FY2016 Annual Report
National Program 212 –Soil and Air

Introduction

National Program (NP) 212, Soil and Air, conducts research to improve the quality of soil and atmosphere 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.

Agricultural systems function as a subset within the Earth's broad terrestrial soil-atmosphere continuum. Mass and energy exchange processes occur within and across this continuum and agricultural practices can significantly affect the processes. Emissions from agriculture to the atmosphere affect air quality and increase atmospheric greenhouse gas (GHG) concentrations. GHG emissions result from the natural cycling of carbon (C) and nitrogen (N) and these emissions also contribute to climate change. A changing climate impacts discrete agricultural crop and animal systems, broad range and pasture systems, and the underlying soils – by altering precipitation and temperature patterns and increasing the atmospheric carbon dioxide (CO_2) concentration. The impacts of climate change create challenges to agriculture and its soil resources, and also offer new opportunities for agricultural production and enhancement of soil quality.

Soils are a crucial matrix for agricultural operations and serve as a boundary resource between agriculture and the atmosphere. Soils as a matrix in agricultural systems must be managed to meet rising global demands for food, feed, fiber, fuel and ecosystem services while maintaining soil productivity and limiting undesirable interactions between soils and the atmosphere.

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

During FY 2016, 92 full-time scientists working at 21 locations across the U.S. were actively engaged in 30 ARS-led and 116 cooperative research projects in NP212. ARS-lead projects were approved through the ARS Office of Scientific Quality Review in late 2010, making this the final year of implementation of these projects. The gross fiscal year 2016 funding for NP212 was $44 million.

Personnel News for NP212

New additions to the NP212 team in 2016 are*:*

- **Dr. Dave Knaebel**, formerly of GroundworX Analytics, LLC, was hired by ARS's Office of National Programs in August 2016 as the new NPL for Soil Biology.
- **Dr. Catherine Stewart** joined the Soil Management and Sugar Beet Research Unit in Ft. Collins, CO as a Research Soil Scientist. Dr. Stewart will develop a research program on soil carbon sequestration and cycling of carbon. The SMSBRU also welcomed a new postdoctoral research associate in 2016; **Dr. Grace Miner** earned a doctorate in Crop Physiology at Colorado State University in 2016. She will be working on a CSU/USDA-ARS cooperative research project studying how long-term soil and crop management can be used to adapt to climate change by increasing soil health, nitrogen use efficiency, and productivity.
- The Grazinglands Research Laboratory in El Reno, OK welcomed three new postdoctoral research associates in 2016: **Dr. Pradeep Wagle** is an ecologist studying evapotranspiration monitoring with eddy covariance systems. **Dr. Tanka Kandel** is a soil scientist monitoring greenhouse gas emissions using static chambers under different crop, tillage, fertilizer, and grazing systems. **Dr. Pradeep Adhikari** is an agronomist studying crop modeling with Decision Support System for Agrotechnology Transfer (DSSAT) to evaluate soil and water management strategies under changing climate conditions.
- The Northwest Sustainable Agroecosystems Research Unit in Pullman WA hired two scientists to support the Long Term Agroecosystem Research (LTAR) program: **Ian Leslie,** formerly of the University of Idaho, is a Support Physical Scientist, providing leadership in carrying out field activities and planning experiments that contribute to sustainable agroecosystems. **Bryan Carlson**, formerly of Washington State University, is a Resource Information Specialist, providing leadership in data management and performing statistical analysis of data.
- **Dr. Amanda Ashworth** was recently hired as a Soil Scientist at the Poultry Production and Product Safety Research Unit (PPPSRU) in Fayetteville, AR. Dr. Ashworth was previously a postdoctoral research associate with the Dale Bumpers Small Farms Research Center in Booneville, AR. Amanda's work aims at quantifying plant-soil-water quality benefits from improved poultry manure management. The PPPSRU also welcomed new postdoctoral research associate **Dr. Cristiane Pilon**. Dr. Pilon is originally from Piracicaba, Brazil and received a Ph.D. in crop physiology from the University of Arkansas. She is working on the long-term effects of various grazing management strategies and buffer strips on soil erosion and nutrient runoff from pastures fertilized with poultry litter.

The following scientists left or retired from the ranks of NP212 in 2016:

- **Dr. Kim Cook,** formerly of the Food Animal Environmental Systems Research Unit, Bowling Green, KY, is now the Research Leader of the Bacterial Epidemiology & Antimicrobial Resistance Research Unit, Athens, GA.
- **Dr. Jonathan Lundgren**, Research Entomologist from the North Central Agricultural Research Laboratory in Brookings SD, left ARS in 2016.
- **Dr. Rufus Chaney** of the Crop Systems and Global Change Laboratory in Beltsville MD, ARS Hall of Fame member, retired in 2016 after 47 years of service with ARS. We'd call that dedicated.

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

The following scientists in NP 212 received prominent awards in 2016:

- **Dr. Stephen A. Prior** was inducted as a Fellow of the American Society of Agronomy (ASA) during the 2016 Annual International Meeting of ASA.
- **Dr. Jorge A. Delgado** of the Soil Management and Sugar Beet Research Unit in Ft. Collins, CO received an International Service in Agronomy Award from the American Society of Agronomy in recognition of his outstanding contributions in research, teaching, extension, or administration made outside of the United States by a current agronomist.
- **Dr. Hero T. Gollany,** Research Soil Scientist with the Soil and Water Conservation Research Unit, Pendleton OR, was selected by the American Society of Agronomy as a 2016 ASA Fellow Award recipient for her service to the society.
- **Dr. Jane Johnson** of the Soil Management Research Laboratory in Morris MN was named a fellow of the American Society of Agronomy in 2016.
- **Dr. Sharon Papiernik**, Supervisory Research Soil Scientist in the North Central Agricultural Research Laboratory in Brookings SD, was named a Fellow of the Agrochemicals Division of the American Chemical Society.
- **Dr. Lisa Durso,** Research Microbiologist with the Agroecosystem Management Research Laboratory in Lincoln NE, was named an "Excellent Associate Editor" by the Journal of Environmental Quality.
- The United States Composting Council awarded **Dr. Rufus Chaney** of the Crop Systems and Global Change Laboratory in Beltsville MD the first "Jerome Goldstein Lifetime Achievement Award" for his research and contributions in the field of composting.

The quality and impact of NP 212 research was further evidenced in 2016 by the following:

- 153 refereed journal articles published
- 2 new patent applications submitted and 4 new patents issued
- 1 current cooperative research and development agreement and 4 new material transfer agreements with stakeholders
- Administration or development of 7 web sites for academia or stakeholders.

In 2016, NP 212 scientists participated in research collaborations with scientists in: Australia, Bolivia, Brazil, Canada, China, Congo (Democratic), Ecuador, Germany, Jordan, Korea, Malawi, Mexico, Namibia, New Zealand, Peru, Puerto Rico, Spain, Taiwan, and Turkey.

Significant Accomplishments for FY2016

This section summarizes significant and high impact research results that address specific components of the FY 2011 – 2015 action plan for NP 212. Each section summarizes accomplishments of individual research projects in NP 212. Many of the programs summarized for FY 2016 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. This National Program is organized into four components:

1. Enable Improvements of Air Quality via Management and Mitigation of Emissions from Agricultural Operations
2. Develop Knowledge and Technologies for Reducing Atmospheric Greenhouse Gas (GHG) Concentrations through Management of Agricultural Emissions and Carbon (C) Sequestration
3. Enable Agriculture to Adapt to Climate Change
4. Maintaining and Enhancing Soil Resources

Component 1: Enable Improvements of Air Quality via Management and Mitigation of Emissions from Agricultural Operations

Atmospheric emissions from agriculture are under increased scrutiny due to potential negative global environmental effects and threats to human and animal welfare. Emissions also contribute to localized tensions between agriculture and residential communities with visibility impairment (haze) and nuisance odors. Major classes of emissions include particulate matter (PM), volatile inorganic compounds (primarily ammonia, nitrous oxide, and hydrogen sulfide), volatile organic compounds (VOCs), and those arising from pesticide applications. Often these emissions exist as mixtures and, thus, adjustments to production practices for abatement may decrease the release of one material while changing the emission character or magnitude of other materials.

Selected FY16 Accomplishments

Enhanced-efficiency nitrogen fertilizers can reduce nitrous oxide emissions from cropping systems. Nitrous oxide gas emitted from soil represents lost nitrogen. Nitrous oxide is also a potent greenhouse gas. ARS researchers in Kimberly, Idaho, monitored greenhouse gas emissions from a silage corn–barley–alfalfa rotation that received a commercially-available stabilized urea fertilizer (SuperU®) or conventional granular urea in the spring, or dairy manure in the fall or spring. They found that SuperU reduced nitrous oxide emissions by 52% when corn was grown, but nitrous oxide emissions were not reduced when barley was grown. There also was no difference in emissions between spring and fall manure applications. While >50% reductions in nitrous oxide emissions were observed using SuperU, in all cases, nitrous oxide emissions from soils were less than 1% of the applied nitrogen. This work demonstrates that SuperU can reduce nitrous oxide emissions from selected (e.g., corn) irrigated cropping systems in the semiarid western United States.

The Greenhouse gas Reduction through Agricultural Carbon Enhancement network (GRACEnet) project. Historical major GRACEnet product developments include establishment of field/laboratory measurement protocols, a standardized Excel data entry template, software to perform quality control of data entry, a web-accessible GRACEnet database with field measurements, site characterization data, land management information, and 163 manuscript citations, with 12 of these citations entered during FY 2016. The GRACEnet databases continue growing, with over 159,000 records entered into GRACEnet during FY 2016, for a grand historic total of 587,000 records about soil greenhouse gas (GHG) emission, biomass, soil chemical properties, management, amendments, or other important related measurements. A significant portion, 136,000 soil greenhouse gas (GHG) emission records, were entered during FY 2016, adding to a grand total of over 247,000 GHG measurements in GRACEnet. A large portion of these recorded databases on the website have been released to the public. The GRACEnet project has increased the accuracy of GHG emission estimates reported in the U.S. national GHG inventory, including the latest inventory published during 2016. Additionally, the GRACEnet project has been used to develop scaling factors to quantify the GHG reductions of improved management practices imbedded in decision support tools. In addition, GRACEnet data are now being used to validate the underlying models used by the NRCS Carbon Management Evaluation Tool [COMET]-Farm decision support tool.

Multiple management changes are needed to reduce direct N_2O emissions. Strategies have been proposed for reducing nitrous oxide (N_2O) emissions by modifying the rate, source, timing and/or placement of nitrogen fertilizers. Studies have shown, however, that modifying only one of these components by itself does not consistently reduce N_2O emissions. ARS scientists in Saint Paul, Minnesota conducted field studies over two corn growing seasons to examine multiple combinations of practices that altered the fertilizer rate, application timing and/or use of microbial inhibitors. The results showed that only the most intensive combination – one that used split application timing together with microbial inhibitors at reduced N application rate – was able to decrease N_2O emissions. These results demonstrate that multiple changes to conventional farming practice will be needed to effectively reduce N_2O emissions.

Continuous cropping systems increase soil carbon and reduce carbon dioxide emissions. Most cropping systems in the Pacific Northwest dryland production region are losing soil organic carbon over time. Soil conservation requires the development of farming systems that are productive and that preserve soil carbon. ARS researchers in Pendleton, Oregon used field experiments and models to measure and predict how different cropping system options affect soil carbon. Continuous cropping to winter wheat using no-till methods was found to increase soil organic carbon and also reduce carbon dioxide emissions. These results will encourage the development and adoption of continuous winter wheat cropping systems.

Wind erosion and climate change in the Pacific Northwest. Warmer and drier climates forecast for the coming decades could impact agriculture and wind erosion in the Pacific Northwest. ARS scientists at Pullman, Washington, in collaboration with scientists at University of Idaho, simulated the impact of climate change on wind erosion and PM_{10} emissions using state-of-art climate forecasts and wind erosion technologies. PM_{10} is particulate matter less than or equal to 10 microns in diameter and of concern in the Pacific Northwest where PM_{10} emissions from agricultural lands can cause elevated atmospheric PM_{10} concentrations that exceed the National Ambient Air Quality Standards. While currently a concern in the Pacific Northwest, the conducted simulations predicted that PM_{10} emissions are anticipated to decrease over the next decades. Specifically, agricultural and atmospheric climate models predict that by 2050, the Pacific Northwest will experience enhanced agricultural biomass production owing to CO_2 fertilization. This enhanced biomass production will have the beneficial effect of protecting soil from erosion. Therefore, for the Pacific Northwest, both wind erosion and PM_{10} emissions from soils are predicted to decrease by 2050.

Rising carbon dioxide will increase rice yield reductions caused by rising temperatures. Rice yields in many parts of the world are decreasing due to climate change. ARS scientists in Beltsville, Maryland, tested whether rising atmospheric carbon dioxide would alleviate or exacerbate this problem, using a diverse range of rice germplasm. In all types tested, seed production problems at high temperature were exacerbated by elevated carbon dioxide. Some wild lines were less affected, and these could provide genes useful to incorporate into commercial lines for future climates.

Effect of antibiotics on atrazine degradation. The routine use of herbicides in grain production systems that also utilize manure for fertility will result in the co-application of veterinary antibiotics (VAs) present in the manures and herbicides to field soils. The VAs may impact soil microbial activity and, by extension, herbicide degradation rates. ARS scientists in Columbia, Missouri evaluated the interactions between these amendments on herbicide fate. In the absence of manure, the complete breakdown of the corn herbicide atrazine in soil was reduced by the presence of two VAs, sulfamethazine and oxytetracycline. However, in the presence of manure, atrazine breakdown was significantly reduced, regardless of the VA concentration in the soil, suggesting that other components of the manure had a greater inhibitory effect on atrazine breakdown than the VAs. Assessments of soil microbial ecology indicated that the VAs did alter the community structure but not nearly to the extent that manure addition did. The results demonstrated that manure application had a greater effect on atrazine degradation than VAs, suggesting that the presence of VA residues found in land-applied manure are unlikely to alter atrazine fate in soil. These findings are important as they indicate that herbicide persistence will not be greatly affected by land application of VAs when manure is used as a fertilizer source.

Quantifying hydrogen and odor emission from animal systems. Hydrogen sulfide (H_2S) gas from swine manure slurries are a health risk and odor nuisance. Increasing use of dried distillers' grains with solubles (DDGS) in swine diets has contributed to increasing levels of H_2S emissions. ARS scientists in Ames, Iowa completed an animal feeding trial that investigated the effect sulfur levels and sulfur sources in swine diet have on H_2S emissions. Increasing sulfur levels in swine diets significantly increases hydrogen sulfide emissions and odor; additionally, dietary sources enriched with sulfur amino acids also increase sulfur odor emissions. Information from this study will be of value for growers, engineers, and regulatory officials on developing guidelines for alternative diets to reduce sulfur levels in diets which contribute to increasing hydrogen sulfide emissions.

Electronic nose sensors can be used to detect odors from biosolids. Gas monitoring tools, such as electronic nose sensors, have evolved over the last decade and are a promising approach for applications where rapid and automated detection of specific gases or patterns of gases are required; further, they can also be used to discriminate between air samples containing complex mixtures of compounds. However, little information is available on the application of sensor arrays to monitor the processes involved with the treatment and use of biosolids, which are used as an alternative fertilizer source. ARS scientists in Beltsville, Maryland, conducted studies to examine the feasibility of a series of electronic nose sensors to discriminate between treatment of biosolids stabilized with different amounts of lime and to explore their ability to detect key odors in comparison to using an array of sophisticated analytical instruments. The electronic nose sensors were able to discriminate between lime dosages for alkaline stabilized biosolids and showed close agreement with sophisticated analytical instrumentation, but the analytical instruments could detect the gases at much lower concentrations. These results are expected to provide important information on the use of commercially-available electronic nose technologies to increase the effectiveness of biosolids treatment programs and to assist in reducing odor complaints when biosolids are applied to agricultural fields.

Component 2: Develop Knowledge and Technologies for Reducing Atmospheric Greenhouse Gas (GHG) Concentrations through Management of Agricultural Emissions and Carbon (C) Sequestration

Agriculture GHG emissions to the atmosphere are among the documented anthropogenic factors driving climate change. Land management practices may be altered to reduce GHG emissions. Agriculture also provides an opportunity to sequester C in soils, thus offsetting GHG emissions and offering a partial solution to slowing the forces of climate change. Increasing production without increasing emissions also presents an opportunity to decrease the emissions intensity of certain agricultural commodities.

Selected FY16 Accomplishments

Increasing soil carbon sequestration and reducing carbon dioxide emissions under conservation tillage management. Documentation of soil chemical properties such as carbon sequestration in long-term conservation tillage versus conventional tillage experiments is rare, simply because there are few existing experiments and less financial incentive to maintain extremely long projects. ARS scientists at Florence, South Carolina, created a long-term (34 year) tillage and crop management experiment using sandy soils. The study showed that it takes a few decades to accumulate a significant amount of topsoil organic carbon, and furthermore, that conservation tillage resulted in a net increased accumulation of about 7 metric tons per hectare of soil organic carbon compared to conventional tillage. Therefore, during the 34-year course of this experiment, 25 metric tons of carbon dioxide equivalents per hectare were sequestered. These results affirm the benefits of conservation tillage management for U.S. agriculture through increasing soil organic carbon as well as reducing agriculture's impact on greenhouse gas emission.

Integrated remote sensing approach for retrieving leaf area index at field scales. Leaf area index is a key biophysical parameter used for land surface flux estimation, water resource management and crop growth monitoring. While coarse resolution leaf area index data at the kilometer scale are available from the NASA Terra Moderate Resolution Imaging Spectroradiometer and these data products are sufficient for global, continental and regional scale applications, field-scale applications require a leaf area index with higher spatial and temporal resolutions. An automated mapping method for leaf area index has been built to generate 4-day time-series of leaf area index at 30m resolution by ARS scientists in Beltsville, Maryland. Application of this method over central Nebraska from 2002 to 2012 showed promise for frequent mapping of leaf area index at field scales using current operational satellites. This approach demonstrates the potential uses for crop modeling at field scales, which is required by the National Agricultural Statistics Service for crop condition monitoring and yield estimation.

Cattle play a major role in nutrient cycling of grassland ecosystems. In grassland rangeland ecosystems, cattle can play a substantial role in the redistribution of nitrogen and other nutrients. ARS researchers in Ft. Collins, Colorado, and collaborators at

Colorado State University, are studying the effects of cattle excrement patches on nitrous oxide (N_2O) and methane (CH_4) fluxes on cool-season, pasture, and warm-season-dominated native rangeland of the shortgrass steppe in northeastern Colorado. Greenhouse gas Emission Factors (EF; i.e., percent of added N emitted as N_2O-N) in this ecosystem were found to be substantially less than the Intergovernmental Panel on Climate Change (IPCC) Tier 1 Default EF for manured pasture, indicating that during drought conditions, the IPCC Tier 1 Default EF significantly overestimates emission from both the shortgrass steppe (SGS) native rangeland and cool-season pasture. While the Tier 1 Default EF values are used to approximate annual N_2O emissions from different ecosystems or managed systems, these ARS measurements indicate that substantially less N_2O is emitted from these systems in comparison to the default values. These data are important for providing better values for estimating agricultural impacts on N_2O emissions.

Soil physical structure is a key determinate of greenhouse gas emissions. Knowledge of the processes controlling greenhouse gas (GHG) emissions is critical for developing mitigation practices to reduce these emissions from agricultural activities. ARS researchers in Saint Paul, Minnesota evaluated the factors influencing GHG emission rates under both field and laboratory conditions. The data showed that 72% of the GHG variability was explained by soil physical properties such as soil texture, porosity, and bulk density and this suggests that the soil physical structure is a major factor controlling soil GHG emissions. These results are significant to farmers and policy makers because agricultural practices alter these soil physical properties and furthermore, this information will assist scientists and engineers in developing improved models for predicting net GHG emissions for various management options.

Species and media effects on soil carbon dynamics in the landscape. Agriculture is unique in that activities which were once carbon dioxide (CO_2) sources can become carbon (C) sinks by using management practices that increase C storage in biomass and soils. However, little work has investigated the contributions of plants in the urban landscape (representing ~148 million acres across the U.S.) for mitigation of climate change via C storage. ARS scientists in Auburn, Alabama grew three common ornamental shrubs (cleyera, Indian hawthorn, and loropetalum) in containers for one season using pinebark (the industry standard), clean chip residual, or WholeTree as potting substrates before transplanting into the landscape. Soil CO_2 efflux was monitored by an automated carbon dioxide efflux system for 1 year. Plant growth and soil C as a result of potting substrate were assessed. Soil CO_2 efflux was unaffected by species or substrate. Pinebark plots had higher soil C levels, suggesting that pinebark decomposed slower and thus has greater soil C storage potential than the two alternative substrates. These results indicate that urban landscapes have a large C storage potential that could help mitigate climate change.

Arbuscular mycorrhizal fungus increases on-farm yield of tomato. Agricultural scientists constantly search for ways to increase crop yields with the same or reduced input of resources. One option is the intentional use of naturally occurring symbioses such as the one formed by arbuscular mycorrhizal (AM) fungi. ARS researchers in

Wyndmoor, Pennsylvania conducted seven years of experimentation at a conventional vegetable farm which showed a statistically significant average increase in yield of tomato fruit of 6% for AM-fungus-inoculated vs. uninoculated plants. Inocula were produced on-farm at a cost of $0.003 per plant (not counting labor), resulting in a significant cost-benefit ratio for vegetable farmers. In comparison, the United Nations' Food and Agriculture Organization data show that for corn—one of the most intensively managed, fertilized, and genetically engineered crops in the world—the average yearly increase in yield in the U.S. over the past 25 years was 1.2%. Inoculation with AM fungi shows promise as an effective way to increase grower yield at minimal cost.

No-till increases sustainability of crop residue harvest. Crop residues like corn stover perform important functions that promote soil health and provide ecosystem services that influence agricultural sustainability and global biogeochemical cycles. Corn stover harvesting for livestock feed, bedding, and cellulosic ethanol production has been rising and is expected to increase in the future. In a four-year study, ARS scientists in Brookings, South Dakota evaluated the effect of corn residue removal from a no-till corn-soybean rotation on crop yields, greenhouse gas (GHG [e.g., CO_2, N_2O, CH_4]) fluxes, and net global warming potential. Corn and soybean grain yields were not significantly affected by residue removal. Residue removal did not significantly affect GHG fluxes from corn; however, significantly higher (107%) N_2O fluxes were observed in soybean with residue removal compared to control plots. All field plots were a net source of CH_4 during a four-year test period. Soil organic carbon (SOC) increased in both treatments during the study, with a lower rate of SOC accumulation with corn residue removal compared to plots without residue removal. Because of the net gain in SOC in all plots, net global warming potential was negative for both treatments. This finding indicates that under local soil-climatic conditions, no-till practices can permit biennial corn stover harvesting without increasing global warming potential. However, our results also show that repeated corn residue harvesting may increase nitrogen loss from fields as N_2O. These data fill specific knowledge gaps for life cycle analyses of regional bioenergy cropping systems.

Component 3: Enable Agriculture to Adapt to Climate Change

Mechanisms for adapting to climate change are critical for continued agricultural production and stewardship of natural resources. An understanding of the impacts of climate change on natural and managed ecosystems provides insights needed to formulate strategies for addressing vulnerabilities and exploiting potentially beneficial aspects of climate change. Mechanisms for identifying and detecting indicators of impacts are key to formulating management responses. Adaptive responses to climate change must be evaluated for impacts on ecosystem function and potential feedbacks on the climate system and subsequent consequences for sustainability and reinforcement, or offset of, climate change mitigation strategies.

Selected FY16 Accomplishments

Positive effects of CO_2 on crop growth vary with temperature. ARS researchers in Beltsville, Maryland, conducted an international study using 13 to 26 crop models for wheat, corn, and rice in order to assess the effects of increasing temperature and CO_2 on yields. Common assumptions were used among all models. The research showed that a cut-off point where the positive effects of CO_2 concentration could compensate for the potentially negative effects of temperature increases on yields could be identified from these simulations. The research is useful to climate change researchers who use and interpret crop models and policy experts who use results from simulation models.

Crop residue effects on fall precipitation capture. In the Mediterranean-type climate of the Pacific Northwest, while thick layers of crop residues are often left on fields at harvest, they are not effective in preventing significant amounts of evaporation over the summer fallow period - and these residues are often removed or tilled into the soil. ARS researchers at Pendleton, Oregon used weighing lysimeters, field plots, and samples from farmers' fields and learned that residue cover approaching 100% is very effective at improving deep penetration and storage of early fall rains. Residue cover of less than 50% was much less effective, and small rain events would often evaporate completely. Since small rain events are very important to wheat yields in semi-arid areas, this information has encouraged farmers to develop ways to maintain and plant through higher levels of residue cover and has reduced the desire to remove residue from the field. In addition to yield increases, these practices will help protect soil quality and provide improved climate stability.

Beneficial fungi increase drought tolerance in wheat. Abiotic stresses, particularly drought, reduce grain yield of wheat in many semiarid regions of the world. In the inland northwest, even during periods of extreme drought, patches of green and vibrant spring wheat were observed growing in the midst of wheat stunted by severe water stress. Arbuscular mycorrhizae (AM) interactions were present in these patches and these enabled greater accumulation of limited water by the wheat. ARS scientists in Pullman, Washington, determined that drought appears to have enhanced AM relationships with wheat, thus inoculation of seed or soil with AM fungi may hold potential to increase grain yield during drought. Inoculation of seeds prior to planting, or soil amendments represent a relatively low-cost approach that farmers can use to maintain and perhaps increase grain yields even during drought conditions.

Crop rotations for soil fertility and sustainable agriculture. Development of crop rotations that support sustainable agriculture requires an understanding of the complex relationships between soils, crops, and yield. To better understand these relationships, ARS scientists in Brookings, South Dakota measured how soil chemical and physical attributes, as well as corn and soybean growth and grain yield, responded to simple and complex crop rotations that contained row crops as well as annual and perennial forages. When compared to a simple corn/soybean rotation, rotations that contained wheat or alfalfa produced greater corn grain yield while seed nitrogen (N) concentration was significantly greater only in rotations containing alfalfa. Soybean seed yield was about also 10% greater and seed protein concentrations were about 3% greater in the alfalfa rotation compared to the other rotation treatments. It is hypothesized that the increased soil N when alfalfa is included in the rotation played a role in increasing seed yield and N concentration. Alfalfa-induced increases in soil N would allow farmers in the northern Great Plains to reduce nitrogen fertilizer rates by 45% and still maintain yields when corn follows alfalfa in rotation. Maintenance of crop yields under reduced nitrogen fertilizer application rates would increase farm profitability and decrease the potential of environmental contamination.

Component 4: Maintaining and Enhancing Soil Resources

Soil productivity must be enhanced to meet increasing global food, feed, fiber, and fuel demands. Likewise, soil degradation through erosion and decreased physical (e.g., structure, compaction, infiltration), chemical (e.g., acidification, salinization, nutrient depletion), and biological (e.g., losses in biodiversity, reduced nutrient cycling, lowered soil organic matter) properties and processes must be mitigated to ensure critical goods and services provided by soil resources are maintained.

Selected FY16 Accomplishments

Humic products cause increased growth of corn roots. Humic product vendors often claim their products promote crop root growth--which would enable faster crop uptake of water and nutrients and potentially contribute to soil carbon stocks and erosion control—yet no formal data exist for this claim. ARS researchers in Ames, Iowa measured corn root growth in a defined soil volume at three crop growth stages in three consecutive years using humic products from two collaborating companies. In most cases root length increased with product application by at least 15-20% for all root size classes by the final sampling time each year, with most of the response occurring later in the growing season. Proportional increases in root biomass were the same or greater than root length, suggesting denser or thicker roots as well. Enhanced root carbon input into the soil provides one potential explanation for initial findings that soil physical properties are improved with long-term application of humic products, and suggests that humic products might allow farmers to mitigate detrimental effects of intensive agriculture on soil health.

A well-tested Soil & Water Assessment Tool (SWAT) model for quantifying impacts of winter cover crops on water quality. A management tool was needed for quantifying the impacts of winter cover crops on water quality at watershed scales. As part of the Conservation Effects Assessment Project (CEAP), ARS scientists in Beltsville, Maryland, evaluated the effectiveness of winter cover crops on nitrate loads into the streams, using the Soil & Water Assessment Tool (SWAT) model within the Choptank watershed in Maryland. When calibrated using remotely sensed data, the SWAT model showed promise to be used as a management tool for evaluating winter cover crops' effectiveness as well as their impact on reducing nitrate loads into the streams for improving water quality. The improved predictive power of the SWAT model arises from the employment of improved representations of agricultural practices across the watershed (e.g., crops; rotations) and the growth dynamics of winter cover crops used. A validated version of the model will be useful for agricultural producers and regulatory agencies for assessing risks and benefits associated with winter cover crops to improve water quality at watershed and basin scales.

Corn residue harvesting changes both soil hydrology and soil aggregation. Reducing or eliminating tillage is recommended to protect soil resources when crop residues like corn stalks are harvested. However, information is lacking on whether conservation tillage strategies are sufficient to provide any protection when residues are aggressively harvested. ARS researchers in Morris, Minnesota and collaborators compared soil aggregation and water infiltration in fields with and without tillage, with no residue or maximum residue harvested. In both tilled and not tilled crop fields, soil water retention was improved when full crop stover was returned to the soil. Soils in tilled fields, however, were more exposed to wind and water and had reduced ability to capture rainwater. Fields managed without tillage captured and stored more rainwater when residue covered the soil. This work will aid producers, energy industry, and action agencies to balance the pros and cons of harvesting crop residues such as corn stalks for bioenergy.

Biochar application to soil affects herbicide activity. Biochar is a by-product of the process of pyrolysis conversion of plant material to biofuel. Biochars are being considered as soil amendments that may increase soil nutrients and water holding capacity, but field application of biochar may produce unintended consequences to other crop management practices. In collaboration with university scientists, ARS researchers at Brookings, South Dakota examined the impact of biochar application to the availability of the herbicides atrazine and 2,4-D in soil and how biochar affects the speed of plant germination. Soils amended with biochar produced from corn stover, switchgrass, and Ponderosa pine retained 5 to 10 times more herbicide than untreated soils, with only modest differences due to biochar type. Plants sensitive to these herbicides germinated more rapidly when biochar was present. These data indicate that even low levels of biochar addition to soil can increase herbicide retention by soil but reduce their potential effectiveness against weeds. This information can be useful to growers looking to obtain maximal benefits of biochar without compromising other agronomic practices.

New, lower nitrogen fertilizer recommendation for optimum sugar beet yield. Nitrogen management is critical in sugar beet production to optimize yield and extractable sugar. Current nitrogen fertilizer recommendations for sugar beet in Idaho are seven pounds of nitrogen per ton of beet, including nitrogen in the soil and applied fertilizer. ARS researchers in Kimberly, Idaho, in collaboration with agronomy staff at Amalgamated Sugar Company, used 14 site-years of data to determine that nitrogen requirements could be reduced by 14 to 29% in the Pacific Northwest compared to current recommendations. The average nitrogen recommendation to achieve maximum sugar yield was 4.5 pounds of nitrogen per ton of beet. The new nitrogen recommendations will result in significant cost savings for farmers and less nitrogen loss to the environment.

Nitrogen loss from sandy southeastern soils is driven by hydrology. Overall, conservation tillage practices are an effective method for reducing surface runoff, erosion, and related losses of nitrogen (N). ARS scientists at Tifton, Georgia found, however, that increased subsurface flow facilitated by conservation (strip, ST) tillage increased overall N loss by two-fold. Although surface runoff losses constituted 1.5% of field-applied N under conventional tillage and 1.0% for ST, subsurface losses of N were greater (8.3% for CT and 18.4% for ST). Much of the subsurface flow occurs in the months of January through April (due to high soil saturation and low evapotranspiration) with additional pulses typically associated with tropical (e.g., rain) events. N losses were largely controlled by differences in tillage effect on hydrologic routing as opposed to runoff concentrations. This study demonstrated that although reduced tillage is effective at reducing surface runoff and erosion, it introduces new challenges for nutrient management because enhanced infiltration can lead to increased N losses in subsurface flow.

Long-term crop rotation and tillage impacts on corn, grain sorghum and soybean. Long-term cropping system, tillage, and nitrogen fertilizer studies are essential to understanding production potential and yield stability of corn, grain sorghum, and soybean in rain-fed environments. ARS scientists in Lincoln, Nebraska conducted field studies in the western Corn Belt to evaluate how different tillage practices, crop rotations, and nitrogen fertilizer impact grain yield. Crop rotation has a larger degree of influence than tillage practice on corn and soybean production when evaluated across a wide range of weather conditions. Results indicate that adoption of 2- and 4-yr crop rotations in rain-fed environments can result in high-yielding, more stable corn, grain sorghum, and soybean grain production compared with shorter rotations or continuous cropping under no-tillage. This information will help grain growers optimize their crop rotations for maximum yield.

Visual evaluation of soil structure is useful for assessing sustainability of sugarcane production. Increasing global demand for biofuel has accelerated land-use change in Brazil, primarily through the planting of sugarcane (*Saccharum officinarum*) to replace degraded pastures. ARS scientists in Ames, Iowa collaborated with visiting scientists from Brazil to evaluate the potential of using visual evaluation of soil structure (VESS) to assess effects of sugarcane production practices on soil health/soil quality. Based on a scale of 1 to 5 (1 being best) the average VESS scores for native vegetation, pasture, and sugarcane were 2.0, 2.7, and 3.1, respectively. The VESS scores accurately reflected laboratory measurements of soil physical properties, suggesting that they can be a reliable indicator of soil structural quality in tropical soils. A VESS score of 3.0 can be used as a warning point for changing current management practices to ones that create a better soil physical condition for crop production on Brazilian soils.

Earthworms play important roles in soil ecology. Earthworms are responsible for a number of important processes in soil modification and restructuring—they decompose surface litter, move organic matter from the surface down into the soil, digest and decompose soil organic matter, and create tunnels that alter soil porosity. Earthworms are often divided into functional groups based on their feeding and burrowing behaviors, and it is assumed that all species within each functional group will have similar effects on soil organic matter. ARS researchers in Beltsville, Maryland, found that certain earthworm species differentially affected soil microbiological activity, the incorporation of surface litter into soil organic matter, and the abundance of soil bacteria and fungi. These effects varied according to the specific earthworm species rather than the earthworm functional group, highlighting the need to incorporate species information into studies on earthworms and soil organic matter. These results will be useful to soil ecologists and may lead to strategies for managing earthworms and other soil biota in improving sustainability of agroecosystems.

Cover crops affect the soil microbiome. Cover crops are used in sustainable agricultural systems to suppress weeds, scavenge nutrients, and add organic matter to the soil. Nitrogen fixing cover crops can also supply nitrogen to the subsequent cash crop. Cover crops have been shown in past studies to affect the soil microbiome, but results varied depending on which cover crops were used and whether they were incorporated into the soil or left on the surface. ARS researchers in Beltsville, Maryland, examined the effects of 8 different cover crop species, grown singly or in combination, while they were still growing. Cover cropping increased soil microbial biomass relative to a no-cover-crop control, and specific cover crops were found to differentially affect the soil microbiome. Oat and rye cover crops differentially increased arbuscular mycorrhizal fungi (AMF), which are beneficial symbionts of many crop plants; hairy vetch cover cropping increased the total biomass of soil fungi. These results may lead to intentional management of the soil microbiome, in order to enhance soil health, through selection of appropriate cover crops.

Biochar addition to soil as a management strategy. There is growing evidence that biochar can both be degraded by soil microbes and that it modifies their abundance, community composition and activity. ARS researchers in Fort Collins, Colorado, along with collaborators from China and Colorado State University, studied the effects of biochar application rate and soil type on microbial community composition. After 30 months, 90% of the added biochar remained in the soil, regardless of biochar addition rate. This response suggests that the sequestration of soil carbon (C) from biochar addition is proportional to biochar addition rate. Biochar decay rates changed as a function of soil organic carbon (SOC), with a lag in incorporation in soils with higher SOC concentrations, suggesting that microbes use biochar as a C source only after accessible SOC is exhausted. This study suggests that in soils without continuous fresh soil C inputs, biochar decay will proceed very slowly and common biochar field application rates will be beneficial for the soil microbial community.

A cutting-edge tool to aid the standardization, normalization and technology transfer of metagenomics data. The advent of next-generation DNA sequencing has led to a dramatic increase in metagenomics analysis of microbial populations from a variety of fields (e.g., soil, human, animal). However, current analysis platforms do not allow for the convenient storage, standardization, or normalization necessary for efficient technology transfer and cross-study analyses. myPhyloDB is a new web-based local server developed by ARS scientists in Fort Collins, Colorado that provides an easy-to-use graphical interface that stores metagenomics data in a SQL database and allows users to standardize, normalize, and analyze data from multiple projects. The standardization, normalization, and analytic capabilities of myPhyloDB add new functionality to the DNA sequence processing capabilities of Mothur – the most widely cited bioinformatics program (4000+ citations). The first version of myPhyloDB has been downloaded or distributed via CD-ROM to more than 60 users, from scientists in fields ranging from soil microbial ecology to human health and nutrition.