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INTRODUCTION

Climate change impacts on soil, water, and biodiversity conservation

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The effects of the atmosphere on climate, particularly the effects of carbon dioxide (CO_2) concentration, have been studied and related to Earth's temperature by physical and climate scientists since the 1800s (Fourier 1824; Arrhenius 1896). However, as industrialization rapidly increased greenhouse gas (GHG) emissions, agriculturalists and conservationists were largely unaware of the link between fossil fuel emissions and warming in the atmosphere. Now, it is increasingly clear that the pace of climate change has been more rapid and societal impacts more severe than scientists projected.

The world's population recently passed 8 billion people and is projected to grow throughout this century to over 10 billion people. In the past year, we witnessed severe floods and droughts on all continents of the globe, often with the same region experiencing drought followed by flood. In 2022, the United Nations Climate Change Conference (COP27) grappled with the global response to climate change, reaffirming commitment to limit global temperature rise to 1.5°C (2.7°F) above preindustrial levels and establishing a mechanism for "loss and damage" funding for vulnerable countries hit by climate disasters. While climate change impacts vary from country to country, loss and damage include degradation of soil, water, and biodiversity resources. With the pressure of an increasing human population coupled with the increasing challenges of climate change, the threats to the natural resource base, global food and water security, and the world's ecosystems have never been greater.

For decades, the Soil and Water Conservation Society (SWCS) has raised the alarm about the threats of climate change to our natural resource base and the people and ecosystems reliant on that resource base. Findings highlighted increased risk to soil and water conservation for cropland (SWCS 2003) and the need for better understanding of and tools to deliver conservation in an age of intensified precipitation and increased concentrated flow across the landscape (SWCS 2007). In 2011, the SWCS Board of Directors adopted a position paper 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). In 2014, the *Journal of Soil and Water Conservation* (JSWC) published a special issue focused on impacts of climate change on agricultural productivity and the coproduction of ecosystem services (Morton 2014). With accelerating climate pressures on the resource base, this new special issue of the JSWC has been developed to advance understanding of the soil-water-climate systems and technologies and policies that can improve resilience of the agro- and natural ecosystems.

As part of the SWCS 75th anniversary publication, Steiner and Fortuna (2020) synthesized knowledge of complex, interactive processes of climate change, GHG emissions, and carbon (C) sequestration related to soil, water, and biodiversity conservation as understanding evolved through time. They identified the need for diverse, robust science and technology development 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" (Steiner and Fortuna 2020) (figure 1). In addition, they recommended education, conservation delivery, and policy actions needed now to secure the soil, water, and biodiversity resource base into the future. Their synthesis provided the framework for this special collection of papers focused on conservation implications of climate change across a wide range of agroecosystems.

Climate change impacts on soil and water conservation is the focus of thousands of research projects worldwide, so comprehensive coverage is not possible in one journal issue. However, with the imperative to stabilize and then reverse GHG concentrations in the atmosphere, there are integrative approaches for climate adaptation and mitigation that can help realize the multiple objectives and benefits needed from working landscapes. In this special issue, the authors address conservation policy, challenges in complex systems, and current understanding and tools that can help conservation practitioners to stay abreast of new knowledge and technologies as they respond to immediate needs for conservation on the land.

In the A Section papers, we focus on critical policy issues (Manale 2023; Schattman et al. 2023). In the Research Section, two research editorials (Brown 2023; Archer et al. 2023) present insights into critical concerns and paths forward for western rangelands, including the challenges of invasive annual grasses into rangelands. Research papers in this special issue synthesize findings on how climate change affects C and nitrogen (N) responses to conservation and management in rangelands (Kutos et al. 2023) and croplands (Franzluebbers 2023; Shrestha et al. 2023). Bell et al. (2023) introduce the importance

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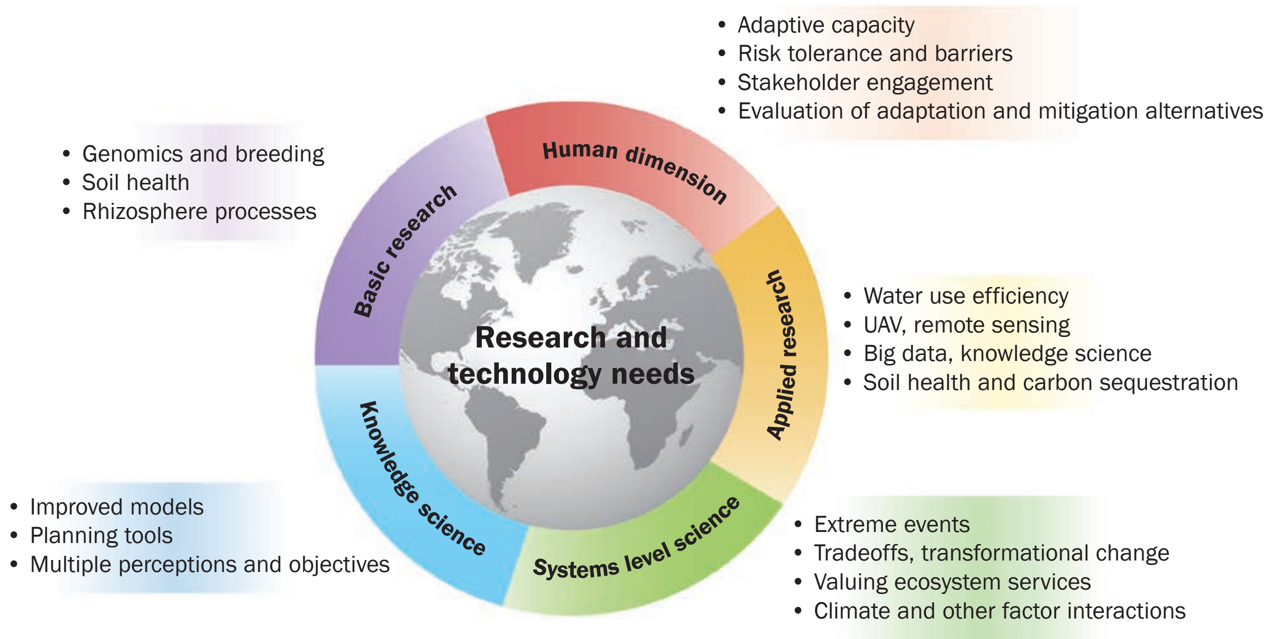
Figure 1
Complex, transdisciplinary research is needed to address basic understanding of climate change impacts on natural resources and to develop tools and methods to apply that knowledge at multiple scales (adapted from table 1 in Steiner and Fortuna [2020]).



of the soil microbiome in soil processes and elucidate soil microbiome responses to temperature, moisture, and cellulose amendments, contrasting the responses in soils from a diverse, perennial prairie ecosystem and a monoculture annual corn (*Zea mays* L.) agroecosystem. Kelly and Kebreab (2023) evaluate the potential for additives to mitigate methane (CH_4) emissions from grazing ruminants, addressing one of agriculture's largest contributions to warming potential. Watts et al. (2023) explore climate mitigation co-benefits associated with conservation practices implemented to address other resource concerns. Finally, in the last part of this special issue, Moore et al. 2023 present a framework to quantify agricultural contributions to the national GHG reductions that are needed to manage slowing the pace of climate warming and climate change to be more in line with the US Nationally Determined Contribution to the Paris Agreement.

CONSERVATION POLICY: ADAPTATION, MITIGATION, AND ENVIRONMENTAL JUSTICE

Conservation is supported through many agencies in the United States, but for working lands conservation, USDA programs are critical. Manale (2023) elucidates through an environmental justice lens how agricultural land management and conservation affect not only agriculture and those directly associated with managed land but also the population and ecosystems at large. Unfortunately, many unintended, negative consequences of agricultural management have significant effects on populations and communities that have limited ability to cope with those effects. Many USDA agricultural conservation and research programs can ameliorate the climate change impacts through integrating mitigation and adaptation actions. In an era of increasing extreme weather events, land retirement programs reduce the severity of impacts on communities located in floodplains. Targeted location of wetlands and land retirement programs can capture runoff contaminated with N, phosphorus (P), and sediment to prevent adverse impacts on water quality. Crop insurance programs can help mitigate the economic costs of extreme heat on crops and livestock, thereby reducing economic shocks in food prices. Moving forward, conservation programs and research direction need to equitably address needs of small, beginning, and minority farmers to promote agricultural productivity in the face of heat stress, pests, and drought, and support conservation practices to reduce the severity of extreme event effects on the most vulnerable communities to meet demands of environmental justice.

Schattman et al. (2023) point out that "sustainability, regenerative practices, and climate change adaptation and mitigation look different in different regions, in rural areas versus urban areas, in different agricultural sectors, and for farms of different scales" (Schattman et al. 2023). They recommend continued and additional support for farmers through research support, producer funding, technical assistance, outreach and education, and peer-to-peer learning. They further recommend integration of climate adaptation and mitigation into farm bill conservation programs and policy to ensure that federal agriculture programs and other tools for adapting to climate change are available to all who steward the land, echoing messages in Manale's (2023) paper that negative effects of climate change will fall disproportionately on those who can least afford it. Their discussion illustrates our vulnerability to supply chain disruptions similar to disruptions "associated with the COVID-19 pandemic and recent extreme weather events, which significantly challenged our ability to get food to those who need it" (Schattman et al. 2023).

CHALLENGES IN COMPLEX SYSTEMS

Complex interactions among multiple pests and the effects of climate change pose significant challenges to the management of productive ecosystems and the conservation of soil and water resources (Campbell et al. 2023). Dynamic interactions between pests are occurring at landscape scales and across multiple systems, requiring new approaches to pest management that extend beyond specific environmental contexts. Campbell et al. (2023) consider the impacts of climate change on pest movement and adaptation, identify potential outcomes for the conservation of soil and water, and highlight research and management gaps in dynamic, cross-system, pest-climate interactions.

Conservation on extensive rangelands have historically received limited coverage in the JSWC, but rangelands cover vast areas of the western United States and the world and are facing serious challenges from increasing temperature and increasing frequency and intensity of extreme events. In a broad-ranging research editorial, Brown (2023) focuses on rangeland ecosystems that have transformed or are in the process of transforming in the face of historical management and climate change to a less desirable ecological state. As ecosystems are transformed, an individual's or group's ability to adjust operations to maintain a viable, productive socioecological system is critical. Rangeland restoration typically requires high levels of input and partial abandonment or major revision of production goals and has frequently been unsuccessful. Moving forward, Brown (2023) recommends implementation of programs that include flexible, long-term financial support with opportunities for combinations of rangeland management, redefinition of ecosystem service goals, and increased technical decision support. More viewpoints and sources of knowledge are necessary to implement transformational responses to climate change.

A specific rangeland conservation challenge is invasive annual grasses, which have increasingly impacted terrestrial ecosystems across the western United States (Archer et al. 2023). Weather variabilities associated with climate change and increased atmospheric CO_2 are making the challenges of managing invasive annual grasses even more difficult. Research has focused on understanding the mechanisms underlying annual grass invasion and assessing patterns and responses from a wide range of disturbances and management approaches. For interactions of weather extremes and wildfire in the complex ecosystem, Archer et al. (2023) recommend collaboration across the research community and with land managers to develop and implement conservation and restoration practices based on human values and ecosystem resiliency. The adaptive integrated weed management (AIWM) framework described includes an eco-informatics approach based on models and scalability. Additionally, Archer et al. (2023) identify novel control methods such as biological control with endophytes that reduce competitiveness of invasive grasses and recommend better use of short-term weather forecasting to increase the odds for rangeland restoration. As for conservation of all types of agroecosystems, AIWM requires strategic planning and sustainable integrated tactics that increase ecosystem resilience in the face of climate change.

CURRENT UNDERSTANDING AND TOOLS

Kutos et al. (2023) synthesized a large body of research on rangeland ecosystems, which are a globally important reservoir for soil C. While past management of rangelands has resulted in significant losses of soil C, compost amendments have been proposed to increase soil C sequestration while providing co-benefits to rangeland ecosystems and land managers. Findings from grasslands and shrublands in eight countries and on five continents indicate that compost amendments improved net primary productivity, forage production, and belowground C content. Compost additions also increased soil stability, water retention, and nutrient availability, as well as reducing erosion. The authors found little to no effect of compost addition on plant diversity and very few studies investigating effects on soil microbial community and function. Both field and modeling studies demonstrated that the changes in soil C from compost additions can result in long-term C storage. These important findings suggest that compost amendments may contribute to rangeland resilience to climate change with the additional benefit of climate change mitigation via soil C sequestration.

Enteric CH_4 emissions is a significant contributor of US agriculture to the nation's GHG emissions. In a review paper, Kelly and Kebreab (2023) present the potential for feed additives to mitigate enteric CH_4 emissions from ruminant livestock. As the efficacy of this approach is further documented, this could provide a conservation practice to mitigate enteric CH_4 from the vast grazing lands as well confined ruminant livestock systems.

Analysis of land use impacts on C and N from research stations across North Carolina revealed that the root zone enrichment approach allowed separation of management and pedogenisis effects (Franzluebbers 2023). Variations in soil type and management within a region were equally influential in determining soil C and N contents. Root-zone enrichment of soil organic C decreased with increased management disturbance in cropland, grassland, and forest systems, with similar findings for total soil N. Root-zone enrichment provided an integrated soil profile assessment and indicated that conservation agricultural management approaches will foster surface-soil organic C and N restoration across a diversity of soil types in the southeastern United States.

In an analysis based on numerous, published field studies from across the midwestern United States, Shrestha et al. (2023) elucidated interactive impacts of multiple management practices, soil texture, and rainfall on nitrate (NO_3^-) leaching. Not unexpectedly, unfertilized perennial systems exhibited the lowest NO_3^- leaching, but even limited rotations such as corn–soybean (*Glycine max* [L.] Merr.) compared to continuous corn were beneficial. Nitrate leaching in sandy soils exhibited a greater sensitivity and amplified response to increasing N fertilizer amount, but no-tillage soil management was effective at reducing NO_3^- leaching in sandy and silty loam soils. The authors concluded that a changing climate is making it more challenging to reduce NO_3^- leaching and in some cases more drastic land use changes from row crops to perennial systems may be needed.

While other authors have taken a meta-analysis approach to synthesize findings on topics that have been widely studied, Bell et al. (2023) report on an incubation study on the soil microbiome's role in cycling and storage of soil organic C. A comparison of responses of soil microbiomes from annual monoculture (corn) and perennial diversified (prairie) cropping systems showed that perennial prairies supported more diverse prokaryotic and fungal communities compared to annual corn soil. With the addition of C, the corn microbiome resulted in significantly higher respiration compared to prairie, and that response was amplified under warmer temperatures. Under wet conditions decomposers became more abundant, while under dry conditions fungi dominated. These findings highlight the need to consider microbial functions in developing sustainable agroecosystems.

Watts et al. (2023) explored the GHG mitigation potential of conservation practices implemented to address different resource conservation concerns. They implemented studies in Ohio, Indiana, and Alabama to investigate effects of cover crops, rotation, and gypsum treatments on continuous soybean and corn–soybean cropping systems. While no consistent patterns in GHG emissions were observed across sites and years, treatment differences were observed for one or more GHG within specific years and at each site. The warmer/wetter climate in Alabama resulted in greater CO_2 efflux, while climate and soil factors at the northern sites resulted in greater nitrous oxide (N_2O) efflux. Methane emissions were generally low and the sites tended to be small net sinks of CH_4. While this study found minimal and inconsistent impacts on GHG emissions and global warming potential, the responses seen at different sites and years indicate that more controlled and focused studies on impacts of nutrient concentrations, soil microclimate, and soil properties could lead to new conservation practices to mitigate GHG emissions from croplands.

The final research paper presents a framework to estimate reductions in GHG emissions from the agricultural sector to align with the US Nationally Determined Contribution to the Paris Agreement (Moore et al. 2023). The framework was built using USDA-based publicly available inventory data and mitigation potentials from the COMET-Planner tool. The paper presents results for 2017 levels of conservation practice adoption and two 10-year growth scenarios: business-as-usual (BAU) and accelerated adoption rates. The accelerated adoption scenario indicated over twice the level of adoption and associated reduction of GHG emissions compared to BAU. Results from different farm resource regions indicate likely benefits of different programs and strategies for different regions, which can guide conservation delivery initiatives to meet national climate goals.

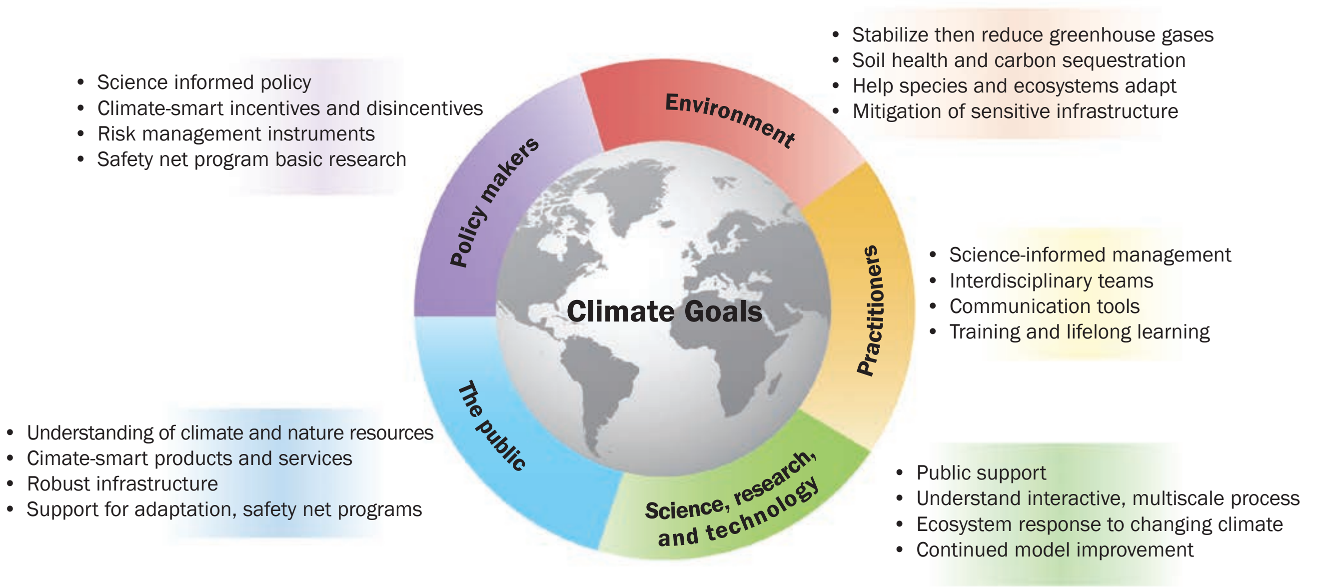
CALL TO ACTION

Steiner and Fortuna (2020) posed a call to action to secure the soil, water, and biodiversity resource base in the face of climate change that included stabilization and then reduction of GHG concentrations in the atmosphere, improving soil health and sequestering C in soils and working landscapes, developing new practices and systems to help species and ecosystems adapt to climate change, and mitigating risks to sensitive infrastructure. To meet these large challenges, they proposed specific goals for science, research and technology; practitioners; policy makers; and the public (figure 2). This JSWC special issue was developed to take stock of the current state of our knowledge, highlight complex and recalcitrant challenges that remain, and consider policy options that reduce climate change risks, promote conservation of our natural resource base, and ensure protection of vulnerable communities and people from climate impacts. Taken as a whole, the papers presented in this special issue address this call to action. The research papers share new findings related to management approaches to increase soil organic C (Kutos et al. 2023; Franzluebbers 2023) and decrease N leaching (Shrestha et al. 2023) in major agricultural land management systems. New knowledge about the importance of the soil microbiome points the way forward to improved systems in the future (Bell et al. 2023), and the findings of Watts et al. (2023) indicate that co-benefits of GHG mitigaton may be associated with conservation practices implemented for other purposes and that additional research in this area is needed. Additionally, Kelly and Kebreab (2023) present promising results for use of feed additives to reduce enteric CH_4 emissions from ruminant livestock, thereby mitigating one of agriculture's significant contribution to global atmospheric GHGs. Moore et al. (2023) present a framework to estimate conservation impacts on GHG emissions to better meet US national goals under the Paris Agreement.

Campbell et al. (2023) raise our awareness of the complex and multiscale interactions that are increasing insect, disease, and weed pressures in the face of climate change. They also point the way forward by highlighting promising new technologies and decision support systems that can enhance our ability to adapt and mitigate against pest pressures on our agricultural and natural ecosystems. Archer et al. (2023) propose new management and restoration approaches for one of the most challenging pest problems—annual grass invasion into western rangelands. Brown (2023) recommends flexible, long-term financial support with opportunities for combinations of rangeland management, redefinition of ecosystem service goals, and increased technical decision support that includes more viewpoints and sources of knowledge to implement transformational responses to climate change.

Policy at many levels shapes our options to address climate change through translation of science to real world applications. Schattman et al. (2023) advocate for incentives that promote climate smart technologies and systems. Manale (2023) emphasizes the importance of keeping environmental justice at the forefront of our actions as we develop and implement risk management instruments and safety

Figure 2
Meeting climate goals for the environment requires actions of everyone (adapted from table 2 in Steiner and Fortuna [2020]).



net programs to support individuals and communities impacted by climate change.

While climate effects on soil and water conservation are vast, this collection of papers addresses some of the issues and options for understanding and responding to the challenges to resource conservation posed by climate change and its associated effects (both direct and indirect) and interactions. They also present some important questions and viewpoints that the editors hope will inspire thoughtful action to address these urgent needs with particular attention to environmental justice.

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