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Climate Change, Greenhouse Gas Emissions, and Carbon Sequestration: Challenges and Solutions for Natural Resources Conservation through Time

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Climate and Conservation Prior to 1945

Climate and land management are recognized as key drivers affecting soil and water conservation practices that maintain or enhance the capacity of land to withstand erosion or degradation (Delgado et al. 2011; Gantzer 2020; Lal 2020). Since recorded time, people have adapted to climate and climate change by developing innovative concepts and technologies that benefited past and present societies (Butzer and Endfield 2012). Stable climatic periods and the expansion of humanity's collective knowledge have led to stationary societies that are dependent on management of agriculture, forests, and other natural resources (Butzer and Endfield 2012). These factors in most instances have led to the expansion of our intellectual, cultural, and economic opportunities. However, humanity's ability to control the environment has also at times led to poor land management that has reduced or harmed the natural resource base and resulted in historic environmental and ecological disasters. Drought and erosion led to or contributed to societal instability and mass relocation of large numbers of individuals many times throughout history. For

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example, Mesopotamia, one of the first empires of human history circa 4500 BC; the end of the classic Mayan period (800 to 1000 AD); and, more recently, the Dust Bowl of the 1930s in the United States all resulted in environmental and social devastation.

The effects of the atmosphere on climate, particularly concentration of carbon dioxide (CO_2), have been studied and related to Earth's temperature by physical and climatic scientists since the 1800s. The potential for atmospheric concentrations of gases to increase Earth's temperature was dubbed the "greenhouse" effect by Joseph Fourier. Fourier (1824) postulated that the earth's temperature was determined by the amount of heat absorbed from the sun and trapped by the atmosphere. He described the atmospheric effect as similar to sunlight passing through the glass of a greenhouse which retained the heat, and he theorized that the concentration of gases in the atmosphere was related to this effect. The greenhouse gas effect was quantified by Arrhenius (1896) who identified arithmetic increase in Earth's temperature with geometric increases in CO_2 in the atmosphere. Despite the existence of this knowledge base in the physical and atmospheric sciences, the concepts were not widely known outside of these scientific communities. As industrialization led to the development of mechanized equipment with associated greenhouse gas emissions, agriculturalists and conservationists did not understand the link between the use of fossil fuels and emissions that contributed to warming in the atmosphere.

The Dust Bowl in the US Great Plains resulted from poor land management throughout the first two decades of the 20th century coupled with severe drought (Bennett et al. 1936). As the magnitude of the Dust Bowl became obvious, the Roosevelt administration established the US Great Plains Committee. Their report, entitled "The Future of the Great Plains," described how crop and livestock management, "modern equipment" costs, expansion of farm size, and absentee land ownership beginning in the early part of the 1900s played a greater role in the Dust Bowl disaster than the severe drought conditions themselves. Climatic variation, in contrast, was considered to be inevitable and beyond the scope of human intervention (Bennett et al. 1936). The committee's recommendations included, but were not limited to, soil erosion control, water conservation, and conservation education as well as economic investments, zoning, providing grants, and relocation of displaced persons. Additionally, by the 1930s, cropland in the humid southeastern United States had suffered decades of massive soil degradation by water erosion. These dramatic losses of soil to wind and water erosion led to recognition of the serious challenges erosion posed to the US agricultural and natural resource base.

The US Department of Agriculture (USDA) Soil Conservation Service (SCS) was established in 1935. During the early years of the conservation movement, erosion control on cropland received more abundant resources than erosion control on rangeland and grasslands. Similarly, erosion related to intense precipitation received greater scientific and policy attention than erosion related to intense winds. At the time of the establishment of US soil and water conservation programs, land managers, the public, and soil scientists viewed climate as a stationary process, where the climate of the past provided a basis for projecting future climate for a region.

Progress to Present

Milestones 1945 to Present. Gaps in knowledge and technology prevented most scientists and land managers in the early part of the 20th century from understanding the mechanisms behind the cycling of elements and energy between land, air, and water systems. This limited their ability to design experiments of sufficient complexity to understand what factors and interactions lead to climatic change. Infrastructure for data collection and minimal communication among disciplines was also limiting. Public interest and support of conservation policies, programming, and research were in their infancy. When the USDA Agricultural Research Service (ARS) was established in 1953, ongoing soil and water conservation research was transferred from SCS to ARS. Through the early years, when ARS quantified erosion processes and developed erosion prediction models (Flanagan 2020), climate was viewed as stationary, and climate factors in the models were calculated based on statistical properties of historic climate records.

Establishment of the long-term CO_2 monitoring station at Moana Loa, Hawaii, in 1956 by Charles Keeling (Keeling et al. 2001) was a seminal step toward widespread recognition of the increasing CO_2 concentrations in the earth's atmosphere and growing recognition of the risks of future climate change associated with increasing greenhouse gas concentrations. The findings from Keeling and colleagues were one key factor that led to establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988 to access scientific, technical, and socioeconomic aspects of climate change, its potential effects, and options for adaptation and mitigation. Throughout the 20th century there was growing recognition of serious challenges of human-caused climate change, which require major efforts in adaptation and mitigation.

In the second half of the 20th century, major environmental laws were enacted, which resulted in paradigm shifts in conservation management and support for the creation of networks for the collection of environmental variables descriptive of soil, vegetation, water, climate, and species. The Clean

Water Act (CWA), initially enacted in 1948, focused primarily on discharge of industrial and sewage waste into open waters. It was revised in 1972 to include surface water quality standards. The Clean Air Act of 1963 regulates air quality at the federal level via the US Environmental Protection Agency (EPA). Similar to the CWA, the EPA works through state and local agencies to monitor and enforce the regulatory standards. Conservation priorities broadened with enforcement of these environmental laws that extended the natural resources of concern to include soil, water, air, wetlands, biodiversity, and endangered species (Gantzer et al. 2020). This shift in focus was reflected in the name change of the USDA SCS to the USDA Natural Resources Conservation Service as well as the name change of the Soil Conservation Society of America to the Soil and Water Conservation Society (SWCS).

Throughout the mid-20th century to present, diverse conservation practices were developed and implemented, including structural practices, such as terraces, grassed waterways, and flood retarding structures; and agronomic practices, such as improved crop varieties and crop rotations, conservation tillage, nutrient management, more efficient irrigation, and soil health management, which involves the assessment of inherent and dynamic soil properties serving as indicators of soil function (Fox 2020; Delgado 2020). In recent decades, there has been increased recognition of the role of soil biology in maintaining the functions of hydrologic regulation, nutrient retention, filtration, buffering, degradation of organic and inorganic materials, and carbon (C) sequestration, leading to a "soil health" movement in agriculture. As the scope of conservation programs broadened and understanding of climate change increased, research programs in USDA evolved to a more systems research approach to understanding interconnected processes that impact mitigation of and adaptation to climate change to sustain agriculture, forestry, and the natural resource base (Kremer and Veum 2020; Karlen 2020; Fisher 2020).

The US Global Change Research Program was established in 1989 by a presidential initiative, followed by passage of the Global Change Research Act of 1990, which mandated that National Climate Assessments be delivered to Congress at intervals no longer than four years. Four National Assessments have evaluated climate projections, potential impacts for key sectors and regions of the United States, as well as adaptation and mitigation options (USGCRP 2018). Since then, the scientific community has applied a variety of models to evaluate soil and water processes, crop growth and management, rangelands, and watershed-scale hydrologic processes (Flanagan 2020) in order to evaluate management impacts and options. In the meteorological community, national databases of climate were developed that were applied using stochastic approaches to evaluate climate impacts on a wide range of land management and conservation practices. However, as the climate community produced ever-improving models of the global climate system, the magnitude of climate change and impacts became clearer. Specifically, simulations of land use and management and conservation practices under future climate scenarios have highlighted the serious risks to the sustainability of our food production systems and natural resource base. Increasing computational capacity with the advent of computer applications and digital imaging have enabled researchers to improve understanding of environmental services from the land on scales ranging from a soil pedon to landscapes, from genomics to ecosystems, and from in situ gas measurements to global climate processes. The new knowledge base and technology have enabled researchers to capture the transient nature of climate and to link climatic effects to land management and plant growth and on a regional and global scale.

The SWCS has undertaken a number of special projects and communication efforts that relate to climate change at the local chapter to international levels. The outcome of these efforts culminated in reports that highlighted increased risk to soil and water conservation for cropland (SWCS 2003) and a need for better understanding of and tools to deliver conservation in an age of intensification of precipitation and increased concentrated flow across the landscape (SWCS 2007).

Lessons Learned. As we moved from the 20th century into the 21st century, it became increasingly clear that we are in the midst of a changing climate. The onset of climate change has been more rapid than projected and the societal impacts more severe. This poses a challenge to accelerate efforts to develop robust new technologies and to take a systems approach to avoid unintended consequences of solutions to one problem giving rise to the next, often greater, problem. It also places a burden on practitioners to stay abreast of new understanding and technologies as they respond to immediate needs for conservation on the land. Because of the large contrasts in climate and vulnerabilities of agricultural and forestry systems across the United States, the USDA established Regional Climate Hubs in 2013 to identify critical regional vulnerabilities and impacts and to foster effective communications and partnerships to promote adaptation and mitigation strategies, practices, and technologies. The Climate Hubs have demonstrated enhanced communication within USDA; with other federal, state, and local agencies; and most importantly, across stakeholder, practitioner, and researcher networks.

Plans for the Future

Climate change is ongoing and complex within an inherently dynamic system. Agricultural and forest systems dominated by human intervention are equally complex and dynamic, spanning from the natural resource base to production enterprises to the human dimensions of food security and rural community sustainability. There are large economic, ecological, and social risks of vulnerable agricultural, forestry, and natural ecosystems exposed to climate stressors. Therefore, it is essential to develop new knowledge and technologies for adaptation at multiple scales of agricultural and forest systems and strategies to improve resilience of the systems themselves and the people dependent on them.

Adaptation is defined by the IPCC as the process of adjustment to actual or expected climate and its effects. In human systems, including agriculture, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, such as forestry or rangelands, human intervention may also reduce emissions of greenhouse gases, thereby mitigating against future intensification of climate change. Adaptation requires an understanding of climate effects, but also the capacity to resist or become more resilient to change or to transition. At some level of stress, the existing agricultural or forestry or rangeland system may become so maladapted to the prevailing conditions that transition to a different system is required. For annual crops, this may be reasonably straightforward. However, for forestry and rangelands, the long-lived, perennial species cannot easily migrate to other regions nor can new species be easily introduced. Many practices, technologies, and strategies for an agricultural or forestry system to respond to climate stresses will have both adaptation and mitigation elements, and should be approached in an integrated manner following climate smart agriculture principles (Mann et al. 2009).

The agricultural sector contributes to greenhouse gas emissions, particularly nitrous oxides associated with fertilization of crops and methane associated with ruminant livestock production and manure management. Additionally, the long history of cultivation and erosion have resulted in large amounts of soil C being emitted to the atmosphere over the centuries. However, because agriculture is based on primary production whereby plants fix CO_2 from the atmosphere into carbohydrates, the building blocks of plant and animal life, there is a large potential for agriculture to mitigate greenhouse gas emissions by sequestering C in soils and plants, particularly perennial plants or plants that are harvested as a renewable energy source.

Future Research Questions and Technology Needs. The SWCS Board of Directors adopted a position paper in 2011 stating that climate change poses a formidable challenge to food security and the environment, and that soil and water conservation could play a large role in mitigating and adapting to climate change (SWCS 2011). The position paper focused on increasing soil C, maintaining soil cover, cultivating perennial bioenergy crops, adopting agroforestry practices as buffers, targeting conservation to sensitive areas of the landscape, and increasing the efficiency of crop production inputs. Moorberg (2020) recently published an annotated bibliography about these and other conservation practices that may provide adaptation or mitigation benefits for a wide range of land uses. Because of the complex, interactive processes involved in soil, water, and biodiversity conservation, all of which are impacted by a changing climate, support for diverse, robust science and technology development is critical in several areas, including basic research in genetic and biogeochemical processes, applied science and technology development and delivery, integrated landscape-scale and systems-level research, the human dimension of soil and water conservation in an age of climate change, and knowledge science (table 1).

Goals. In the face of climate change, action is needed now. It is important to develop clear and focused goals so that actions and investments can have the greatest impacts on mitigating climate change risks and helping individuals and communities adapt to the changing conditions. The goals delineated in table 2 will require considerable public, private, and government support to move in the right direction.

Opportunities. While the challenges are daunting, there are many opportunities to accelerate our response to the changing climate to reduce future risks. With the imperative to stabilize and then reverse greenhouse gas concentrations in the atmosphere, there are opportunities for mitigation on agricultural and forestry landscapes by applying an integrative systems approach to land management and conservation that recognizes the multiple objectives and benefits needed from working landscapes (Shukla et al. 2019). In science and technology development, there are exciting new frontiers in genetics and knowledge science that can accelerate development of robust crop materials, more efficient agronomic inputs, better risk assessment, and improved models and forecasts to guide decision making. For practitioners, there is great potential in tapping entrepreneurial opportunities in consulting and marketing that will come with evolving environmental markets and climate-smart conservation technologies. For policymakers, there is opportunity to embrace the power of environmental markets and climate-smart incentives and the need to address environmental justice issues whereby the most vulnerable are most impacted by the changing climate, both in the United States and globally. As these challenges are addressed, there is a pressing need for SWCS

Table 1

Research and technology needs to advance the art and science of soil and water conservation.

Areas of research	Research and technology needs
Basic research to improve understanding of genetic and biogeochemical processes	• Support research on genomics through applied breeding to develop plant and animal germplasm, varieties, and breeds with heat, cold, drought, flooding, and pest tolerance, to enhance primary productivity. • Develop better understanding of soil health and rhizosphere processes.
Applied science and technology development and delivery	• Develop and deliver improved technologies to promote efficient use of water of varying quality and assessments of policy option impacts. • Support engineering research to improve systems, processes, and measurement capacity, including realizing the potential of unmanned aerial vehicles, remote sensing, and other high spatial-temporal data from multiple sources. • Develop and implement technological infrastructure and institutions to use big data from drones and remote sensing for adaptation research. • Develop systems that promote soil health and soil carbon sequestration on working lands.
Integrated, landscape-scale or systems-level science	• Improve understanding of how ecosystems respond to and recover from extreme events and provide education and outreach to enhance adaptive capacity. • Support landscape-scale and systems-level research to discern tradeoffs and better optimize agroecosystems to changing climates, including knowledge to guide transformational change when existing systems cannot be sustained under new climate conditions. • Develop methods for valuation of noncommodity ecosystem services. • Evaluate interactive effects of nonclimate and climate stressors on ecosystem responses.

The human dimension	• Develop improved understanding of and methods to increase adaptive capacity in the social, ecological, and economic realms and deliver programs to enhance adaptive capacity. • Conduct cost-benefit analyses of adaptation and mitigation practices and develop improved tools for life cycle analyses of agricultural systems under contrasting management, economic, policy, and climate scenarios. • Describe the effects of risk tolerance and barriers to adoption of practices and develop education and outreach programs to overcome barriers. • Use behavioral science approaches to understand and support adoption of new practices. • Apply behavioral sciences to support stakeholder/community engagement and participatory science.
Data to information to knowledge science	• Across all sectors, there is a need for improved decision support models and planning tools. Different users will have different specific requirements, but with the level of uncertainty about climate and the multiple objectives of various users, such tools can support dialog and consensus building about possible options.

Table 2

Actions needed now to secure the soil, water, and biodiversity resource base into the future.

Goals	
For protection of the environment	• Stabilize and then reverse greenhouse gas concentrations in the atmosphere. • Mitigation practices to build soil health and sequester carbon in soils and working landscapes. • Mitigation practices to help species and ecosystems adapt to changing climate. • Structural and operational mitigation of sensitive infrastructure.

For science, research, and technology	• Public support for science. • Better understanding of soil biological, chemical, and physical interactions. • Continued improvement in global climate models, adaptation models, and decision support systems. • Better understanding of ecosystem response to changing climate.
For practitioners	• Translation of science to real-world land management applications. • Interdisciplinary teams equipped with state-of-the-art communication tools. • Training and life-long learning opportunities.
For policymakers	• Translation of science to real-world policy applications. • Incentives that promote climate smart technologies and systems, and disincentives for technologies and systems that accelerate climate change. • Risk management instruments and safety net programs to support individuals and communities impacted by climate change.
For the public	• Literacy about climate, soils, water, and other natural resources. • Affordable, climate-smart products and services. • Structural and operational mitigation of sensitive infrastructure. • Support for adaptation and access to safety net programs.

to continue to lead in the art and science of conservation, to provide venues to bring together diverse groups to tackle tough issues, and to educate and advocate for conservation of the natural resource base, which we will leave to our future generations.

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Resources to Learn More

- History of Research at the US Department of Agriculture and Agricultural Research Service. https://www.ars.usda.gov/oc/timeline/about/
- More Than 80 Years Helping People Help the Land: A Brief History of NRCS. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/about/history/?cid=nrcs143_021392
- USDA Climate Hubs. https://www.climatehubs.usda.gov/
- US Department of Commerce, National Oceanic and Atmospheric Administration NOAA Research, Earth System Research Laboratory Global Monitoring Division. https://www.esrl.noaa.gov/gmd/obop/mlo/webmuseum/timeline/1956dedicationofmlo.html

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