FY2023 Annual Report
National Program 212 – Soil and Air

Vision
Productive and sustainable agricultural systems managed to optimize soil function and minimize impacts on air and water resources.

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 helps develop 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.

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.

The three main components of the 2021-2025 Soil and Air Action Plan are:

- Soil Ecosystem Research
- Atmospheric System Research
- Agroecosystem Inputs and Byproducts Research

Activities and Impact: During FY 2023, NP212 had 84 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 FY23 was $50M. NP212 scientists initiated 17 new incoming collaborative agreements, and 20 new outgoing agreements. NP212 scientists also generated 142 peer-reviewed publications, two new invention disclosures, and filed one new patent application. There were 177 students and post-docs training within NP212 research projects, and NP212 scientists interacted with more than 4500 students at various outreach events.

Significant Accomplishments for FY2023

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 FY2023 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

Matching biochars to soil types can improve carbon and nutrient cycling. Biochars are made from high temperature, low oxygen combustion of plant or waste materials. They may have environmental and production benefits when applied to agricultural soils, but this depends on the biochar properties, which are a function of how the biochars are made. ARS researchers in Morris, Minnesota, and University of Georgia collaborators conducted short-term laboratory incubations to evaluate how adding poultry litter-based or pine chip-based biochars to two Georgia soils affected carbon sequestration and nutrient delivery. The ability of these biochars to improve soil carbon content and nutrient cycling depended on specific properties. This cost-effective laboratory screening approach can help scientists and eventually land managers design biochars suitable to specific soil types, thus improving the likelihood that biochar land applications can achieve desired, site-specific benefits.

Cover crops increase soil organic carbon and corn yields. The impact of cover crops on soil carbon is often inconsistent, and research is needed to estimate their benefits at regional to national scales to help conservation agencies like the Natural Resource Conservation Service assess the benefits of cover crop incentive programs. ARS researchers in Morris, Minnesota, contributed to a meta-analysis of published literature that assessed how cover crops in corn systems increased soil organic carbon. They estimated that current cover crop/corn production systems are sequestering 5.5 million tons of carbon per year in the United States and have potential to sequester 175 million tons per year globally. In addition to increasing soil organic carbon, adopting cover crops into a production practice increased corn yields by 23 percent. Climate scientists and action agencies can use this integrated analysis to improve carbon inventory estimates and validate the value of cover crops as a climate smart practice.

Quantifying how conservation programs reduce GHG emissions. To provide land managers, producers, and researchers with estimates of how climate-smart conservation might reduce GHG emissions, ARS researchers in Corvallis, Oregon, and Fort Collins, Colorado, developed the web-based, interactive Carbon Reduction Potential Evaluation (CaRPE) Tool (https://carppe.shinyapps.io/CarpeTool/) to visualize and estimate the climate benefits of implementing conservation practices on croplands and grazing lands. The scientists developed a framework for applying CaRPE-based estimates to croplands under six management practices and the Conservation Reserve Program (CRP) for existing (2017) and projected practice adoption rates. Current estimates suggest that 134.2 M tonnes of carbon dioxide equivalents (CO2e) per year have been or continue to be reduced by these conservation practices on a cumulative total of 133.5 Mha of cropland. Projected estimates, assuming a business-as-usual scenario, predict an additional reduction potential of 48.7 M tonnes CO_2e per year over the next 10 years. CaRPE and this new assessment framework provide land managers and conservation planners with tools for optimizing and selecting conservation practices that could maximize the reduction of GHG emissions.

Fungal inoculation enhances nutritional crop quality. Arbuscular mycorrhizal fungi (AMF) are naturally occurring soil fungi that form symbiotic associations with plant roots and can enhance plant mineral nutrient uptake. However, their development as agricultural products has been limited by their complex genetics and technological challenges to their cultivation. ARS researchers in Wyndmoor, Pennsylvania, used controlled inoculation trials to identify favorable AMF biofertilizer compositions to improve crop yield and crop nutritional content. In addition to enhancing mineral nutrient content, inoculation trials of potatoes, beans, asparagus, wheat, and oats confirmed that AMF are involved in plant bioaccumulation of the antioxidant ergothioneine, an amino acid synthesized by only fungi and certain bacteria. Ergothioneine recently gained significant attention as a vitamin that prevents neurodegenerative disorders and cardiovascular disease in humans. Inoculating native soil with AMF spores doubled the ergothioneine content of wheat and oats, which are widely consumed cereal grains whose nutritional fortification has potentially far-reaching public health benefits. Inoculation of another staple crop, potatoes, increased tuber ergothioneine content nine-fold and overall antioxidant activity more than two-fold. This research will help develop crop-specific formulations of AMF biofertilizers to improve crop yields and the nutritional quality of food.

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

Soil additives used to reduce N_2O emissions have unintended water quality impacts. Nitrous oxide (N_2O) soil emissions account for more than 50 percent of the total GHG budget of the U.S. agricultural sector. Many approaches are being investigated for reducing N_2O emissions, including products that contain nitrogen-fixing microbes (NFM) or chemicals such as urease inhibitors (UI) and nitrification inhibitors (NI) that target specific microbial processes driving emissions. In a 2-year field study of corn production, ARS scientists in St. Paul, Minnesota, found that the benefits of these additives for reducing N_2O emissions were counteracted by increased leaching of nitrate out of the root zone, which can negatively affect local and regional water quality. In some cases, the increased nitrate leaching completely offset the reduced N_2O emissions after accounting for the potential conversion of nitrate to N_2O in receiving waters. These results will help researchers, policy makers, and regulators identify and develop agricultural management practices that can consistently and effectively reduce the footprint of U.S. agriculture.

Tannins in cattle diets reduce GHG emissions from manure. Plant tannins have shown promise in reducing GHGs from various agricultural activities; however, data are lacking on how plant tannins affect methane and nitrous oxide emissions from dairy cattle manure. In one experiment, ARS researchers in Bushland, Texas, and Lincoln University (New Zealand) founds that adding tannins to dairy heifer feed reduced urine nitrogen by 12 percent, which in turn reduces the manure nitrogen that leads to nitrous oxide emissions. In another experiment, the ARS scientists and Texas A&M AgriLife Research collaborators found that adding condensed tannins (CT) directly to dairy cattle manure at two dose levels (4 percent and 8 percent) reduced cumulative nitrous oxide emissions by more than 40 percent. Based on these 'proof-of-concept' results, CT appear to be a promising method for reducing GHG emissions from composted dairy cattle manure. Further research is needed to determine the long-term effects of CT treatment and the feasibility of scaling up CT application to dairy cattle manure at dry lots typical of the Southern High Plains.

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

Reducing methane emissions from swine manure. Typical swine manure management using anaerobic lagoons causes substantial methane emissions and increases agriculture's GHG footprint. Retrofitting lagoons with solid-liquid separation to remove volatile solids modules could help reduce methane emissions, but quantitative reduction measurements are needed to design best management practices. ARS researchers in Florence, South Carolina, quantified methane emissions using two full-scale swine waste treatment systems, a conventional lagoon-based system and an experimental lagoon-based system retrofitted with a solid-liquid separation module. Methane emissions were 65.9 percent less with the solid-liquid separation treatment, and average annual methane emissions were 20.3 kg in the baseline scenario and 6.9 kg methane per finishing pig in the experimental scenario. This new information will help effectively mitigate methane emissions from regional manure management.

Nitrogen management reduces fertilizer inputs for sugar beet. As crop genetics and agricultural practices change, research is needed to make sure fertilizer practices are continuously updated so fertilizer inputs match crop demand. This helps reduce overapplications that can cause unnecessary costs to producers and detrimental environmental impacts such as N_2O emissions and nutrients in groundwater or downstream surface waters. ARS researchers in Kimberly, Idaho, developed a new "static-range" nitrogen fertilizer application approach for sugar beet production to replace the widely used "yield-goal" approach. At current sugar beet yield levels and nitrogen fertilizer prices, the "static" approach will reduce fertilizer application rates by 60 to 80 lb/ac, saving growers $42 to $56/acre or upwards of $9 million dollars annually. The approach was adopted by the Amalgamated Sugar Company and the University of Idaho in production guidelines and has been implemented across the production region where approximately 20 percent of U.S. sugar beet production is concentrated.

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

Remote sensing technologies improve Maryland cover crop programs. Winter cover crops are gaining importance as conservation tools in the Chesapeake Bay watershed for outcomes like increasing water infiltration, reducing soil erosion, improving soil nitrogen, and possibly sequestering carbon in soils. The Maryland Department of Agriculture (MDA) created a popular cost-share program with specific planting and termination requirements to encourage cover crop use. Participants typically report cover crop termination dates that are verified through labor-intensive field visits. Using remote sensing imagery, ARS scientists in Beltsville, Maryland, developed a within-season termination (WIST) algorithm and refined it for the freely available Harmonized Landsat and Sentinel-2 (HLS) data to detect cover crop termination dates. In related research, the Beltsville scientists, along with the U.S. Geological Survey and MDA, evaluated the program's new delayed termination (after May 1) incentive designed to promote springtime biomass accumulation. They studied cover crop biomass, nitrogen, and carbon accumulation with regular- and delayed-terminated fields using satellite remote sensing and in situ measurements. The delayed-termination fields accumulated additional biomass, nitrogen, and carbon, and were found to be more cost-effective than early-termination base payments. Combined, this remote sensing research offers valuable support for the cover crop program by reducing staff field visits by half and improving the potential for beneficial agroecosystem services.

Measurements quantify the importance of spring soil nitrous oxide emissions. Soil emissions of nitrous oxide (N_2O) account for more than 50 percent of the total GHG budget of the U.S. agricultural sector. Accurate estimates of N_2O emissions from all agricultural sources are needed to identify practices that can reduce emissions and track how management mitigates emissions. ARS researchers in Fort Collins, Colorado, and university partners used bottom-up modeling and atmospheric gas inversions to quantify large, snowmelt/soil thaw-induced N_2O pulses in the north-central U.S. region during early spring. They found these pulses increased annual N_2O emissions from croplands and grasslands by 6 to 16 percent. These improved estimates are now being incorporated into the Environmental Protection Agency's annual Inventory of U.S. Greenhouse Gas Emissions and Sinks.

Measuring in-season soil nitrogen predicts corn yields after legume cover crops. Winter cover crops are gaining importance as conservation tools for increasing water infiltration, reducing soil erosion, and improving soil nitrogen use for crop production. Producers are especially interested in knowing if growing legume cover crops that fix nitrogen can supply nitrogen to subsequent cash crops and help reduce fertilizer applications. However, nitrogen availability following cover crops is difficult to predict because it depends on seasonal patterns of nitrogen transformations that are site- and year-dependent. ARS researchers in Brookings, South Dakota, implemented crop rotations at two sites to evaluate how fall rye, sweet clover, and vetch cover crops affected nitrogen availability to the following corn crop under no-till conditions. Corn yields were greatest following legume cover crops (sweet clover and vetch), and soils had the most nitrogen availability both seasonally and at times of peak corn nitrogen demand. The researchers compared numerous methods for estimating soil nitrogen availability after cover crops and found that an in-season nitrogen mineralization measurement better estimated corn yields than measurement approaches using pre-season soil nitrogen or cover crop biomass and nitrogen content. These results are critical for developing new soil testing approaches that producers can use to determine fertilizer nitrogen application rates following legume cover crops.

Nitrogen loss risks with relay-and double-cropping practices. Relay cropping soybean with a winter oilseed crop in the Upper Midwest could potentially increase farmer revenue while providing the environmental benefits of a winter cover crop. As part of work conducted in the Upper Mississippi River Basin Long-Term Agroecosystem Research (LTAR) network, ARS researchers in Ames, Iowa, compared the environmental and agronomic performance of a corn-soybean rotation with a relay cropping system of corn-winter camelina-soybean. Despite the inclusion of a winter cover, the winter camelina system did not reduce nitrate leaching, and management changes to accommodate the winter camelina crop increased nitrous emissions three-fold in the camelina-soybean phase of the relay cropping system. Most of this increase occurred following fall fertilizer application to the camelina, whereas later spring sidedress-nitrogen applications resulted in only minor increases in nitrous oxide emissions. This study provides scientists and growers working to develop the winter camelina relay cropping system with new information and tools for optimizing production and reducing nitrogen losses to the environment.