FY2022 Annual Report
National Program 212 – Soil and Air

Introduction
The mission of the Soil and Air National Program (NP212) is to conduct scientific research that provides fundamental knowledge of soil-crop-air system dynamics and that leads to the development of technologies and practices producers can readily use to improve management of soil resources, reduce impact on air resources, efficiently use inputs, and contribute to ecosystems services. The vision for NP212 is productive and sustainable agricultural systems managed to optimize soil function and minimize impacts on air and water resources.

Background
U.S. agricultural production has seen enormous progress due to advances in scientific discovery, technology development, and efficient management. Despite such gains, agricultural supply chains continue to be challenged to increase production for a growing population and to do so through management that maintains farm efficiency and profitability, preserves natural resources, is resilient to changing climate, and instills public trust. The goals of NP212 are to help farmers meet their challenges through research that:

- develops fundamental knowledge of and practices for soil-based management that contribute to greater agricultural productivity, reduced reliance on inputs, resilience to disturbances, and ecosystem services.
- advances the understanding and monitoring of atmospheric emission, transport, and deposition processes, and develop management strategies and support tools to reduce the release or mitigate the effects of gases, chemical emissions, particulate matter, and odorants while ensuring productivity and ecosystem health.
- develops management practices and technologies to enhance the efficient use of manure, byproducts, and agricultural chemicals such as pesticides and fertilizers, and minimize their losses to the environment; and
- at a systems level, develops soil-crop-air strategies, technologies, and practices that ensure producers can adapt to climate change and extremes, remain resilient and profitable, and provide abundant food, feed, fiber, renewable energy, and ecosystems services.

Healthy soil is the foundation for sustainable production, and the focus on its importance continues to increase. Benefits of healthy soils include more efficient nutrient cycling and pest control, and associated cost reductions and environmental benefits of reduced reliance on inputs. Healthy soils can help increase resilience to extreme weather, such as droughts and excessive precipitation, through increased soil moisture retention and better water infiltration. Healthy soils are also associated with reduced greenhouse gas emissions and climate change mitigation, both of which are driven by enhanced soil carbon sequestration. Research in NP212 strives to develop the practices and technologies that improve soil health and the metrics for how much soil health is improving. This is a broad need for the entire agricultural community, but especially for burgeoning ecosystem services markets that are interested in establishing financial incentives for producers to adopt sustainable management.

There is growing focus on how agricultural production contributes to greenhouse gas emissions including nitrous oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4) from soils, animal facilities, and manure storage and processing. There is also interest in reducing agriculture's impact on air quality due to emissions of odors, particulate matter, and gases such as ammonia (NH_4) and volatile organic compounds from agrochemicals. NP212 research intends to more accurately monitor and quantify agricultural atmospheric emissions and develop practices and technologies for producers to reduce emissions.

Agricultural landscape management and production practices are also linked to environmental emissions, such as nutrient and other agrochemical loss to surface and groundwater. A need also exists to address emissions and the fate of high-priority biologicals, including pathogens of concern and genetic elements that confer resistance to antibiotics. Agricultural production also represents an opportunity to beneficially use societal and agricultural byproducts to improve soils and/or to improve atmospheric conditions. NP212 research focuses on developing efficient and environmentally benign uses of inputs, as well as animal manures, to optimize production and minimize their negative effects on the environment.

Agricultural production is a systems process where few, if any, farm enterprises operate in isolation. NP212 research considers systems-level processes and develops systems-level practices and technologies (such as crop rotations that provide quality animal feed, improve soil health, and provide opportunities for efficient land application of manures) that are often the most attractive and relevant options for producers to adopt on their farms. This systems research requires a combination of both physical experimentation and simulation modeling, which in turn requires a team-oriented, multidisciplinary approach to research.

2022 News for NP212

Activities and Impact: During FY 2022, NP212 had 80 full-time scientists working at 19 locations across the U.S. who were actively engaged in 22 ARS-appropriated projects, and 97 cooperative projects. Base funding for FY22 was $47.8M. NP212 scientists initiated 14 new incoming collaborative agreements, and 22 new outgoing agreements. NP212 scientists also generated 125 peer-reviewed publications, one new invention disclosure, and one new patent. There were 173 students and post-docs training within NP212 research projects, and NP212 scientists interacted with more than 1700 students at various outreach events.

Personnel News for NP212

New scientists in NP212 in 2022:

- The Sustainable Agricultural Systems Laboratory (Beltsville MD) welcomed Research Chemist **Dr. Matthew Fischel**. His research seeks to understand mineral-associated organic matter in long term cropping systems.
- **Dr. Octavia Crompton** is a Research Scientist in Hydrology and Remote Sensing Laboratory (Beltsville, MD), she joins us from Duke University where she completed a Postdoc. She earned her Ph.D. from the University of California, Berkeley. She will be working on NP212 activities but will be engaged with LTAR. She is a hydrologist and a modeler.

The following scientists retired from or left the ranks of NP212:

- Drs. Daughtry and Dr. Hunt, who provided key leadership and research contributions for the Hydrology and Remote Sensing Laboratory (Beltsville, MD), have retired.

The distinguished record of service of these scientists is recognized world-wide, and they will be missed in NP212.

Significant Accomplishments for FY2022

The following sections summarize significant and high impact research results that address the components of the FY 2021-2025 action plan for NP212. Many of the programs summarized for FY2022 include significant domestic and international collaborations with both industry and academia. These collaborations provide extraordinary opportunities to leverage funding and scientific expertise for ARS research by rapidly disseminating technology, which enhances the impact of ARS research programs.

Component 1. Develop fundamental knowledge of and practices for soil-based management that contribute to greater agricultural productivity, reduced reliance on inputs, resilience to disturbances, and ecosystem services.

Selected Accomplishments

Limited irrigation and fertigation can reduce climate impact. Irrigated farmland is some of the most productive agricultural land in the United States, but observations indicate that it is challenging to maintain crop yields and nutrient availability when water supplies are limited. ARS researchers in Fort Collins, Colorado, and Colorado State University collaborators tested alternative approaches to limited irrigation and other water saving strategies, including drip fertigation where nutrients are also delivered via precision-placed irrigation system. Researchers found that limited irrigation reduced greenhouse gas emissions (GHG) by from 15 to 50 percent and conserved water but reduced maize yield in some years. Findings also generally indicated that an irrigated drip fertigation system deployed in a sandy loam soil with little organic matter resulted in total GHG emissions that were one-tenth of literature-based measurements from sprinkler-irrigated maize systems. Both conserving water and reducing GHG emissions will be increasingly vital in developing sustainable agricultural systems in the arid U.S. West. These extremely low GHG emission values will be used to further refine the U.S. Agriculture and Forestry Greenhouse Gas Inventory, which catalogs best agricultural management practices.

Humic products benefit corn grain yield. Humic products are liquid or solid materials that are made from young coal deposits. Vendors claim that applications of humic products can increase crop growth and fertilizer use efficiency. To test these claims, ARS scientists in Ames, Iowa studied how the application of humic products affected the growth of corn that had received five different rates of nitrogen (N) fertilizer amendments. At the higher N rates, the humic treatments led to significant increases in grain yield that exceeded yields resulting from N amendments alone. These results suggest that humic use can replace some N fertilizer input while still meeting grain yield targets and might indicate that the humic substances enhanced crop use of applied N fertilizer. However, at lower N rates humic applications led to lower grain yields, and observations indicated the reduced yields resulted from late-season growth inhibition. These findings suggest humic products are biostimulants that promote plant growth, but their effects do not include influencing the availability of soil nutrients. These findings are useful to researchers who study the benefits of using humic products to enhance crop growth, the humic product industry, and land managers who seek to avoid excessive N fertilizer applications and reduce N losses to the environment.

First continuous soil property maps for Quapaw Tribal Lands. Tribal Reservations have only very basic soil information relative to other U.S. agricultural producers, and this information deficit creates a critical need for soil management tools for enhanced food security on Native American Tribal Lands. ARS researchers in Fayetteville, Arkansas, created the first high-resolution digital maps of soil properties of Quapaw Tribal Lands for sustainable soil resource management. These high-resolution soil property maps set the baseline for versioning and production of new spatial soil information for the Quapaw Tribal Land for crop suitability maps and sustainable intensification. Current and future map versions will be used for soil, crop, and land-use decisions at the farm and Tribal-level for increased agricultural productivity and economic growth.

Maximizing the productivity and benefits of silvopasture grazing systems. Silvopastures combine animal and tree production in one agroecosystem and may be a mechanism to mitigate agronomic risk by allowing producers to respond to variations in markets while providing ecosystem services such as reduced cattle heat stress during summers and greater carbon sequestration. It is anticipated that these types of multifunctional systems will be one route to enable sustainable intensification under changing climate conditions. ARS researchers in Fayetteville, Arkansas, used global positioning system (GPS) cattle tracking devices to tease out soil-tree-forage-animal linkages in a 17-year agroforestry site. They found cattle prefer grazing (88% greater) native grasses compared to introduced forages in silvopastures, and that soil moisture status and associated nutrient distribution and root decomposition can be used as indicators of animal grazing preferences across landscapes. Using machine learning approaches, scientists determined that water distribution patterns drove grazing response and that animal grazing preferences were influenced by forage quality and soil nutrients. Results illustrate how digital tools can be used to improve silvopasture utilization and enhance ecosystem services in these systems and associated pastures. These improvements would allow for sustainable intensification of forage-based livestock production to meet growing protein demands and the need for environmentally responsible production.

Component 2. Advance the understanding and monitoring of atmospheric emission, transport, and deposition processes, and develop management strategies and support tools to reduce the release or mitigate the effects of gases, chemical emissions, particulate matter, and odorants while ensuring productivity and ecosystem health.

Selected Accomplishments

Model development and improvement for national greenhouse gas (GHG) inventories and decision support tools. ARS researchers have provided substantial advancements to our ability to accurately estimate GHG emissions and to implement practices that reduce these emissions. For example, ARS researchers in Fort Collins, Colorado, collaborated with Colorado State University to calibrate DAYCENT (Daily CENTURY) with high frequency nitrogen oxide (N_2O) observations from gas flux towers, and validated their findings with observations from additional experimental sites. Improving the model resulted in an average 22 percent increase in emission estimations from 1990 to 2017 relative to the previous inventory. Additionally, ARS in Fort Collins and in Corvallis OR contributed to the development of the interactive Carbon Reduction Potential Evaluation Tool (CaRPE Tool), which couples cropland and grazinglands data from the USDA Ag Census with county-level GHG emission reduction coefficients reported in COMET-Planner for the United States. Data from the CaRPE Tool have been used by American Farmland Trust in sworn testimony before the Congressional House Select Committee on the Climate Crisis to explore the potential role of agriculture in reducing GHG emissions and combating climate change. State summary reports from CaRPE tool implementation have shown how adopting conservation practices could help reduce GHG emissions and similar findings have been transferred to non-governmental organization partners (e.g., the U.S. Climate Alliance, The Nature Conservancy) and 23 state agricultural departments to prioritize the implementation of GHG-mitigating conservation practices in agriculture.

Conservation practices to reduce nitrogen (N) loss. Croplands with corn and soybean in the central United States are highly productive, but they pose a risk to the environment when N is lost as nitrate in subsurface drainage or as gaseous nitrous oxide (N2O) emissions. Sustainable farming management practices that reduce these impacts without sacrificing yield are needed. ARS scientists in Ames, Iowa, assessed both nitrate losses and N2O emissions in cropping systems using two conservation practices: cover crops and no-till management. Overall, neither practice consistently reduced both nitrate losses and N2O emissions, indicating the two are not linked. No-till management did not affect either one. Cover crops reduced nitrate losses but not N2O emissions. Rather, greater N2O emissions were linked with fertilizer N applications and weather patterns. It was discovered that in these systems, the mechanisms regulating nitrate loss and N2O emissions were not linked. Therefore, it will be necessary to combine multiple conservation practices to reduce environmental impacts from N amendments in these systems.

Component 3. Develop management practices and technologies to enhance the efficient use of manure, byproducts, and agricultural chemicals such as pesticides and fertilizers, and minimize their losses to the environment.

Selected Accomplishments

Recovering and expanding manure's fertilizer value for a secure U.S. agriculture. Recent and unprecedented fertilizer cost increases are impacting agricultural production, causing food prices to skyrocket and increasing concerns over national and international food security. The USDA "Manureshed" management research program was developed to examine the entire spectrum of manure production, distribution, use, and economics. It has also developed innovative systems to recycle fertilizer nutrients between U.S. animal and crop production systems, effectively turning these agricultural waste byproducts from a liability into a beneficial resource for crop producers and a source of income for livestock producers. Led by ARS scientists in USDA's Long-Term Agroecosystem Research (LTAR) network, Manureshed takes advantage of USDA's extensive data systems, stakeholder networks, and innovative technologies to identify and promote efficient and impactful opportunities for manure nutrient recycling across agricultural supply chains. Manure brokers used products from the Manureshed initiative to develop a market platform that connects animal producers who have surplus manure with crop farmers who can use it. Manureshed data and concepts have been integrated into continuing education curricula for extension agents, and USDA’s Economic Research Service is using expertise from the Manureshed initiative to write a national-level report on manure recycling that will be a useful resource for researchers and stakeholders. These results have identified opportunities to improve the use of manure fertilizer across much of the United States, with major cost savings expected in the crop farming sector where manure is used instead of expensive commercial fertilizers.

Identifying and reducing contamination risks in Minnesota public wells. Public wells that provide drinking water for many communities can be contaminated by fecal material from humans, agricultural livestock, and/or wildlife. This fecal material can contain pathogenic microorganisms that cause gastrointestinal infections in humans, but the risk of infection associated with this contamination is unknown for most locations in the United States. ARS researchers in Marshfield, Wisconsin, collaborated with the U.S. Geological Survey and Minnesota Department of Health to estimate the risk of infection for public wells using an approach called quantitative microbial risk assessment. Risk estimates were based on nine different waterborne pathogens measured in nearly 1,000 water samples collected from 145 public wells throughout Minnesota. Results indicate that the risk was highest for public wells that provide water for people outside their homes such as from places served by non-community wells - like those found at rural restaurants or gas stations, and lower for public wells that provide residential drinking water to homes. However, the ability to reduce infection risk by disinfection of public well water was unexpectedly low. Risk estimates were dominated by the protozoan parasite Cryptosporidium, which is resistant to the predominant forms of disinfection used in the study (e.g., chlorine disinfection). Infectious disease risk could thus be reduced by adding additional treatment steps such as filtration or ultraviolet disinfection, particularly to non-community public wells, creating safer drinking water conditions for all.

Removing antimicrobial resistant bacteria from manure prior to land application. The presence of bacteria (including pathogenic and antibiotic resistant strains) in manure is an impediment its effective utilization in agricultural production. Manure treatments have been developed to remove pathogens, but the treatments had not been evaluated for how well they remove the antimicrobial resistant bacteria and their resistance genes. ARS researchers in Bowling Green, Kentucky, along with Western Kentucky University scientists, evaluated the impact of three commonly used manure treatments. They found that covered lagoons, anaerobic digestion at higher temperature, and properly managed composting were effective in removing resistance genes. Reductions in covered lagoons can be enhanced if followed by other post treatment methods such as biofiltration. They also found that anaerobic digestion at elevated temperatures significantly reduced levels, and while straight composting of raw animal manure reduced levels, anaerobic digestion of the compost can reduce levels more than 80 percent. These findings indicate that the three methods are effective and highlight the need to choose proper treatment technologies to mitigate antibiotic resistance when other co-benefits are also possible (e.g., production of biofuel from anaerobic digestion, or of compost for biofertilizer). By improving the safety of the resulting manure products, these technologies will also lead to healthier environments as well as economic incentives for their wider utilization by manure producers and users.

Applying the One Health approach to study foodborne infections. It is critically important to use a One Health approach to determine the burden of foodborne pathogens along beef cattle processing and distribution chains and develop microbial risk assessment and mitigation strategies. ARS researchers in Bowling Green, Kentucky, collaborated with international researchers at Addis Ababa University and Ghent University to study the prevalence of *Salmonella* and *Escherichia coli* O157 in cattle, retail beef, and diarrheic patients. *E. coli* O157 was detected at about the same proportion from cattle (7 percent) and retail beef (6 percent), and half as frequently in diarrheic patients (3 percent). Genetically similar strains of *E. coli* O157 were obtained from cattle, retail beef, and humans, suggesting potential cattle -to-human transmission through beef. The team also found considerable *Salmonella* contamination of retail beef and shared genetically similar strains between cattle and retail beef. Although the link with humans could not be established, the propensity of *Salmonella* transfer from cattle to retail beef is a potential public health risk, and the genetic similarities indicate that the cross contamination likely occurs at the slaughterhouses. This information can help improve hygienic practices, guidelines and policies for slaughterhouses and retail shops through training and process control to ensure meat safety.

Component 4. At a systems level, develop soil-crop-air strategies, technologies, and practices that ensure producers can adapt to climate change and extremes, remain resilient and profitable, and provide abundant food, feed, fiber, renewable energy, and ecosystems services.

Selected Accomplishments

Demonstrating the benefits of high utility crop rotations. In 2000, ARS researchers in Brookings, South Dakota, established a replicated no-till field experiment comparing a 2-year corn-soybean crop rotation with a set of 4-year crop rotations containing corn and soybean. Increases in crop rotational diversity led to increased yields of greater than 20 percent and greenhouse gas emission reductions of more than 20 percent. The diverse rotations also increased sequestered soil carbon (C); suppressed plant pathogens; and, from an economic perspective, reduced input costs by 14 percent. The rotation treatments have completed five full cycles and prompted other national and international multilocation studies across a range of soil and climatic conditions. Results from all these studies demonstrated that diverse crop rotations produce higher yields that increase with time and that yield stability increases in the face of adverse growing conditions. Diverse crop rotations increase soil C via modification of the soil microbial community and increased soil C is associated with increased plant available water and resistance to drought. These efforts will also help improve standardized testing procedures to verify the success of improved management practices and they provide a robust foundation for decision making and policy formulation that advance sustainable food production systems around the globe. Results have been shared with local NRCS and conservation districts, the South Dakota Soil Health Coalition, and U.S. Northern Plains producer groups. They have applicability to corn- soybean production regions in the United States, Canada, and Europe. Increased adoption of these practices will lead to improved economic and agroecosystem sustainability and productivity for multiple regions of the United States and other countries.

Improving soil carbon predictions under future climate change scenarios. Soil organic carbon (SOC) accumulation/depletion models help us understand climate change impacts arising from and impacting agriculture. One key challenge in most of these models is their ability to accurately represent soil processes that affect SOC storage. ARS researchers in Pendleton, Oregon; Beltsville, Maryland; and Lincoln, Nebraska, worked with researchers at the Woodwell Climate Research Center and University of Nebraska-Lincoln to fine-tune the potential carbon pool decomposition rates in the widely used DAYCENT model with measured SOC data obtained from long-term ARS studies. They then compared output from the modified model to output from the default model to evaluate how the measured SOC data affected current and future scenarios of climate change impact on SOC storage in the U.S. Great Plains region. The modified model generated more accurate predictions of current SOC levels and SOC losses in croplands, managed grasslands, and soils converted from native vegetation to cropland. When applied to future projections of SOC loss or gain, SOC losses were predicted under all modeling scenarios by both models, but the modified model projected losses by the end of the 21st century that were 3 percent higher in croplands and 29 percent higher in grasslands, compared to the current model. These results with the improved modified DAYCENT approach give soil carbon modelers and scientists a more accurate model and updated information to address climate change impacts on farm systems. Policymakers can use the information to adjust climate change projections and their potential short- and long-term impacts on agriculture.