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The Future of Soil, Water, and Air Conservation

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The Soil and Water Conservation Society (SWCS) held its 75th conference in 2020, a journey that started with its first meeting held in Chicago in December of 1946. At the time, there was not a professional society to support the new profession of soil conservation. However, Hugh Hammond Bennett, the "father of soil conservation," and a few other conservationists began discussions about the need to develop a professional society in this emerging new field. In addition to meetings, these founding members provided an outlet for research and discourse through the *Journal of Soil and Water Conservation*. Today, the SWCS (first known as the Soil Conservation Society of America) is a multidisciplinary professional society that serves as a catalyst to bring together conservation practitioners, scientists working in conservation, and other professionals working in related fields.

The chapters of this anniversary publication have primarily focused on the history of conservation during the last 75 years, with some including even earlier history. This unique collection covered the history of soil and water conservation practices, irrigation, adaptation to a changing climate, soil health, nutrient management, carbon (C) sequestration, soil and water conservation modeling, conservation policy, conservation economics, social aspects of implementation of conservation, precision conservation, water quality and quantity, and other

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related topics. Both scientific and practitioner manuscripts explored the topics to present a more complete view. The authors presented their topics from the perspective of how the history of conservation in the United States during the last 75 years has advanced the goals of soil and water conservation.

Evolution of Soil and Water Conservation

In "The Soil and Water Conservation Society: The Society's Beginning," Gantzer and Anderson (2020) described some of the early history of SWCS and reported that in the early 1900s there was a misconception that soil productivity was inexhaustible and soil fertility was permanent. The authors reported that efforts of conservationists, led by Hugh Hammond Bennett, shifted the perception that natural resources were absolute and raised public awareness that the United States needed a soil and water conservation movement and policy. The 1929 US congressional budget approved the first 10 US Department of Agriculture (USDA) research stations, which conducted soil erosion research and generated key data in the early 1900s. Gantzer and Anderson (2020) reported that Bennett used this early data, together with the detrimental effects of soil erosion leading to the disastrous Dust Bowl during the 1930s, to call attention to the need for a national policy for soil and water conservation. Bennett's work contributed to the enactment of Public Law 46, which established the USDA Soil Conservation Service (SCS) in 1935. Bennett, who was appointed the first chief of SCS, and a few other conservationists began discussions about the need to develop a professional society in this emerging new field. The field of soil and water conservation has evolved since the 1930s and has been embraced around the world, including by the United Nations, which promotes conservation agriculture for food security and sustainability.

Providing a global perspective, Lal (2020a) presented recommendations for "Advancing Climate Change Mitigation in Agriculture while Meeting Global Sustainable Development Goals." He discussed some of the sustainable development goals of the United Nations, such as ending poverty, achieving zero hunger, clean water, and sanitation, pointing out that we are behind in reaching these goals. Lal reported that if they are not achieved, it will be difficult to improve sustainability; for example, if the goal to achieve zero hunger is not met, that will continue to complicate other sustainability efforts. Lal explained how soil C sequestration, which can benefit climate change adaptation and mitigation, can also improve soil properties and advance sustainability. The information presented supports the author's conclusion that we will need to use soils to sequester C and promote soil health in order to decrease greenhouse gas emissions and achieve the goal of zero emissions by 2050. Lal argued that agriculture can be a key solution for climate change mitigation and adaptation during the 21st century, rather than a source of greenhouse gas emissions, while also addressing related environmental problems. Lal also delved into the ways worldwide restorative/regenerative agriculture can contribute to sustainable development goals. Lal reported that adoption of conservation agriculture and other practices that sequester C are critical for advancing sustainability and food security.

Importance of Social and Economic Factors

The relationship between socio-technical and economic changes during the last 75 years, agricultural land use, and soil and water conservation adoption in the United States was covered by Arbuckle (2020) in "Ecological Embeddedness, Agricultural 'Modernization,' and Land Use Change in the US Midwest: Past, Present and Future" and Morton (2020) in "Social Understandings and Expectations: Agricultural Management and Conservation of Soil and Water Resources in the United States." Morton discussed the importance of the Morrill Acts of 1862 and 1890, which formed the basis for the land grant university system, the key to transferring scientific knowledge related to agriculture. She stressed that in the last 75 years, and even since the creation of the Morrill Acts over 100 years ago, there was a social benefit in training of farmers for agricultural production. She reported that basic research in agricultural disciplines was translated for training and use by farmers to better manage agricultural systems to increase production. Morton (2020) reported that promoting the adoption of conservation practices by agricultural landowners has been a challenge since the 1935 establishment of the SCS. She noted that although farmers' decisions have always been complicated by production, price, and technology risk, public policies, insurance products, and expert advice have helped farmers manage the risk of sustainable farming practices and decisions that enhance conservation.

Economic incentives have been crucial for on-the-ground conservation practice application during the last 75 years. In "A History of Economic Research on Soil Conservation Incentives," Wallander et al. (2020) discussed the ways economic incentives have helped policymakers and conservation planners encourage practice adoption. The authors presented the early framework for applying economic tools to analysis of soil conservation as well as recent, more complex, and targeted approaches. These conservation economics efforts laid the groundwork to make environmental markets a reality today. Reed (2020) suggested in "Ecosystems Services Markets Conceived and Designed for US Agriculture" that potential market values are large and can provide economic opportunities for farmers who apply soil and water conservation practices. The potential market value is currently estimated at \$5.2 billion for C credits and \$8.7 billion for water quality credits (Reed 2020). These new pollution mitigation markets will require involvement of farmers and their advisors, corporate entities, market administrators, and verifiers. The credits that the farmers acquire by implementing best management conservation practices and soil and water conservation practices need to be quantified, monitored, and verified using satellite imagery, soil testing, and other methods. In chapter 8, Fox and Brandt (2020) presented a case study for protecting ecosystems with a water quality trading program for the Ohio River basin. They reported that there are currently 20 water quality trading programs in the United States and that a breakthrough in water quality trading was achieved by the Ohio River Basin Water Quality Trading Project (the first multistate trading program) through use of soil and water conservation best management practices to trade the benefits of ecosystems services in a watershed.

Social and economic factors influencing conservation practice knowledge and adoption are greatly affected by policy, and in the United States, farm bills have been important for development of conservation policy. Delgado (2020a) reported that agricultural legislation contributed to the development of a national policy creating the SCS and soil and water conservation policies that were catalysts in achieving one of the larger successes in natural resources during the last century: the significant reduction of soil erosion rates to improve the sustainability of agricultural systems, which are critical for food security nationally and worldwide. Agricultural legislation helped to shift the false notion that soil productivity is unaffected by poor management to the understanding that soil resources need protection as a national asset for food security. In "Soil and Water Conservation Society and the Farm Bill: A Historical Review," Otto (2020) tracked the 18 farm bills passed by Congress and explained how civic engagement and efforts such as those of Hugh Hammond Bennett, farmers, and conservationists were funneled to confront the disastrous national issues of the Dust Bowl and lost productivity from eroded soils. Civic engagement has been converted into action through a series of bills passed to address specific, timely issues over the last 75 years, benefitting the nation and the world.

Managing Water Quantity and Quality Challenges

The history of soil and water conservation in the United States and the world has shown that great challenges are dynamic, and once a given challenge is addressed, others emerge. New challenges for water resources are described by Tsegaye et al. (2020), who discussed water availability for agriculture, current impacts of management, and the potential effects of a changing climate.

They reported that agriculture in the Northeast is driven by abundant precipitation. While southeastern agriculture is also driven by rainfall, the authors noted that irrigation has increased in the region, with negative impacts to groundwater resources via groundwater depletion occurring in the Atlantic Coastal Plain, along the Gulf Coastal Lowlands, and in the Mississippi Embayment. Agriculture in the southeastern United States will potentially be negatively impacted due to a changing climate that could cause droughts and extreme precipitation events (Tsegaye et al. 2020). Additionally, although the Midwest is one of the most productive areas of the world, and it enjoys an abundant water supply driven by precipitation, it is also one of the regions of the United States that is projected to be impacted by climate change due to warmer and wetter winters and springs, more severe and prolonged summer droughts, and greater intensities of storms throughout the year (Tsegaye et al. 2020). Tsegaye et al. (2020) reported that the increased intensity and duration of summer droughts will put pressure on development of irrigation systems for this region, which will increase the use of surface water resources.

The Great Plains region is among the parts of the country that are negatively impacted by a lack of precipitation, as it is a dry region with low water availability, but it is a region where irrigation plays an important role driven by climate, with rainfall and snowfall increasing from west to east. Another important factor is that evapotranspiration increases from north to south in the Great Plains. This region, where agricultural productivity can be doubled or tripled with increased availability of water, is dependent on irrigation from surface water and groundwater resources. Tsegaye et al. (2020) reported that water availability in the Pacific Northwest is highly dependent on winter snowpack, and agriculture and intensive livestock production are driven by irrigation. A changing climate will potentially reduce western mountain snowpack and increase variation in snowpack storage of water, which will continue to drive competing demands.

Since agriculture is one of the largest water users, an important goal is increasing water use efficiency. In "Water Optimization through Applied Irrigation Research," Yost et al. (2020) reviewed irrigation systems and how they have been used to improve water use efficiency. Policymakers, scientists, engineers, practitioners, educators, and farmers have contributed to the improvement of irrigation systems and agricultural water use, and technologies have been the main reason for these achievements. Yost et al. wrote that technological advances have contributed to continued increases in irrigation optimization.

Improving water use efficiency is one way to conserve water, but another component is water quality. In "Water Quality," Delgado (2020) reported that advances during the last 75 years in soil and water conservation contributed greatly to protecting water quality. This was realized by conservationists who raised awareness of the national erosion problem, policymakers who enacted laws that protect water quality, and personnel who collected data, developed best management practices, and implemented conservation practices on the ground. Delgado asserted that one of the biggest environmental successes of the 21st century was the enactment of laws that contributed to the study of soil erosion and amazing advances in applied and basic research and technology transfer (e.g., research programs that provided data used to create the Universal Soil Loss Equation [USLE] and other models that started the quantification of how land management affects erosion). Delgado observed that the SCS transferred technology to farmers to apply conservation practices to prevent future catastrophic erosion events like those that occurred in the 1930s, and to increase conservation on the ground for food security and the sustainability of agricultural systems. The Federal Water Pollution Control Act of 1948 brought the concept of water quality to national attention and also contributed to reducing erosion and sediment nutrient transport to water systems. However, with the advent of the Green Revolution and increase in nutrient and agrochemical application beginning in the 1950s, nutrients were lost from agricultural systems. Congress responded with the Federal Water Pollution Control Act Amendments of 1972, the Clean Water Act of 1977, and the Water Quality Act of 1987 to address these developing concerns. Delgado (2020a) noted that although reduction in erosion was an incredible 20th century conservation success story that contributed to the protection of water quality, the losses of nutrients remain an unresolved environmental problem to this day. Humanity cannot repeat the errors of the past century if it is to improve future water quality (Delgado 2020a, 2020b).

Drainage of land also affects water quality and water budgets. In "Agricultural Drainage: Past, Present, and Future," Shedekar et al. (2020) discussed drainage systems in the United States related to soil and water conservation. Benefits of drainage include removal of excess surface water, improvement of trafficability, and enhanced crop productivity. Disadvantages include greater nutrient and pesticide losses through drainage pathways and loss or alteration of habitat and associated plants and animals. The authors concluded that the benefits of drainage in most systems outweighed the disadvantages. Schafer et al. (2020) presented the potential benefits of implementation of drainage water management systems in the field to improve environmental performance and farm economic viability.

Staver (2020) further described the growing role of dissolved nutrients related to water quality and soil conservation in chapter 17. He discussed the history of dissolved nutrients from the 1830s, when the moldboard plow was introduced, to current times. Excessive tillage, which causes losses of organic C and nitrogen (N), occurred through the 1940s, when yields declined due to lost organic matter and N, and continues in some areas today. The Green Revolution altered the soil nutrient balances, and soil nutrient accumulation and losses increased because of the added nutrients. To address this water quality menace, Moody and Bruulsema (2020) suggested a new nutrient management approach including use of the "4R nutrient stewardship" approach. They reported that the industry's view has changed from an approach of building depleted soil fertility to a new, 21st century approach, where the fertilizer industry considers the impact of nutrient stewardship on economic, social, *and* environmental outcomes. Moody and Bruulsema related that consumers are more aware of environmental issues related to nutrient losses, and this will put more pressure for changes at the farm level to increase stewardship.

Also related to water management and quality, Mushet and Calhoun (2020) discussed how, with regard to wetlands, management has altered during the last 75 years, changing the landscapes across different regions. The authors reported that by the 1600s to 1700s, some farmers were already working to eliminate wetlands by draining and converting them to agricultural land. This process was accelerated in the 1800s to early 1900s when advanced technology for drainage was introduced. These massive efforts to drain wetlands to increase agricultural production prior to the 1960s changed to wetland conservation beginning in the 1960s to 1970s, following recognition that wetlands provide ecological benefits (services) as an essential part of the landscape. Mushet and Calhoun made a strong case for the consideration of wetlands as an integral part of ecosystems. Lemke et al. (2020) presented the case for advancing constructed wetlands to improve ecosystem benefits but acknowledged that the primary constraint for establishment of wetlands was the cost of converting highly productive farmland acres to wetlands.

In summary, there have been tremendous achievements in preserving soil and water quality, including one of the greatest in the 20th century, reduction of erosion rates in the United States. These advances in technology increased water use efficiencies and the capability to grow more food per unit of water applied. Additionally, these advances in conservation of water quantity and quality have helped feed a large percentage of the human population. With that said, we have not resolved the challenge of nutrient losses from agricultural systems, and we continue to significantly impact water (e.g., nitrate [NO_3-N]) and air (e.g., nitrous oxide [N_2O-N], ammonia [NH_3-N]) resources. The emerging challenge of a changing climate will exacerbate the challenges in water quantity and quality, and we will need to continue finding solutions during the 21st century for water management and food security.

Advancing Assessments of Erosion and Implementation of Soil and Water Conservation on the Ground

In "Modeling Soil and Water Conservation," Flanagan et al. (2020) reviewed conservation modeling efforts during the last 75 years. They reported that the first research on water erosion was in 1917 on seven erosion plots in Columbia, Missouri, and that the creation of the USDA SCS in the 1930s provided the inception for modeling soil erosion. The SCS expanded research on the effects of water on erosion with the creation of 35 soil conservation experiment stations located across the nation. Erosion data were used for calibration and validation of mathematical equations and modeling efforts in soil erosion. Flanagan et al. reported that with the creation of the USDA Agricultural Research Service (ARS) in 1953 and the establishment of the ARS National Runoff and Soil Loss Data Center (NRSLDC) in 1954 at Purdue University, research on soil erosion increased. Both ARS and the NRSLDC, in cooperation with university cooperators, significantly advanced soil erosion modeling efforts. Flanagan et al. reported advances with mathematical descriptions of soil erosion before 1965. They also reported that the NRSLDC stored 10,000 plot years of natural runoff plot data that were statistically analyzed to develop the first erosion prediction model in 1965, the USLE, as well as the first wind erosion equation (WEQ). They observed that modeling erosion has significantly advanced with the models that followed USLE and WEQ and described the more recent models' functions and impact.

The last 75 years has seen a change in how we understand the effects of intensive agriculture on soil health. In the 1930s we used the impact of management on erosion to assess how soil productivity is diminished and how conservation practices can reduce rates of erosion and transport of sediment, soil organic matter, and nutrients off site. Kremer and Veum (2020) discussed in "Soil Biology Is Enhanced under Soil Conservation Management" how those historical goals, which initially focused on protection against soil erosion and losses of nutrients, evolved into new goals that included the care of soil biology and soil health. Karlen (2020) reviewed the evolution, assessment of, and future opportunities of soil health. He proposed that although soil health is a new concept, it has evolved slowly, reflecting SWCS efforts in areas of soil condition, management, protection, and quality. Karlen also noted that many scientists and engineers have contributed to the SWCS mission of advancing the science and art of good land and water use and have contributed to current soil health endeavors. Karlen suggested that a focus on soil health will improve soil management and can help achieve increased global food, feed, fiber, and fuel. Fisher (2020) provided in-field examples of practices that can improve soil health and build resilient cropping systems, including cover crops. The potential negative impacts of intensive agriculture to soil health and soil organic C content could be reduced by applying soil and water conservation practices or switching to less intensive management. Use of cover crops, conservation agriculture, and conservation tillage are examples of management options that can minimize losses of soil C and negative impacts to soil health.

In "Cover Crops: Progress and Outlook," Kladivko (2020) reviewed the history of cover crop use. She reported that cover crops have been used as green manures for thousands of years in China, the Middle East, and Rome to improve soil fertility. In the 1930s, Bennett recommended the use of cover crops to reduce erosion. However, after the 1930s cover crops use declined, due to the Green Revolution and intensive agriculture with increased use of fertilizer inputs, an era Kladivko called the "dark ages" for the use of cover crops. As the use of many practices, such as wetlands and minimum tillage, began to increase in the 1970s and 1980s, the use of cover crops increased, especially in areas where no-till was emerging. As we increase use of cover crops, we should use the 4Rs of cover crops as described by Delgado and Gantzer (2015), selecting the "right cover crop, using the right time of seeding and termination, using the right management practices, and planting the cover crop at the right location" (Kladivko 2020). Kladivko promoted the need to build on the research that has been conducted during the last 100 years to expand the use of cover crops. Carlson and Bower (2020) reported that from a conservation practitioner's point of view, when we use cover crops, we obtain different benefits in agricultural systems and conservation, and they can be part of the solution to many natural resource and conservation problems.

The many conservation practices that have been discussed in the chapters of this book affect soil chemical, physical, and biological properties. Several chapters have reviewed how management practices affect availability of nutrients and nutrient losses. Delgado and Sassenrath (2020) reported that 4R+ management (also called precision conservation or the 7Rs) is an approach that can help reduce nutrient transport across watersheds by connecting nutrient flows from fields to buffer areas, riparian areas, wetlands, and watersheds. Other practices affect soil health and soil biology. Arriaga et al. (2020) wrote about how physical properties of soils have changed with land management, conservation practices, and machinery during the last 75 years. Soil physics measurements are key to assessments of impacts of management and conservation efforts. Knowledge of chemical, physical, and biological soil properties has been used to develop tools that can conduct assessments of management practices. These technological advances of the last 75 years have facilitated assessments of how management can affect erosion processes or other pathways of nutrient losses, such as atmospheric and leaching pathways. Advances in basic and applied research have helped provide solutions that have been implemented on the ground for soil and water conservation.

Climate Change Creates New Challenges in Soil and Water Conservation for Food Security

Current and future conservation challenges include a changing climate. In chapter 22, Steiner and Fortuna (2020) discussed use of natural resource conservation for managing aspects of climate change. They wrote that in 1953 the soil and water conservation research conducted at the SCS was transferred to the ARS to quantify erosion processes and develop erosion prediction models. In 1956, the long-term carbon dioxide (CO_2) monitoring station at Moana Loa, Hawaii, was established, and it has been important in monitoring the effect of anthropogenic activities on atmospheric concentrations of greenhouse gases. The authors asserted that agriculture can be part of the solution to mitigate and adapt to climate change since it has great potential to mitigate greenhouse gas emissions by sequestering C in soils and plants. Steiner and Fortuna reported that it may be easier to adapt cropping systems to a changing climate than rangelands and forests systems that cannot easily migrate to other climatic regions where different species cannot easily be introduced. Lal (2020b) reported in "Conserving Soil and Water to Sequester Carbon and Mitigate Global Warming" that erosion reduces C sequestration by removing organic matter. Although some transported soil C is subject to reaggregation and stabilization, erosion significantly contributes to emissions of methane (CH_4), N_2O, and CO_2, which then contribute to increased greenhouse effects. Because of this, soil and water conservation is important for maintaining the C sequestration process in agricultural systems. Lal (2020b) argued that we need to implement soil and water conservation practices to reduce losses of CH_4, N_2O, and CO_2, which generate greenhouse emissions, and noted that cover cropping can be a significant method to reduce erosion and contribute to C sequestration. Climate change has been identified as one of the greatest challenges that we will be confronting during the 21st century by a large number of scientists and organizations, such as the Intergovernmental Panel on Climate Change (United Nations 2018).

The Future of Conservation

The chapters of this book describe the last 75 years of successes and failures in soil and water conservation; the impact that they have had on sustainability, agricultural productivity, and food security; and the potential to use agriculture for climate change mitigation and adaptation. Together, this presents a compelling case for the importance of soil and water conservation for all of humanity. The authors reviewed the past and present of soil and water conservation as well as discussed future conservation opportunities. They showed that key advances in soil and water conservation were driven by research that was used to transfer information to policymakers and inform the public of the need for soil and water conservation efforts. An example of this is the creation of the SCS and the national soil and water conservation policies that were implemented to address tremendous challenges of the Dust Bowl and loss of productivity caused by nutrient depletion in the early 1900s. This **golden era of soil and water conservation** (1930s to 1980s) saw many policy developments and the positive impacts that conservation research and practice implementation had on the land.

The greatest successes of soil and water conservation in the 20th century were driven by joint efforts of policymakers (e.g., US Congress), conservation practitioners, universities, and extension personnel—agencies that were formed during this era. These include the SCS (today known as the Natural Resources Conservation Service [NRCS]) and the ARS, federal and university scientists, farmers, the private industry, professional societies such as the SWCS, nongovernmental organizations, and others. Advances in soil and water conservation have contributed to reduced erosion, protection of water quality, and the development of more sustainable agricultural systems. There is much to learn from this era in soil and water conservation and how society responded to major conservation challenges.

In the 1950s and 1960s, society responded to another great challenge that arose as global human population exploded and food demand surged. During the Green Revolution (1950s to 1970s), one of the greatest figures was Norman Borlaug, the "father of the Green Revolution," who received the Nobel Peace Prize in 1970 for his work to intensify agriculture and increase production across the United States and the world. Research during this time had also contributed to conservation practices that were implemented to maintain the sustainability of agricultural systems. Although soil and water conservation are not often mentioned as an important factor in the Green Revolution, by conserving soils and helping maintaining the sustainability and productivity of agricultural systems during the latter half of the 20th century, soil and water conservation was indeed an essential component of the success.

New Challenges. The history of agriculture in the 20th century shows that independent of achievements and advances in soil and water conservation in one decade, they may be followed by new challenges, some that may emerge from the successful solutions to a given problem. For example, new water quality problems surfaced due to the excessive application of nutrients following the success stories of past soil conservation efforts and the Green

Revolution. It became clear by the new millennium that there are both persistent and new challenges, which include the following:

- Water quality challenges because of losses of nutrients, mainly N and phosphorus (P). As detailed in this book, N and P have been identified as major and persistent nutrients degrading water quality across the United States, contributing to hypoxic water bodies.
- A continuing need to increase agricultural production for the growing global population.
- The new effects of intensive agriculture. Although sustainability has been improved from soil and water conservation practices, intensive agriculture still contributes to loss of soil organic C and soil quality and health. (This challenge bears some resemblance to the early 1900s when the plow increased the cycling of nutrients and soil nutrient content was reduced. Today, intensive agriculture continues to reduce soil organic matter levels, and although nutrients are being applied, intensive agriculture nonetheless has some detrimental impacts on soil health and quality.)
- The new challenge of climate change. A changing climate and the occurrence of extreme weather events in some regions because of more extensive storms will increase the potential for erosion and flooding. Conversely, limited precipitation causing extensive droughts in drier climates of the country will increase the potential for wind erosion. Declining snowpack, lower water balances, and higher evapotranspiration resulting from climatic changes will likely increase demand on available surface and groundwater water resources for irrigation and reduce water for aquatic species. Climate change presents major challenges to soil and water conservation and sustainability efforts as well as to agricultural production, highlighting the need for research on use of conservation practices for climate change mitigation and adaptation (Delgado et al. 2011).

These challenges will influence environmental quality and productivity. History has taught us that to confront the soil and water conservation challenges of the 21st century, such as a changing climate, we need to use a focused joint approach that includes actions and cooperation from all stakeholders (e.g., US Congress, conservation practitioners, universities, extension personnel, federal agencies, scientists, farmers, private industry, etc.). Lal et al. (2012), in a *Journal of Soil and Water Conservation* feature paper about adapting agriculture to drought and extreme weather events, wrote, "Together, we must move away from a piecemeal and crisis-driven approach, and adopt holistic and integrated national policies aimed at sustainable management of limited and fragile natural resources."

Mitigating Soil Losses to Adapt to Climate Change Will Provide Billions of Dollars in Returns

Using the Argabright et al. (1995) assessment of the changes in erosion rates from 1930 to 1992, as well as data from a USDA NRCS (2010) report on the changes in erosion rates from 1982 to 2007, together with the history of the development of policies, agencies, laws, best technologies, and practices for soil and water conservation in the United States, Delgado (2020a) concluded that the period from 1930s to the 1980s was a **golden era of soil and water conservation**. Argabright et al. (1995) reported that the 1930s water (sheet and rill) erosion rates for crop agriculture in the northern Mississippi Valley Loess Hills decreased from 33.4 Mg ha^{-1} (14.9 tn ac^{-1}) from 1930 to 14.1 Mg ha^{-1} (6.3 tn ac^{-1}) in 1992, with 80% of the reduction occurring by 1982. The reduction in erosion rate via water (sheet and rill) and wind pathways from 1982 to 1992 was about 30% for US cropland (USDA NRCS 2010), and Argabright et al. (1995) reported a reduction of 20% for the Mississippi Valley Loess Hills region. The USDA NRCS (2010) reported a reduction in water (sheet and rill) erosion in US cropland from 9.0 Mg ha^{-1} (4 tn ac^{-1}) in 1982 to 6.1 Mg ha^{-1} (2.7 tn ac^{-1}) in 2007. For this same period, the wind erosion rate decreased from 7.4 to 4.7 Mg ha^{-1} (3.3 to 2.1 tn ac^{-1}). Delgado (2020a) extrapolated that the Argabright et al. (1995) erosion reduction estimates from the 1930s to the 1990s was a good ballpark estimate for the United States. He also used the percentage of reduction in erosion rate from 1992 to 2007 reported by USDA NRCS (2010) to estimate the erosion rate nationally. We acknowledge that erosion rates vary across the landscape and depend on many factors, including site-specific ones. For example, there are sites that are being eroded (e.g., top of a catena), sites that are receiving soil deposition (e.g., bottom of a catena), and sites that being eroded and receiving soil deposition (e.g., middle of a catena).

Delgado (2020a) estimated that by 2007 the United States was losing soil at an average rate of 0.51 mm y^{-1} (0.02 in yr^{-1}) compared to the 1930s when the United States was losing soil at a rate of 2.9 mm y^{-1} (0.11 in yr^{-1}; readers will recall that the 1930s was when the Dust Bowl occurred, before the establishment of polices and a federal agency [SCS/NRCS] to reduce erosion rates). The Delgado (2020a) rate of 0.51 mm y^{-1} strongly overlaps with the average rate of soil loss for US cropland presented by Montgomery (2007), who reported a range from 0.2 to 1.5 mm y^{-1} (0.01 to 0.06 in yr^{-1}) for US and global croplands, with an average soil loss of 0.95 mm y^{-1} (0.04 in yr^{-1}) for US croplands. The Delgado (2020a) estimate of the erosion rate for US cropland of

0.51 mm y^{-1} for 2007 agrees with the average soil loss of 0.95 mm y^{-1} reported by Montgomery (2007).

Bakker et al. (2004) reported that for every 10 cm (3.9 in) of soils lost from the surface, 4.3% of soil productivity is lost (yields are reduced). They also reported that the reduction in yields due to the erosion of the next 10 cm will be much larger since the relationship is not linear, but convex. Using the soil erosion rate estimated by Delgado (2020a), we estimate that US cropland has lost an average of 117 mm (4.6 in) of soil since the 1930s. If it were not for the critical actions that took place during the golden era of soil and water conservation, such as the enactment of key pieces of legislation and policies that contributed to the creation of the SCS/NRCS, and collaborative efforts among agencies, farmers, conservationists, universities, the private industry, and others, this loss would have been as high as 261 mm (10.3 in). These joint efforts prevented an average loss of 144 mm (5.7 in).

Using the Bakker et al. (2004) estimate of the impacts of erosion on yields, we estimate that although erosion rates have decreased since 1930, intensive agriculture has reduced potential yields by 5.2%. However, if no conservation practices were implemented, we estimate that reduction in potential yields would be close to 16.5%. This suggests that the implementation of national soil and water conservation policies and the development of best practices during the last 75 years have resulted in 11.3% higher yields than if no soil and water conservation policies or practices were developed and implemented since the 1930s. In 2019 the value of the corn crop was approximately $52.9 billion (Statista 2020a), and the wheat crop value was around $8.8 billion (Statista 2020b). From these numbers, we can estimate that the 11.3% higher productivity is equivalent to a crop production value of about $7.0 billion. If we consider the entire crop area in the United States and the economic value of all the soil conserved since the 1930s, the impact of all of the soil and water conservation policies and practices since then is likely in the hundreds of billions of dollars. This conservation analysis shows that soil and water conservation practices help agricultural systems maintain higher yields and increase crop production value by billions of dollars.

Climate change threatens to increase negative impacts to soil productivity, and there is a need to use conservation practices to adapt to this threat (Delgado et al. 2011). Pruski and Nearing (2002) reported that erosion rates will increase by 1.7% for every 1% increase in total rainfall due to climate change. If, as projections suggest, climatic changes will alter precipitation patterns (e.g., droughts that lead to increased wind erosion), we will again be facing a soil erosion menace in the next 75 years. Even with the increase of soil and water conservation efforts in intensive agriculture, it has been estimated we have lost about 11.7 cm (4.6 in) of soils during the last 75 years, which translates to a significant productivity loss. There are opportunities to use conservation agriculture, minimum tillage, no-till, cover crops, crop residue management, and other practices while considering site-specific factors to minimize the loss of soils during the next 75 years. The challenge of climate change to soil in the next 75 years is real, and its impact will be measured in how many millimeters of soil we lose each year. We can continue reducing the rate of soil loss with conservation agriculture, precision conservation, the 4Rs of cover crops, and other conservation strategies to reduce erosion and help us adapt to a changing climate. Using this assessment to project and compare the effects of climate change on future soil losses under scenarios with and without the use of conservation practices for climate change adaptation, we project that the use of these conservation practices will provide returns in the billions of dollars.

Forecasting Future Conservation Developments

It is difficult to forecast where soil and conservation may go in the future. To better understand this difficulty, consider technology 75 years ago. In 1945 there were no personal computers, no geographic information systems (GIS), no modeling, no global positioning systems (GPS), no artificial intelligence, no machine learning, no remote sensing, no drones, no big data, no Internet, no cell phones, no capability for spatial assessments of nutrient management or geostatistics, no agricultural machinery for precision management of fertilizer and agrochemical applications spatially across a field. None of these technologies were available in 1945. We simply don't know what solutions will be available in 2095 and how they will benefit soil and water conservation, nutrient management, and ecosystem services.

However, if we project where soil and conservation may be headed, a question to ask is, Where will humans be living in 2095? Will humans be living on the moon or Mars? Among the goals of space programs, such as the National Aeronautics and Space Administration (NASA) Artemis program, is to develop a sustained, long-term presence on the moon. It is unclear where we will be in 75 years as far as the potential for a permanent presence on the moon and sources of food for future exploration of space, but if we develop a permanent presence on the moon or even other planets, conservation will be at the center of future space agriculture for nutrient management and water management. Liu et al. (2016) reported on the potential to use artificial photosynthetic systems to chemically reduce CO_2 in combination with microorganisms to synthesize biomass, fuels, or chemical products. We need to ask ourselves if in the future we could capture solar energy using bioengineering with a computer chip that could perform artificial photosynthesis to feed humans and/or animals while in space or on Earth.

A second question for the future is, How will food be grown? Data suggest that most food will still be produced in agricultural fields. However, it is possible that more vertical farming will be done in urban environments or close to urban centers. Vertical farming is controlled-environment agriculture where plants are grown using hydroponics and similar techniques and are sometimes accompanied by aquaculture where fish are farmed in the same system (Wikipedia 2020). These techniques are being used today to grow food but are costly and energy dependent. While these techniques are viable in some small markets today, current projections do not suggest that these production systems will be used to feed large population centers in the next 75 years. Costs of producing food this way will have to be significantly reduced. However, it appears likely that the future of food security for humanity will depend on care of finite soil and water resources to improve water quality and soil health, and to increase agricultural productivity for a growing global population in a changing climate. One question to ask is, Could solar energy provide cheaper energy, together with more efficient management using robotics to make vertical agriculture more viable when located close to large urban centers?

There is potential for microbiome research to improve soil health understanding and connect improvements in soil health to crop quality and animal and human nutrition in the future. It is conceivable that new advances in soil biology will enable the development and application of new biostimulants (materials for environmental modification to stimulate bacteria) to soil and cropping systems as amendments to help increase nutrient use efficiencies, water use efficiencies, and yields, and possibly increase food quality and agricultural sustainability. Advances in soil biology will continue, and there is potential to maximize the interactions of soil microbes and crops to increase productivity. We may also benefit from developing a national soil repository (Manter et al. 2018). Research in these areas is needed to improve knowledge of how cropping systems, varieties, soil, and weather interact with management, and how this knowledge can be used for improving long-term sustainability. It may also be possible to learn how to use new biostimulants to address issues related to climate change mitigation and adaptation. More questions emerge: Could genetic engineering, nanotechnology, and nanorobotics in crops, animals, or microbes provide solutions in the next 75 years that could contribute to increased soil and water conservation, including regeneration and improvement of soil systems that have been degraded? What about solutions that improve monitoring of agricultural systems for better management with these technologies?

Advances in modeling are cascading, and big data, artificial intelligence, and machine learning will likely help provide solutions to challenges in soil and water resource management (Delgado et al. 2019a, 2019b). Future decades should advance robotics use in agriculture, and management methods will contribute to increased agrochemical use efficiencies and reduced environmental impacts (Delgado et al. 2019a, 2019b). Open-access databases, including Agricultural Collaborative Research Outcomes System (AgCROS), are facilitating expanded exchange of agricultural data (Delgado et al. 2018). As databases grow in the future, artificial intelligence and machine learning should enable access to large volumes of information and contribute to the development of new models and analyses across regions, nations, and the globe. Recent advances in machine learning and artificial intelligence should facilitate the development of new agronomic management practices to increase nutrient use efficiencies while reducing nutrient losses to the environment in the next decade. Additionally, new monitoring tools, sensors, and biosensors may allow better monitoring of field conditions for improvement of water management to reduce nutrient leaching and off-site transport of agrochemicals. Another question to ask is, Could robotics, artificial intelligence, machine learning, drones, and other related technologies help improve management for soil and water conservation, and improve weather forecasts to help make improved management decisions?

While the 4R approach is a helpful tactic to improve nutrient use efficiencies, to reduce transport of nutrients across a watershed it will be necessary to use precision farming and precision conservation together. This concept has been developed into the 7Rs for nutrient management and conservation, also called 4R+ (Delgado 2016; Delgado et al. 2019a). Precision conservation has the potential to improve placement and design of buffers, riparian buffers, sedimentation traps, denitrification traps, wetlands, and other conservation practices that could contribute to reducing the transport of nutrients across watersheds and subsequent environmental impacts (Berry et al. 2003; Delgado and Berry 2008). Precision conservation will also help improve the placement of waterways, contour stripping, and other conservation practices within a field. Such measures will increase the effectiveness of conservation practices in the future. When thinking about the future, there are many variables to consider, but one point is certain: no matter where we grow food or how we grow food, or what new technologies we use for agricultural production, soil and water conservation, including management of water and nutrient cycles (e.g., C, N), will need to be at the center of agricultural systems and their surrounding environments.

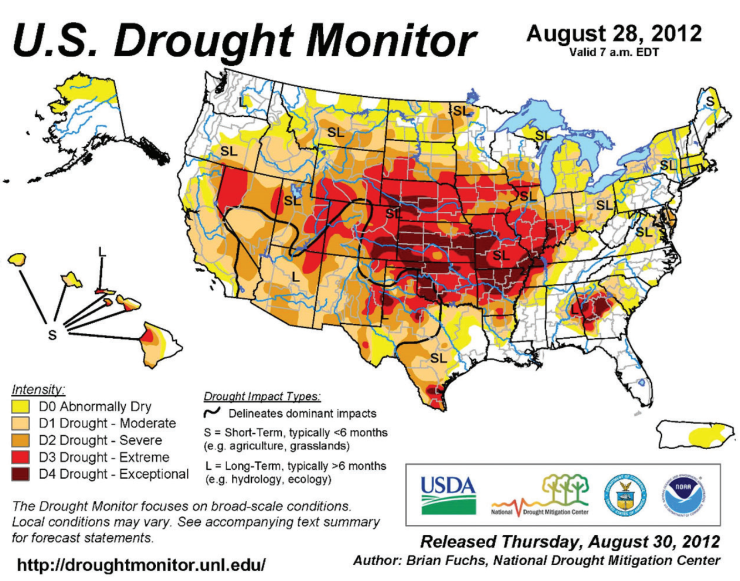
Climate Change Mitigation and Adaptation. The 21st century will be very different from the 20th, which had a more consistent, temperate climate. With climatic changes enhancing projected extreme weather events in coming years (heavy rainfall, droughts, and severe weather), we will need to factor this variability into plans to manage agricultural systems and use risk factors when we design conservation systems and make management decisions for agricultural systems. Hundred-year storm events may be bigger and may occur more frequently (perhaps to the extent that they may even become a norm), so conservation practices will need to be adjusted for the variability and intensity of these weather events, and managers will need to consider how such weather will influence nutrient losses, erosion losses, surface transport of nutrients and agrochemicals, denitrification, and atmospheric losses of N.

There still could be points in the future for a given region where the effects of a changing climate may affect water balances, temperatures, or weather to such a great extent that drastic changes may be required to successfully adapt to them. Lal et al. (2012) reported that during some years extreme weather events may be so severe that it may not be possible to adapt, as was the case in 2012 when the nationwide drought was so great that crop failure was observed at some locations (figure 1). Farmers, policymakers, and personnel working in conservation will need to consider such future changes and evaluate what will be the best crop rotation or agricultural systems, consider introduction of different crops better suited to adapt to the changed climatic conditions, or even develop and use new plant varieties. Another factor limiting productivity may be precipitation changes that alter water resources requiring adaptation of irrigation systems. For example, in regions where there has historically been sufficient precipitation but more frequent growing-period droughts are projected, farmers may need to develop water storage systems to supplement water for irrigation or develop infrastructure for pumping water from groundwater resources that are not currently used. However, if floods increase, altered drainage systems or different planting systems, such as raised beds, may need to be considered. Delgado et al. (2011) described the principles for using soil and water conservation management practices for climate change mitigation and adaptation and noted that only countries that implement policies and practices for climate change mitigation and adaptation will have the opportunity to achieve food security (figure 2).

If responses to a changing climate start influencing the choice of irrigation methods used (such as switching from surface to drip irrigation to increase water use efficiencies), farmers may need to begin to monitor the potential

Figure 1

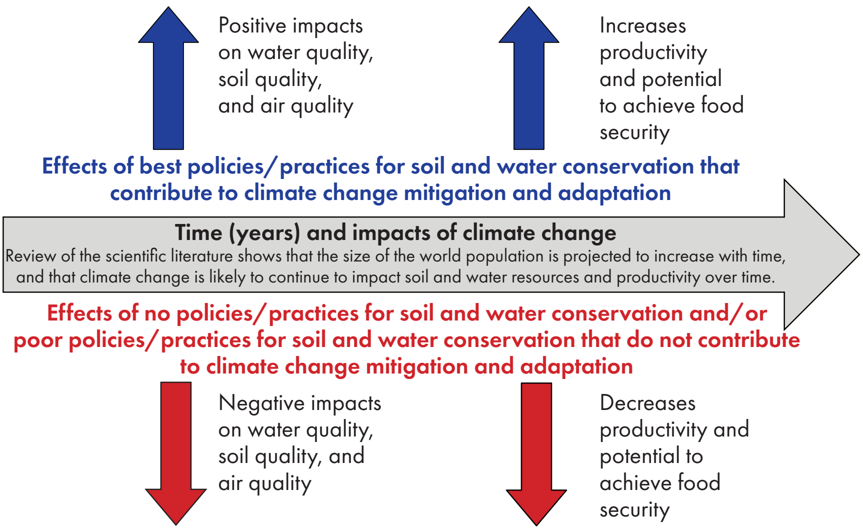
Drought severity levels across the United States. Notice the severity and extensiveness of drought across the middle region of the United States that extends from the Colorado Rockies, across the Great Plains, and to the Mississippi and Ohio River valleys (Simeral 2012; Lal et al. 2012).



effects on salinity levels and may need to consider use of varieties or crops more resistant to higher salinity. While it is difficult to predict weather changes, authors in this book present projections of future weather events that suggest shifts in the water balance for regions in the United States. Research will be needed to better integrate the use of models projecting a changing climate with erosion models to make better erosion assessments for regions and evaluate how management practices will address the projected weather changes at the regional level (e.g., Northeast, Pacific Northwest, etc.). There is also a need to connect weather and erosion analyses to models that can assess the impacts on soil health and greenhouse gas emissions. While it will surely be a daunting effort to join these models for regional evaluations, this work may be achieved within the next 75 years. Such an undertaking will require the use of open-access databases, big data, machine learning, and artificial intelligence to help in conducting regional evaluations and plans for soil and water conservation.

Figure 2

There is a close relationship between climate change, limited global water and soil resources, population growth, and food security. As climate change impacts the world's soil and water resources, it threatens to negatively impact food production (i.e., decrease food production and/or food production potential). As the climate changes, conservation practices have the potential to help us achieve maximum sustainable levels of food production, which will be essential to efforts to feed the world's growing population. Good policies/practices for soil and water conservation will contribute to positive impacts on soil and water quality, soil productivity, and efforts toward achieving and/or maintaining food security. These good policies/practices will contribute to climate change mitigation and adaptation. Poor policies/practices for soil and water conservation (or a lack of policies/practices) will contribute to negative impacts on soil and water quality, soil productivity, and efforts toward achieving and/or maintaining food security (Delgado et al. 2011).



A Bright Future in Soil and Water Conservation

Independent of future climate changes, we project that new technological advances (e.g., new varieties resistant to drought, new biostimulants, new models, and use of robotics in agriculture with machine learning and artificial intelligence) will aid in the development of new conservation and best management practices to create a changed agriculture in the 21st century. In the 1930s, a new agriculture was created with an emphasis on conservation efforts (**golden era of soil and water conservation**), followed by a period of more intensive agriculture with higher nutrient inputs and greater cultivation (**Green Revolution**). In recent decades, agriculture has increasingly been shifting to a new, smart agriculture using GIS, GPS, remote sensing, and modeling (**era of smart agriculture**). The era of smart agriculture started in the 1990s with precision farming and also encompasses the introduction of precision conservation in the early 2000s and the more recent technological advances (1990s to present). Scientific breakthroughs in biostimulants, genetic engineering, machine learning, artificial intelligence, robotics, and bioengineering will contribute to a new era in soil and water conservation during the next 75 years.

Society has learned that we need to keep conservation management at the center of land use to develop sustainable agricultural systems for food security. History shows that when we develop or implement new agricultural advances, we must conserve the soil, water, and biologic resources to provide solutions for wise land use. Cooperation among policymakers, research centers, conservation practitioners, federal agencies, the private industry, farmers, consultants, nongovernmental organizations, and all others working in conservation will be necessary to conduct research, identify and implement best practices, and confront the challenges of the future. Even if we successfully tackle current great challenges, we must remain vigilant to emerging challenges. With new tools and technologies, we must not forget to use and improve existing tools such as cover crops. We must learn from history. For example, while wetlands were once perceived as only obstacles to farming, we now understand that these ecosystems are a key component of the landscape, with essential functions for a sustainable environment and society. All working in conservation of soil and water need to be mindful to develop systems to maximize productivity and reduce environmental impacts in the future. With all the tools available in the conservation toolbox today, the future looks bright. However, as described by authors in this book, teams who have worked together in the past must continue soil and water conservation efforts, which are an integral part of both food security and national security, in the United States and globally.

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