Soil Science Society of America
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Soil Science Society of America Grand Challenges

We submit the following two grand challenges:

- **Grand Challenge #1**
  As soil comprises the base of the ecosystem services pyramid that sustains life on the planet, and is also the source of significant biodiversity on earth, ***our grand challenge is to understand how species abundance and distribution and coupled hydrobiogeochemical processes in soil, the most dynamic portion of the critical zone, control ecosystem services at the field and landscape scales.***

- **Grand Challenge #2**
- As soil provides the essential media for the production of food, feed, fiber, and biofuel feedstock production and the survival of past and future civilizations is linked to sustaining the soil resource, ***our grand challenge is to develop and extend information and technology needed to improve and maintain the productivity and sustainability of the global soil resource.***

Should the United States make it a priority to achieve these grand challenges?
Yes.

What existing activities in the public and private sector could the United States build on to achieve this challenge?

The public sector activities:
- National Institute of Food and Agriculture (NIFA) Hatch, McIntire-Stennis and Smith-Lever formula funding: Land Grant University (LGU) scientists, through research, education and extension, bring science into practice. USDA NIFA formula funding (Hatch and McIntire-Stennis) of experiment stations provides the base required to address local priorities and immediate concerns, while Smith-Lever funds allow LGUs to transfer new technologies and consult with stakeholders.
- Agricultural Research Service (ARS): ARS research and technology transfer programs ensure high-quality and safe food, and other agricultural products; assess the nutritional needs of Americans; help to sustain a competitive agricultural economy; enhance the natural resource base and the environment; and provide economic opportunities for rural citizens, communities, and society as a whole.
- National Science Foundation
- Department of Energy
- Environmental Protection Agency
- Department of the Interior

- The U.S. Geological Survey (USGS) which collects, monitors, analyzes, and provides scientific understanding about natural resource conditions, issues, and problems. The diversity of our scientific expertise enables us to carry out large-scale, multi-disciplinary investigations and provide impartial scientific information to resource managers, planners, and other customers.
- The National Resources Conservation Service (NRCS) which works with landowners through conservation planning and assistance designed to benefit the soil, water, air, plants, and animals that result in productive lands and healthy ecosystems.
- USDA Forest Service

Private and public sector consultants and advisers help transform research into action—e.g. the Soil Science Society of America—Certified Professional Soil Scientists and Certified Professional Soil Classifiers, Cooperative Extension, National Resource Conservation Service Personnel, and eOrganic activities all contribute to better transformation of research into practice to overcome these challenges.

Private firms invest in research and development activities to increase their expected long-term profitability. Overall, the proportion of industry R&D as a percentage of total R&D continues to grow in the United States, resulting in new products and partnerships between public and private researchers. Public and private collaborations can be beneficial for leveraging the skills and resources available to institutions and firms enabling different scales of research and development.

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What are the most important scientific and technical challenges that would need to be addressed to realize this challenge?

Grand Challenge #1

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Key Question Area:
Development of cyberinfrastructure to support multidisciplinary research in earth systems and coupled anthro- and ecosystem sciences.

Many challenges exist in multidisciplinary collaborations, yet there are also several synergies. Capitalizing on these synergies through the formation of new cyberinfrustructure technologies, data standardization and storage will be essential to successful multidisciplinary research and ultimately for the sustainable management of our earth systems.

The traditional approach to the science of complex systems such as soils has been to break the system down into various components such that experts can proceed within each sub-topic intensively. For example, mineralogists would identify clays, organic geochemists analyze humic matter, and microbiologists are experts at identifying the bacteria present. Although a great deal of successful science has occurred in this manner, a more comprehensive approach is possible and necessary to address policy considerations that depend on the ability to predict future behavior. An integrated, multidisciplinary approach is fundamentally more realistic as well because humic matter bonds to clays affecting the stability of both components, while biota interacts with all soil components simultaneously.

Key Questions:

- What computer based tools (i.e., cyber infrastructure) can we develop that will accelerate and increase discovery within integrated, multidisciplinary earth science research?
- What cyberinfrastructure tools can we develop that also improve our abilities to develop better science and engineering education materials and approaches?
- What coupled processes can be better understood and innovations developed with the use of research at the interface between scientific disciplines in the earth and coupled human/ecosystem sciences?

- What data is needed to reduce duplicity, streamline data management and storage, and elevate data quality and use in large scale earth systems evaluation and monitoring?
- What are the feedback systems operating across temporal and spatial scales that are needed to better understand issues pertaining to water quality, climate change, and extreme weather predictions?
- How do we develop coupled curricula that will compliment cyberinfrustructure technologies so that students in earth/soil science can readily and efficiently interact and compliment the work of students/researchers in other related areas?
- How do we assemble communities that can build or help facilitate the development of successful data sharing platforms?
- How can we develop and interconnect multiple databases that can process several different levels of detail for data that include spatial and temporal associations?
- How can we develop interoperable databases that allow for integration of data from multiple disciplines and tools to utilize these databases?
- What multidisiplinary graduate education efforts can be developed that involve both the physical and IST sciences to develop the new cyberinfrusctructure for earth/soil sciences?

Key Question Area:
Developing interdisciplinary approaches to managing coupled anthro- and ecosystem functions at the soil-atmosphere interface that will drive solutions for sustained human and ecosystem health, adaptation to climate change, and food and water security.

Processes that occur at the soil-atmosphere interface have a profound effect on human and ecosystem health. These processes occur at several scales, among all phases of matter, and exist within complex feedback cycles which are constantly in flux. These complex feedbacks impact the changes in atmospheric concentrations of greenhouse gases (GHGs) and ultimately exert significant control on the global climate. They also play a significant role in:

- particulate matter emission and deposition;
- essential plant nutrient levels in soils and oceans;
- the ability of soils (and oceans) to sequester carbon;
- local and regional albedo changes affecting snowpacks and snow melt;
- the distribution of pathogens; and
- human and ecosystem health.

As a result, the soil-atmosphere interface affects nearly every process on Earth controlling air and water quality. However, it is not enough to look at these processes in the context of natural systems alone. Today, anthropogenic systems are solidly entrenched in how the feedbacks at the soil-atmosphere interface function. For example, the capacity of soil to provide food and water for human systems, as well as other terrestrial life may be compromised if we do not better understand the options we have for managing them. As a result, critical information must come from new, bold, and interdisciplinary research that unearths how non-linear soil-atmosphere processes and feedbacks can be better estimated.

Key Questions:
The major scientific questions that must be addressed to find solutions to climate change, food and water security, and increased human and ecosystem health are:

- What soil factors and processes regulate gas and particulate matter exchange with the atmosphere?
- What are the critical feedback mechanisms between soils and the atmosphere related to: air quality, soil fertility, food production, ecosystem health, biodiversity, greenhouse gases, water quality, particulate matter deposition, and climate forcing?
- How have the dynamics of water, gas, and particulate matter fluxes historically responded to past/present land-cover/landuse (LCLU) change? Based on this knowledge, to what extent are they likely to change in response to predicted LCLU and climatic changes?
- How do feedback mechanisms between soils and the atmosphere differ in human-managed ecosystems from those in natural systems?
- What are the scales of critical soil-atmosphere interface processes? At what scale(s) can soil-atmosphere feedback mechanisms be modeled?
- What critical soil/vegetation parameters or diagnostics can be used to estimate the critical threshold for wind erosion?
- What critical feedback mechanisms control water vapor movement between soils and the atmosphere? How do these mechanisms drive weather and climate?
- What soil processes drive atmospheric chemistry and size, composition, and quantity of particulate matter? How can we quantify these processes?
- What effects do atmospheric chemistry and climate change have on soil biodiversity, pathogenic microorganisms, and prevalence of viruses?

Grand Challenge #2

As soil provides the essential media for the production of food, feed, fiber, and biofuel feedstock production and the survival of past and future civilizations is linked to sustaining the soil resource, ***our grand challenge is to develop and extend information and technology needed to improve and maintain the productivity and sustainability of the global soil resource.***

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Key Question Area:
Developing tools that allow us to expand on our knowledge of the rhizosphere, a cross-cutting research area with implications to ecosystem function, climate change, sustainability, and food, energy, and water security.

Research on rhizosphere processes, or the processes that occur in the area around a plant root inhabited by microorganisms influenced by plant exudates, has illuminated the intimate role these microbes play in plants accessing sparingly soluble nutrients from soil (e.g. mycorrhiza and P) or the atmosphere (e.g. Rhizobia and N). The interactions occurring at this interface area ultimately ensure the stability and productivity of both natural and agro ecosystems.

However, we still have a primitive understanding of the complex hydrobiogeochemical processes and feedback systems in the rhizosphere and the implications to nutrient and water use efficiency in plants and controls on terrestrial C and element dynamics. For example, the amount of plant exudates produced is approximately 40-50% of the total net carbon fixed by a plant, yet compared to above ground biomass, very little is known about the genetic controls over the quantity or chemical composition of these exudates. Because processes occurring in the rhizosphere influence a breadth of natural phenomena, such as nutrient acquisition, chemotaxis, water stress tolerance, disease resistance, mineral weathering, and symbiotic associations, developing a holistic understanding of rhizosphere processes is essential for understanding natural and managed ecosystem function.

Major breakthroughs in our knowledge of rhizosphere processes have been hampered by the complexity of the system as well as the lack of tools available to interrogate these systems. The advent of robust metagenomic tools, along with other "omics" technologies coupled with advanced analytical techniques and approaches, has greatly enhanced our capabilities to investigate these complex systems. We are now discovering that, together with edaphic and climactic conditions, microbial diversity in the rhizosphere can be influenced by plant species and that there are complex positive and negative feedbacks between microbial consortia and plants.

Key questions:

- What intrinsic (genetic) and extrinsic (e.g., temperature, moisture, geochemistry) factors influence plant exudate profiles?
- What are the critical positive and negative feedback systems between plants and microorganisms in the rhizosphere?

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- Do critical positive and negative feedback systems between plants and microorganisms differ between natural ecosystems and ecosystems that have been selected and managed for production of food, feed, fiber and biofuel production?
- What triggers (e.g., nutrient and water stress, infection, etc.) alter the amount and chemical composition of exudates?
- Do plant exudates control the kinetics of nutrient and water acquisition by plants, and if so, what are the mechanisms for changing rates of nutrient and water acquisition by plants?
- What is the role of plant exudates at directing biodiversity in the rhizosphere and what are the critical feedbacks with microorganisms and mesofauna?
- How does plant breeding for desirable properties from the standpoint of food, feed, fiber, and biofuel feedstock production alter the exudate profiles and, thus, biogeochemical processes below ground?
- What are the complex signaling processes between plants and microorganisms and how are the signaling cascades regulated?
- What is the role of plant exudates at controlling soil physical characteristics (e.g., soil structure) and how are they regulated?
- What is the relative role of plant exudates at fueling microbial processes that control elemental cycling in the critical zone?
- What are the roles of rhizosphere processes in species invasion?
- How can exudate profiles be modified to promote specific outcomes (e.g., nutrient and water acquisition, enhanced soil C sequestration, disease and pest resistance, production of novel enzymes, antibiotics, etc.)?

What kinds of R&D investments (e.g. supports for individual investigators, small teams, centers, research infrastructure, etc.) should the United States Government emphasize?

R & D investments are needed that support multidisciplinary, regional, and interdisciplinary efforts, as well as public-private partnerships.

What are the appropriate roles of the government, industry, academia and other stakeholders in achieving this challenge, and what new forms of collaboration should be explored? What are the appropriate roles for pre-competitive collaboration and market-based competition?

All of these stakeholders have a role. For example, academia has a role in research and education. The government has a role to develop the publically funded research, outreach, and extension. Industry's role is to take research and expand it to deliver a marketable product.

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What are the economic, ethical, legal, and societal issues raised by pursuit of this challenge? What roles are there for researchers and scholars in the humanities and the social and behavioral sciences?

The most poignant economic, ethical, legal, and societal issue raised in pursuit of this effort is intellectual property rights related to germplasm access, availability, and ownership, as well as security of research patents. Implications of these issues need to be identified and discussed before a consensus about approach can be reached.

Other ethical issues include: impact on production costs, food quantity and quality, food security, and rural economics.

Clearly, there is a strong role for basic science researchers to integrate findings with the social and behavioral sciences.

In addition to investment in R&D--what are other policies should the United States Government be considering to achieve this challenge and to realize the broader economic and societal benefits associated with related scientific and technological advances (e.g. procurement, incentive prizes, development or adoption of technical standards, international collaboration, targeted investment in education and workforce development, sponsorship of pilots or test beds, changes in legal, regulatory or other public policies)?

Workforce development in the soil sciences is essential to ensure that all levels of education and training-- middle and secondary, university and post graduate-- have the number of capable, qualified individuals required to meet these grand challenge.