It also includes abiotic factors, such as local climatic and chemical factors and the physical structure and functioning of ecosystems, which have a determining effect on agricultural biodiversity.

Agricultural biodiversity encompasses socio-economic and cultural dimensions. Many people depend on agricultural biodiversity for sustainable livelihoods. It is also a source of traditional and local knowledge and of recreation and tourism associated with agricultural landscapes.

Challenges to agriculture and biodiversity

According to the UN Convention on Biological Diversity,[69] agriculture confronts two main challenges in relation to biodiversity:

1. To sustain agricultural biodiversity and ecosystem services provided by, and necessary for, agriculture

2. To mitigate the negative impacts of agricultural systems and practices on biodiversity which is not used directly whether in the same or other ecosystems

Farmers, ranchers, scientists, conservation organizations, industry and the public can work together to identify large-scale patterns in projected climate change, and patterns in current factors that influence local-scale impacts on biological diversity.[72]

By working together, we can predict and make our best effort to predict how habitat or needed resources (water, food, light) could change and affect plants, animals, microbes and other form of biological diversity. These predictions, or bets, can help us plan to protect individual species and communities that could be most impacted.[72] This also allows us to predict the impacts from biological diversity on our food production systems and protect them before changes happen.

Contribution to important species

Honey bees as pollinators are vital (see Figure 13) and monarch butterflies (see box) are among the species that good agricultural biodiversity practices can help support.

Honey bee movements and crops requiring pollination in the United States

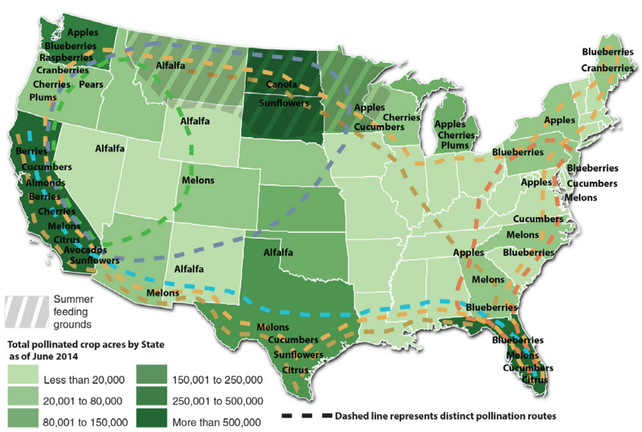

Figure 13

Honey bees and other pollinators are a vital part of U.S. agriculture — supporting production of most of the fruits, nuts, and vegetables grown in the United States, with an approximate $19 billion in agricultural production annually.73 Honey bees and other insects also pollinate approximately 80 percent of flowering plants worldwide

Source: Honey Bee Health Coalition. (2014). Bee Healthy Roadmap: Improving Honey Bee Health.

USDA Economic Research Service (2017). Land Use, Land Cover, and Pollinator Health: A Review and Trend Analysis.

Honey Bee Health

Honey bees and other pollinators are a vital part of U.S. agriculture — supporting production of most of the fruits, nuts, and vegetables grown in the United States, with an approximate $19 billion in agricultural production annually.[73] Honey bees and other insects also pollinate approximately 80 percent of flowering plants worldwide. Honey bees face a variety of challenges including: poor nutrition; incidental pesticide exposure; parasites; and diseases. Overwintering honey bee colony losses have ranged from 22 percent to 37 percent over the last 11 years, — compared to a historical average of 10 percent to 15 percent.[74] Beekeepers must replace these colony losses to meet pollination and honey production demands.

Supporting Monarch Butterflies' Habitat

The annual migration of monarch butterflies from Mexico through the U.S. to Canada is one of the world's great natural phenomena, yet the eastern monarch butterfly population has declined by more than 80 percent over the past two decades due to a variety of challenges. In order to ensure the population can recover from severe weather events and to protect its migration, there is a pressing need to restore and enhance habitat for monarchs. Monarch adults only lay their eggs on milkweed, and their caterpillars eat nothing but milkweed.

Farmers for Monarchs, an initiative of the Keystone Monarch Collaborative, brings together farmers, ranchers, land owners and other stakeholders to support the monarch. Since most of the land along the monarch migration path is in private hands, landowners and farmers are uniquely situated to support the monarch.

Habitat plantings can fit into many niches on the agricultural landscape, including conservation lands, grazing lands, rights-of-way, field margins, and yard and garden areas. Milkweed and other nectar-producing flowers planted in these areas yield multiple on-farm benefits, including attracting pollinators, improving soil health and water quality, housing the natural enemies of crop pests, and increasing wildlife diversity.[75]

NEXT STEPS

Adopt new precision business management tools for farms and agricultural supply chains to leverage conservation practices for economic, environmental and community resiliency. Using tools that can target acres for production and habitat conservation can be impactful, as they are based on the economic performance of each square foot in the field.

Support farmers in using precision agriculture technology and software to map profitability and unlock pathways for greater production efficiency and environmental gains by allocating inputs for production/profitability and transitioning low-profit areas of fields to conservation efforts such as pollinator habitat.

Encourage initiatives like Farmers for Monarch that connect farmers to federal and state conservation programs that allow farmers to earn good returns on marginal crop lands and technical help and cost-sharing incentives for establishing habitat and implementing other conservation practices on their lands.

MITIGATION AND ADAPTATION

In a world facing significant natural resource constraints, the agriculture sector stands uniquely positioned to enable mitigation and adaptation through its huge carbon storage potential.

Carbon storage and cycling is a balance between emissions and sequestration that is dynamic and in-flux. The agricultural sector is improving production efficiencies with technology to change the balance to capture more carbon than is emitted each year – and move the sector beyond carbon neutral to net-negative emissions.

Ambitious carbon drawdown within reach

The most powerful contribution that agriculture can make to climate adaptation and mitigation is avoiding emissions of current soil banks through avoiding land use change from native to agricultural and agricultural to urban uses and the untapped potential to sequester carbon in the soils while mitigating GHG emissions such as nitrous oxide through nitrogen management. U.S. agriculture can bank carbon and become net-negative across the sector. This presents a need and an opportunity to work proactively with farmers to set collaborative corporate commitments to reduce carbon emissions across agricultural supply chains (especially scope 3 emissions).[76]

Respected global researchers have recognized the rapid decarbonization pathway offered, in part, by agriculture. Recent findings from the Stockholm Resilience Centre and others assert that by 2050, the world will have reached net-zero CO_2 emissions, with a global economy powered by carbon-free energy and fed from carbon-sequestering sustainable agriculture.[77]

Agricultural ecosystems such as those in the soil can play a significant role in carbon dioxide removal and sequestration, through practices that increase the amount of organic carbon stored in living plants, dead plant parts and the soil.

According to the National Academies of Science, Engineering and Medicine (NASEM), climate-smart agriculture technology practically achievable today could store .25 Gt CO_2 Eq. per year. That's a 46 percent drop in sector emissions (or 3.8 percent of total U.S. emissions).[38]

Take that a step further and add frontier technology to farming practices, and agriculture would achieve net-negative emissions, reducing as much as 147 percent CO_2 Eq, to -.4.0 percent of total U.S. emissions or approximately the equivalent of planting 13.2 billion trees.[7]

> With frontier technologies invested in and implemented, agriculture would achieve net-negative emissions, reducing as much as 147 percent CO_2 Eq, to -4 percent of total U.S. emissions.[38]
>
> – Negative Emissions Technologies and Reliable Sequestration: A Research Agenda," National Academies of Sciences, Engineering, and Medicine

These frontier technologies are approaches that are still in a basic research phase and not yet tested for widespread deployment, and include biochar amendments, advanced crop breeding or phenotyping for high carbon input root systems.

Many of the practically achievable climate-smart land management practices, such as more diverse crop rotations; use of cover crop; reduced tillage, precision nitrogen management, and improved grazing systems, are "sufficiently mature, both scientifically and in practice, to materially increase carbon storage if widely deployed in the U.S. and globally."[38]

The benefits of annual carbon drawdown in agriculture could start within as little as two to five years after adoption of technologies.[79] The practically achievable technologies are well researched, increasingly marketed and have gained greater farmer acceptance.[33,38] However, shared risk and creative financing models are needed to further improve adoption rates.

Further out, long-range frontier technologies could happen within 10-15 years. These full benefits of carbon removal cascade when partnering across sectors to escalate investment and scale adoption.

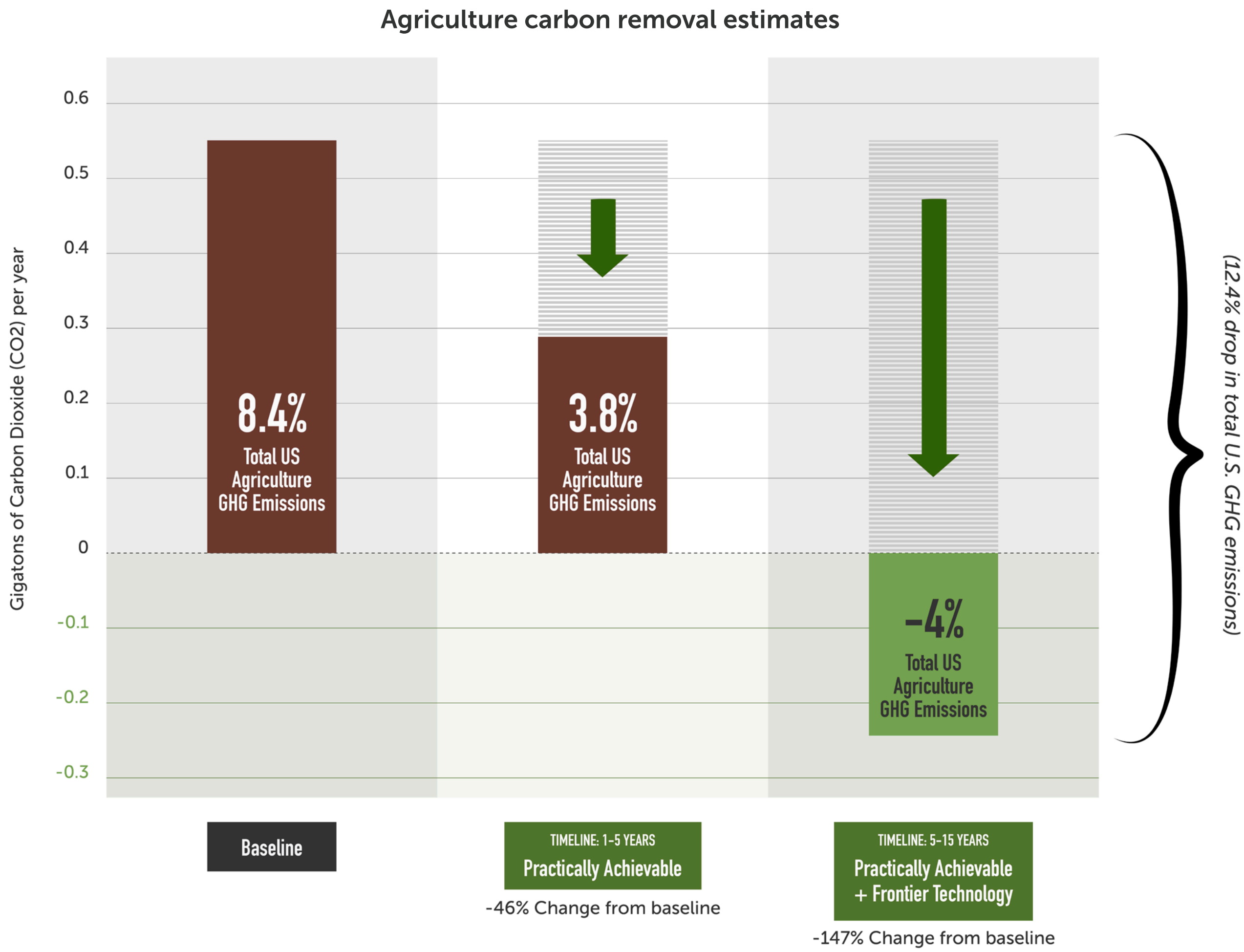

Figure 14

Agricultural ecosystems can play a significant role in carbon dioxide removal and sequestration, through systems that increase the amount of organic carbon stored in living plants, dead plant parts and the soil. In 2017, U.S. greenhouse gas emissions totaled 6.5 Gt of CO_2 Eq. – with agriculture representing a baseline of 8.4 percent. Practically achievable technologies examples include cover crops, no-till, precision animal manure and rotational grazing. Frontier technology examples include biochar amendments, advanced crop breeding or phenotyping for high carbon input root systems. The estimates provided in this figure are generally conservative and do not account for food waste emissions reductions and many of the positive contributions from animal agriculture (such as extracting nitrogen, phosphorus and soil amendments through manure fractionation and feed ingredient efficiency gains) towards moving the sector to net-negative carbon emissions. Further, the integration of row crop and livestock agriculture provides enhanced carbon and nitrogen cycling benefits for plants, animals and humans.
Source: U.S. Environmental Protection Agency. (2019). Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2016. National Academies of Sciences, Engineering, and Medicine. (2019). Negative Emissions Technologies and Reliable Sequestration: A Research Agenda.

Technologies being deployed today

Many practices that contribute to carbon drawdown are increasingly being used across the U.S. In wheat, corn and soybean production systems, farmers are using no-till or mulch-till across 60 to 70 percent of planted acres from 2005 to 2016 (See Figure 15).[80]

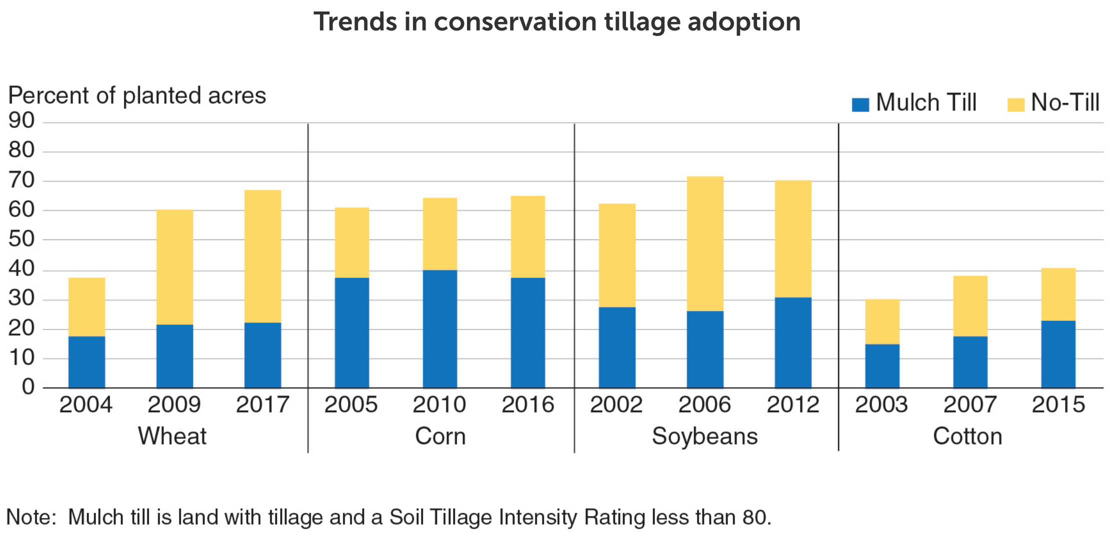

Figure 15

Note: Mulch till is land with tillage and a Soil Tillage Intensity Rating less than 80. In wheat, corn and soybean production systems, farmers are using no-till or mulch-till across 60 to 70 percent of planted acres from 2005 to 2016.
Source: USDA Economic Research Service. (2018).

The use of cover crops to bank carbon is also dramatically on the rise (See Figure 16). Cover crops have been used more widely each year from 2010 to 2015 and were used on approximately 11 million acres (out of approximately 100 million corn and soybean acres suitable for cover crops) in 2015.[81]

By addressing the barriers to use of cover crops, it will be possible to scale the impact of this technology even further. Barriers include timing to grow and manage cover crops, finances to buy cover crop seed and manage them well and weather preventing preparation for main cash crops.

Land-based animal manure applications increase soil organic matter and organic carbon along with additional important soil characteristics such as aggregate stability (how well the soil binds to itself to resist erosion) and nutrient cycling (nitrogen and phosphorus-based plant food).[24]

Conservation tillage and no-till (low disturbance or no disturbance of soil for growing crops), especially in combination with cover crops and land-based animal manure applications, have the potential to bank 1 ton of carbon per acre per year.

Accounting for agriculture's continuous improvement in mitigation and adaptive potential could account for greater solutions in the models that were analyzed and greater gains for U.S. agriculture.

Use of cover crops on farmland for crops and livestock by USDA region

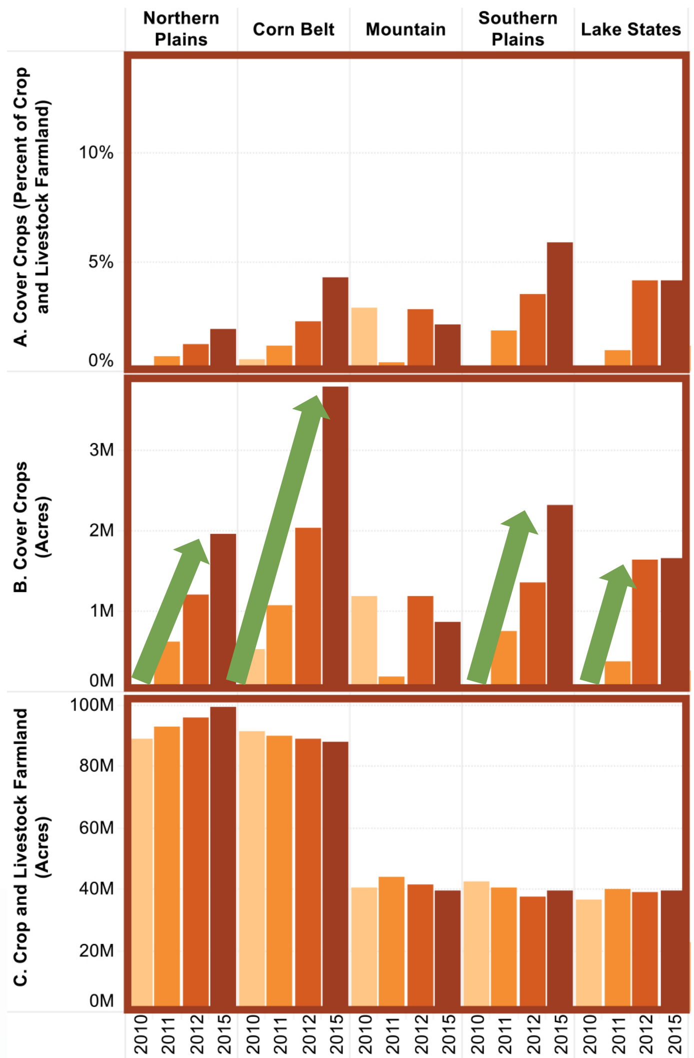

Figure 16

In wheat, corn and soybean production systems, farmers are using no-till or mulch-till across 60 to 70 percent of planted acres from 2005 to 2016.
Source: USDA Economic Research Service. (2018) Agricultural Conservation on Working Lands: Trends From 2004 to Present.

Continuous improvement

Continuous improvement in agriculture productivity will also play a key part in improving the sector's resiliency. Global agriculture productivity has increased by 1 percent while simultaneously increasing production, resulting in the global greenhouse gas emissions for all of agriculture to remain stable since 1990.[82] The United States farm output has increased by 1.48 percent per year between 1948 and 2015 – while total farm input use has increased by only .1 percent per year over the same period.[83]

All agriculture production regions are expected to improve productivity due to technological progress, and globally are projected to increase by 38 percent.[84]

Worldwide animal agriculture is expected to increase productivity, reduce greenhouse gases, and improve livelihoods.[85] Estimates from the IPCC report of 2014 suggest even higher lines of around 70 percent.[86]

By collaborating across the food and agriculture systems, and exploring innovative new forms of investment, we can maximize the power of farming and ranching to achieve net zero (or negative) greenhouse gas emissions for agriculture.

U.S. agricultural outputs, inputs and total factor productivity, 1948-2015

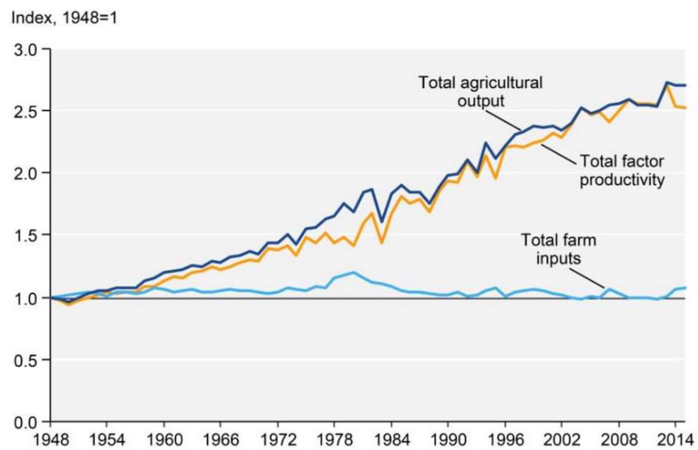

Figure 17

The United States farm output has increased by 1.48 percent per year between 1948 and 2015 – while total farm input use has increased by only .1 percent per year over the same period.
Source: U.S. Department of Agriculture Economic Research Service. (2019). Agricultural Productivity in the U.S.

NEXT STEPS

Increase deployment of carbons smart technologies that are mature and practically achievable for soil carbon sequestration.

Conduct research to increase the focus on and implementation of science-based targets for land, water, biodiversity and health across the agricultural value chain.

Build public-private partnerships and coalitions to bring essential tools for the advancement of data collection and technology integration.

CONCLUSION AND INVITATION

This report has sought to underline the need to drive greater innovation, better manage enterprise risk and bolster supply chain resiliency in U.S. food production systems. Nourishing a growing planet in the face of climate change will require a huge leap forward in seizing the opportunities the agriculture sector can offer for food security, climate mitigation and other ecosystem service solutions. Further, the carbon sequestration numbers provided throughout this paper are very conservative – and do not fully account for significant pathways such as food waste emissions reductions and many of the positive contributions from animal agriculture (such as manure fractionation and feed ingredient efficiency gains).

With at least $2.3 trillion in annual investments needed to meet the global demand of increased food production by 2030,[87] it is also critical to improve understanding of the promising investment opportunities through realized agricultural ecosystem service co-benefits and to identify research and programming gaps.

Throughout this report, we have outlined a number of next steps for further action and we invite you to join us. If we are to create a stronger, more vital and sustainable agriculture system, collaboration will be key. In partnership, we can work to enhance understanding of current agricultural science, food supply chain production systems and the tangible value capture propositions necessary to motivate action.

In an open, honest and solutions-oriented dialogue, we can together marshal the incentives needed to spur change, creativity and innovation in shaping the 21st century sustainable food system.

Three key messages to take forward in our ongoing dialogue:

1. Broaden the knowledge base

First, we must improve understanding of the gaps in our knowledge to provide a solid foundation for the most effective actions. While agriculture has tremendous potential, we do not fully understand, nor account for the positive contributions from several current pathways providing benefits to ecosystems services. For example, animal agriculture is only briefly included within the most prominent reports on future sustainable food systems and these seldomly include current technologies that improve water quality, carbon sequestration and feed conversion efficiency (e.g. precision manure application, manure fractionation technology, manure digesters, animal genetic improvements, or feed additives for improved efficiency).

Similarly, we have an opportunity to invest in precision agriculture data systems across crop and rangeland to simultaneously benefit farmers and supply chains. Data collection and utilization can benefit farmers through better understanding and value from climate smart agricultural system co-benefits to water, carbon sequestration, biodiversity, economic and production resiliency. Importantly, this will also help farmers and supply chains understand the variation in stacking co-benefits to improve likelihood of positive impact in continuous improvement programs.

Agricultural value chain partners, conservation organizations, academic groups, government agencies and society must more broadly invest together to understand current gaps in science, education, value delivery, communication and partnerships. In that way, we are better equipped to develop strategies for most effectively utilizing resources in addressing gaps.

2. Identify shared value

Second, we need to identify the value propositions within each of our organizations and then support shared values through partnerships and collaborations across production systems and value chains. Value capture propositions must be better understood and articulated to all food supply chain sectors to realize and internalize the benefits from investments in agricultural ecosystem services.

3. Rally broad-based support

Support must come from all corners. Broad coalitions must work together to provide financial, reputation, regulatory incentives and support strategies for agricultural sustainability across the economic, environmental, and social spheres, within research, education, and communications. All players in the value chain have the opportunity to co-create and align their vision for sustainable agriculture.

We extend an invitation to all the stakeholders in the food value chain to join us in advancing this dialogue towards outcome-based climate-smart practices that enhance the agricultural ecosystem services on which we all depend.

We welcome your comments and feedback to this paper.

Please email us at **science@usfraonline.org**. We look forward to continuing a fact-based, science-driven, solutions-oriented dialogue to shape a joint vision of the 21st century sustainable food system.

APPENDIX

U.S. Farmers and Ranchers Alliance Science Advisory Council

Steven V. Brock

Senior Advisor, Council on Strategic Risk and Senior Fellow, Center for Climate and Security

Steve Brock serves as Senior Advisor at the Council on Strategic Risk as well as a Senior Fellow at the Center for Climate and Security in Washington, D.C. He is also the Co-Founder and President of Earth Ethic, an environmental and agribusiness consultancy focused on agricultural as a powerful and integral solution to global challenges we face. Steve has a B.S. in Marine Engineering from the United States Naval Academy, an M.S. in Natural Resource Strategy from the National Defense University, and an M.A. in National Security Studies from Georgetown University.

Pipa Elias

Soil Health Strategy Manager, North America Agriculture Program, The Nature Conservancy

Pipa Elias is Soil Health Strategy Manager for The Nature Conservancy's North America Region. She joined TNC in 2014 as a Senior Policy Advisor for land use and climate change and has published more than a dozen reports on sustainable forestry and agriculture related to climate mitigation. Pipa holds an M.S. in Forestry from Virginia Tech and a B.S. in Environmental Science from the University of Notre Dame.

Greg Gershuny

Interim Director of the Aspen Institute Energy and Environment Program (EEP) and Managing Director and the James E. Rogers Energy Fellow, Aspen Institute

Greg Gershuny serves as the Interim Director of the Aspen Institute Energy and Environment Program (EEP) and is the Managing Director and the James E. Rogers Energy Fellow of the program. Prior to joining the Aspen Institute, Greg served as the Associate Director for the U.S. Department of Energy Office of Energy Policy and Systems Analysis as well as Chief of Staff to Energy Policy Director Melanie Kenderdine. He is a graduate of George Mason University.

Dr. Nicholas Goeser

Vice President, Sustainability Sciences and Strategy, U.S. Farmers & Ranchers Alliance

Nicholas Goeser joined the U.S. Farmers & Ranchers Alliance in 2019 as its Vice President, Sustainability Sciences and Strategy. He currently leads the USFRA Science Advisory Council of grower, agricultural industry, foundation, conservation and academic organizations to help prioritize engagement strategies and collaborative ventures to capture and deliver value across agricultural supply chains. Nick previously served as Vice President of Production and Sustainability for National Corn Growers Association. Nick holds an M.S. in Agronomy and a Ph.D. in Horticulture from the University of Wisconsin.

Dr. Jerry Hatfield

Laboratory Director, Laboratory for Agriculture and the Environment, United States Department of Agriculture – Agricultural Research Service

Jerry Hatfield is the Laboratory Director of the Laboratory for Agriculture and the Environment, United States Department of Agriculture – Agricultural Research Service, where he has served since 1989. He is the is the author of 457 refereed publications, the lead author on "The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity," and a member of the IPCC process that received the 2007 Nobel Peace Prize. Jerry holds an M.S. in Agronomy from the University of Kentucky and a Ph.D. in Agricultural Climatology and Statistics from Iowa State University.

Dr. Brett Kaysen

Assistant Vice President of Sustainability, National Pork Board

Brett Kaysen is the Assistant Vice President of Sustainability for the National Pork Board, where he leads the organization-wide effort to establish pork as a responsible protein choice. Prior to this role, he was the Western Regional Sales Director for the U.S. Pork Business at Zoetis. Brett holds a B.A. in Animal Science, an M.A. in Agricultural Extension Education, and a Ph.D. in Animal Sciences, Management Systems from Colorado State University.

Dr. Marty Matlock

Executive Director, University of Arkansas Resiliency Center and Professor of Ecological Engineering, Department of Biological and Agricultural Engineering, University of Arkansas

Marty Matlock is the Executive Director of the University of Arkansas Resiliency Center and a Professor of Ecological Engineering at the University of Arkansas. Marty serves on the USEPA Science Advisory Committee for Agriculture, and previously served on the U.S. Secretary of Agriculture's Committee for the 21st Century. He serves as sustainability science advisor for 12 food and agricultural product companies, as well as the World Wildlife Foundation and Environmental Defense Fund. He holds a B.S. in Soil Chemistry, an M.S. in Plant Physiology, and a Ph.D. in Biosystems Engineering from Oklahoma State University.

Dr. Frank Mitloehner

Professor and Air Quality Extension Specialist, University of California – Davis

Frank Mitloehner is a Professor and Air Quality Specialist in Cooperative Extension in the Department of Animal Science at the University of California, Davis, where he started his career in 2002. He also serves as adjunct professor at Northwest Agriculture and Forestry University (NWAFU) in Yangling, China. Frank has served as chairman of a global United Nations Food and Agriculture Organization (FAO) hosted partnership project to benchmark the environmental footprint of livestock production. He received his M.S. in Animal Science and Agricultural Engineering from the University of Leipzig, Germany, and his Ph.D. in Animal Science from Texas Technical University.

Dr. John Newton

American Farm Bureau Federation

Dr. Newton is the Chief Economist for American Farm Bureau Federation, the largest organization of independent farmers in the United States. In this role, Dr. Newton is responsible for the management of Farm Bureau's economics department and coordinates and conducts analyses used for the development of and the advocacy for Farm Bureau policy. Prior to joining Farm Bureau, Newton worked for the United States Department of Agriculture as an agricultural economist and was detailed to both the Senate Agriculture Committee and the USDA Office of the Chief Economist. Following his service to USDA and the Congressional Committee, Dr. Newton was an award-winning faculty member at the University of Illinois Urbana-Champaign.

Dr. Dan Northrup

Director of Special Projects

Dan Northrup is Director of Special Projects at Benson Hill Biosystems where he works on sustainability and nutrition. Previously he was a consultant for the Advanced Research Projects Agency for Energy agri-energy portfolio. Those programs developed technologies to breed for enhanced productivity and deeper root systems to allow better nutrient capture, improve soil health, and boost soil carbon deposition. Prior to this role, he researched functional genomics at the National Institutes of Health. Dan received his B.S.E. in Biomedical/Medical Engineering from Duke University, and his Ph.D. in Immunology from the University of Pennsylvania.

Dr. LaKisha Odom

Scientific Program Director, Foundation for Food and Agriculture Research (FFAR)

LaKisha Odom joined the Foundation for Food and Agriculture Research (FFAR) in September 2016 as a Scientific Program Director. At FFAR, she spearheads scientific direction of the Healthy Soils, Thriving Farms challenge area and manages a portfolio of projects that address issues in soil health, water scarcity, plant efficiency, ecosystem services, and developing the next generation of food and agricultural scientists. LaKisha received her B.S. in Environmental Science from Tuskegee University, her M.A. in Environmental Resource Policy from The George Washington University, and her Ph.D. in Integrative Biosciences from Tuskegee University.

Dr. John M. Reilly

Co-Director, MIT Joint Program on the Science and Policy of Global Change

John Reilly is a Co-Director of the Joint Program and a Senior Lecturer at the Sloan School of Management. He has also served in multiple capacities on the Intergovernmental Panel on Climate Change (IPCC), was the Co-Chair of the U.S. National Agricultural Assessment on Climate Variability and Change, served on early committees in the Federal government that shaped the direction of the U.S. Global Change Research Program, and participated in a wide range of other advisory committees. He holds an M.S. and a Ph.D. in Economics from the University of Pennsylvania, and a B.S. from the University of Wisconsin.

Dr. Charles (Chuck) Rice

University Distinguished Professor, Vanier University Professorship, Kansas State University

Charles (Chuck) Rice is a University Distinguished Professor and holds the Vanier University Professorship at Kansas State University. He serves on the Board of Trustees for CIAT, the International Tropical Agriculture Research Center based in Cali, Colombia. He also chairs the Board on Agriculture and Natural Resources of the U.S. National Academies of Science, Engineering, and Medicine. Internationally, he served on the UN Intergovernmental Panel on Climate Change to author a report on Climate Change in 2007 and 2014 and was among scientists recognized when that work won the Nobel Peace Prize in 2007. Chuck received a B.S. in Zoology from the University of California-Davis, and a Ph.D. in Biochemistry from the California Institute of Technology.

Dr. Mickey Rubin

Executive Director, Egg Nutrition Center

Mickey Rubin is the Executive Director of the Egg Nutrition Center. Prior to joining the Egg Nutrition Center, Mickey spent 8 years as Vice President of Nutrition Research at National Dairy Council. He is also the author or co-author of numerous peer-reviewed scientific papers and textbook chapters covering the topics of nutrition and exercise science. Mickey earned a B.S. in Kinesiology from Indiana University-Bloomington, an M.S. in Exercise and Sport Science from the University of Memphis, and a Ph.D. in Exercise Physiology from the University of Connecticut.

Dr. Alain Vidal

Director of Partnerships, World Business Council for Sustainable Development

Alain Vidal recently joined the World Business Council for Sustainable Development (WBCSD) as Director of Partnerships - Food Land and Water, based in Geneva, Switzerland. He also serves part time for the International Union for Conservation of Nature (IUCN) as Senior Expert, Food & Agriculture for the Global Business and Biodiversity Programme. Alain is also a corresponding member of the French Academy of Agriculture and Consulting Professor at AgroParisTech University. Alain received his Ph.D. in Water Science from the University of Montpellier.

Dr. Ying Wang

Vice President of Sustainability and Food Systems Research, Innovation Center for U.S. Dairy.

Ying Wang is the current Vice President of Sustainability and Food Systems Research at the Innovation Center for U.S. Dairy. She also leads the International Dairy Federation Sustainability Steering Group and serves as environment lead on the IDF Science and Program Coordination Committee. She received a B.S. in Analytical Chemistry from Lanzhou University, an M.S. in Tribology from the Chinese Academy of Sciences, Lanzhou Institute of Chemistry and Physics, an M.S. in Environmental Health and Safety Management from the Rochester Institute of Technology, and a Ph.D. in Polymer Chemistry and Physics from Sun Yat-Sen University.

About U.S. Farmers and Ranchers Alliance

U.S. Farmers & Ranchers Alliance (USFRA) convenes food and agriculture stakeholders and consumers in an inclusive dialogue on the sustainable food systems of the 21st century. We aim to elevate food and agriculture as the solution for sustainability, positioning farmers and ranchers as the key change agents. Collectively, we believe that farmers and ranchers uniquely enable the sustainable food systems of the future by nourishing our communities, natural resources, and planet.

Vision

Farmers and ranchers uniquely enable the sustainable food systems of the future by nourishing our communities, natural resources, and planet.

Mission

We connect farmers and ranchers to food and agriculture stakeholders to co-create sustainable food systems.

Values

Leadership

Bold food systems leadership—driving shared values and outcomes—is required to solve the sustainability challenges of the 21st century.

Solutions

Every farmer is the steward of their land and can unlock the potential of every acre for our sustainable future. Farmers will continue to get it done.

Collaboration

Our sustainable future can only be secured through food systems-wide collaboration where every stakeholder voice is valued.

Science-based Innovation

Science should guide us in developing solutions that will allow us to farm on tomorrow's land

Consumer Connections

Strong connections between farmers and consumers are essential to sustainable food systems.

We welcome your comments and feedback to this paper.

Please email us at **science@usfraonline.org**. We look forward to continuing a fact-based, science-driven, solutions-oriented dialogue to shape a joint vision of the 21st century sustainable food system.

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