FY 2009 Annual Report
National Program 202- Soil Resource Management

Introduction

The thin layer of soil at the surface of the earth functions as the central resource for sustaining life. Soil management is one of the critical factors controlling plant production, which in turn supports animal production. Soils also remove impurities, protecting water and air quality. A balance needs to be reached between the short-term use of the soil and the long-term sustainability of this critical resource. Protecting, preserving, and enhancing the soil resource are key elements of this National Program.

The goal of the Soil Resource Management National Program is to enable sustainable food, feed, fiber and energy production while protecting the environment. Research is conducted to understand soil physical, chemical, and biological properties and processes, to facilitate the development of soil management practices that overcome limitations to productivity and to improve soil, water and air quality. Developing tools to aid soil management decisions and to assess the sustainability of soil management practices is an important part of this effort. Research within this National Program can be described in four broad areas: (1) soil properties, processes and functions; (2) soil management for crop production; (3) soil management for environmental stewardship; and (4) decision tools for soil management. Selective accomplishments from these four areas are described in the following section.

Soil Properties, Processes and Functions

Review articles in *Science* magazine and a conference on Frontiers in Soil Science hosted by the National Academy of Science have drawn attention to the importance of the soil resource and to our incomplete knowledge of soil properties, processes and functions. Considerable research will be needed to support management practices and systems that can overcome soil limitations to crop production and provide soil, water and air quality benefits.

Selected Accomplishments

Discovering the important roles played by tannins in soils. Tannins are plant-derived products that link herbage production, nutritive value, animal physiology, pathogen survival, and environmental quality in a web of nutrient utilization and availability. ARS scientists have demonstrated that some specific tannins can attach to soil, affect the solubility of organic nitrogen, and may even reduce the toxic effects of aluminum and copper to plant roots. However, knowledge of tannin in agro-ecosystems and how tannins can be used in managed systems is fragmentary. ARS scientists have deployed a systematic campaign of sampling to determine the patterns and magnitude of phenolic substances entering the soil. New methods were developed to measure phenolics in soils and plants, and the effects of these substances determined for soils collected from 25 ARS locations in the US, and from several sites in Canada. The objective was to determine if plants in traditional pasture and forest-grazing systems are a source of phenolic substances, especially tannins, and how the substances influence soil formation and nutrient cycling processes. They found that tannins in soil affect soil cation exchange capacity and metal-related soil chemical processes, and that soil tannin patterns vary with plant species and soil depth.

Poultry litter application and pastures can increase soil microbial diversity. The diversity of microorganisms in soil is enormous, but very little is known about how long-term agricultural land management affects the composition and genetic diversity of soil bacteria and fungi. A collaborative research effort among scientists at the University of Georgia, Mississippi State University, and the ARS in Watkinsville, Georgia investigated the role of typical long-term land management systems on microbial diversity in soils of the Georgia Piedmont. The management systems which were investigated were broiler litter versus inorganic fertilizer application on conventionally tilled cropland, hayed pasture, and grazed pasture. A forest stand planted in the mid 19th century served as a control area. Soil bacterial diversity was greater under pasture systems than under forest, suggesting that forage, fertilizer application, and cattle grazing can increase the diversity of soil microorganisms. Like the forest, conventionally tilled cropland with inorganic fertilizer had a low diversity of soil microorganisms. Regardless of whether land was in crops or pasture, broiler litter application had a positive influence on nutrient accumulation and soil microbial activity and diversity. Contrary to a general decline in plant and animal diversity when converting natural systems to agriculture, conservation agricultural systems with wise use of animal manures can improve soil quality by increasing the number and types of microorganisms in soil. These results have important implications for scientists and land managers in their attempts to preserve global genetic diversity, and for society to understand the impact of agriculture on the environment.

Soil microbial community structure in tomato cropping systems. Soil microbes play vital roles in agroecosystems, carrying out important functions such as cycling nitrogen, turning crop residues into humus, and inhibiting plant pathogens. Scientists at the Beltsville Agricultural Research Center studied the effects of plastic mulch and cover crops on soil and rhizosphere microbial communities in tomato cropping systems. Both vetch and rye cover crops increased soil microbial biomass and decreased the proportion of Gram-positive bacteria. Some of the increase in microbial biomass occurred during the winter as cover crops were growing, suggesting that root exudates from the cover crops were supporting microbial growth, but there were also further increases in late spring and early summer. Roots and shoots from both vetch and rye each contributed to the increase in microbial biomass. Vetch shoots increased the total amount and proportion of Gram-negative bacteria, fungi, and mycorrhizal fungi in the tomato rhizosphere. Other factors, such as soil temperature, soil moisture, soil texture, tomato yield, and cover crop biomass, had much less effect than cover cropping. The ability of cover crops to increase soil microbial biomass and alter microbial community structure may be useful in improving soil quality and sustainability of agroecosystems.

Developed improved method for extraction of microbial lipid biomarkers from soil. Extracting and analyzing the types and amounts of fats from soil is often done to obtain detailed information on the types and number of bacteria, fungi, and other organisms living in soil. Often termed "lipid biomarker analysis", the technique, is a valuable tool in soil quality assessments and soil microbial ecology research. A limiting factor in its application is that analytical procedures are complex and time-consuming. An alternative lipid extraction technique, pressurized liquid extraction (PLE), was compared to a conventional extraction method in four soils with differing physical and chemical properties. PLE extraction efficiency was greater than the conventional method for about half of the saturated fatty acids in the phospholipid fraction from all soils, and for the neutral lipid fraction from a coarse textured soil. Lipid profiles determined by the two methods were nearly identical. Overall, the PLE method proved to be more efficient at extracting soil-borne microbial lipids, while not altering microbial community information. PLE improves limits of detection, uses less solvent, can be automated, and is more rapid than the conventional method. These factors indicate that PLE is a substantial improvement over the traditional extraction method. Results demonstrate that PLE based soil-lipid biomarker methods can improve laboratory productivity, reduce amounts of waste generated, and increase the sensitivity soil microbial community estimations used for soil quality assessments and research designed to evaluate the role of soil microorganisms in regulating soil processes.

Optimization and validation of advanced method for measuring soil microbial activities. Soil microorganisms are essential to the functioning of agricultural soils, yet current methods to measure their activities have severe limitations. The lack of an inexpensive, easy to use measurement approach for soil microbial activities hampers attempts to understand the complex linkages among compartments (e.g., soils, plants, and soil microbes) in agricultural systems. Experiments that optimize a novel assay of microbial activities and validates the use of this assay with agricultural soils were conducted by ARS scientists in Brookings, SD. Results document the utility and the advantages of this respiration-based assay of soil microbial activities and promote its use by other researchers. By providing an effective means of measuring soil microbial activities, there is opportunity for advancing understanding of the ecological relationships in agricultural systems. With adequate knowledge, agricultural management practices can be adjusted to achieve maximum economy and environmental sustainability.

Soil quality under agroforestry documented for claypan soils. Little is known about how certain soil conservation practices affect the biological and physical properties that influence soil quality. ARS scientists studied changes in soil carbon, bulk density, soil aggregation, and soil enzyme activity in grass and agroforestry buffers at different landscape positions. While certain soil conservation practices, such as planting grass buffer strips at the bottoms of sloping fields, are known to reduce soil losses, their long-term effects on soil quality have not been documented. Grass buffer or agroforestry (pin oak trees) strips were previously established within a no-till corn-soybean cropping system on two adjacent watersheds to reduce soil erosion on a gently sloping claypan landscape in northeastern Missouri. The cropped areas always had higher soil bulk densities than the grass or tree buffer strips, likely because perennial vegetation encourages greater rooting volume and higher porosity thereby lowering density. Higher aggregate stability in buffer areas also suggests that an improved soil structure developed in the claypan soils; soil carbon and soil enzyme activities were greater in the grass and agroforestry soils than in the cropped soils. These were directly related to decreased soil bulk density and increased aggregation, which suggests better aeration, water infiltration, and organic matter stabilization. These results are important because they quantify the improvement of soil quality by the soil conservation practices of grass buffer and agroforestry strips established on landscapes prone to degradation by erosion and compaction.

Soil Management for Production

The soil resource supports sustainable food, feed, fiber and energy production. However, agricultural productivity of soils can be limited by erosion, loss of organic matter, compaction, low fertility, poor water infiltration and storage, acidification, and the buildup of salts and toxic trace elements. Soil management practices and systems to overcome these limitations need to be developed and evaluated to sustain and enhance the productivity of soil resources.

Selected Accomplishments

Long-term assessment of hydrologic, soil, and water quality response to conservation tillage in the southern Atlantic Coastal Plain. Sustainable production of cotton, peanut and other crops in the southeastern U.S. Coastal Plain requires that growers minimize negative environmental impacts and reduce costs through water conservation. To this end, conservation practices such as strip-tillage offer significant benefits. Nine years of data were compiled from a comprehensive study in south-central Georgia. When compared to conventional-tillage, strip-till provided equivalent crop yields and resulted in about two times less surface runoff and five times lower sediment loss. Reduced herbicide losses were also documented. Significant increases in subsurface water loss have been documented for strip-till, possibly increasing the risk of agrichemical losses and transport to groundwater. Overall, the research has quantified the benefits of strip-tillage and will likely promote increased rates of adoption of the practice by providing data to allow direct cost-benefit analyses for comparison with traditional tillage practices.

Alternative tillage systems are economically viable in the northern Corn Belt. While no-till crop production can provide conservation benefits in the northern Corn Belt, farmers continue to use conventional tillage due to concerns about yield reduction and economic risk. Reduced tillage systems such as strip tillage have been proposed as an alternative that may provide many of the conservation benefits of no-till while maintaining productivity and economic returns. ARS scientists at Morris, Minnesota evaluated the economic performance of no-till and strip-till systems to determine if they can be profitable alternatives to conventional tillage systems for corn and soybean production in the northern Corn Belt. Results showed that average profits were higher with no-till and some strip-tillage alternatives than for moldboard plow tillage; these alternatives were also less risky than conventional chisel and moldboard plow systems. These results are important to farmers in the northern Corn Belt, demonstrating tillage practices that can increase profitability while protecting soils and the environment.

Crop Rotation as a Substitute for Fertilizer Nitrogen in Corn Production. In many areas of the US, the complex crop rotations, once extensively used by farmers, have been supplanted by intensive monoculture or short rotation cropping. In collaboration with South Dakota State University, ARS scientists in Brookings, South Dakota and Morris, Minnesota, conducted long-term experiments to investigate the effects of complex crop rotations containing forage legumes on soil fertility, corn yield, and nutrition. In rotations where corn followed a forage legume, corn grain yield was stable across all nitrogen (N) input levels. Conversely, under continuous corn and corn-soybean rotation treatments, corn yield decreased as N input level was reduced. Data suggest that the substitution of complex crop rotation for fertilizer nitrogen in corn production may be an environmentally and economically sustainable practice.

New documentation of skip-row planting successes and failures. In collaboration with university colleagues, ARS scientists at Akron, Colorado have documented increased yields for skip-row (or wide row) plantings of dryland corn and sorghum. The practice is most useful in the drier portions of the central Great Plains. Their findings indicate that as conventional yields drop below 60 bushels per acre, skip-row planting increases grain yields. As conventional yields increase above 60 bushels per acre, skip-row planting neither increases or decreases dryland grain yields. Dryland corn and sorghum yields west of Colorado's border with Kansas tend to average less than 60 bushels per acre, indicating that millions of dryland acres would benefit from this practice. With sunflower, skip row planting has not shown a consistent advantage or disadvantage with one exception—seed size. Skip-row planted sunflowers produce larger seeds, which is a desirable characteristic for confection sunflowers (roasted and salted sunflower seeds).

Surface banding of phosphorus is successful in Midwestern soils. Phosphorus (P) is an essential nutrient for plant growth and often needs to be applied to the land for optimum crop production. To be effective, however, the fertilizer must increase the amount of plant-available P in the soil, and the plant root system must be able to take advantage of this increase. ARS scientists at Ames, Iowa found that the P in liquid fertilizer dribbled on the soil surface after soybean harvest moved approximately 10 cm down into the soil. The highest concentrations were found three weeks after application, but at least some of the applied P could still be detected the following spring. Three years of field research suggest that P applied to the soil surface after crop harvest will move into the profile, where it will be less subject to loss in runoff or by erosion during the winter months. These results benefit both commercial growers and the fertilizer industry by providing nutrient management alternatives that maximize crop utilization and minimize potential nutrient losses.

Soil Management for Environmental Stewardship

Soil management practices impact water and air quality by influencing the fate and transport of contaminants, and the biogeochemical processes that control nutrient and carbon cycling in soil. Research is needed to document the environmental impact of soil management practices, including those designed to overcome limitations to crop production.

Selected Accomplishments

Water soluble anionic polyacrylamide increases yields of furrow irrigated crops. Soil erosion produced by furrow irrigation reduces soil productivity and results in serious off-site environmental damage. Water Soluble Anionic Polyacrylamide (WSPAM) is used on millions of acres of furrow irrigated fields to control soil erosion, but its long-term effectiveness and influence on crop productivity have not been evaluated. A seven-year study at the Northwest Irrigation and Soils Research Laboratory, Kimberly, Idaho, showed that WSPAM reduced soil erosion from furrow irrigation by 20 tons per acre, while increasing dry bean yield 14% and silage corn yield 4.5%. The use of WSPAM to prevent soil erosion improves crop productivity, offsetting the cost of the practice to the producer.

Tillage and nitrogen fertilizer source influence nitrous oxide emissions. Crop management practices can influence the amount of nitrous oxide (a greenhouse gas) emitted from irrigated cropping systems. Nitrous oxide (N_2O) emissions monitored during the 2007 and 2008 growing seasons showed that, when comparing nitrogen sources, a no-till continuous corn system had less N_2O emissions than a conventional-till system. Nitrous oxide emissions were reduced further (up to 50%) in the no-till system when enhanced efficiency nitrogen fertilizers (controlled release and stabilized nitrogen sources) were used, compared to the urea nitrogen fertilizer commonly used by farmers. This work provides new knowledge that can be used to develop crop management practices to reduce N_2O emissions in irrigated cropping systems of the western U.S.

Nitrogen fertilization methods for subsurface drip irrigation. Interest in subsurface drip irrigation (SDI) for corn is increasing in semi-arid regions due to restricted irrigation allocations and perceived increases in water and nutrient use efficiency. ARS and university cooperators demonstrated that applying nitrogen fertilizer with SDI at various corn growth stages increases yields and gross return due to nitrogen application, and reduces nitrogen leaching in soils compared to concentrated early-season applications. This information demonstrates to producers the benefits of an alternative application method to use nitrogen fertilizers more efficiently, increase farm profits, and reduce nitrate contamination of groundwater.

Improving soil quality and crop yield utilizing cover crops. The benefits of cover crops to soil quality and productivity have been known for decades, but they have been underutilized in part due to the low cost of purchased agricultural inputs. As input costs continue to rise, producers are reexamining the use of cover crops within their production systems as a source of weed, insect, and disease suppression and as a green manure. Research has been conducted to evaluate the impact of utilizing cover crops within complex no-till crop rotation systems. Results show that the incorporation of cover crops improves trafficability, increases in-season nitrogen availability, and decreases pressures from crop pests.

Soil biochar amendments reduce leaching of nutrients from soils. Loss of plant nutrients from soils due to leaching is both an economic loss to farmers and can adversely impact water quality in local streams and reservoirs. Biochar is a co-product of the pyrolysis platform for producing renewable energy products from biomass. A 45-week soil column leaching study conducted as part of the ARS Biochar and Pyrolysis Initiative has shown that biochar applications on a typical Midwestern agricultural soil substantially reduce the leaching of several nutrients following the application of swine manure to the soil. Soil incorporation of 2% Biochar, produced by the slow pyrolysis of hardwood lumber, reduced leaching loss of nitrogen by 11%, and of phosphorous by up to 69%. Soil biochar applications also reduced leaching of calcium, magnesium, sodium, potassium, and silicon. By helping to keep these nutrients in the soil, biochar helps to improve both nutrient use efficiency and reduces the risk that the nutrients will contaminate surface and ground water. The results suggest that adding biochar to soils can enhance the sustainability of the emerging bioenergy industry.

Evaluation of crop growth in copper-affected soils. Copper sulfate solutions are used in hoof baths to protect dairy cows from hoof disease. The used copper sulfate solution is washed out of dairy barns into wastewater lagoons, and eventually applied to fields. Research at the Northwest Irrigation and Soils Research Laboratory, Kimberly, Idaho, determined that land application of copper-laden liquid dairy waste should cease when plant-available soil copper exceeds about 50 parts per million. If applications continue, accumulating copper in plant tissue will exceed the dietary intake threshold level for cattle, even though plants show no symptoms of copper toxicity. This information can help producers prevent soil copper issues associated with applying dairy wastewater to crop land.

Long-term assessment of hydrologic, soil, and water quality response to conservation tillage in the southern Atlantic Coastal Plain. Sustainable production of cotton, peanut and other crops in the southern Atlantic Coastal Plain requires that growers minimize negative environmental impacts and reduce costs through water conservation. To this end, conservation practices such as strip-tillage offer significant benefits. Nine years of data were compiled from a comprehensive tillage study in south-central Georgia. On average, strip-till provided equivalent crop yields and resulted in about two times less surface runoff and five times lower sediment loss than conventional-tillage. Reduced herbicide losses of 2 to 40-fold were also observed. Significant increases in subsurface water losses have been documented when using strip-till, potentially increasing the risk of agrichemical losses via subsurface runoff. Overall, the research has quantified the benefits of strip-tillage and will likely promote increased rates of adoption of the practice by providing data that allows direct cost-benefit comparisons with traditional tillage practices. Data were used by the USDA-NRCS to a calibrate simulation model for use in the Conservation Effects Assessment Program (CEAP).

Decision Tools for Soil Management

Producers and their advisors need tools to facilitate soil management decisions, assess the sustainability of soil management practices, and predict the environmental benefits of these practices.

Selected Accomplishments

Improved fertilizer recommendations reduce the cost of production. Agricultural crop producers rely on fertilizer recommendations to provide guidance in the application of fertilizers in a cost-efficient manner. The Grassland Soil and Water Research Laboratory in Temple, Texas developed new methods of soil analysis that improve fertilizer recommendations. Over 300 soil samples from Texas and Oklahoma, representing over 50,000 acres, were analyzed, and fertilizer recommendations provided to the land managers. On average, the recommendations resulted in cost savings of $20.00 per acre, or a net saving of $1 million/year for the land managers.

Crop reflectance sensing to guide corn nitrogen application. Increasing fertilizer costs, and environmental concerns associated with nutrients moving from agricultural fields into streams, rivers, and oceans, have corn farmers interested in methods to help them apply precisely the amount of nitrogen (N) fertilizer that the corn requires. This research was conducted to assess the utility of light reflectance sensors for determining the most profitable N application rates for corn. Results demonstrate that sensor-based variable-rate N fertilizer applications could generate an increase in returns ranging from $5 to $50 per acre, depending on the soil type. As fertilizer costs increase relative to the price of corn, the value of using canopy sensors for N management will also increase. Reduced N applications will save farmers money while benefitting the environment by reducing N losses.

NIR estimates of key soil profile properties. Sensors that can estimate soil properties without the need for sampling are a promising approach to obtaining the data required to characterize spatial variability in soils. Optical reflectance sensing of surface soils in the visible and near infrared (NIR) wavelength bands has been successful in this regard, but few have investigated this approach within the soil profile. In this research, laboratory visible-NIR reflectance measurements were obtained for surface and profile soil samples from five Midwestern states, and compared with soil physical and chemical properties. Good results were obtained for soil carbon, clay, cation exchange capacity, and calcium, and analyses identified appropriate spectral ranges and calibration techniques to improve accuracy. Because NIR measurements can be obtained quickly and inexpensively, these findings may lead to more efficient soil measurement techniques and improve soil management for production and environmental sustainability.

New nitrogen index tools. A new Nitrogen Index that produces qualitative nitrogen loss rankings based on quantitative nitrogen balances, annual inputs, soil N dynamics, and yields for the entered scenarios was transferred to NRCS, The University of Puerto Rico, and INIFAP. This new N Index is easy to use and accounts for N transformations and dynamics that include N mineralization from soil organic matter and crop residues, residual soil NO3-N, leached NO3-N, and N lost through denitrification and ammonia volatilization. The new California Nitrogen Index was tested and approved by NRCS and is being considered for wider adoption in California. The Mexican Nitrogen Index tool for forage systems is being adopted and used by INIFAP scientists across different states of Mexico. A Caribbean Nitrogen Index prototype was transferred to USDA NRCS and University of Puerto Rico. The concept of the Index was also transferred to IVIA in Spain to be used across Spain’s Mediterranean region.

Field Validation of Existing Simulating Models. In collaboration with ARS colleagues in Fort Collins, ARS Scientists at Akron, Colorado have documented and validated the usefulness of the DSSAT v4.0 and RZWQM2 models for accurately simulating field measured yields of wheat, corn, and proso millet in six dryland cropping systems at Akron, Colorado (conventional tilled winter wheat-fallow, no-till wheat-fallow, no-till wheat-corn-fallow, no-till wheat-corn-proso millet, no-till wheat-proso millet-fallow, and no-till wheat-corn-proso millet-fallow). Average long-term yields of the three crops in different rotations were simulated well. Simulation results confirm the potential for using RZWQM2 to simulate dryland crop rotation yields under varying weather and soil conditions, and to provide results that will aid in the creation of decision support tools for dryland crop rotation selection.

Models can be used to predict soil organic carbon for cropping systems in the southeastern USA. Agricultural management systems are being evaluated to improve soil quality and sequester soil organic carbon with modified decision support systems. Scientists from the USDA-Agricultural Research Service in Watkinsville, Georgia and Beltsville, Maryland, USDA-Natural Resources Conservation Service, and Texas A&M University tested the performance of a recently modified decision support system (EPIC v. 3060) against a simpler decision support tool currently used by the USDA-Natural Resources Conservation Service, to identify soil management systems that contribute to improved soil quality. Management systems common to the southeastern US, such as corn/cotton/cover crop rotation systems with and without tillage, were evaluated at three locations (Blackland Prairie in Texas, Coastal Plain in Alabama, and Mississippi Valley Uplands). All but one of the systems were predicted to have higher soil carbon after fifty years with the largest increases in the clay soil of the Blackland Prairie and with added dairy manure fertilizer in the sandy soil of the Coastal Plain under no tillage. Soil carbon decreased in the silt loam soil in Mississippi with conventional tillage (traditional management). No-tillage management of cotton with a wheat cover crop and other crop rotations with high-residue producing crops increased soil carbon. These results will be important to land managers and policy makers for improving soil quality and reducing carbon emissions from agricultural operations in the southeastern US, although there is still a great need for field-based measurements of soil quality in conservation management systems to fully validate these tools.

Future

The NP 202 Soils Research Program is being combined with the NP 203 Air Quality and NP 204 Global Change programs to form the NP 212 Climate Change, Soils and Emissions Research Program. Following a workshop in May 2008, research directions for air quality and climate change research were developed and formalized in the NP 212 Action Plan. The existing NP 202 Action Plan has been integrated into the NP 212 Action Plan. Current NP 202 Soils projects will continue according to the schedules set by the NP 202 Action Plan.

Soil research under NP 212 is Research Component 4: Maintaining and Enhancing Soil Resources. Problem statements for the research include Controlling soil erosion, Preventing soil degradation, Improving soil management and the efficient use of soil water, and Improving nutrient cycling and use.