FY2018 Annual Report
National Program 212 –Soil and Air

Introduction

The Soil and Air National Program (NP212) conducts research that seeks to improve the quality of atmospheric and soil resources that both affect and are affected by agriculture; to understand the effects of climate change on agriculture; and to prepare agriculture for adaptation to climate change. Its research focuses on science-based approaches that (1) expand, maintain, enhance, and protect soil resources essential for U.S. agricultural production; (2) optimize the management of crop nutrients and greenhouse gas emissions (GHG) from agricultural soils and byproducts, and (3) explore options for agricultural production management in the face of global climate change.

Background: Agricultural systems function within the complex soil-atmosphere (and water) continuum. Mass and energy exchange processes occur both across and throughout this continuum - and agricultural operations have substantial effects on the processes and on the magnitude of fluxes between the soil and atmosphere – wherever agricultural systems are in place.

As one component of the continuum, agricultural soils are a crucial and dynamic resource: they must be managed to meet rising global demands for food, feed, fiber, fuel and ecosystem services and - via strategic, science-based management - they must be managed to maintained to enhance soil productivity and limit undesirable interactions between soils and the atmosphere.

Likewise, the atmosphere is also a crucial and dynamic component in agriculture. For example, uptake of atmospheric nitrogen (N) by soil microbes increases soil fertility, yet, nitrogenous emissions [e.g., nitrous oxide (N_2O) and ammonia (NH_3)] from soil ecosystems to the atmosphere may affect air quality and increase atmospheric greenhouse gas (GHG) concentrations. Similar trends between atmospheric and soil carbon (C) fluxes exist: C fixation from atmospheric CO_2 to carbohydrates is performed by leguminous plants and photosynthetic microorganisms found in soils. Other microbes (and plants) also release C to the atmosphere in the form on CO_2 and CH_4 (primarily). While the GHG emissions from any soil is considered a natural part of the critical natural C and N cycles, altered emissions found in agricultural operations can also change flux dynamics that contribute to climate change.

A changing climate can furthermore impact agricultural production at all scales - ranging from small- to large-scale cropping and orchard operations and from small pasture to large rangeland cattle operations (and others). These impacts are not limited to GHG changes, but can arise through alterations in precipitation and temperature patterns. Climate change impacts create challenges that need to be met in managing agricultural operations to reduce GHG emissions while concurrently maintaining or enhancing the productivity of their underlying soil resources. These changes also present new opportunities for agricultural production research and strategy development and for investigation of new approaches to enhance soil quality and to holistically mange the soil-air continuum.

The variability of the atmosphere, soils, and plants, and the complexity of interactions among these systems require collaborations by ARS scientists conducting NP212 research. Formal and informal Cross Location Research (CLR) projects including the Greenhouse gas Reduction through Agricultural Carbon Enhancement network (GRACEnet), Resilient Economic Agricultural Production (REAP), a number of CLR soil microbiome research efforts, and field campaigns focused on air quality and remote sensing of soil moisture are successful examples. Synthesis and integration of information, including sources outside NP212, by CLR projects increases the utility and impact of ARS research. Efficient assimilation of data from NP212 projects into existing and future collaborative data bases will enhance synthesis and integration analyses and expand research opportunities.

Activities and Impact: During FY 2018, NP212 had 89 full-time scientists working at 23 locations across the U.S. who were actively engaged in 23 ARS-appropriated projects and 111 cooperative research projects.

The quality and impact of NP 212 research was further evidenced in FY 2018 by the following:

- 189 refereed journal articles published;
- two new patent applications and one new invention disclosure submitted; and
- six new material transfer agreements with stakeholders

In FY 2018, NP 212 scientists participated in research collaborations with scientists in Australia, Belgium, Brazil, Cambodia, Canada, China, Congo (Democratic), Egypt, Ethiopia, Finland, Germany, Ireland, Italy, Mexico, Netherlands, New Zealand, Northern Ireland, Philippines, South Korea, Spain, Sweden, United Kingdom, and Uruguay.

Significant Accomplishments for FY2018

The following sections summarize significant and high impact research results that address the three specific components of the FY 2016-2020 action plan for NP212. Many of the programs summarized for FY2018 include significant domestic and international collaborations with both industry and academia. These collaborations provide extraordinary opportunities to leverage funding and scientific expertise for USDA - ARS research by rapidly disseminating technology, which enhances the impact of ARS research programs.

Component 1. Management and stewardship of soil resources

The first component of the Soil and Air National Program is: "Management and stewardship of soil resources" and research in this component focuses on research and development of management approaches that promote agricultural soil fertility and sustainability – that promote "healthy" soils that together provide tools for good stewardship of our nation's soils. While difficult to quantitatively define "healthy" soils, they are considered to be ones that are managed to maintain and even improve their agricultural sustainability, productivity and resilience to both disturbances and diseases. Healthy soils are key to continued and future agricultural productivity. In addition to being productive, resistant to disease, and sustainable, healthy soils also have features that enable them to resist external fluctuations (e.g., climatic disturbances, invasive pests) that would negatively affect a less "healthy" soil. Specifically, health soils are managed to be richer for crop and animal production and resistant and resilient to extreme climatic events (e.g., droughts, intensive precipitation, and higher and lower temperatures). These climatic events are of emerging importance, because they are increasing in frequency and intensity, and adversely affect both agricultural productivity and soil resources. In addition, healthy soils can moderate problems arising from either wind or water erosion, owing to erosion's impact on current and future production. The Soil and Air national program builds on the foundational discoveries and agricultural management efforts that have been recently developed to protect soil. For example, in some settings, tillage and the lack of cover cropping or cover residue contribute to off-site transport of soil particles, and therefore reduced tillage or no-till research, along with extensive cover crop research conducted by NP212 scientists has had fundamental impacts on reducing erosion. Finally, soil compaction, soil acidification, and buildup of salts also contribute to soil degradation, and NP212 scientists conduct research to address these by investigating the positive impacts of, for example, cover cropping and biochar amendments. By conducting research that examines and establishes approaches for soils to be productive, resistant to disease, sustainable and more resilient to climate change –Soil and Air scientists are improving the ability of our agricultural soils to perform even under a wide range of disturbances.

Selected Accomplishments

Nitrous oxide emissions are likely to increase in a warmer world. Emissions of nitrous oxide (N_2O) from fertilized soil in crop fields are an indicator that nitrogen is not being used efficiency by the crops, which increases farming production costs and has negative environmental effects. N_2O is also a potent greenhouse gas that is involved in ozone depletion. A key question to understand is how N_2O emissions will respond to expected changes in global climate. ARS scientists in St. Paul, Minnesota investigated this question using a 6-year data set of N_2O emission data in conjunction with a mathematical model to estimate regional N_2O emissions within the U.S. Corn Belt. Annual N_2O emissions were found to be highly sensitive to climatic variations; in the warmest spring (2012), more than 7 percent of the nitrogen applied was emitted as N_2O, nearly double the expected rate. Factoring in expected trends in climate change and nitrogen fertilizer use, regional N_2O emissions are projected to substantially exceed previous projections in the coming decades. This represents an additional challenge to the already difficult task of reducing N_2O emissions and other nitrogen losses from agricultural production systems.

A holistic method to study soil health and sustainability. Characterization of key microbial and plant chemicals (metabolites) in soil contributes to our understanding of how the soil and its microbial communities influence and are affected by agricultural management practices. This information is critical for enabling productive, sustainable agriculture. ARS scientists in Beltsville, Maryland, optimized a method to increase the number of metabolites of interest (e.g., indicative of key soil function or state) that can be extracted from soil. In addition, a creative modification of the extraction method allowed the scientists to isolate and analyze distinct biologically important lipids that can be used to characterize the microbial composition of the soil. These tools provide scientists and stakeholders with a better way to improve the process of metabolite analysis – one that saves time, reduces costs, and enables the characterization of soil microbial communities. This research represents a cutting-edge advance in metabolomic analysis of soils and is expected to lead to better soil health management practices.

Remote sensing provides farmers with information for better agronomic practices. Precision farming is an advanced method of managing farms that in some instances uses measurements of variation within a field to determine the rates at which fertilizers and agrochemicals should be applied. Satellite information can be a source of this information, but farmers need timely and reliable information about their fields. Frequent satellite imagery at high-spatial resolution would be ideal for monitoring vegetation and crop conditions at the sub-field scale but are not available. For example, Worldview satellites can provide 2-meter resolution images, but too much time—more than 7 days—elapses between measurements. The new Planet satellites, however, provide daily images, but at a coarser resolution. ARS scientists in Beltsville, Maryland, developed powerful data-fusion techniques that enable them to combine Worldview and Planet satellite images to produce daily, 2-meter resolution images. Three different data-fusion techniques were compared; all three can generate high-quality images and have comparable performance over different landscapes. Generation of daily high-resolution images at the sub-field scale will help individual farmers better manage their crops and enhance both production and environmental quality.

Nitrogen Index helps farmers better manage fertilizer, save money, and protect the environment. A problem faced by agricultural producers around the country and world is the proper use of nitrogen fertilizers. Agricultural system managers (e.g., farmers, landowners, government agencies) need data and information and tools to help them easily assess how their management decisions can increase the nitrogen use efficiency of crops - or conversely, how their management decisions result in the loss of necessary nitrogen from the soil. Version 4.5.1 of the Nitrogen Index was developed by ARS scientists in Ft. Collins, Colorado, to enable users to quickly conduct assessments of the effects of their management practices on nitrogen use efficiencies and to better manage their use of this important fertilizer. The index is now being used in California, Kentucky, South Dakota, Bolivia, Brazil, several Caribbean nations, Ecuador, Mexico, and other locations. Surveys conducted in 2016, 2017, and 2018 demonstrate that the index is in widespread use by farmers in many of these locations and has been downloaded or distributed more than 2,000 times by users in 65 countries and used by at least 4,500 farmers who manage more than 240,000 acres. The index is also used in academic settings, where it has served (and serves) as a teaching tool for over 1,500 undergraduate students and over 430 graduate students; in these settings, it has been downloaded by at least 560 professors, crop consultants, or other professionals. The Nitrogen Index is available free and can be downloaded through the ARS webpage.

Component 2. Managing nutrients in agroecosystems

The second component of the Soil and Air National Program Action Plan focuses on research and development to enable agricultural producers to optimize nutrient use in their agroecosystems. The development of such best nutrient management practices will ensure that producers can use optimal soil nutrient levels to meet the requirements of crops and forages. These management practices furthermore enable good economic returns, lead to higher sustainable yields, lower environmental impacts, and increase the sustainability of their operation's ecosystem services. For example, optimizing nitrogen and phosphorous inputs through efficient management practices is a critical component to balance increasing economic returns for land managers while at the same time, reducing losses of these agricultural pollutants into watersheds. Achieving this optimization requires more information about nutrient inputs and cycling from fertilizers, manures, composts, agricultural byproducts, cover crops, and other nutrient sources. Data from long- term nutrient management studies that incorporate crop varieties for a wide range of soil types and environments are essential. The efforts of the Soil and Air scientists focusing on these efforts will enable agricultural producers to optimize their use of nutrients, save money, and lower losses of expensive fertilizers to the environment.

Selected Accomplishments

Poultry litter significantly lowers production costs for biofuel production. Under the Energy Independence and Security Act of 2007 and the Renewable Fuel Standard program, 36 billion gallons of biofuels must be produced annually by 2022, more than twice the level currently being produced. Temporal patterns of biofuel crop growth, composition, and nutrient removal affect the development of models for predicting optimal harvest times and nutrient inputs for large-scale, sustainable bioenergy production. ARS researchers in Fayetteville, Arkansas, completed a series of experiments that evaluated environmental aspects and economic feasibility relative to the cost of specific fertilizers needed to grow biofuel crop switchgrass in the mid-South. They found that poultry litter was less expensive than synthetic fertilizer for production, which lowered the break-even price for a user by nearly 50 percent per acre. The research team further developed models that would enable a user to predict both within-season changes in production and nutrient cycling. These models give users the ability to simulate productivity trade-offs, and the resulting information can be used for both economic and environmental analyses that lead to more sustainable bioenergy production.

Microbial inoculants can reduce nitrous oxide emissions from nitrogen fertilizer application. The loss of N_2O is of concern not only because the loss of nitrogen from the soil means that plants cannot use it, but it is also a potential contributor to global warming. Over the past few decades, N_2O emissions related to agriculture have increased worldwide due to several factors, including increases in cultivated crop area, excessive application of nitrogen fertilizers, and livestock production. But loss of N_2O from inorganic fertilizer is considered to be the largest contributor from agriculture as a whole. ARS researchers in Auburn, Alabama, have identified microbial inoculants that can improve both plant production and plant nutrient efficiency. Development of these microbial inoculants was conducted to reduce N_2O losses that may arise from fertilizer nitrogen use. ARS research led to the discovery that specific combinations of soil microorganisms applied with fertilizer can reduce N_2O emissions, which was the basis of a new U.S. patent. The newly patented microbial inoculant will help reduce N_2O emissions from production agriculture and could lead to an income stream in the carbon trading market while reducing the effects of greenhouse gas emissions.

Weather conditions affecting nitrous oxide emissions from beef cattle feed yards. Nitrous oxide is a greenhouse gas that contributes to climate change. Owing to its high nitrogen content, manures in beef feed yards can be a major source of this N_2O. Whereas the effects of rainfall dynamics on N_2O emissions from manures have received much study, little is known about the effects of other variables such as temperature or temperature fluctuations. Scientists from ARS laboratories in Texas and Nebraska working with colleagues at Texas A&M AgriLife Research studied N_2O emissions after rainfall events at eight different manure temperatures that ranged from 41° to 115°F. These temperatures are representative of those encountered in beef production operations during winter and summer, respectively. After a rainfall, N_2O emissions increased with increasing temperature, and there was a sharp jump in emissions above 88°F. This information is relevant to animal production operations because air temperature is difficult to control in feeding pens. One practical recommendation for feedlot managers to reduce N_2O emissions is to keep feedlot pens dry, especially during the hot summer months.

A newly developed tool provides accurate estimates of nitrate surface runoff. The Soil Vulnerability Index (SVI), recently developed by the Natural Resources Conservation Service (NRCS), is a practical tool for identifying fields that have a high risk of nutrient-related pollutant transport out of the farm landscape, by surface runoff and/or by leaching. ARS scientists from Beltsville, Maryland, tested the suitability of the SVI method on the Choptank River watershed that is found in Delaware and Maryland. Outputs from a computer simulation model, the Soil and Water Assessment Tool (SWAT), were compared to the SVI classification scheme. Results indicated that although the SVI method was less accurate at identifying nitrate pollution caused by leaching, it was more accurate at estimating surface runoff of organic nitrogen. Based on the pollutant type of interest, NRCS state offices and other local agricultural management agencies can use the SVI method to classify crop fields that are vulnerable to surface runoff and leaching processes.

Treating poultry litter with alum reduces phosphorus leaching. Although adding alum to poultry litter is a well-known practice to reduce ammonia emissions and phosphorus runoff, scant information is available on the effects of using alum to treat phosphorus leaching. ARS researchers in Fayetteville, Arkansas, found that treating poultry litter with alum decreased phosphate leaching by 86 percent. Research was conducted using intact soil cores taken from a small plot study that had been being evaluated for nutrient dynamics for 20 years. Cores from 52 plots were exposed to natural rainfall, and phosphorus leaching was measured for 1 year. At the highest poultry/alum litter application rate (4 tons/acre), alum reduced total phosphorus concentrations in leachate by 80 percent and the total mass of phosphorus leached was reduced by 86 percent, compared with untreated litter. Currently, alum is added to the litter of more than 1 billion broiler chickens each year in the United States, and its inclusion has a beneficial economic effect of $10–20 million through improved air and surface water quality. In many parts of the country where soils are sandy, such as the Delmarva region in the Mid-Atlantic, poultry litter application is limited because of the risk of phosphorus leaching. This study demonstrated that alum greatly reduces the risk of phosphorus leaching, which provides a management option to growers to help reduce phosphorous runoff and thus improve surface water quality.

Water quality effects from phosphorus can be substantial in the Chesapeake Bay watershed. Agricultural phosphorus loss from fields and resulting water quality degradation continues to be an issue in the Chesapeake Bay watershed. Because many soils in the watershed have high levels of phosphorus, information is needed on how long it will take to reduce those levels and how much phosphorus levels will decrease. ARS researchers in Madison, Wisconsin, developed and used the Annual Phosphorus Loss Estimator (APLE) model to estimate soil phosphorus drawdown and loss for cropland in Maryland. They showed that a reduction in soil phosphorus levels throughout the state could reduce phosphorus loss to the Chesapeake Bay by 42 percent. However, it may take 30 to 40 years to reach the 42 percent target. Combining soil phosphorus drawdown with aggressive soil conservation could reduce phosphorus loss by 63 percent. There is potential to substantially reduce phosphorus loss from Maryland soils to the Chesapeake Bay, but it will require a continued effort to reduce both soil phosphorus and phosphorus transport from all cropland.

Optimizing poultry litter use for crop production. There is a large body of work showing that poultry litter (PL) is widely used as a nutrient source for crop production. However, crop yield in response to PL application is often different from yields resulting from the use of inorganic fertilizer (IF), depending on soil type, management conditions, and PL application practices. ARS researchers in Auburn, Alabama, reviewed 90 studies consisting of 866 observations from the scientific literature using statistical methods that combine results from multiple studies to identify common effects of PL and IF application. This evaluation showed several important findings: that the beneficial effect of PL compared with that of IF was greater in acidic soil than neutral or alkaline soils, and greater in medium-textured soils such as loams compared with light-textured sands or heavy-textured clays. Furthermore, conservation tillage with PL provided the greatest improvement to crop productivity; PL application rate, timing, and method also influenced crop productivity; the greatest benefits were observed when PL was applied at the highest application rate, more than 10 days before sowing, during consecutive years, and applied as surface broadcast or a subsurface band beside the crop row rather than incorporated with tillage. Overall, this comprehensive and quantitative review showed that the benefits of PL are comparable to those of IF; however, the greatest benefits were observed with long-term annual (3 or more) litter applications. Results from this study will aid extension personnel and agricultural land practitioners in prescribing PL use in crop production systems.

New soil health measurement allows analysis of multiple enzymes in one sample. Farmers are interested in how their management and cropping practices promote, sustain, or degrade soil health. They need simple soil health tools to help them select sustainable soil management practices, but simple measures of soil health have been difficult to develop. The enzyme activities of soil organisms are highly sensitive to management and represent measures of soil functions, but the current protocols are time consuming because each enzyme is measured separately. To solve this problem, ARS scientists in Lubbock, Texas, and Morris, Minnesota, developed an assay that can measure multiple enzyme activities in one soil sample, thus simplifying the measurement and providing a protocol that is adaptable to many climatic zones and cropping systems. This method provides a powerful index related to soil health. The new assay will enable producers and land owners to assess soil health and then adopt cropping practices that improve soil health.

Component 3. Reducing environmental risk of agricultural operations

The third component of the Soil and Air National Program Action Plan focuses on research that evaluates approaches to lower environmental risks that may arise from agriculture. One of the most commonly thought of risks that agriculture is thought to pose arises from chemicals that are used in agriculture (e.g., fertilizers or pesticides) that migrate off-site and have undesirable consequences to surrounding environments. The potential loss of such contaminants from agricultural landscapes to the surrounding environment can pose potential risks to plant, animal, and human health. However, environmental risks arising from agriculture may not only include the agrochemicals of concern (e.g., fertilizers and pesticides), but also gases; odorants; volatile organic compounds (VOCs); other airborne contaminants (e.g., particulates of less than 10µm [PM10]); pharmaceutically active compounds (PACs); and even pathogens, antibiotic-resistant bacteria, antibiotic-resistance genes, heavy metals, and other contaminants. Not only is off-site transport of high concern, but the generation, transport, and loss of these constituents and other materials of concern if of importance. Furthermore, their generation, loss and transport processes may be exacerbated by changing weather patterns attributed to climate change. Therefore, NP212 scientists conduct critical research that will help understand the dynamics of, and reduce the presence and impacts of, these potentially hazardous contaminants in agricultural systems – which is the focus of this component of research.

Selected Accomplishments

Antibiotic resistance is more common in natural prairies than in organic farming operations. Bacteria that are resistant to antibiotics are found throughout the natural world, even in areas where antibiotics have never been used. The use of antibiotics in modern agricultural production is a concern for the public and research community alike because it is thought that irresponsible antibiotic use may lead to the development of antibiotic-resistant microorganisms that could affect human health. ARS researchers in Lincoln, Nebraska, found that antibiotic resistance to two classes of antibiotics was detected at high levels in 13 Nebraska organic farming operations. Interestingly, most of the resistance genes were detected more frequently in nearby natural prairie soils than in soils on the organic farms. This information suggests that farming practices that use manure do not lead to an increase in long-term antibiotic resistance in the soil. The findings will inform and support U.S. policy positions for national and international trade negotiations around antibiotic use in U.S. agricultural products.

Beef cattle raised without antibiotics have lower levels of resistant bacteria than conventionally raised beef cattle. There is an increasing concern that antibiotic use in food animals leads to antibiotic-resistant foodborne bacteria. ARS scientists from Clay Center, Nebraska, and Bowling Green, Kentucky, in collaboration with Colorado State University researchers, investigated the health of beef cattle raised without antibiotics. Fecal samples were collected monthly over 1 year from 30 cattle raised without antibiotics, and 30 conventionally raised cattle at a commercial slaughterhouse. Levels of third-generation cephalosporin-resistant E. coli, erythromycin-resistant Enterococcus species, and erythromycin and tetracycline resistance genes were significantly lower in cattle raised without antibiotics. Resistance to most of the remaining antibiotics, and the levels of bacteria such as Salmonella, were not different between the two groups. This study indicates that optimized antibiotic stewardship can reduce the burden of antibiotic resistance associated with food animal production systems. Results of this study can be used for quantitative risk assessment to further quantify the effect of raising beef cattle without antibiotics to reduce human exposure and subsequent possible infections from antibiotic-resistant bacteria.

Novel gas-permeable membranes greatly reduce gaseous ammonia in poultry barns. Conservation and recovery of nitrogen from livestock and urban wastes is important for both economic and environmental reasons. ARS researchers in Florence, South Carolina, developed new systems using gas-permeable membranes to collect and reuse ammonia that is harvested from waste in poultry barns and thus removing ammonia from the air. The membrane manifolds are suspended inside the barns and the gaseous ammonia closest to the litter is removed. The technology has been demonstrated at University of Maryland Eastern Shore chicken houses through a National Institute of Food and Agriculture grant. In rooms fitted with the ammonia recovery system, the ammonia level decreased 46 percent in the air and 45 percent in the litter, and bird mortality was reduced 47 percent. The new system offers poultry producers a better way to manage ammonia and bird health in their poultry barns.

Ground soybean hulls can be used in swine operations to reduce manure odors. Odors from confined animal feeding operations can be a nuisance to neighbors. Ground soybean hulls contain a naturally occurring enzyme called soybean peroxidase, which has been shown to reduce odors from swine manure in laboratory tests. ARS scientists in Bushland, Texas, and researchers at Iowa State University carried out a farm-scale experiment in a realistic swine production setting to further evaluate how odors could be reduced. The team found that applying ground soybean hulls to swine pens resulted in a 36 to 80 percent reduction in the chemicals most responsible for swine odor. The total treatment cost, including materials and labor, was $2.62 per marketed pig. These results give swine producers and consultants a new and cost-effective way to reduce odors.

Microbial risk assessment related to agricultural operations. Human exposure to gastrointestinal pathogens by environmental routes—particularly through drinking water—is an important public health burden. Quantitative microbial risk assessment (QMRA) is a method that can predict this burden, but QMRA predictions have not been validated for many pathogens. ARS researchers in Marshfield, Wisconsin, compared QMRA predictions to epidemiological measurements collected during outbreaks of waterborne gastrointestinal disease, and confirmed that QMRA can reliably estimate human disease rates due to waterborne gastrointestinal pathogens. Policymakers and agricultural engineers can use QMRA to accurately predict the health burden of pathogen exposure, including exposure to pathogens that originate on livestock farms and pollute ground and surface water during manure disposal. Such predictions of health burdens are crucial to evaluating public health and environmental policies related to agriculture.