FY2005 Annual Report for Soil Resource Management National Program 202

Introduction

Soil is an extremely complex and dynamic system of physical, chemical, and biological properties and processes. While the primary expectation of this resource is to provide nutrients and water to support plant and animal productivity, it is also being used for recycling of biosolids, manures and other byproducts and removing impurities to benefit water and air quality. Management and use of soil for crop and grassland production can have a profound impact on sustainability and long-term preservation of soil quality. Misuse or mismanagement of this valuable resource will strongly influence air, water, and environmental quality. Key elements of this National Program include protecting, preserving, and enhancing the soil resource.

Although people in agriculture have long recognized the importance of soil, the general public does not view soil as an important resource. Recently, *Science* magazine identified soil as the “Final Frontier,” thus drawing attention to the importance of this resource and to our incomplete knowledge of soil properties, processes, and functions. Considerable research will be needed to further understand soil physical, chemical, and biological properties and processes. This information will allow management practices and systems for food, feed and fiber production to be developed and evaluated for their soil, water and air quality benefits. Decision tools need to be developed to predict where management strategies should be used and the environmental benefits that will occur from application of improved practices and systems.

The Soil Resource Management National Program is focused on five areas of research: (1) soil conservation and restoration, (2) nutrient management, (3) soil water, (4) soil biology, and (5) productive and sustainable soil management systems. Selected accomplishments from these five research areas are described in the following section.

Accomplishments

<u>Soil Conservation and Restoration</u>: Soil degradation, through human activities and natural forces, has reduced the productivity of our soils and damaged adjacent ecosystems. Soil degradation can result from accelerated soil erosion, loss of vegetative cover, oxidation of soil organic matter, and impairment of soil physical, chemical, and biological properties. Research is needed to develop practices and approaches to prevent soil degradation and to remediate soils where degradation has already occurred.

Equipment traffic, repeated grazing, and natural consolidation can cause compaction in agricultural soils, limiting root growth and movement of water, air, and nutrients. Compacted soil layers have been shown to limit yield and reduce overall productivity of many Southeastern U.S. soils. Researchers at Florence, SC, found that long-term conservation tillage nearly doubled soil organic matter and increased yields in dry years on Coastal Plain soils. However, deep tillage improved yields more than long-term conservation tillage. Complementary work at Auburn, AL, showed that site-specific subsoiling was a cost-effective alternative to deep tilling entire fields. This research, conducted under a Cooperative Research and Development Agreement with Deere and Co., showed that cotton yields were not decreased by site-specific subsoiling, but fuel savings could be as much as 59%. These studies show that subsoiling is often needed for efficient crop production, but further development of technologies to provide quick measures of soil compaction could enable producers to till only those areas that need treatment, thus saving time, fuel, and money.

Soil erosion remains a major cause of soil degradation in the U.S. and around the world. If soil erosion is not controlled, agriculture cannot be sustained in the long-term. Erosion can degrade the quality of agricultural soils, and introduce sediment, nutrients, pesticides and pathogens into surface waters. Erosion of agricultural lands occurs about 17 times faster than soil formation, and about 90 percent of all U.S. cropland is losing soil faster than the sustainable rate. About 1.5 to 2.0 billion tons of soil is lost from fields annually through soil erosion. On-site impacts of erosion include reduced productivity through loss of plant nutrients and organic matter and reduced ability for the soil to absorb and retain water for subsequent plant use. However, erosion of soil caused directly by tillage implements, so called “tillage erosion” has only recently become recognized as an important contributor to soil degradation. Researchers in Morris, MN, have demonstrated that intensive tillage moves large quantities of topsoil from convex slope positions and to concave positions. Research demonstrated that spatial variability in soil properties (e.g. top soil depth) and soil productivity (e.g. wheat yields) in undulating landscapes was significantly influenced by direct removal of topsoil through repeated intensive tillage operations. Thus tillage erosion, as well as wind and water erosion contribute directly to soil degradation.

A combination of factors including soil formation processes, geographical location, climate, cropping history, tillage practices, composition of fertilizers, soil amendments, irrigation water, and/or external contamination processes have caused some soils to be degraded. Some soils have become impaired from acidification by mining activities or nitrogen fertilizer management practices; salt buildup due to irrigation; or rendered unproductive or toxic due to accumulated levels of nutrients, salts, trace elements, or chemicals. In any of these situations, remediation or restoration measures may be needed to improve soil productivity, protect human health, and/or prevent environmental degradation. Researchers at Riverside, CA, have developed and demonstrated protocols to use rapid extensive geospatial measurements of apparent soil electrical conductivity to characterize soil salinity and direct soil sampling in critical areas. Mapping of soil salinity allows targeting of remediation practices to areas with the greatest salt accumulation. These tools are being utilized by irrigation districts in their salinity assessment programs and will be a valuable asset to researchers and managers involved in precision agriculture where inputs are tailored to needs and off-site environmental impacts are minimized.

Nutrient Management: Nutrient losses from over-application of animal manures and/or inefficient use of fertilizers on cropland represent a major non-point source of pollution to surface and ground water resources. Management practices must be developed that optimize the use of fertilizers and recycling of animal manure nutrients.

Scientists at Beltsville, MD, were able to reduce fertilizer nitrogen (N) inputs without reducing grain yields, and researchers at Ft. Collins, CO, demonstrated that the NLEAP model could successfully predict residual nitrate nitrogen and nitrate leaching potential. Both of these research programs showed that N use-efficiency of corn was increased by nearly 50% compared with conventional recommended practices, and environmental risks were reduced, when fields were subdivided into a mosaic of “response zones” based on soil properties, landscape position, and remotely sensed datasets. When large amounts of N are applied to corn to ensure high grain yields, N not taken up by the crop often contaminates surface and ground water resources. These techniques can reduce N application based on synchronization of spatial and temporal variability of N demand with site-specific N applications to minimize nitrogen runoff and leaching impacts on the environment without reducing crop production.

ARS scientists from Saint Paul, MN and colleagues from the University of Wisconsin, Stevens Point found that denitrification of excess nitrate was enhanced in pastures compared to corn cropland. Enhanced denitrification was attributed to increased available carbon to serve as a food source for the bacteria. Enhanced denitrification converts the potential pollutant nitrate to harmless dinitrogen gas, thus reducing the environmental threat to ground and surface waters. These results provide an additional example of how well-managed agriculture can help protect public resources.

Phosphorous (P) is a major environmental concern because of the susceptibility of many aquatic ecosystems to eutrophication. Manure is a major source of P in many agricultural systems. Scientists in Beltsville, MD, determined that much of the P in dairy manure exists in the form of phytic acid, and not as inorganic P as generally assumed. This organic P form is less rapidly released from the solid phase so it has different fate and transport characteristics. ARS scientists in Temple, TX, have developed a new soil phosphorus extractant that maintains pH close to that of the natural soil yet gives results that are significantly correlated with those of existing extractants. These new developments will allow improved prediction of the movement and fate of manure and soil P within agricultural ecosystems. Improved assessment of the risks for offsite contamination will lead to more efficient management of agricultural nutrients.

Soil Water: Water is the driving force governing crop production and nutrient movement, fate, and efficiency in the field. Understanding the complex interactions of soil physical properties and landscape positioning on soil water dynamics will be critical to conserving natural resources while sustaining US agricultural productivity. Since over 70 percent of US agriculture is non-irrigated, water availability is often the most limiting factor controlling crop growth and yield.

Researchers at Mandan, ND and Bushland, TX analyzed precipitation patterns and alternative cropping system to identify water-efficient cropping systems for semi-arid environments. Integrated crop-livestock systems in the central Great Plains can take advantage of the bimodal annual precipitation pattern to produce high quality forage by establishing a broad leaf crop like pigeon pea during the normally non-cropped period between winter wheat harvest and seeding. Seeding short- and medium-maturing grain sorghum cultivars in a timely fashion optimizes grain yield and provides sufficient residues for successful conservation tillage management in the southern Great Plains. Producers can take advantage of these finding to tailor their cropping sequence to their precipitation patterns and thus develop their own sustainable cropping systems.

Prediction of water infiltration into soil is critical for many water budget, soil erosion, hydrologic, and plant growth studies, but, potential infiltration rates vary spatially and temporally. Researchers at Pendleton, OR, discovered a sample size bias in water infiltration measurements. They demonstrated that cores of 20 cm or less in diameter can produce infiltration estimates that are about half of the saturated flow rate of 45-cm cores. Through extensive field measurements under a variety of soil conditions, they demonstrated that the phenomenon is not due to soil disturbance by the core wall, is not a function of probability, and is found under both rapid and slow infiltration conditions. Since hydraulic conductivity is a key factor in soil water models, improvements in measurement techniques is vital to the effectiveness of modeling efforts.

Researchers in Stoneville, MS found that winter flooding of rice fields can promote degradation of rice straw and reduce winter weeds. Fermentative conditions were maintained in surface soils during winter flooding, based upon nitrate loss and accumulation of organic acids such as acetic acid. Following removal of flooding, nitrate concentrations in previously flooded soil were equal or greater than in not flooded soil. Winter flooding of rice fields creates conditions favorable to no-till rice soybean rotation through enhanced fermentative rice straw degradation and weed suppression.

Soil Biology: Soil microbial communities are poorly understood, yet critically important to soil health. Research will be needed to provide a better understanding of the dynamics of soil microbial communities and their relationship to soil quality. Specifically, it is important to know how: agricultural management practices influence soil organisms; to enhance beneficial interactions between and among roots and soil biota; to manage soil organisms to control plant diseases, plant pests, and weeds; and to promote soil organisms for more efficient degradation of pesticides and other harmful and toxic compounds.

Researchers in Beltsville, MD, have developed a rapid and sensitive method for identifying bacteria by fatty acid analysis. This new method is three times faster and twenty times more sensitive than current methods, permitting the identification of bacteria in less time and from smaller samples. Increased ability to detect and predict the fate and transport of harmful organisms in the environment is increasingly important in light of emerging disease and bio-security threats.

The accelerated degradation of agrochemicals following repeated application to soils has been reported, but the time required for the development of this enhanced degradation is not well understood. Researchers in Stoneville, MS, determined that degradation of the corn herbicide atrazine was enhanced in less than two years. In fields receiving applications every one or two years the atrazine half life was 9 to 10 days compared to 17 days from areas with no atrazine application history. Accelerated degradation of some chemicals can develop within a single season. Researchers in Tifton, GA, found that persistence of the fungicide tebuconazole, an active ingredient favored by Atlantic Coastal Plain peanut farmers, decreased from 43 to 5 days after three applications due to adaptation of soil microbiological communities that degrade the pesticide. Pesticide persistence in soil must be long enough to provide for effective control; however, long-term persistence may have negative consequences if products remain available for transport in runoff or leaching for extended periods. These findings represent knowledge that is needed to optimize pesticide application timing and frequency, thus minimizing input costs and enhancing environmental quality.

High molecular weight anionic polyacrylamide (PAM) has been shown to reduce soil erosion and protect water quality, but some land managers and public agencies have hesitated adopting or promoting PAM use because of lack of information on the potential long-term consequences on soil microbial ecology. However, results of a long-term study conducted by researchers in Kimberly, ID, showed that massive applications of PAM had only minor and inconsistent effects on soil microflora. These results help to alleviate concerns about potential side effects of far (1000 fold) lower PAM applications that have demonstrated low-cost benefits for erosion control and water quality protection.

Arbuscular mycorrhizal (AM) fungi colonize plant roots, establishing a symbiotic relationship which increases crop yield with lower input of fertilizer and pesticides. The problem is how to maximize the efficient use of the organisms to deliver nutrients such as nitrogen to the host plants. Experiments carried out by ARS scientists in Wyndmoor, PA in collaboration with scientists from New Mexico State University and Michigan State University demonstrated how the supply of photosynthate from the plant controls the movement and transfer of nitrogen to the host. The existence of this pathway and control mechanism and the high flux of nitrogen through it indicate that the AM symbiosis can effectively transfer large amounts of nitrogen from the soil to plant roots. This means that the symbiosis has a more significant role in the global nitrogen cycle than had been widely believed and will help devise strategies to optimize nitrogen use-efficiency.

Productive and Sustainable Soil Management Systems: Because of increasing economic and environmental concerns associated with current agricultural practices, there is a need for developing new management systems that are more sustainable and are easily adoptable by producers. Improving or maintaining soil quality, protecting the environments, and land productivity are perhaps the most critical component to be considered in developing sustainable management practices. Such practices, protocols or recommendations, however, are successful when they can be used to effectively manage and conserve soil and water resources while maintaining or increasing farm profitability.

There is a need for developing more comprehensive soil quality indices/tools for assessing the sustainability of land management practices. The Soil Management Assessment Framework (SMAF) developed by ARS researchers in Ames, IA, was demonstrated to have wide applicability using case study data from Georgia, Iowa, California, Washington, Oregon, and Idaho. A set of indicators is selected and transformed into scores based on site-specific algorithmic relationships to soil function. Scored values or a combined index can be used to scientifically determine differences due to land management. This tool can be used by the Natural Resources Conservation Service to determine the effectiveness of management practices supported by funds from USDA Conservation Programs. This tool will allow producers to select practices that will protect soil, water, and air resources.

ARS researchers in Athens, GA, have demonstrated that endophyte infection of tall fescue altered soil microbial activity, increased soil carbon sequestration, and improved soil aggregation, thereby reducing runoff, improving water quality, and helping to offset rising carbon dioxide in the atmosphere. Tall fescue is an important cool-season grass in the southeastern USA. The plant is naturally infected by a fungus that produces a variety of low-level toxins that adversely affect animal growth. On the other hand, the fungus helps the plants survive the hot humid conditions of the region. After twenty years of tall fescue management, soils with a higher percentage of plants infected with the endophyte had higher levels of soil carbon and nitrogen, and this extra carbon was located in intermediate size soil aggregates. These results help scientists understand the ecological impacts of animals grazing tall fescue, and may help to identify and develop other similar associations for increasing soil carbon storage.

ARS researchers in Kimberly, ID, in cooperation with ARS locations in Raleigh, NC, Watkinsville, GA, Dubois, ID, and Madison, WI have accumulated a substantial body of data showing that cattle, sheep, and goats prefer forages cut in the evening to similar forage cut in the morning. This preference may be prompted by diurnal changes in simple sugars in the plants. These results help to explain the inconsistent acceptance by animals of apparently similar forages and identify an additional management tool that livestock producers can utilize to increase forage quality and animal productivity.

Researchers in Lubbock, TX, found that no-tillage cropping systems were as beneficial as conservation grassland in improving soil biogeochemical and physical properties of sandy soils in semi-arid regions. In the 0 to 5 cm depth, conventionally tilled cropland had about 20% lower levels of most soil properties considered important in indicating the quality of soil for crop growth.

ARS researchers in Beltsville, MD, have made great strides in the development of remote sensing and direct sampling procedures to improve our ability to rapidly assess soil conditions affecting productivity and environmental risk. Beltsville scientists have developed mid-infrared spectroscopy as a reliable and rapid method of measuring soil carbon content and composition of soil samples regardless of variation in soil mineralogy. Techniques developed using ground-based spectra were successfully extended to classify airborne and satellite hyperspectral images to provide maps of residue cover and tillage intensity that are critical inputs to models predicting carbon sequestration and environmental risk. This combination of direct sampling and remote sensing technologies facilitates precision conservation and site-specific management of agricultural landscapes that require knowledge of soil properties in both space and time.